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Enforcement Technology Options for California Marine Protected Areas

AUTHORS:
Karen Garrison
Dana Rollison
Natural Resources Defense Council

NRDC
NATURAL RESOURCES DEFENSE COUNCIL

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NRDC Director of Communications: Lisa Benenson
NRDC Deputy Director of Communications: Lisa Goffredi
NRDC Policy Publications Director: Alex Kennaugh
Design and Production: www.suerossi.com

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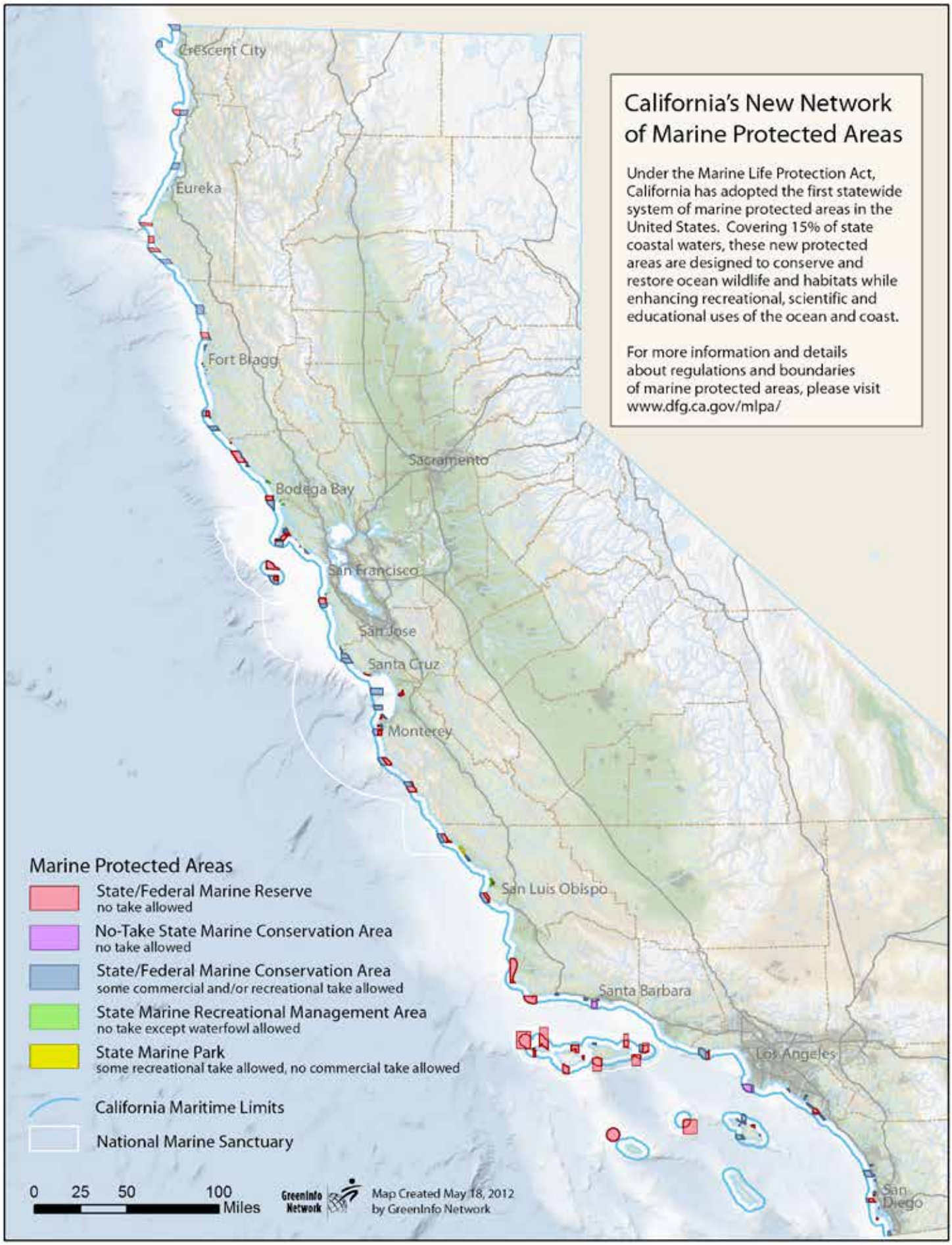
OVERVIEW

This paper summarizes information on technology options that could help enhance enforcement of marine protected areas (MPAs) in California's ocean waters. In some cases, the utility of the tools we examine extends well beyond MPAs. The purpose of this paper is to review the pros and cons of various technologies to help inform smart investments, ensure that the California Department of Fish and Wildlife (CDFW) can take full advantage of funding opportunities as they arise, attract more resources for wardens, and, ultimately, make ocean enforcement as effective as possible.

CDFW wardens have a daunting charge: enforcing fish and wildlife laws in a state with 38 million people, across a huge terrestrial landscape and an 840-mile coastline that includes a relatively new network of MPAs. California's marine protected area network made the state a national leader in ocean management and put it in a position to drive national policy on enforcement and compliance. Yet it currently trails Oregon and Washington in the use of up-to-date electronic systems for managing citations. Many components contribute to successful enforcement, including outreach and education aimed at securing compliance; engaged, informed, and observant citizens; fast and effective reporting mechanisms; well trained and equipped wardens; an effective system of penalties for violations; and partnerships among law enforcement entities ranging from wardens, park rangers, and lifeguards to National Marine Sanctuary and U.S. Coast Guard enforcement personnel. The authors view technology as just one piece of this picture, but one that can make an invaluable contribution.

All enforcement technologies depend on having an adequate number of wardens in the field. The state also needs to make the most of each warden by equipping its force with cost-effective tracking and communications technology. With technological tools for enforcement advancing in sophistication and reach, now is an excellent time to examine relevant tools, identify those that would provide significant improvement at a reasonable price, approach potential partners, and take action to upgrade enforcement capacity.


California's New Network of Marine Protected Areas
Under the Marine Life Protection Act, California has adopted the first statewide system of marine protected areas in the United States. Covering 15% of state coastal waters, these new protected areas are designed to conserve and restore ocean wildlife and habitats while enhancing recreational, scientific and educational uses of the ocean and coast.
For more information and details about regulations and boundaries of marine protected areas, please visit www.dfg.ca.gov/mlpa/
Crescent City
Eureka
Fort Bragg
Sacramento
Bodega Bay
San Francisco
San Jose
Santa Cruz
Monterey
San Luis Obispo
Santa Barbara
Los Angeles
San Diego
Marine Protected Areas
State/Federal Marine Reserve
no take allowed
No-Take State Marine Conservation Area
no take allowed
State/Federal Marine Conservation Area
some commercial and/or recreational take allowed
State Marine Recreational Management Area
no take except waterfowl allowed
State Marine Park
some recreational take allowed, no commercial take allowed
California Maritime Limits
National Marine Sanctuary
0 25 50 100 Miles
GreenInfo Network
Map Created May 18, 2012
by GreenInfo Network

SUMMARY OF KEY FINDINGS

This paper evaluates potential additions to the current technology toolkit relative to explicit criteria, including whether a technology is compatible with and enhances existing resources, helps provide reliable data that will stand up in court, and has a track record of successful application with appropriate scale. Using these criteria, we identify several tools that should be given priority consideration:

- **Upgrading CDFW's records management system (RMS)**—used for tracking citations and other information—from paper citations to electronic tickets would allow information to be easily transmitted and analyzed. In addition to improved efficiency, upgrading the department's RMS would lay the groundwork for the use of promising options like predictive tracking software to identify incident hot spots, and targeted warden presence and/or radar and camera surveillance in those hot spots. This option meets the evaluation criteria and provides a foundation for other critical steps. We, therefore, consider it a top priority.
- **Predictive policing—**analyzing spatial data on warnings and citations to identify violation hot spots—would help CDFW systematically target enforcement resources in the relatively near term. Given its statewide reach, its value for enhancing CDFW effectiveness, and its compatibility with other tools, we rank predictive tracking methods as a priority option.
- **Vessel monitoring systems (VMS)** would provide real-time spatial tracking of participating vessels and facilitate geofencing, which provides notification when a vessel crosses an identified boundary. Designed for enforcement purposes, these tamper-resistant systems produce protected data and can provide a reliable record for use in court when vessel position is reported frequently enough, though the data generally need to be substantiated by direct observation. VMS is already in wide use along the Pacific coast; the fact that a portion of California's commercial fishing vessels already carry it would reduce the significant cost of equipping the state's entire commercial fleet. This tool meets the evaluation criteria and ranks as a priority measure. Furthermore, even without a fleetwide system, the option of requiring MPA violators to install and use VMS appears to have low costs and clear benefits as a tool for reducing future violations. It should be investigated and, if feasible, pursued right away.
- **Targeted radar and camera surveillance** could aid enforcement in violation hot spots, particularly those with current radar equipment, and help detect vessels not carrying VMS. This option ranks as a potential priority tool. Systematic research into the availability of radar equipment in known incident hot spots would help determine the feasibility of this tool.

This paper also identifies several tools that fail to meet all the above-mentioned criteria and therefore warrant lower priority at this time:

- **Fishing forecasting services,** which use oceanographic data to predict movement of migratory fish, have a one-kilometer resolution, which makes this tool unlikely to be useful for enforcing nearshore MPAs.
- **Fishing behavior detection technologies** may be helpful in the future, especially if CDFW works with a company to tailor a system to its needs. But at this time the scale of these systems—oriented toward large ships—does not match CDFW's MPA responsibilities.
- **A shipboard broadcast system called an automatic identification system (AIS)** is now used primarily for avoiding collisions between large ships. Its Class B units provide frequent vessel position data at a fraction of the cost of VMS. As of March 2016, AIS will be required on fishing vessels over 65 feet, and it may well have a greater role in enforcing protected areas in the future. However, its open-source, unprotected data make it less useful than VMS at this time for making a case in court.

Further, our review finds that more expensive hardware such as drones and unmanned surveillance vehicles are not currently practical solutions for routine enforcement, given a limited budget and large enforcement area, except potentially through partnerships and on a targeted basis.

Finally, our analysis shows that there is no single best choice of technology. Just as CDFW is most likely to win a court case if it has multiple corroborating sources of data, its enforcement efforts will benefit most from a package of technology options. The selected options should complement each other, build on CDFW's strengths, and be applied at an appropriate scale.

RECOMMENDATIONS

Based on our analysis and findings, we recommend the following steps.

- CDFW should take prompt action to implement an electronic RMS that is compatible with those in Oregon and Washington. That undertaking should include a careful assessment of the bare minimum of data types needed for enforcement of California MPAs and fisheries regulations, identification of personnel responsible for managing the data, consideration of ways to make relevant information accessible to the public, and collaboration with the Ocean Protection Council (OPC) on program design and funding. To promote system compatibility and learning across states, CDFW, OPC, or another entity should consider convening a workshop involving RMS experts and information technology staff from California, Oregon, and Washington. CDFW should also investigate the potential for partnerships with other state agencies, such as the Department of Parks and CalFire.
- CDFW should investigate the feasibility of requiring violators of MPA or fisheries regulations to install and use VMS for any future fishing by that operator and vessel. If that option is deemed feasible, CDFW should implement such a requirement as quickly as possible.
- CDFW should determine more precisely how many vessels would need VMS in order to achieve coverage of the entire California commercial fleet.
- Where hot spots of MPA violations and related incidents have been identified, we recommend that CDFW investigate whether sufficient radar units are in place to allow radar surveillance of those locations, and whether those units are operated by cooperative entities. This analysis would help determine the feasibility of radar surveillance in those hot spots.

I. EXISTING RESOURCES

CDFW currently operates with a fairly stable annual budget of approximately $70 million for enforcement on land and in state marine waters. A joint enforcement agreement for fisheries with the National Oceanic and Atmospheric Administration (NOAA) provides another $1 million, and the Minerals Management Service Mitigation Fund and Department of Water Resources provide additional small amounts of funds. CDFW is charged with enforcing regulations not only for fisheries and MPAs, but also for pollution, wildlife, and habitat on land and at sea; for homeland security; and for drug trafficking. To carry out its responsibilities for fishery and MPA enforcement, CDFW currently uses a variety of enforcement technologies and collaborative partnerships.

CDFW WARDENS

Available enforcement platforms include six large patrol boats based in Berkeley, Moss Landing, Morro Bay, Ventura, Los Angeles, and Dana Point; each boat has a lieutenant, an engineer, and four game wardens. An additional crew of coastal wardens has small skiffs for nearshore enforcement, but they also respond to wildlife and pollution issues inland.

RECORDS MANAGEMENT SYSTEM

CDFW's current records management system is based on paper tickets and does not have the capacity for temporal and spatial trend analysis, identification of hot spots for violations, or data sharing among states.

COLLABORATIVE ENFORCEMENT

CDFW collaborates with District 11 of the U.S. Coast Guard, but fisheries enforcement is not the Coast Guard's main priority, and officers are generally not suitably trained to detect all fishing violations. CDFW also collaborates with the National Marine Sanctuary Program, the National Park Service, and the State Parks Department on enforcement of MPA regulations.

AIR FLEET

Several twin-engine aircraft owned by CDFW have offshore monitoring capability, and a U.S. Coast Guard helicopter is used for onshore monitoring. CDFW has also occasionally used aircraft from the Coast Guard's fleet of C-130s—transport planes that can carry rescue and oil pollution-control equipment.

VESSEL MONITORING SYSTEMS

NOAA Fisheries requires that commercial fishing vessels participating in the federally managed Pacific groundfish, albacore tuna, and drift gill net fisheries have VMS. These systems were required to help enforce spatial restrictions such as rockfish conservation areas and essential fish habitat protection areas. An estimated 200 to 300 California-registered fishing vessels (out of about 3,000 total licensed California commercial fishing vessels) currently carry VMS as part of federal fishery management plans or treaties. Though these systems are monitored by NOAA enforcement and were

required by the federal government, we include them among CDFW resources because they already track participating vessels' passage through MPAs, and because they would help reduce the cost of equipping all California commercial fishing vessels with VMS.

CITIZEN SUPPORT

CalTIP, a confidential witness program, allows citizens to report violations directly to wardens. To update the technology and improve the reporting rate, CDFW recently adopted Tip 411, a service widely used by other law enforcement agencies that allows citizens to anonymously report tips through text, web, and mobile applications. The citizen and a warden can engage in an anonymous conversation if additional information is needed, and if a tip leads to prosecution, the citizen can receive an award. Reporting rates are now increasing: 3,763 tips were logged in 2013 and 4,242 in 2014, with marine tips accounting for about 20 percent of those totals.[1]

CAMERAS

Several cameras installed by entities other than CDFW currently focus on MPAs or special closures,[2] but only one set, installed and operated by the City of Laguna Beach, is routinely used for enforcement purposes. See the Appendix for location and purpose of cameras currently installed in or near coastal MPAs.

By all accounts, CDFW is understaffed for the enormous amount of territory wardens must cover and the varied threats they address. The technological options prioritized in this paper do not substitute for increasing California's warden force but can help expand its reach and effectiveness in the marine portion of its beat. The following sections provide a discussion of pros and cons of potentially promising enforcement technologies and an initial look at costs where that information was readily available.

II. CRITERIA FOR EVALUATION

We evaluated technology options using the criteria below. If a technology meets a preponderance of the criteria, we consider it a priority option. A different choice of criteria could be equally or more relevant. The point of this section is to explicitly detail our criteria. Our cost evaluation is very preliminary; more analysis would be needed before making decisions on the basis of cost.

- **Compatibility**
  Does it fit with, harness, and/or enhance existing resources for enforcing MPAs? Is it compatible with similar technologies in other jurisdictions? For example, a new electronic record management system for California will have more value if it is designed to be compatible with the systems used in Oregon and Washington.
- **Maturity**
  Is the option readily available in a form applicable to California MPAs, or would significant changes be needed to adapt it to CDFW needs? Is the technology still being pilot-tested, or has it matured beyond the first generation? A cutting-edge technology may well be worth some investment of time by CDFW to help tailor the tool to California's needs. For the purposes of this paper, however, the authors favor mature technologies for major investments.
- **Data integrity**
  Will the option help provide reliable data that will stand up in court? For example, does a tracking system provide relatively frequent position data (e.g., once per quarter hour or half hour)? A compelling court case will typically require data from more than one source, and the data supplied by each source must be dependable and detailed enough to support an enforcement action.
- **Scale**
  Can the option be applied statewide, or is it better suited for targeted use? Both scales are important, and use of some targeted tools can proceed simultaneously with statewide tools. But for the purposes of this paper, we give more weight to tools with statewide application. Scale also involves whether the tool is appropriate for the size of fishing vessels typical on the California coast, and whether its spatial resolution is adequate to support court cases and withstand legal challenges.
- **Cost**
  Is information available on the option's cost? Do preliminary cost data suggest this option will not be cost effective at this time?

III. RECORDS MANAGEMENT SYSTEM (RMS)

FINDINGS

CDFW's greatest self-reported technological need is software to improve its data management system for citations, warnings or other incidents, and supporting information. In addition to improving efficiency, an upgraded RMS would lay the foundation for other promising options, facilitating the analysis of trends and a move toward predictive tracking, as described in Section IV below.[3] An electronic records system could immediately provide information on any previous violations and incidents, registered weapons, and other information involving a suspect, contributing to officer safety and effectiveness. It would have statewide and regional application. Oregon and Washington already have such systems; California lags behind. The legislature has recognized the importance of electronic records management by DFW and asked for a report on its feasibility by January 1, 2016 (see Section 702.1 of the California Fish and Game Code). We find updated RMS meets all the criteria outlined above, and therefore it ranks as a top priority.

We recommend that CDFW take prompt action to implement an electronic RMS compatible with those in Oregon and Washington. That undertaking should include a careful needs assessment of the bare minimum of data types needed for enforcement of California MPAs and fisheries regulations, identification of personnel responsible for managing the data, consideration of ways to make relevant information accessible to the public, and collaboration with the OPC on program design and funding. To promote system compatibility and learning across states, CDFW, OPC, or another entity should consider convening a workshop involving RMS experts and information technology staff from California, Oregon, and Washington.

DISCUSSION

An improved RMS would allow CDFW to strategically target enforcement efforts and use its limited resources more efficiently. For example, an upgraded system could improve CDFW's ability to identify incident hot spots by electronically cataloging and mapping citations and other incidents. It could also streamline the process by allowing an officer to write a narrative of an incident that populates an electronic form, is immediately uploaded to the agency's internal system, and is sent directly to court.

A survey of records management systems across several states revealed a variety of systems in place.

- The internal IT team at the Florida Fish and Wildlife Conservation Commission developed ArrestNet, which uses both mobile computers and paper tickets. The commission is exploring the use of IBM's SPSS predictive policing software, discussed in Section lV below.
- The Fish and Wildlife Division of the Oregon State Police, the U.S. Department of Interior, Los Angeles Police Department, California Highway Patrol, and a range of other enforcement agencies currently use the Niche Records Management System. The system tracks violators from "incident to incarceration or exoneration," is compatible with predictive policing software, has some internal capabilities for predictive analytics, and is "future proof," with free upgrades and compatibility checks. The system costs $1,400 per sworn officer with a minimum of 500 officers, so CDFW would need to adopt the technology with another agency or agencies.
- The Washington Department of Fish and Wildlife utilizes CODY RMS interfaced with SECTOR. The system allows officers to scan a suspect's driver's license and write a narrative of the crime that populates an electronic form. The information is immediately uploaded to the agency's internal systems and sent to court, eliminating the need to mail paper tickets. CDFW has discussed the possibility of implementing CODY and has received a detailed quote from the company.

Compatibility of any new California RMS with those in other states would help keep violators from slipping through the cracks as they cross state lines.

IV. PREDICTIVE TRACKING

FINDINGS

The limited resources of CDFW can be optimized by targeting patrols to areas prone to MPA violations; illegal, unreported, or unregulated fishing; or other incidents. CDFW already uses the collective experience of its wardens to target geographical hot spots of potential violations. The agency could make that process more systematic by using predictive tracking methods that provide spatial analysis of data on violations and reported incidents. We examine three tracking methods: (1) predictive policing, (2) fishing forecasting, and (3) fishing behavior detection software.

Predictive policing has been successful in major cities. Given the statewide reach of this tool, its track record, and its ability to focus—and thus enhance—CDFW enforcement resources, we find that it meets the evaluation criteria and ranks as a priority option. Its costs appear to be reasonable but need a closer look. Fishing forecasting, an analytic tool used mainly by fishermen to predict the location of target migratory species based on oceanographic data, may have value as a fishery enforcement tool. But its one-kilometer resolution makes it unlikely to be useful for enforcing MPAs in California's three-mile zone. Fishing behavior detection uses remote sensing and behavioral analytics to identify suspicious fishing activities and is a promising but relatively new field of study. Because fishing behavior detection technologies are in the early stages of development and oriented toward large vessels, they do not match well with CDFW's responsibilities at this time. With input from wardens, these tools could be adapted and may hold promise for future use on California's coast.

DISCUSSION

Predictive Policing

Predictive policing involves using technology and data analysis to track enforcement activities by location, in order to proactively address enforcement needs. Ocean areas where crimes are likely to occur can be predicted by compiling data from such sources as historical VMS and AIS[4] tracking, radar and camera images, geofencing, past enforcement actions, CalTIP information, weather reports, and other big data sources, and analyzing these data with a variety of software systems.

An example of this predictive software is PredPol, which was created by a team of PhD mathematicians and social scientists in collaboration with the Los Angeles and Santa Cruz police departments. It inputs the type, time, and location of a crime into a sophisticated algorithm to predict the probabilities of future crimes in areas of space and time. The software needs two to ten years of past data. That means recent CDFW data would need to be digitized (or the department could wait to fully implement a PredPol system until it had collected a few years of digital data). PredPol can work with any database, is entirely cloud-based, and is delivered to law enforcement in Google Maps. The software requires an annual subscription of tens of thousands of dollars a year but needs no support staff.

A range of law enforcement agencies including the Memphis and Miami-Dade police departments use IBM SPSS Predictive Analytics software. This software has a data-mining workbench that pulls from disparate sources, selects target variables, and runs simultaneous models. IBM SPSS works with any records management system and can run on one computer to a server that pushes information to multiple platforms, depending on the need. The system can cost anywhere from $20,000 to $2 million, but the needs of CDFW are most likely in the lower end of the spectrum.

Fishing Forecasting

Many recreational and commercial fishermen use fish forecasting services like Roffer's Ocean Fishing Forecasting Service and SeaStar to target their fishing efforts. These services integrate oceanographic data including water temperature, orientation of local currents, and the presence of upwelling to predict the locations of migratory fish, particularly species such as tuna, swordfish, and sharks, in the 200-mile Exclusive Economic Zone beyond California's state waters. Because this technology has a resolution of one kilometer, it is unlikely to be valuable for MPA enforcement in state waters. For migratory species enforcement, however, this method could help enforcement personnel stay on top of changes in movement patterns and locations of fish and fishermen and diversify the sources of information available for targeting enforcement activities.

Fishing Behavior Detection

Fishing behavior detection is a very new field of study. Companies like SkyTruth, SpaceQuest, and Windward use remote sensing and behavioral analytics to identify unusual behavior or illegal, unreported, and unregulated (IUU) fishing. Because these technologies are still in the early stages of development and in most cases are being used for tracking ships and operations larger than those common on the California coast, the companies would need to work closely with CDFW personnel to create and tailor the software to CDFW's specifications.

- SkyTruth combines multiple satellite-based technologies including VMS, AIS, and Synthetic Aperture Radar (SAR)[5] images to track both broadcasting ships and silent ships and detect suspicious behavior such as silencing AIS, rendezvousing with vessels to "transship" fish, and engaging in active fishing-pattern movements in restricted areas. The company currently focuses only on offshore areas but is willing to work with CDFW to tailor a system to its needs.

- SpaceQuest manufactures satellites and tracks and analyzes broadcasting ships in a manner similar to SkyTruth's, but it currently utilizes only AIS along with intermittent satellite data. One person can install the software and a "coastal station" (a six-foot vertical antenna that can be attached to the wall of a building plus a small device that connects to the Internet) in no more than a day, at a cost of $1,100 to $1,400 per full day of installation time. Each coastal station can detect vessels within a radius of 30 to 40 miles. While there are no ongoing costs to use these stations to track vessels via satellite data, combining that data with the fishing algorithm would cost roughly $10,000 to $15,000 per month. The system provides a screen view of all vessels broadcasting AIS messages, shows overlays of spatial restrictions, and highlights vessels likely to be engaged in fishing activity. It can be viewed on a web browser by any registered user. Sharing the system with other entities such as the Coast Guard could reduce costs, but the system's inability to track the vast majority of California fishing vessels, which do not carry AIS, means it would not be useful for the state's marine enforcement unless the state required AIS for all licensed commercial fishing vessels.
- MarInt, offered by Windward, is a global predictive maritime analytics system that continuously collects AIS reports, SAR images, and optical satellite images and integrates the information with unclassified commercial ships' databases and open-source intelligence to create a comprehensive maritime picture. It builds a profile for each vessel, including historical paths, to establish contextual patterns and applies predictive analysis algorithms to detect anomalous behaviors and patterns. This system focuses on maritime security rather than IUU fishing or protected area enforcement.

V. COOPERATIVE TECHNOLOGIES

FINDINGS

The term "cooperative" refers to monitoring technologies that involve fishermen carrying a device on board, usually as a requirement for fishing, not as a voluntary action. Cooperative technologies facilitate collection of data on activities such as fishing routes, start and stop locations, and catch and bycatch. These data can be used to track vessel movement and monitor compliance with fishery and MPA regulations. Examples include VMS, AIS, electronic logbooks, and electronic monitoring.

Use of VMS for all California commercial vessels, including commercial passenger fishing vessels (CPFVs), would greatly enhance CDFW's ability to ensure compliance of participating vessels with MPAs and other spatial regulations. VMS was designed for vessel tracking and enforcement purposes; it is highly tamper-resistant and its data are protected. It allows wardens to see overall patterns of movement by the commercial fleet. When reported frequently enough, VMS position data can provide a reliable record for use in court, though it generally needs to be substantiated by direct observation or other corroborating data.[6] The system facilitates geofencing, which involves creating a virtual box around an area of interest that triggers notification when a vessel crosses the boundary, and can provide high-quality data for predictive policing (see Section IV).

We find that VMS meets our evaluation criteria and ranks as a priority option. This mature technology is already in wide use on the Pacific coast. It is worth noting that some of its costs will be defrayed due to the fact that many California vessels already carry VMS. But the cost of equipment and data processing will still be significant, making this option a potential candidate for phased implementation. Furthermore, VMS could be put in place more quickly and inexpensively if it were used on a selective basis, for example by requiring any vessel operator found in violation of MPA or fisheries regulations to carry it as a condition of continuing to fish. That approach would also likely reduce future violations.

We therefore recommend that CDFW investigate the feasibility of requiring violators of MPA and fisheries regulations to install and use frequently-reporting VMS, possibly as one of its administrative penalties. If such a requirement is deemed feasible, CDFW should take action to implement it as quickly as possible. We *also* recommend further investigation of the number of vessels that would need VMS in order to achieve full coverage of California's commercial fleet.

AIS is currently used primarily for large ships (more than 65 feet long). Designed for collision avoidance and safety purposes, this system is just beginning to be used to support fishery enforcement. Class B transmitters have appeal due to their low price (about $600) and their geographic reach of 20 to 100 nautical miles. A land-based receiver network would be needed to ensure a strong and reliable signal from these low-power devices; more research is needed to identify any gaps in California's system of shore-based receivers, which are operated by the Coast Guard. Additional technicians

would be needed to analyze data for California fishing vessels. Because AIS is an open, publicly shared system that anyone can purchase and install, its data are not as legally actionable as data from VMS. One option for use of AIS is a requirement that all vessels entering an MPA carry AIS, which would make traveling through an MPA without AIS a violation. We rank AIS as a lower-priority enforcement tool because it does not fully meet our data-integrity and maturity criteria as an enforcement tool.

Electronic logbooks could be valuable for detecting trends, predictive tracking of cooperating commercial vessels, and collecting fishery-dependent data for use in fishery management. They do not provide real-time data for MPA enforcement.

It is important to note that cooperative technologies, particularly VMS and AIS, help facilitate MPA compliance by vessels that carry a tracking device. If the main violators are small skiffs, private recreation boats, or other vessels for which these tools would be impractical, systems like radar or cameras that help track vessels without onboard devices will be more effective. Commercial vessels typically have higher capacity and greater potential to harm ocean resources in a shorter time than sport vessels; nonetheless, analysis of California's most common types of violations could help inform decisions about whether to invest in cooperative or non-cooperative technologies, or some combination.

DISCUSSION

Vessel Monitoring System (VMS)

VMS is composed of a transceiver unit—capable of transmitting and receiving signals—that sends its global positioning system (GPS) coordinates with 10-meter resolution to a monitoring station onshore by means of a communications satellite.

VMS would help wardens spot MPA violations by commercial fishing vessels and high-impact recreational CPFVs in real time and would help track potential historical violations and trends. It will also have significant benefits for fishery management.

VMS units are currently required by NOAA Fisheries for all participants in the commercial Pacific groundfish fishery to help enforce place-based regulations, such as the rockfish conservation area and areas protected as essential fish habitat. They are also required for the gill net and albacore tuna fisheries. The groundfish fishery is based primarily in federal waters, 3 to 200 miles from the coast, but also includes fishing activity inside state waters, up to 3 miles out from the shore.

VMS is a mature and proven technology. Being tracked is unpopular with many in the fishing industry, but these units provide several benefits for fishermen, including increased safety and improved capacity to keep in touch with markets and communicate for other purposes at sea.

VMS units can monitor only the position and speed of a vessel (not whether fishing is occurring), so potential violations detected with VMS need to be substantiated with direct observation or corroborating evidence, or via a regulatory scheme that eliminates ambiguity. For instance, a vessel may be required to stay out of a particular area altogether or, as with existing groundfish regulations, be required to maintain a continuous transit through a protected area. A recent court decision challenged the ability of VMS to provide adequate proof of the latter at the current once-per-hour ping rate. Coupling technologies may prove to be one solution. Use of current VMS systems could serve as an early warning for potential violations, while a data logger or other technology could provide a finer-scale assessment of vessel activity.

Though GPS coverage is continuous, VMS units typically report a vessel's position every one to two hours to a fishery monitoring center where data are collected and analyzed. Pacific coast groundfish permit holders, for example, report every hour. At a higher cost, the reporting rate can be increased to build a stronger record for enforcement purposes. New VMS systems can report on vessel position every hour with a packet of positions every several seconds over the past hour. These units have not yet been approved by NOAA for use in West Coast fisheries, but it is likely that approval could be obtained without great difficulty.[7] California could address this problem by approving new VMS units for fisheries not already covered (or working with NOAA Enforcement to secure federal approval for newer units) or possibly by requiring fishermen to install and use a data logger along with their VMS unit to continuously record vessel location and speed. Regulations would also be needed, requiring, for example, that data be kept for a year or other set period of time.

Several software packages, such as TrackWell VMS, are available for vessel tracking. This software provides a customized map of broadcasting vessels that includes vessel location and speed; it can track automatic identification systems in addition to VMS. TrackWell VMS can search and run statistics on repeat violators, lock onto and follow vessels' movements, and alert an officer when a vessel reaches a specific speed or crosses a geofence demarcating an area of interest, such as an MPA. The program can be installed as local software or on the cloud and typically costs several hundred thousand dollars, not including support and maintenance contracts.

Software now being developed uses algorithms to interpret vessel movements as certain activities, such as fishing, which allows officers to target their patrols. Additional information regarding this software can be found in Section IV under Fishing Behavior Detection.

The typical annual cost to agencies for operating a fisheries monitoring center, which processes and interprets the data collected by VMS, is between $50,000 and $500,000. Adoption of VMS in California fisheries would be more affordable if the state partnered with NOAA and used the existing NOAA West Coast monitoring center, with the state fully or partially paying the cost of additional technicians.

A VMS unit approved by NOAA for the groundfish fishery costs $2,500 to $3,300, plus installation. A data logger costs about $300. Monthly operating costs range from $10 to $170, depending on the reporting interval. California now has about 3,000 licensed commercial fishing vessels, of which approximately 10 percent already have VMS. A number of currently licensed vessels fish very little and might choose to forgo a license if required to purchase VMS. If VMS were required for marine CPFVs, up to 450 vessels would need to purchase units (a small number of inland water CPFVs would not need a unit). The federal government reimbursed commercial vessel owners in the Pacific groundfish fishery for the equipment and installation cost of two-way VMS units; if funding were available, the state could consider a similar program for some or all of its commercial vessels.

In the near term, selective use of VMS could have an important place in California's enforcement efforts. The potential of requiring MPA violators to install and use frequently reporting VMS should be investigated now. If that option is deemed feasible, CDFW should pursue it as quickly as possible.

Automatic Identification System (AIS)

AIS is a shipboard broadcast system that functions like a transponder and operates through the very-high-frequency (VHF) maritime band. Ships equipped with AIS can broadcast information to other vessels and coastal management authorities on shore including position, navigational data (heading, speed, rate of turn, etc.), and ship identity (maritime mobile service identity [MMSI] number, call sign, name, type of ship, etc.). Operated by the Coast Guard and originally intended for navigational safety and collision avoidance, AIS has a far higher reporting rate (from every six minutes to every two seconds) than the VMS units now required in the Pacific groundfish fishery. Its range is limited to about 20 to 100 nautical miles, which would encompass rockfish conservation areas and California MPAs. Currently, the International Maritime Organization requires AIS on cargo and passenger ships and large tankers traveling through international waters; most fishing vessels have not been subject to AIS requirements, but regulations published in January 2015[8] will expand the AIS requirement to fishing vessels 65 feet in length or longer.

AIS can potentially improve fisheries enforcement by monitoring vessel movement. Because each unit typically has several unused data slots available to transmit additional information, AIS could be integrated fairly easily with other vessel monitoring technologies, such as electronic monitoring sensors on hydraulic fishing equipment. As with VMS, AIS can establish distinctive movement patterns to potentially identify fishing activity, but suspected violations need to be substantiated with direct observation. Moreover, frequent position reporting produces a high volume of data that makes real-time tracking impossible.

AIS could also be adapted to display MPA boundaries on vessels with electronic chart displays, potentially improving voluntary compliance and shifting the burden of proof in prosecuting violations. This could be done at a considerably lower cost of installation and maintenance than for the radar beacon (RACON) system currently utilized to mark navigational hazards, but the technology has been applied in this manner only in preliminary trials.

The fact that AIS is an open-source, publicly shared system allows many people to participate in tracking vessels all over the globe. But that openness also means its data are not as legally actionable as data from the protected, tamper-resistant VMS systems.

The range of AIS can be extended by mounting AIS receivers on microsatellites, potentially reaching more than 1,000 nautical miles. ExactEarth, a subsidiary of COM DEV, has a fully operational constellation of satellites that can provide commercially available space-based AIS (AIS-S) services. Although AIS-S has the benefits of an extended range, four years of vessel-tracking data, and the ability to flag suspicious ships, the refresh rate of the constellation of satellites is less than 30 minutes in poleward regions and less than 90 minutes in equatorial regions, a reporting rate similar to that of VMS. More important, the extended range would not be needed for enforcement of California MPAs or most of its fisheries.

AIS Class A transponders—required for large vessels—typically cost $5,000 or more and produce a strong and reliable signal. Government agencies may opt to use Class B transponders, which cost about $600, for smaller vessels. Though Class B units have less power and produce a weaker signal, a network of shore-based receivers greatly improves the reliability of those units. More research is needed to determine whether California's existing shore-based receivers constitute a complete network.

The cost of AIS-S—a few million dollars for a yearly subscription—appears to be prohibitive for use by CDFW; however, this fee is based on use by national governments and similarly scaled organizations. AIS-S data from a national subscription may be available to local government agencies at minimal cost, but technicians would be needed to process the data from either AIS or AIS-S.

Regardless of cost, the current focus of this technology on large, non-fishing vessels, its relatively untested use as an MPA or fishery enforcement tool, and its unprotected data make AIS a lower-priority option based on our data-integrity and maturity criteria.

Electronic Logbooks

Electronic logbooks automatically record vessel location at set intervals and allow ship personnel to input other information (haul start, haul stop, catch amount, etc.) at each location. The contents of these logbooks can be transmitted to an enforcement entity via a cell phone system, as soon as the vessel comes into cell range of shore.

The quality of this technology depends substantially on the accuracy of the information logged by the crew. The information is not provided to enforcement agents in real time, so it cannot be used to catch violators of spatial restrictions in the act. It can, however, provide regulatory agencies with detailed monitoring and timely data on catch by cooperative vessels and can be used to reconstruct the history of a fishing trip, especially in conjunction with VMS. Those functions make it potentially valuable for detecting trends and for predictive tracking of participating commercial vessels (see Section IV).

Electronic Monitoring Systems (EMS)

EMS uses onboard video recorders and a suite of sensors and data processors to record activities on parts of a fishing vessel, typically where gear is deployed and retrieved and where fish are brought on board or processed. Sensors must also be placed on hydraulics, winches, and other fishing equipment to detect when fishing activity is under way. This information is continuously logged while a vessel is at sea and is integrated with recorded GPS location and vessel speed. EMS costs approximately $8,000 to $10,000 for installation and about $150 per sea-day per vessel, though costs can vary considerably. Generating real-time information is not currently possible due to the large volume of data generated. The data must be processed by a trained analyst. While the detailed and continuous coverage provided by EMS could be helpful for MPA enforcement, its cost and lack of real-time data raise significant challenges.

VI. NON-COOPERATIVE TECHNOLOGIES

FINDINGS

Non-cooperative technologies provide data on vessels regardless of whether they carry a tracking device. That makes them particularly valuable for detecting violations by recreational boats and other vessels that do not carry tracking devices like VMS or AIS, and for monitoring hot spots of violations. Acoustic surveillance, radar imaging, and optical imaging, discussed below, may offer potential for targeted surveillance of hot spots, once identified. Of these options, cameras and radar appear to be most promising, contingent on various factors. To be effective, cameras must be installed in a tamper-proof location with a clear view of an MPA; use of radar will likely be affordable only if some radar equipment is already in place in a location of interest.

The Marine Law Enforcement Information Network (MLEIN) in the Chesapeake Bay is an example of how these technologies can be combined to help coordinate and direct enforcement resources. It uses geofencing with radar to identify hot spots and potential violations and to dispatch enforcement personnel at times and places where violations are suspected. The MLEIN system took advantage of preexisting radar systems to keep the project more affordable, linking the radar data from various sources through a software platform. Radar can provide imaging data on vessels that do not carry VMS or whose operators deliberately turn it off. Elements of the MLEIN system are likely to be applicable in California.

Where hot spots of MPA violations and related incidents have been identified, we recommend that CDFW investigate whether sufficient radar units are in place to allow radar surveillance of those locations, and whether they are operated by cooperative entities. This analysis would help determine the feasibility of radar surveillance in those hot spots.

DISCUSSION

Data Integration: MLEIN Case Study

Officers in the field need to receive data from various sources in a form they can use. When several sources are available, integrating data requires a data processing station (such as NOAA Enforcement's Fisheries Monitoring Center) where raw data can be analyzed and translated into an electronic map or other useful form. Maryland's MLEIN system provides an excellent example of data integration (also called data fusion).

MLEIN is a system of cameras and radar that allows officers to track and monitor vessels. Natural Resources Police (NRP) have nine radar systems and several long- and short-range cameras that cover the entire Chesapeake Bay. These radar and camera systems are owned and operated by a variety of agencies and integrated by NRP with VidSys in conjunction with CommandBridge software systems. VidSys links AIS, VMS, radar, and camera feeds to an interactive map that officers can access and control with only an Internet connection. VidSys is currently used by a wide range of entities including the Los Angeles Police Department, the City of Oakland, Bay Area Rapid Transit, and Apple, Inc. The cost of the software depends on the number of integrated systems and typically ranges from $150,000 to $300,000.

MLEIN also allows officers to target areas and receive email and text notifications when a geofence is breached. In Maryland, for example, an officer can zoom in on a vessel to monitor its behavior and identify vessels up to seven miles away. The network can also record vessel movements with date and time for pattern recognition and hot spot location. NRP uses the system to track nighttime oyster poachers, among other uses. About 15 agencies in the area now use the data integration platform, not just for enforcement but also for activities such as search and rescue.

MLEIN was developed with a $5.6 million Port Security Grant from the Department of Homeland Security and an additional $1 million from the state. IT personnel are needed to run the network; their duties include updating software and maintaining the camera and radar systems. The feasibility of this specific system in California depends on the extent of the camera and radar infrastructure along the coast. If existing infrastructure is minimal, cameras and radar can be placed in areas that have a high rate of violations or critical ecological importance. While the length of the California coastline poses a challenge for this system, the close proximity of most MPAs to the shoreline is ideal. Affordability is the biggest challenge to applying a system like this in California, but the state may be able to utilize a number of its elements in target areas.

Acoustic Surveillance

Passive acoustic systems use hydrophone arrays and other sensors to pick up sound waves from vessel engines. Vessel position, engine type, and potentially vessel speed, activity, and identity can be determined. Commercial systems can cover up to tens of kilometers, depending on the number of sensors and size of the array. The two main varieties, bottom-mounted hydrophones and offshore buoys, can be connected to shore by fiber optics or can transmit data via satellite or radio, achieving real-time or near-real-time surveillance. Use of these systems would require careful analysis to minimize impacts to sensitive ecological areas and marine life. Additional evaluation would be needed to determine whether these systems would be affordable and compatible with the protection purposes of MPAs. Because of these uncertainties and potential conflicts, we consider this approach a low priority.

Radar Imaging

Radar systems identify objects such as vessels by transmitting radio waves as electromagnetic radiation and detecting their reflection off the objects. Because radio waves travel in a straight line, their detection range is limited to the horizon, but raising the height of the radar can increase the range. Radar can be mounted on shore, aircraft, vessels, buoys, and other platforms. Radar meets most of our evaluation criteria, though its cost is likely to be prohibitive for anything other than targeted use. Research on existing radar installations maintained by the Coast Guard and other entities, particularly in select hot spots of suspected violations, would help determine how feasible these systems are in any given location. We note below two ways radar capacity can be expanded.

- **High-Frequency Over-the-Horizon Radar (OTH)**
  OTH and high-frequency surface wave radar (HFSWR) can provide continuous, real-time detection of vessels hundreds of kilometers away, but it cannot identify a vessel or its activity and therefore should be used in conjunction with other enforcement technologies. The U.S. Navy currently uses OTH for offshore surveillance, and the U.S. Drug Enforcement Agency and U.S. Coast Guard have successfully field-tested HFSWR.
- **Synthetic Aperture Radar (SAR)**
  SAR uses the forward motion of a satellite or aircraft to mimic the receiving abilities of a large antenna to produce high-resolution images. Satellite images are not available until three to four hours after acquisition, the revisit time for an area can take several days, and each image can cost about $4,000 to $5,000, making this technology useful primarily to spot-check areas of interest.

Optical Imaging Systems

Optical imaging systems rely on visual, infrared, and radar cameras to produce images that provide data on vessel activity as well as oceanographic and biological information.

- **Fixed-Camera Systems**
  Emerging camera technologies vary dramatically in price, reporting time, and resolution. The staff necessary to monitor real-time and delayed video feeds prohibits large-scale implementation, so targeted use is essential. These tools may be particularly useful in areas where the intensity of violations is known or suspected to be high. Several software packages are in development to review video and document vessel movement, but none are advanced enough yet to identify a ship or its actions.

  Camera systems are now in use in a number of California MPAs, most often for wildlife monitoring and interpretation purposes (see Appendix). An important exception occurs in Laguna Beach, where three live-feed cameras overlook the Laguna Beach State Marine Reserve (SMR) and connect directly to monitors in a marine safety dispatch center. If a marine safety officer or dispatcher witnesses a violation, he or she can immediately dispatch a lifeguard, animal services, or police department response unit. The center responds to observed MPA violations in addition to aquatic safety issues and violations of city ordinances. These cameras are the only ones on the coast currently used routinely for enforcement purposes. Other cameras and webcams already in place may hold promise for MPA enforcement, but that potential has not been systematically evaluated.

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- **Airborne Sensor Systems**
  A range of traditional visual, infrared, and radar imaging camera systems can be mounted on aircraft. The technologies vary in required aircraft, swath width, resolution, and price. Systems can produce a multitude of data and services including multispectral images, oil spill mapping, sea surface temperature, etc. Use of CDFW aircraft of aircraft from enforcement partners may be possible for this purpose; however, the efficiency and cost of this option likely makes this technology appropriate for extremely targeted use only.
- **Space-Based Optical Imagery**
  Several satellites in polar orbit can produce visible and infrared images of target areas, but due to sensitivity to weather conditions and darkness, limited swath width, long revisit times, and a high price per image, almost no research and development has been completed on software for vessel detection. This technology may have potential for targeted enforcement in the future, but further analysis of response time, geographic coverage, and image resolution is necessary to determine whether this tool would be economical for CDFW's purposes.

Electronic Intelligence (ELINT)

Electronic signals intelligence systems locate ships and aircraft using signals from the vessels' electronic systems, such as radar. The technology has been used almost exclusively for military purposes, but there are commercial packages such as the CS-3030 ELINT System that provide law enforcement agencies with antennas, receivers, signal processors, software, and operator workstations based

on land, ships, or planes. Further research is necessary to determine whether this option is financially and operationally appropriate for use by CDFW.

Integrated Sensor Systems

Surveillance technologies are often more powerful when unified. Several companies have produced commercially available sensor packages. For example, the MSS-6000 and Radar Ocean Master systems contain a suite of tools including radar, infrared/ultraviolet scanners, camera and video systems, and data processing centers. As with electronic intelligence, additional research is needed to determine whether the cost and applicability of integrated sensor systems make them a viable option for MPA enforcement by CDFW.

Customized Airborne Surveillance

Surveillance packages are offered through companies that own and operate their own aircraft and sensor suites, eliminating the need to purchase and maintain expensive technologies and platforms. Enforcement agencies place their own personnel on each flight because the companies, such as Provincial Aerospace, do not have law enforcement training. These packages are likely to be appropriate only for very targeted, high-stakes activities.

VII. PLATFORMS

FINDINGS

A variety of at-sea and airborne platforms are available for mounting surveillance technologies, in addition to piers and other options on land. CDFW relies primarily on manned patrol boats equipped with marine law enforcement officers to enforce MPA regulations through citations. The platforms discussed below may amplify the effectiveness of those patrols but are in no way a substitute for them. Modifications to patrol vessels and occasional targeted use of manned aircraft through partnerships with entities like the Coast Guard or the nonprofit Lighthawk organization, which coordinates volunteer pilots to fly for conservation purposes, appear to be the most promising additional platforms.

DISCUSSION

Manned Patrol Vessels

The most common platform for surveillance technologies is the manned patrol vessel. A value of this platform is its ability to facilitate investigation of vessel activity based on data from other sources; that value can be increased by modifying shipboard sensors to increase their range past the line of sight. Potential adjustments include raising radar above sea level on a tethered balloon or Helikite (a helium balloon with flexible fabric wings and a keel) to significantly increase its range; utilizing visible-band cameras and thermal imagers instead of binoculars to stabilize imagery and increase the range of operating conditions; and applying additional processing to video signals to help automate vessel location. Further research is necessary to determine whether these sensor modifications would be cost-effective for CDFW.

Unmanned Surface Vehicles (USVs)

USVs are small vehicles originally developed for military application to distance personnel from dangerous situations. The Swedish military's Piraya, Israel's Protector and the U.S. Navy's Spartan Scout are examples of USVs with differing capabilities, including multiunit simultaneous operation by a single operator, eight hours of endurance, and a 5,000-pound payload, respectively. A USV would provide an advantage over manned patrol vessels only if it had an extremely long range or could be run with other vessels simultaneously by one operator.

Buoys

Buoys are anchored units that can be configured for a specific surveillance need; they can be active or passive, surface or subsurface, unpowered or powered, and shore-linked or offshore. They have numerous applications, including as aids for navigation and platforms for vessel monitoring structures such as AIS relays and acoustic systems. The majority of California's MPAs are sufficiently close to shore that they do not require the more expensive powered buoys. Installing new buoys can involve permitting hurdles, potential habitat impacts, and maintenance costs.

Manned Aircraft

Aircraft, similar to manned patrol vessels, can vary greatly in endurance, range, speed, and operational cost. The length of the California coast and relatively high cost of owning and operating aircraft is potentially prohibitive. Use of CDFW aircraft; partnerships with the U.S. Coast Guard, which has 211 aircraft; and use of commercial contractors, such as Provincial Aerospace, may be feasible ways to increase access to aircraft in situations where their need can be anticipated. The nonprofit Lighthawk may also be a potential partner.

Aerostats and Airships

These vessels are non-rigged structures that float through the use of a lightweight gas such as helium. The most well-known airships are the blimps that are often used for advertising. The advantage of these vessels is their ability to hover in one location for an extended period of time and to support a variety of different sensors. The MAP program, established

by the U.S. Coast Guard in the 1980s, placed sophisticated radar on two vessels over Key West and Miami and was highly effective in aiding the surveillance of drug and illegal alien activity at a fraction of the cost of traditional aircraft and helicopter surveillance. Myriad vessels are available today, including rapidly elevated aerostat platforms, large unmanned airships, unmanned aircraft, and portable surveillance towers. Helikites are the most commonly used type of aerostat. They are small, mobile, and stable in foul weather. While these vessels are relatively inexpensive compared with a plane—a typical Helikite ranges from $150,000 to $450,000—they are still quite costly in the context of CDFW's budgetary constraints.

Unmanned Aerial Vehicles and Systems

UAVs and UASs are aircraft that are self-directed or controlled remotely. They can be equipped with observation technologies similar to those on manned aircraft, including search radar, SAR, optical imaging, and infrared imaging; the information with GPS coordinates can be sent via satellite for real-time enforcement. The aircraft classes include:

- handheld: 2,000-foot altitude, 2-kilometer range
- close: 5,000-foot altitude, up to 10-kilometer range
- near tactical: 10,000-foot altitude, up to 50-kilometer range
- long tactical: 18,000-foot altitude, about 160-kilometer range
- medium-altitude, long-endurance (MALE): up to 30,000-foot altitude, range over 200 kilometers
- high-altitude, long-endurance (HALE): over 30,000-foot altitude, indefinite range

Only the first two types of aircraft have been used for nonmilitary activities, and many of these hobbyist aircraft do not have a suitable range or data transmission capability for enforcement needs. The cost and legality of larger aircraft are prohibitive; each system costs hundreds of thousands to tens of millions of dollars, can require a remote pilot, and is limited by restrictions in civilian airspace. In 2009 the U.S. Coast Guard developed a funding plan to acquire low-altitude, cutter-based, tactical UAS and mid-altitude, land-based, long-range UAS. UAS technology should not be part of a CDFW surveillance system until the technology is more widespread and easily available, but a partnership with the U.S. Coast Guard and/or the West Coast National Marine Sanctuaries may provide an opportunity to use these technologies for spot-checking and pilot programs.

VIII. CONCLUSION

CDFW has many technology choices that could benefit MPA enforcement. Our analysis suggests that a portfolio of complementary technologies that builds on CDFW's strengths is the most effective way to improve enforcement in state waters. Systems that aid in focusing existing resources, such as predictive tracking software and limited use of radar and camera imaging for targeting hot spots, rank as high-priority options according to our criteria.

The ability to apply these systems is predicated on an upgrade of CDFW's records management system to allow for electronic recordkeeping. Because an updated RMS is a precursor for other tracking tools and also has value for fishery enforcement, we consider it a top priority. Partnerships with the California Highway Patrol or other enforcement entities may make such upgrades more available or affordable.

VMS provides the clear benefit of spatial tracking of all vessels covered by the system. If newer units with frequent reporting (or their equivalent) are used, this premier tracking system can provide reliable real-time spatial information and facilitate geofencing. Regulations can be written to mandate use of VMS; however, potential violations generally need to be substantiated and corroborated for sufficient evidence of a violation. VMS meets our criteria for a priority technology. Cost is likely its biggest challenge; phased application of VMS may make these systems more affordable.

These options fit well with current CDFW enforcement practices for protected areas and fisheries, such as its sting operations directed at poachers, its CalTIP program, and its cooperation with county-based collaborative groups and local MPA-watch citizens groups. They should all be considered seriously and explored further.

We rank AIS as a lower priority at this time because its data are less reliable than those produced by VMS and it is just beginning to be used as an enforcement technology. The more expensive, nascent hardware such as drones and unmanned surveillance vehicles are not currently practical given CDFW's limited budget and large enforcement area, with the possible exception of partnerships for occasional use of such tools. Fishing behavior detection systems, in the early stages of development and now used mainly for large ships, do not currently address California's enforcement needs but may have promise in the future.

In sum, the lasting success of California's MPA network relies to a significant degree on the effectiveness of CDFW's enforcement program. California is unlikely to be able to fund implementation of all the promising tools, so prioritization will be needed. Employing cost-effective technologies that leverage existing systems and partnerships will help maximize efficiency and provide CDFW with tools to better protect the state's marine resources. Improved enforcement and compliance will yield benefits for ongoing fisheries management in addition to those provided to MPAs.

REFERENCES

Brooke, S. D., T. Y. Lim, and J. A. Ardron, *Surveillance and Enforcement of Remote Maritime Areas*, Paper 1: Surveillance Technical Options, Version 1.2, Marine Conservation Biology Institute, USA (2010).

Marine Conservation Institute, *Optimizing Surveillance and Monitoring in North Central California's Marine Protected Areas: Recommendations*, Marine Conservation Institute, USA, Report to National Fish and Wildlife Foundation, Grant #26553 (2013).

Richardson, M., *Protecting America's Pacific Marine Monuments: A Review of Threats and Law Enforcement Issues*, Marine Conservation Institute, USA, (2012).

Davis, B. C., and G. S. Moretti, *Enforcing U.S. Marine Protected Areas: Synthesis Report*, National Marine Protected Areas Center, NOAA, Silver Spring, MD, in cooperation with NOAA Coastal Services Center (2005).

Cambone, S.A., P. Pace, K. Krieg, and L. Wells II, *Unmanned Aircraft System Roadmap 2005–2030*, Office of the U.S. Secretary of Defense, Washington, DC (2005).
King, D. M., Enforcement and Compliance in U.S. Commercial Fisheries, Lenfest Ocean Program (2010).

NOAA Coastal Services Center, *Marine Protected Areas Technology Needs Assessment: Final Report*, prepared in cooperation with the National Marine Protected Areas Center, Silver Spring, MD (2003).

National Marine Sanctuary Program, *2011 Annual Report – National Marine Sanctuaries – Florida Keys*, National Marine Sanctuary Program (2012).

National Marine Fisheries Service Office of Law Enforcement, *VMS Unit Cost and Capabilities Survey Report—August 2014, Report to the Pacific Fisheries Management Council*, NMFS (2014).

Bob Farrell (California DFW), *California Needs for Enforcement*, Conference reports from OceanAgenda, a workshop sponsored by Google, US Coast Guard, University of Hawaii, Stanford Center for Ocean Solutions, University of Porto, Anthropocene Institute and Fish 2.0, (April 2014).

Todd Jacobs (NOAA), *Challenges and Successes of Unmanned Aerial Systems*, Conference reports from OceanAgenda, a workshop sponsored by Google, US Coast Guard, University of Hawaii, Stanford Center for Ocean Solutions, University of Porto, Anthropocene Institute and Fish 2.0, (April 2014).

INTERVIEWEES

John Amos, President, SkyTruth

Michael Carver, Deputy Superintendent, Cordell Bank National Marine Sanctuary

Mike Cenci, Deputy Chief, Washington Department of Fish and Wildlife

John Deraedt, Certified Specialist, IBM SPSS

Beth Dieveney, Deputy Superintendent for Science and Policy, Florida Keys National Marine Sanctuary

Kyle Elliott, Director of Sales, Western U.S. and Canada, VidSys

Bob Farrell, Assistant Chief, CDFW North Coast District

Donald Fowler, Director of Business Development and Communications, PredPol

Kolbeinn Gunnarsson, Director of Sales and Services, TrackWell Maritime

Patrick Halpin, Director, Geospatial Ecology Program, Duke University

Dave Heffner, Executive Vice President, CODY Systems

David Hoffman, Director, Western U.S., Niche Technology

Dayna Matthews, West Coast Enforcement Coordinator, NOAA

Jessica McCawley, Director, Division of Marine Fisheries Management, Florida Fish and Wildlife Conservation Commission

Capt. Jeff Samuels, Division Director, Oregon State Police, Fish and Wildlife Division

Lieut. Timothy Schwartz, Oregon State Police, Fish and Wildlife Division

Maj. Mike Sewell, Maryland Natural Resources Police

APPENDIX: STATUS OF CAMERA-BASED MONITORING PROGRAMS AT CALIFORNIA MARINE PROTECTED AREAS, MAY 2014

This appendix summarizes available information on fixed cameras currently in place in or near California MPAs.

1. CITY OF LAGUNA BEACH

Laguna Beach employs three live-feed cameras (and is likely to get a fourth), all overlooking the Laguna Beach SMR. This is the most advanced program in the state, with its cameras directly connected to a dispatch center for marine safety. The cameras link to multiple monitors in the Marine Safety Communications Center and are monitored by either a marine safety officer or a marine safety dispatcher. If those observers witness a violation, they can immediately dispatch a response unit, either a life guard, animal services officer, or police officer.

The cameras are meant to facilitate timely response to MPA violations as well as to monitor aquatic safety and violations of city ordinances. Since the cameras are placed in the areas of highest intertidal impact, MPA violations or disturbances in tide pools are noted most frequently.

2. LA JOLLA SMR

Scripps Institution scientist Ed Parnell has used a network of Nikon Coolpix 8700 still cameras to assess MPA use in hot spots of noncompliance, and he is testing unmanned aerial vehicles for a variety of purposes. A 2010 paper he co-authored[9] showed that fishing continued in and around MPAs, and that commercial passenger fishing vessels had not stopped fishing the La Jolla Reserve. This research was done in 2007–2008, before the expansion of marine reserves via the Marine Life Protection Act and the state's increased focus on MPA enforcement. His work shows that useful data can be generated using low-cost still cameras programmed to take time-lapse photos. It should be noted that the program benefited from having at least four graduate students reviewing subsets of the 35,000 photos ge9erated in one year.

3. POINT PIEDRAS BLANCAS ELEPHANT SEAL CAM

http://www.elephantseal.org/Rookery/livecam.html

This fixed-position wildlife interpretation camera is a joint venture between State Parks and Friends of the Elephant Seal. The camera is located at the boardwalks near the elephant seal rookery at Point Piedras Blancas. It is not being used for enforcement but rather for wildlife monitoring and interpretation. Volunteers from Friends of the Elephant Seal monitor the camera, while State Parks staff at Hearst Castle are in charge of maintenance and operation. There has been no discussion of using a camera here for monitoring fishing violations.

The Montano de Oro State Park has a current proposal for cameras that would take still photographs of birds and wildlife, but would not be intended to document violations.

4. AÑO NUEVO ISLAND ELEPHANT SEAL CAM

http://ngm.nationalgeographic.com/static-legacy/ngm/sealcam

State Parks maintains a camera at Año Nuevo Island for wildlife interpretation. The camera monitors the island's elephant seal colony. Park interpretation specialist Mike Merritt reports that it has been wildly successful in showing park visitors what is happening on the island. For easier maintenance, a rotating camera was replaced with a fixed camera. Still, the fact that the camera is on the island makes maintenance difficult; rangers charged with its upkeep can make only occasional trips for maintenance. There are no plans to use cameras here for monitoring fishing MPA violations.

5. DEVIL'S SLIDE SPECIAL CLOSURE—EGG ROCK

http://www.fws.gov/sfbayrefuges/murre/webcam.htm

USFWS has set up a webcam to monitor the murre colony at Egg Rock at Devil's slide. Pointed at the murres, it captures only the water immediately surrounding the rock.

6. POINT REYES NATIONAL SEASHORE

Point Reyes National Seashore plans to place four or five cameras at Point Reyes MPAs to assist with enforcement. Parks personnel plan to have one camera at the Double Point Special Closure, one at the Arch Rock Special Closure, and two or three at the Point Reyes Headlands special closures. These are Gamefinder still cameras with a zoom doubler. Their resolution is not very high, but is sufficient for the objective of determining whether any boats enter the special closure and thus whether more education is required. The cameras take pictures on a timed schedule and run about $300 each with the zoom lens.

7. SOUTHEAST FARALLON ISLAND

http://www.calacademy.org/webcams/farallones

This project is run by a partnership between the California Academy of Sciences and Point Blue (a non-profit ocean science organization with a long history of Farallones research). Its purpose is primarily wildlife monitoring and interpretation. The camera (an Axis 233D network dome camera capable of rotating 360 degrees) was installed in 2009 and required improving Internet access to Southeast Farallon Island. A live feed of the camera is displayed at the California Academy of Sciences in San Francisco. There is no plan to use the camera for enforcement; there are eyes on the water round the clock at SE Farallon, and violations are logged and reported by the biologists and staff at the island.

ENDNOTES

1 CalTIP data from email communication with Lieutenant Michael Milotz, Law Enforcement Division, CalTIP Coordinator, CDFW, May, 2015; observations about those data are the authors.

2 Special closures are relatively small areas with boating or access restrictions, designated by the California Fish and Game Commission to provide localized protection for sea bird rookeries and marine mammal haul-out sites.

3 Predictive tracking is a method of identifying incident hot spots and forecasting likely fishing behavior using a combination of historic enforcement data and information from other sources.

4 VMS is a satellite surveillance system that uses GPS to monitor the location and movement of commercial fishing vessels. AIS is an onboard broadcast system that transmits position, navigational information, and ship identity using VHF radio transmission. See Section IV for a discussion of these systems.

5 Synthetic Aperture Radar uses the forward motion of a satellite or aircraft to mimic the receiving abilities of a large antenna to produce high-resolution images. See Section V for discussion of this technology.

6 Enforcement Consultants Committee, "Enforcement Consultants Committee (EC) Report on Vessel Monitoring System Ping Rate," Pacific Fishery Management Council, March 2014, http://www.pcouncil.org/wp-content/uploads/H1c_SUP_EC_RPT_MAR2014BB.pdf

7 Personal communication, Dayna Matthews, West Coast Enforcement Coordinator, NOAA Enforcement.

8 Department of Homeland Security, Federal Register, Department of Homeland Security, January 30, 2015. http://www.navcen.uscg.gov/pdf/AIS/80_FR_5281_NOAD_AIS_FR.pdf.

9 Parnell, P.E., P.K. Dayton, R.A. Fisher, C.C. Loarie, and R.D. Darrow, "Spatial patterns of fishing effort off San Diego," *Ecological Applications*, V. 20 Issue 8, pp 2203 to 2222 (2010).