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Review of Whale Conservation Technology

A comprehensive review of emerging technologies, solutions, and cost considerations for reducing whale entanglements off the California Coast

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Background

Whale populations have been impacted by anthropogenic activities since humans started whaling for oil hundreds of years ago. Today the threats facing whales are much different but can still be accredited to human interference in their habitat, with the two most pressing threats being whale entanglement in fishing gear and ship strikes[1]. Effectively protecting whales from these threats requires understanding the situations and environments where whales and humans are likely to come into contact. Achieving this requires rigorous monitoring programs that consider both the location of whales and human activities. Keeping an accurate account of whale populations can be incredibly difficult. Whales are highly migratory animals that can cover large distances quickly and often spend a great deal of their time below water; whale survey methods need to be flexible enough to detect these changes in whale populations. Climate change is driving increased inter and intra-annual variability in migration timing and patterns. Human activities in the ocean are also not static, and extensive monitoring programs are required to keep an accurate accounting of their activities. When an entanglement or ship strike occurs, the impacted whale is not always detected, making it difficult to estimate the true impact of these events on whale populations.

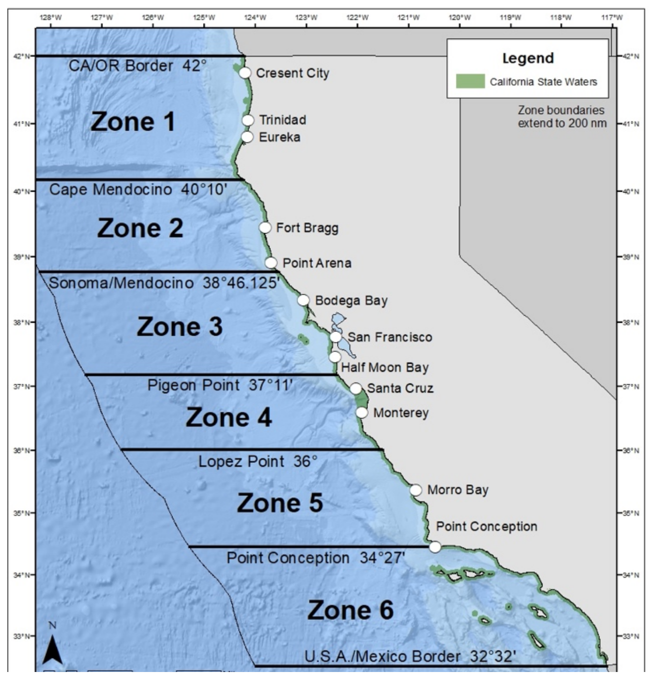

FIGURE 1: MAP OF RAMP ZONES. RISK ASSESSMENTS AND MANAGEMENT ACTIONS ARE APPLIED AT ZONE LEVEL. MAP ACCESSED FROM [CDFW Whale Safe Fisheries]

Beginning in 2014, entanglement in commercial fishing gear became one of the greatest threats facing whales, specifically humpbacks, along the west coast of America. This was because of a marine heatwave (MHW) event that had rippling effects in both whale populations and fishing activities. The

[1] Peter O. Thomas, Randall R. Reeves, and Robert L. Brownell Jr., "Status of the World's Baleen Whales," *Marine Mammal Science* 32, no. 2 (2016): 682–734, https://doi.org/10.1111/mms.12281.

2014-2016 MHW caused an increase in growth of toxic algae which resulted in domoic acid poisoning in Dungeness crab (D. crab). D. crab can't be harvested or consumed while there are elevated levels of domoic acid, so the fishing season was pushed back several months. At the same time, available forage for humpback whales was diminished and concentrated in the inshore areas where the majority of fishing activity occurs[2]. D. crab is fished using traps; the traps are deployed to the ocean floor and attached by vertical lines to a buoy at the surface, the traps are then left for several hours up to several days. During this period whales can become ensnared in the vertical lines. The spatial and temporal overlap in whale feeding locations and fishing grounds resulted in an increase in all whale entanglements off the West Coast from an average of 10 per year pre 2014 to a historic high of 50 in 2015[3].

One result of this MHW and associated entanglement events was the creation of the Dungeness Crab Fishing Gear Working Group (Working Group). The Working Group is a multi-stakeholder collective of conservation organizations (including The Nature Conservancy), D. crab fishermen, scientists, and CDFW and NOAA fisheries managers who convened to better understand and address whale entanglements in California[4]. One of the outcomes of the Working Group is the Risk Assessment and Mitigation Program (RAMP). The RAMP uses near real-time data to reduce the risk of whale entanglement by limiting co-occurrence of whales and fishing gear. Risk assessments are conducted every two weeks throughout the fishing season and require detailed data on whale presence and fishing activity across fishing grounds, which are divided into zones (see figure 1). When data indicates entanglement risk is elevated, CDFW can implement actions on a zone-by-zone basis, with measures including depth constraints, gear reductions, and fishery closures[5] [6]. Enforcement officers ensure compliance with spatial management decisions; however, they need data that is often more detailed than that used by the RAMP.

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[2] Jarrod A. Santora et al., "Habitat Compression and Ecosystem Shifts as Potential Links between Marine Heatwave and Record Whale Entanglements," *Nature Communications* 11, no. 1 (January 27, 2020): 536, https://doi.org/10.1038/s41467-019-14215-w.

[3] Santora et al.; "Making the Sea Safer for Whales," The Nature Conservancy, 2019, https://www.nature.org/en-us/about-us/where-we-work/united-states/california/stories-in-california/making-the-sea-safer-for-whales/.

[4] "Making the Sea Safer for Whales."

[5] "Risk Assessment Mitigation Program Regulations" (California Department of Fish and Wildlife, 2020).

[6] "§132.8. Risk Assessment and Mitigation Program: Commercial Dungeness Crab Fishery," Title 14, California Code of Regulations §132.8. § Government Code Section 11349.3 (2020).

Project Description

The strategy behind the RAMP is to mitigate entanglement risk and impacts to whales by limiting co-occurrence of whales and D. crab fishing gear. To do this, data on the location of whales, the location of fishermen and fishing gear, and where these areas overlap, is needed. While the RAMP has been implemented since 2019, the existing tools and methods for collecting the needed data are inefficient. Whale monitoring depends on manned aerial and vessel surveys that are cost and coordination intensive, are unable to cover broad areas, and are vulnerable to logistical disruption. Monitoring of D. crab fishing activity has historically been limited exclusively to dock side reporting and more recently bi-weekly self-reporting on fishing effort at the zone level. A new CDFW monitoring program requires fishermen to provide their vessel's location for all trips during the fishing season, however the logistics of how this data will be recorded and reported are still unclear[7].

To collect co-occurrence data in the most cost effective and nimble way, emerging technology needs to be considered. Emerging technologies present opportunities to fill data gaps and improve management decisions, however they need to be evaluated in the context of real-world management needs to fully understand their relative advantages.

This study seeks to identify relevant emerging technologies and define and compare them to the suite of traditional survey and monitoring methods, with the ultimate goal of creating a framework that can be used to identify the best approach (or approaches) to improve data collection and inform management decisions under the RAMP. To this end, a comprehensive literature review was conducted to fully understand the capabilities and limitations of emerging and traditional technologies and approaches. Additionally, scientists, fisheries managers, fishermen, conservation practitioners, and industry experts were interviewed to gain real-world insights into the use of these approaches, and any relevant concerns and considerations to include in our framework. Our study is divided into two categories, whale

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[7] California Department of Fish and Wildlife, "Compliance Guide for the California Commercial Dungeness Crab Fishery Electronic Monitoring Program" (CDFW, 2023).

monitoring, and vessel monitoring, to cover the two sides needed to accurately inform on co-occurrence to reduce entanglement risk[8].

This framework is designed to be flexible in evaluating new approaches and techniques as technology continues to advance, by narrowing in on the key considerations of adopting any new data collection method for the RAMP: what data can the approach provide? What are the associated costs? What are the key complexities?

Whale Monitoring

There are many methods and technologies used to survey whales that have been developed and are used to meet a range of marine mammal monitoring objectives– from identifying and studying individual whale behavior to population-level stock assessments. To fulfill monitoring requirements under the RAMP, survey methods need to produce whale counts through surveys with comprehensive coverage across all RAMP zones (see figure 1) on a bi-weekly basis to inform Risk Assessments and management action decisions[9].

This section will seek to analyze possible survey methods by: 1.) identifying the data needed to make management decisions under the RAMP, 2.) defining the suit of survey methods capable of delivering on these data needs, 3.) describing a novel framework for evaluating and comparing these approaches, 4.) applying the framework to the whale survey methods identified as having the greatest ability to provide presence/absence data over large areas in a short time period. Our results provide insights on the relative advantages and disadvantages of existing and emerging survey tools.

Whale Monitoring Data Needs

For the purposes of preventing whale entanglement in stationary fishing gear, whale counts that indicate the presence and distribution of whales over fishing grounds are the most important consideration, but several other factors are also considered including, ocean

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[8] CDFW Whale Safe Fisheries for examples of Risk Assessments (https://wildlife.ca.gov/Conservation/Marine/Whale-Safe-Fisheries)

[9] Ryan Bartling Personal Communication

conditions, forage conditions, and location of recent entanglements[10]. The RAMP makes management decisions on a near-real time basis, through the bi-weekly Risk Assessment process. This means data needs to be available from surveys very quickly, sometimes within a day or hours of a risk assessment due date[11]. It is also important for these surveys to cover a large area so they can sufficiently cover each RAMP Zone[12]. Surveys also need to be designed to optimize detection of humpback whales as the species of primary management concern, and the species that makes up the majority of entanglements[13]. Whale counts are considered a primary data source that can trigger mandatory management action (when a survey count per zone reaches a pre-set quantitative trigger (e.g., 20 whales in a RAMP zone). Together with information on fleet dynamics, ocean and forage conditions, and recent entanglements, whale distribution data informs the management action CDFW will take to mitigate entanglement risk while maintaining fishing opportunity when and where possible.

Whale Survey Methods

The following section describes current and emerging whale survey methods that are in use or have been considered for use to inform the RAMP. The content in this section is adapted from Cubaynes 2019 [14] and refined based on insights from expert interviews and additional literature review.

Manned Visual Surveys

Manned surveys consist of a person or group of people counting whales as they are sighted, typically while operating a predetermined survey protocol. Because they depend on human involvement, manned surveys can also be more expensive than other options in terms of human capital for planning and execution. There are three main categories of manned surveys; vessel, aerial, and land based.

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[10] Bartling
[11] Bartling
[12] §132.8. Risk Assessment and Mitigation Program: Commercial Dungeness Crab Fishery.
[13] "Case Study-- California Dungeness Crab Fishing Gear Working Group" (The Nature Conservancy, n.d.).
[14] Hannah Charlotte Cubaynes, "Whales from Space: Assessing the Feasibility of Using Satellite Imagery to Monitor Whales" (Darwin College, Scott Polar Research Institute & British Antarctic Survey; University of Cambridge, 2019).

Aerial Surveys–

Plane based aerial surveys are completed by flying a predetermined path over the ocean and recording every whale observation. A significant advantage of aerial surveys over vessel or land-based surveys is their ability to cover significantly more area in the same amount of time; however, higher speeds also increase the number of whales that are likely to be missed. Plane surveys are also limited by poor weather conditions or survey needs in remote locations[15]. Manned aerial surveys are the primary tool for gathering whale presence/absence data for decision making in the RAMP. Flights are conducted on a monthly to bimonthly schedule by CDFW through RAMP zones 1-4 and are sometimes complemented by aerial surveys conducted by NOAA and the US Coast Guard. It generally takes 2 weeks from planning through data synthesis, with three days of flying, to cover the 4 RAMP zones[16]. Flights also collect opportunistic data on forage conditions, fishing effort (buoy presence), and data for enforcement needs, when relevant[17].

Vessel-Based Surveys–

Vessel surveys at their most basic consist of humans observing whales from a boat; for gathering presence/absence data, line-transect surveys are typically used. Boat surveys have the advantage of being conducted at slow speed which can lead to high detection probabilities and the opportunity for additional data collection such as animal identification, behavior monitoring, and entanglement monitoring and response. However, they are limited by poor weather conditions and monitoring needs in remote locations, as it can be time and cost intensive to transport vessels and observers to remote areas[18]. There are many different types of vessel surveys that have data collection benefits for specific research goals– the following describe existing vessel-based surveys that have been considered or are used currently in the RAMP:

- Research Cruises: Researchers spend several months onboard collecting data on many species of marine animals. These surveys do not provide data in a fast enough time frame to be useful for informing management decisions under the RAMP.

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[15] Cubaynes.

[16] Bartling, personal communication suggested 3 days of flight time, however RAMP data packages suggest 1 day of flight time.

[17] Bartling

[18] Cubaynes, "Whales from Space: Assessing the Feasibility of Using Satellite Imagery to Monitor Whales."

- Short/Focused Research Surveys: This survey type is similar to the research cruises in that they are staffed with expert scientists and conduct surveys, however these vessels are typically much smaller and conduct shorter surveys, often focusing on one species. These surveys are currently used to collect data for the RAMP. They are deployed to specific regions in RAMP zones to collect data within the 20m to 50m isobaths[19]. These surveys typically provide data for 1-2 RAMP zones per Risk Assessment.
- Fishermen-led whale surveys: In an attempt to increase data collection at lower costs and better incorporate fishermen knowledge into the RAMP, a fishermen-led survey program has been developed and piloted. In these surveys, fishermen, and independent observers when available, conduct comprehensive line transect surveys in RAMP zones 1 & 5. These surveys require 2-4 vessel days per RAMP zone.
- Whale Watching/Citizen Science Data: This type of data is collected by whale watch guides and citizens reporting whale sightings after a trip. An expert working group advisor standardizes the opportunistic sightings data to inform decision-making under the RAMP. While this data source requires no dedicated survey funding and provides consistent, nearly daily data, the data is not gathered in a systematic transect and covers only a small portion of the Monterey Bay (a portion of RAMP Zone 4). There are not consistent-enough whale watching operations throughout the coast for this data source to be considered viable at a broader scale.

Land-Based Surveys–

Land based surveys are conducted from specific land stations near the coast. They have significant cost advantages to vessel and aerial surveys and can be used to survey the same area even multiple times per day. Land surveys, however, can only be used to detect whales traveling close to shore and can also be heavily impacted by weather events that limit visibility. Additionally, survey needs in remote areas are virtually impossible to complete with land-based methods, as it would be extremely resource intensive to transport observers to these locations[20]. Currently the only data from land-based surveys used for the RAMP are collected from the Farallon Islands[21]. These islands have the advantage of being far enough offshore to detect whales in areas that are also being fished. It's unlikely that other land-based

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[19] Bartling

[20] Cubaynes, "Whales from Space: Assessing the Feasibility of Using Satellite Imagery to Monitor Whales."

[21] Bartling

surveys will be useful in collecting data to prevent entanglements due to restrictions on how far the observer is able to see offshore.

Unmanned and Autonomous Surveys

Unmanned and Autonomous Surveys are those which don't rely on direct observation by a human. These can include unmanned aerial systems and acoustic detection. Unmanned indicates that a human is piloting or controlling the device remotely, while autonomous indicates the device is operating and collecting data without direct human involvement. The big data associated with these survey types needs to be analyzed with machine learning algorithms to stay cost competitive.

Acoustic Surveys–

Acoustic surveys are conducted using very sensitive microphones that are either mounted on the ocean floor / an ocean platform (stationary) or are towed through the water on a vessel or surface glider (mobile). These microphones can record 24/7 and can pick up whale vocalizations from a very far distance[22]. Acoustic surveys are very well suited for species which don't frequently surface such as sperm whales[23]. Acoustic monitoring is a completely noninvasive, and inexpensive, way to observe presence of whales, since after the devices are installed the operating and data analysis costs are low. However, because whales can be present and not vocalizing, and it can be difficult to determine the exact location and number of whales, it is not a very effective way to survey whales for presence absence data[24] [25]. For acoustic surveys to provide specific enough data to be useful in reducing entanglement risk across the broad geographic scope of the RAMP program, an elaborate acoustic array would have to be developed that would be costly and not as efficient as other methods[26].

Unmanned Aerial Systems–

Unmanned aerial systems (UAS) consist of an unmanned aerial vehicle (UAV), cameras, other sensors, and a control system. UASs can be referred to by many names including remotely

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[22] Lindsey Peavey-Reaves Personal Communication

[23] Peavey-Reaves

[24] Peavey-Reaves

[25] Bartling

[26] Bartling

piloted aerial systems, in this report they will be referred to as drones. They are remotely operated by a pilot and typically flown on a transect line pattern over a survey area capturing photographs or video footage to be analyzed at a later time[27]. Drone use for conservation and species surveying has rapidly increased in recent years; and as their use increases, equipment costs are lowering, and more advanced data processing structures are being developed. Without special approval from the Federal Aviation Administration (FAA) drones have to be flown within line of sight of the operator thus substantially limiting their surveyable area[28]. Drone surveys are used successfully to monitor whales that travel in groups close to shore, such as gray whales[29]. Use of drones to inform the RAMP would require vessel-based deployment of multiple drones per RAMP zone. As such, drones at their current capacity are not likely well suited to the broad survey coverage needs of the RAMP.

Satellite Based Surveys

Interest in the use of earth imaging satellites to monitor whales has grown in recent years as a remote survey tool with the potential to cover a much larger area than existing survey tools. Research to date indicates VHR satellite imagery (<50 cm resolution) is needed for high fidelity whale detection[30]. VHR satellite imagery is available up to 30 cm resolution and can capture panoramic, near infrared, and infrared images[31]. VHR satellites currently on the market do not continuously capture imagery, but rather capture images based on requests for imagery in a specific time and location (called satellite 'taskings').

Satellite surveys offer the potential for many advancements upon traditional survey methods, namely the ability to cover large areas in a very short period of time. There is also a reduction

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[27] Marine Mammal Commission, "Development and Use of UAS by the National Fisheries Service for Surveying Marine Mammals" (Marine Mammal Commission, 2016).

[28] Marine Mammal Commission.

[29] Trevor Joyce Personal Communication

[30] Peter T. Fretwell, Iain J. Staniland, and Jaume Forcada, "Whales from Space: Counting Southern Right Whales by Satellite," *PLOS ONE* 9, no. 2 (February 12, 2014): e88655, https://doi.org/10.1371/journal.pone.0088655; Cubaynes, "Whales from Space: Assessing the Feasibility of Using Satellite Imagery to Monitor Whales."

[31] "Geospatial Data Pricing Schedule; Prepared for and Confidential to The Nature Conservancy" (Astrea, 2021); Christin B. Khan et al., "A Biologist's Guide to the Galaxy: Leveraging Artificial Intelligence and Very High-Resolution Satellite Imagery to Monitor Marine Mammals from Space," *Journal of Marine Science and Engineering* 11, no. 3 (March 11, 2023): 595, https://doi.org/10.3390/jmse11030595; Cubaynes, "Whales from Space: Assessing the Feasibility of Using Satellite Imagery to Monitor Whales."

in time spent coordinating and conducting satellite surveys with the only components being predetermining when, where, and how large of an image to task. Tasking orders are set with minimum specifications for factors like cloud cover. If specifications are not met, the customer is not charged for the image and image capture will be re-attempted on the next revisit. Unlike manned survey tools, this process of reallocating survey effort based on conditions requires no additional man-hours for survey practitioners. Satellites are also not at all hampered by the cost and complexity of preparing and executing surveys in remote locations. Finally, the ability to image a large area instantaneously offers advantages in mitigating risk of double counting that would occur if attempting to cover large geographic areas through multiple survey efforts and days.

There are, however, a few important considerations for the adoption of satellite technology. These can be categorized based on inherent traits of satellite technology versus those inherent to the early stage of technology development (i.e., requiring development or proof points). Management will need to decide how often satellite images will be tasked and what size the images should be to sufficiently capture whale presence. Weather conditions like clouds or wind (resulting in choppy water) can reduce detection of whales in satellite images[32]. It is also difficult to determine how the total population size is related to the number of whales detected in the satellite image, with a component of this including the uncertainty of how deep into the water a satellite image can detect whales, or how this changes with weather conditions[33] [34].

With the ability to image large areas, satellite-based whale surveys have both the benefit and challenge of producing large amounts of data. Translating raw images into usable data requires additional data processing and development of tools for automated review. For

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[32] Cubaynes, "Whales from Space: Assessing the Feasibility of Using Satellite Imagery to Monitor Whales"; D.S. Ireland, S. Tupper, and W.R. Koski, "Feasibility and Cost Assessment of VHR Satellite Imagery for Humpback Whale Detection off California," to the California Chapter of The Nature Conservancy (LGL Ecological Associates, Inc., 2021); Fretwell, Staniland, and Forcada, "Whales from Space"; Khan et al., "A Biologist's Guide to the Galaxy"; Alex Borowicz et al., "Aerial-Trained Deep Learning Networks for Surveying Cetaceans from Satellite Imagery," ed. Paweł Pławiak, *PLOS ONE* 14, no. 10 (October 1, 2019): e0212532, https://doi.org/10.1371/journal.pone.0212532; Caroline Höschle et al., "The Potential of Satellite Imagery for Surveying Whales," *Sensors* 21, no. 3 (February 1, 2021): 963, https://doi.org/10.3390/s21030963.
[33] Fretwell, Staniland, and Forcada, "Whales from Space."
[34] Höschle et al., "The Potential of Satellite Imagery for Surveying Whales."

satellite surveys to be competitive, machine learning (ML) models to analyze the data need to be developed, otherwise the man hours spent reviewing footage would not be cost competitive. Additionally, affordable access to imagery and satellite capacity to fulfill tasking requests will be key to successful implementation.

Role of Machine Learning

Acoustic sensors, drones, and satellite imagery all produce large data sets that require processing to produce usable whale presence data. Manual review of big data requires significant manhours that can result in long lags between the time of the survey and when data is available. To solve this problem, investment in the development of ML algorithms and processes to operationalize and maintain data analytic systems is needed. The challenge with creating successful ML algorithms to detect whales in satellite or drone footage is creating a large enough training dataset of whale images (see figure 2). Whales are very dynamic and won't always look the same way when captured by drones or satellites, so having a large and diverse set of training images is important. The cost of developing these types of MLops (machine learning operations) is declining, and once developed the costs of processing data should be quite low[35].

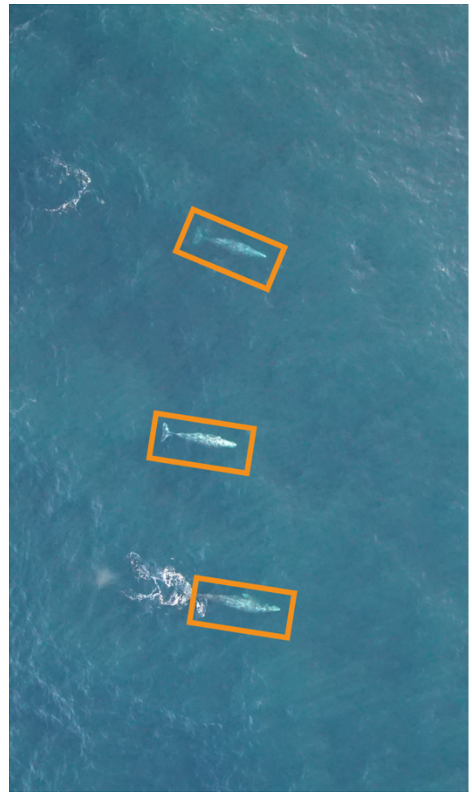

FIGURE 2: DRONE FOOTAGE OF SEVERAL WHALES. THIS IMAGE IS PART OF A TRAINING DATASET THAT CAN BE USED TO DEVELOP ML MODELS
MBNMS-2019-033_MMPA
PERMIT 19091-02 ©TREVOR JOYCE

[35] Vienna Sacomano personal communication

	Is this method currently used for the RAMP?	How large of an area can this method cover?	Can this method provide whale counts?	Is this an emerging or developed technology?
★ Aerial Surveys	Yes	Large	Yes	Developed
★ Vessel Surveys	Yes	Moderate	Yes	Developed
Land-based Surveys	Yes	Low	Yes	Developed
Acoustic Surveys	No	Large	No	Emerging
Drone Surveys	No	Low	Yes	Emerging
★ Satellite Surveys	No	Largest	Yes	Emerging

TABLE 1: SUMMARY OF WHALE SURVEY METHODS DEFINED ABOVE WITH A FOCUS ON THE KEY CONSIDERATIONS FOR FEASIBILITY IN MEETING MANAGEMENT DATA NEEDS. METHODS INDICATED WITH A STAR ARE IDENTIFIED AS HAVING THE STRONGEST POTENTIAL TO MEET MANAGEMENT NEEDS AND WILL BE EVALUATED FURTHER IN SUBSEQUENT SECTIONS OF THIS REPORT.

Framework for Approach Evaluation

The survey methods defined above have been filtered down by their ability to provide presence/absence data at the scale needed for informing management decisions for the RAMP. Based on the definitions and analysis provided above, we consider aerial, vessel and satellite imagery most suitable for RAMP purposes. This section will seek to design a framework capable of evaluating the relative tradeoffs between these methods. The framework can be broken down into three key considerations: 1.) What data they can provide, 2.) Costs, and 3.) Complexities.

What data can be provided:

- *Ability to meet RAMP Marine Life Concentrations data objectives.* Evaluate how well the survey methods meet the core data objective of providing a systematic survey of whale presence and distribution across at least one RAMP zone on a bi-weekly basis. Determine the key advantages and disadvantages each survey type has in collecting this data.
- *Survey area covered.* Surveys that can cover larger areas in a single survey-day are better able to provide near real-time data to inform management decisions.

- *Ability to provide data that contributes to other management objectives.* Survey methods that can provide data for other RAMP considerations, such as ocean/forage conditions and recent whale entanglements have added value.

Costs:

- *Key Cost Drivers.* Survey costs can be variable within and across methods, so literature review and expert interviews were used to identify key cost drivers and relative costs.
    - Some Key Costs Drivers (fixed and incremental)
        - Equipment rental or purchase (plane, boat, etc.)
        - Operator and observer time (salary expense)
        - Analytic costs
- *Human capital costs.* Determine how much time will be required to plan and execute surveys and what the human capital needs are to review and process data.

Complexities:

- *Vulnerabilities.* Consider the key weakness of the survey method that drives its ultimate success or incompatibility with data collection under the RAMP (e.g., vulnerability to environmental conditions, equipment malfunction)
- *State of technology development.* Evaluate how readily these survey methods can plug into the RAMP. Analyze what barriers there are, if any, to implementing this technology for RAMP data collection.

Results

This section applies the framework for tool evaluation to the survey methods and technologies with the best predicted ability to improve the collection of presence/absence data for the RAMP. Those methods include aerial surveys, vessel surveys, and satellite surveys (see Table 1). All of these methods currently provide data or have the potential to provide data on the presence and distribution of whales; by applying the framework we can compare them across other relevant advantages and disadvantages. Analysis is made under the context of current or potential use to inform the RAMP. With regards to satellite imagery, it was necessary to make assumptions regarding several aspects of the framework criteria. We made assumptions based on a feasible scenario as informed by literature review and expert interviews. Specifically, we assumed that satellite imagery is being obtained for free or at a low cost and an ML model has been developed to accurately process the images. With regards to the assessment of aerial and vessel surveys, our primary assumption is that costs and timeframes remain consistent with historical RAMP survey efforts.

Data provided:

RAMP Marine Life Concentrations Data

- Aerial Surveys are able to survey zones 1-4 within 1 day of flying. Aerial surveys have a key advantage in that they are able to cover a large area fairly quickly and can capture more detail than satellite imagery[36] [37].
- Vessel surveys can cover 1 RAMP zone in 2-4 vessel days. Vessels have a key advantage in being able to identify individuals and monitor whale behavior[38] [39].
- Satellite based surveys have potential to sample large ocean areas often, as one or more applicable satellites will revisit an area on at least a bi-weekly basis. The key advantage of this method is the ability to instantaneously capture a large geographic area. However, the ability of satellite providers to reliably respond to tasking requests, and high-fidelity automated detection are still in the proof-of-concept phase.
- Vessel surveys provide the longest observable window due to their slower speeds, providing the most opportunity to see whales surface. Aerial surveys are lower, and while satellite imagery has the benefit of potential capture of a large area, the instantaneous nature makes it more likely to miss submerged whales[40].

Data to support other management objectives

- Aerial and vessel surveys can provide opportunistic data on fishing effort (if large groups of buoys are seen) and ocean/forage conditions, and can spot entangled whales. Additionally, they occasionally collect data on behalf of enforcement agents.
- Satellite surveys have potential to derive insights on ocean/forage conditions[41].

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[36] "2022-23 RIsk Assessment: Available Data," 2023.

[37] Bartling

[38] "2022-23 RIsk Assessment: Available Data."

[39] Bartling

[40] Philip S. Hammond et al., "Estimating the Abundance of Marine Mammal Populations," *Frontiers in Marine Science* 8 (September 27, 2021): 735770, https://doi.org/10.3389/fmars.2021.735770; Federico Sucunza et al., "Assessing Bias in Aerial Surveys for Cetaceans: Results from Experiments Conducted with the Franciscana Dolphin," *Frontiers in Marine Science* 9 (2022), https://www.frontiersin.org/articles/10.3389/fmars.2022.1016444.

[41] Anna Belcher et al., "Experimental Determination of Reflectance Spectra of Antarctic Krill (*Euphausia Superba*) in the Scotia Sea," *Antarctic Science* 33, no. 4 (August 2021): 402–14,

	Aerial	Vessel	Satellite
RAMP presence/absence	-moderate to high area coverage -moderate concern of missed whales	-Lowest area coverage -highest probability of seeing whales surface	-highest potential coverage -highest risk of missed whales
Survey Area	Moderate	Lowest	Highest
Other management objectives	ocean/forage	ocean/forage	ocean/forage (potentially)

TABLE 2: SUMMARY OF THE KEY CONSIDERATIONS OF DATA PROVIDED BY AERIAL, VESSEL, AND SATELLITE WHALE SURVEYS, INCLUDING PRESENCE/ABSENCE DATA PROVIDED, THE AREA COVERED IN ONE SURVEY DAY, AND ABILITY TO PROVIDE DATA FOR OTHER MANAGEMENT OBJECTIVES.

Costs:

Key Cost Drivers

- The results of expert interviews revealed that the key cost driver behind aerial surveys was the fixed costs associated with renting planes and paying observers. Costs for RAMP surveys are approximately $1,500/hr for an 8-10 hour day for single day aerial surveys (accounting for pilot, observers, and plane rental)[42].
- Similar to aerial surveys, the key cost driver behind vessel surveys are the fixed costs of renting the vessel and paying crew. The specific costs vary with the type of vessel survey being conducted. Research surveys conducted for the RAMP typically cost about $2,500 per vessel day, with each vessel covering 25-50% of a RAMP zone[43].
- The key cost drivers behind satellite surveys are the cost of the VHR satellite image. Pricing is opaque and highly variable, but often imagery is charged on a per area basis. For The Nature Conservancy, costs can be as high as >$20/km2, while for NOAA

https://doi.org/10.1017/S0954102021000262; Monique Messié et al., “Satellite-Based Lagrangian Model Reveals How Upwelling and Oceanic Circulation Shape Krill Hotspots in the California Current System,” *Frontiers in Marine Science* 9 (2022), https://www.frontiersin.org/articles/10.3389/fmars.2022.835813.

[42] Bartling

[43] Jenn Humberstone personal communication

Fisheries scientists tasking is available at no cost as part of a large umbrella contract. With the fast rate of growth in availability of VHR imagery satellites, prices are expected to continue to reduce[44].

Human Capital

- Aerial surveys require approximately 1 days' work for a coordinator to organize, several days of travel time, several days of work from on the ground staff, pilot, and typically 2 observers onboard the aircraft[45]. Aerial surveys do not have much work associated with processing data since the observations of whales are noted in flight on an ArcGIS app, and raw counts are used for management decision-making.
- Vessel surveys require a similar amount of planning and travel time to aerial surveys; however, they take much longer to conduct. Typically, four boats over the course of 2 days will cover the same area as one afternoon aerial survey[46]. Again, similar to aerial surveys, there is not much human capital involved in processing data produced by vessel surveys when data collection is done using a data collection application.
- Satellite surveys would likely require initial time to establish a sampling design, but once this is in place preparation and planning should be as simple as setting up a tasking order to a satellite imagery provider or intermediary. The majority of human capital required for satellite surveys would likely be in analyzing data. ML models for identifying whales are in early stages of development and will almost certainly require a 'human in the loop' for operationalization; however, as these models improve, human participation in analysis of satellite data will diminish[47].

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[44] Lianna Gendall et al., "Megafauna from Space: Using Very High Resolution (VHR) Satellite Imagery to Detect Whales and Sharks," *Can. Manuscr. Rep. Fish. Aquat. Sci.* 3248:x+50p (n.d.).

[45] Bartling

[46] Bartling

[47] Khan et al., "A Biologist's Guide to the Galaxy"; Cubaynes, "Whales from Space: Assessing the Feasibility of Using Satellite Imagery to Monitor Whales"; Emilio Guirado et al., "Whale Counting in Satellite and Aerial Images with Deep Learning," *Scientific Reports* 9, no. 1 (October 3, 2019): 14259, https://doi.org/10.1038/s41598-019-50795-9; Justine Boulent et al., "Scaling Whale Monitoring Using Deep Learning: A Human-in-the-Loop Solution for Analyzing Aerial Datasets," *Frontiers in Marine Science* 10 (2023), https://www.frontiersin.org/articles/10.3389/fmars.2023.1099479.

	Aerial	Vessel	Satellite
Key Cost Drivers (*Fixed vs marginal*)	Plane rental (fixed as daily rental)	Vessel rental (fixed as daily rental)	Cost per image area (marginal)
Human Resources (*planning, execution, data analysis*)	Planning and execution	Planning and execution	Data Analysis

TABLE 3: SUMMARY OF THE KEY COST DRIVERS AND HUMAN CAPITAL COSTS OF CONDUCTING AERIAL, VESSEL, AND SATELLITE SURVEYS.

	Aerial	Vessel	Satellite
Planning Time	High	High	Low
Conducting Time	Moderate	High	Low
Data Analysis Time	Low	Low	Moderate*

TABLE 4: SUMMARY OF TIME REQUIRED TO CONDUCT AERIAL, VESSEL, AND SATELLITE BASED SURVEYS. *SATELLITES ARE ANTICIPATED TO REQUIRE MODERATE HUMAN ENGAGEMENT IN DATA ANALYSIS IF USING HUMAN IN THE LOOP ML MODELS, HOWEVER THIS MIGHT BE REDUCED WITH THE DEVELOPMENT OF STRONGER MODELS.

Complexities

Vulnerabilities

- The key vulnerabilities with conducting aerial and vessel surveys are environmental conditions and equipment availability[48].
    - Aerial surveys have a reduced ability to spot whales in turbulent waters or foggy conditions and need a rating of 3 or less on the Beaufort Wind Scale to go out[49].
    - Ideal conditions for vessel surveys are less than Beaufort 4, swell heights below 8 ft, and visibility greater than 1 mile.

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[48] Bartling; Joyce

[49] Bartling

    - Adverse weather conditions also pose a significant logistical challenge; coordinating the vessel/plane and all staff and observers to be in the same place takes time, and sometimes can't be done within a good weather window.
- Satellites images can still be collected during period of bad environmental conditions, however the ability for whales to be detected in that image is significantly decreased[50].
    - However, tasking orders are not considered fulfilled unless they meet criteria for some environmental factors like cloud cover, so the satellite provider assumes the responsibility for adjusting to environmental conditions. Placing repeat tasking orders is typically a streamlined process, making surveying around weather conditions less time consuming with satellite imagery than with aerial or vessel surveys.
- The cost-effectiveness of satellite surveys is also quite dependent on the successful development of an ML model and on market trends of increasing satellite capacity (availability) leading to decreased pricing and increasing reliability.

State of Technology Development

- Both aerial and vessel surveys are standard and widespread both for data collection to inform management decisions in the RAMP and many other scientific and management uses.
- Satellite surveys are a developing technology. VHR satellite imagery has been found to be able to identify whales, however there are no cases of this technology being used for management purposes[51]. The feasibility of its use in the RAMP is tied to successful ML models being developed, and the ability to secure cost competitive VHR satellite images.

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51 Fretwell, Staniland, and Forcada, "Whales from Space"; Khan et al., "A Biologist's Guide to the Galaxy"; Höschle et al., "The Potential of Satellite Imagery for Surveying Whales."

	Aerial	Vessel	Satellite
Key Vulnerabilities	Environmental conditions: cloud cover, wind, sea state	Environmental conditions: wind, sea state	-ML model accuracy -Environmental conditions: wind, cloud cover -Satellite capacity
State of Technology Development	Well Developed	Well Developed	Emerging

TABLE 5: SUMMARY OF THE COMPLEXITIES FACING THE USE OF AERIAL, VESSEL, AND SATELLITE SURVEYS, INCLUDING THE KEY VULNERABILITIES THAT DRIVE THEIR ULTIMATE SUCCESS OR INCOMPATIBILITY WITH THE RAMP, AND THE STATE OF TECHNOLOGY DEVELOPMENT.

Discussion

The results of applying our Framework for Approach Evaluation to aerial, vessel, and satellite surveys led to insights into the potential future use cases of these survey methods, along with avenues for future research.

The key areas where satellite imagery is, or could be, advantageous over traditional survey methods include in situations with survey needs over large areas, in remote locations, or in areas with frequent adverse weather conditions. While the RAMP does not have many remote monitoring sites, its data requirements do require surveys of the entire California coast on a biweekly basis, and many of the high priority RAMP zones are frequently affected by poor weather. This leads us to believe that satellite imagery has huge potential for improving data collection for the RAMP. However, conventional survey methods still have an important role to play in data collection for the RAMP. Traditional methods, such as aerial and vessel surveys, have a longer observable window for the same areas, and as such are likely to observe more whales as they surface. Conventional methods are also superior in circumstances where more detailed information on specific individuals and whale behavior is required. There are also potential benefits from using satellite imagery in conjunction with conventional monitoring techniques, specifically the ability of satellites to provide coarse survey coverage over a large area and use that data to direct boats and planes to locations where more comprehensive surveys are needed.

For satellite imagery to fulfill its potential as a survey tool for the RAMP several developments need to be made. 1.) market trends of increasing satellite capacity (availability) leading to decreased pricing and increasing reliability will need to continue. 2.) ML algorithms that can detect higher percentages of whales more accurately with limited or no human involvement need to be developed. 3.) investment needs to be made into on-the-water proof of concepts and development of survey design and data analysis methods to account for surface availability and other perception bias. It's important to keep in mind that all survey methods need to use correction factors if data is being used for more complex purposes, like species distribution models or abundance estimations. These correction factors still need to be created for satellite surveys.

Future research into this topic should focus on identifying more concrete cost parameters for conventional and satellite surveys, this will allow for a more accurate comparison of the approaches. More work can also be done into identifying the capacity and capabilities of VHR satellite imagery providers under contract with NOAA. This would allow for a more detailed accounting of the path towards actionizing satellite survey tools for the RAMP.

Vessel Monitoring

To successfully mitigate whale entanglement risk, data is needed not only on the location of whales, but also on the location of fishing gear. Trap fishery operations vary substantially depending on the region and target species, ranging from how many traps are on one vertical line, or how often the gear is tended (hauled up and redeployed/moved). The California commercial D. crab fishery operates with single traps per line and is a derby fishery, meaning fishing effort and intensity is highest at the beginning of the fishing season. During this time in particular, efficiency in on-the-water operations is crucial for fishermen's success.

Currently CDFW is pursuing a vessel location monitoring program to improve data on the distribution of fishing effort to inform decision making under the RAMP. A vessel monitoring requirement for the D.crab fishery is in place which requires fishermen to provide a log of their location with at least a 60 second ping rate to CDFW upon request[52]. Currently there are no additional requirements for what type of technology the fishermen need on their vessels to record their location, and many are using GPS plotters[53]. However, CDFW has stated that it intends to move away from GPS plotters, which are easily tampered with and lack automated data transmission, and therefore cannot provide data with enough accuracy or consistency for the RAMP or enforcement. CDFW intends to update monitoring regulations to require use of a vessel location monitoring tool that can record location with at least a 60 second ping rate and automatically transmit this data. CDFW is also interested in exploring the use of hydraulic sensors as a complementary tool that may indicate trap hauling events. There has been a focus on a class of tools called data loggers, many of which can satisfy a 60 second ping rate. However, there are potentially only a few data logger vendors that offer existing integration capabilities with hydraulic sensors (see Appendix for more information).

The technology marketplace for vessel location monitoring is dynamic. There are many different technologies with the capacity to collect location data, as well as different combinations of approaches that offer distinct advantages and disadvantages in terms of data granularity, costs, and complexity. Within a single class of tools, like data loggers, there are also many different types with different features, cost structures, and sensor integrations[54]. In order to support the design of a cost-effective monitoring program, it is critical that CDFW, fishermen and other fishery stakeholders understand the technology marketplace and tradeoffs for various data collection strategies.

This section will seek to analyze these technologies by 1.) identifying the management and enforcement data needs, 2.) defining the suite of technologies capable of fulfilling these data needs, 3.) describing a novel framework for evaluating these technologies, 4.) applying the framework to technologies and combinations thereof that are identified as having the most potential in this application.

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[52] California Department of Fish and Wildlife, "Compliance Guide for the California Commercial Dungeness Crab Fishery Electronic Monitoring Program."
[53] Compliance Guide for California Dungeness Crab Fishery Electronic Monitoring Program, 2023
[54] Appendix 1

Vessel Monitoring Data Needs

CDFW's goals for the vessel location monitoring program can be broadly defined in two categories: 1) Management goals: assessing aggregate fishing effort distribution to inform the RAMP management decisions; 2) Enforcement goals: providing vessel-level confirmation of fishing activity to enforce dynamic closures. Management requires data on a bi-weekly basis to inform the RAMP, while enforcement requires the ability to review vessel-level data on request subsequent to a fishing trip[55].

Aggregate fishing effort can be defined on a spectrum from trap density based on trap location data to a much coarser summary of likely aggregate fishing activity (e.g., inferred from simplified speed thresholds). Even the coarse end of this spectrum represents a significant improvement in data to assess co-occurrence risk under the RAMP, and therefore considerations like costs and complexity of approaches available are key determinants from the state's point of view[56].

Breaking down the data objectives further, we have evaluated the ability of tools alone or in combination with other tools or modeling approaches to provide the following data:

- Differentiating crab-trips from non-crab-trips
- Identifying different vessel activities (transiting/steaming, deploying gear, hauling gear)
- Individual trap deployment locations
- Individual trap haul locations

Technologies Capable of Meeting Management Goals

There are generally two strategies for monitoring co-occurrence: track vessel activity or track gear directly (either as it is being hauled or while it is in the water). These two strategies and supporting tools can potentially be used together to gain a better understanding of fishing effort. Models are incorporated on the backend to collate and analyze data. Fishing effort models can be developed using data with almost any level of granularity. Table 6 provides a summary of tool capabilities and cost ranges,.

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[55] CDFW Personal Communication

[56] CDFW Personal Communication

Vessel Tracking Technologies

GPS Data Loggers

GPS data loggers (data loggers) record vessel location at a predetermined ping rate and transmit data over cellular or satellite networks[57]. Data loggers are usually wired to a boat's power system, but they can run on solar or a rechargeable battery. They have recently become popular with small-scale fisheries in developing countries because they are relatively inexpensive and easy to install, however they are beginning to become more popular with fisheries and management agencies in developed countries because they can efficiently provide fine scale and flexible data for management decisions[58] [59]. Additionally, many data loggers on the market have integrations with other gear and vessel sensors which may provide useful information for fishers and management agencies. CDFW has expressed particular interest in the Archipelago data logger based on its ready integration with hydraulic sensors. There are many more devices currently on the market; see the Appendix for a detailed accounting of their different offerings and features. Location data provided by data loggers can also be used to train and inform models to estimate fishing activity and effort[60].

Vessel Monitoring Systems:

Vessel monitoring systems, or VMS, are a class of data loggers that are approved by the National Marine Fisheries Service (NMFS)[61]. They are required for all vessels participating in the federally managed Groundfish fishery, this includes about 19% - 26% of the D. crab fleet

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[57] *GPS Data Loggers as a Low-Cost Alternative to Vessel Monitoring Systems*, 2015

[58] "GPS Data Loggers as a Low-Cost Alternative to Vessel Monitoring Systems (AK)" (National Fish and Wildlife Foundation, April 2015).

[59] Sara Orofino et al., "Opportunities and Challenges for Improving Fisheries Management through Greater Transparency in Vessel Tracking," *ICES Journal of Marine Science* 80, no. 4 (May 1, 2023): 675–89, https://doi.org/10.1093/icesjms/fsad008.

[60] Tania Mendo et al., "Identifying Fishing Grounds from Vessel Tracks: Model-Based Inference for Small Scale Fisheries," *Royal Society Open Science* 6, no. 10 (October 2, 2019): 191161, https://doi.org/10.1098/rsos.191161; Blake E. Feist et al., "Footprints of Fixed-Gear Fisheries in Relation to Rising Whale Entanglements on the U.S. West Coast," *Fisheries Management and Ecology* 28, no. 3 (2021): 283–94, https://doi.org/10.1111/fme.12478.

[61] Orofino et al., 2023; Orofino et al., "Opportunities and Challenges for Improving Fisheries Management through Greater Transparency in Vessel Tracking"; Bill DeVoe and Story Reed, "ACCSP Collaborative Electronic Tracking Pilot Program in the American Lobster Fishery – Final Report" (ACCSP, September 4, 2020).

[62] [63]. NMFS also sets the required ping rate and collects and manages the data[64]. VMS devices currently installed on D. Crab vessels have a ping rate of every 15 minutes and it would be expensive for fishermen to upgrade to the higher 1/minute ping rate to meet the CDFW monitoring requirements, as the increase to a 15-minute ping rate corresponded to a 50% increase in cost[65] [66]. It can also be difficult to obtain VMS data from NMFS, so there is not a ready opportunity to gain cost efficiency through shared data management systems. In order to see use in the state context, the VMS data would have to directly route to CDFW as well as NMFS instead of the current indirect pull requests to NMFS[67]. Fishermen would also have a hard time finding devices that could satisfy the federal VMS requirements and state technology requirements, but it would need approval by both departments.

Automatic Identification Systems:

Automatic identification systems, or AIS, are a vessel safety feature used to prevent collisions; in 2000 the International Maritime Organization (IMO) required all vessels over 300 gross tonnes to have an AIS device onboard[68]. Additionally, all vessels longer than 65 feet in the United States are required to have an AIS device installed, however some smaller boats may also elect to install the device[69]. These devices can range in price from quite inexpensive for Class B devices which have a shorter range, to very expensive for Class A devices which have a longer range. Since AIS is used for collision prevention, transmission rates increase with vessel speed (from every 2 second to 3 minutes)[70]. AIS signals are either picked up by nearby

[62] "Magnuson-Stevens Act Provisions; Fisheries off West Coast States; Vessel Movement, Monitoring, and Declaration Management for the Pacific Coast Groundfish Fishery," Federal Register, June 11, 2020, https://www.federalregister.gov/documents/2020/06/11/2020-11011/magnuson-stevens-act-provisions-fisheries-off-west-coast-states-vessel-movement-monitoring-and.

[63] Owen R. Liu et al., "Mobility and Flexibility Enable Resilience of Human Harvesters to Environmental Perturbation," *Global Environmental Change* 78 (January 1, 2023): 102629, https://doi.org/10.1016/j.gloenvcha.2022.102629.

[64] "Five Recommendations for Better Utilizing VMS Data to Enhance Fisheries," n.d.

[65] https://www.govinfo.gov/content/pkg/FR-2022-03-02/html/2022-04306.htm

[66] "Magnuson-Stevens Act Provisions; Fisheries off West Coast States; Vessel Movement, Monitoring, and Declaration Management for the Pacific Coast Groundfish Fishery."

[67] "Five Recommendations for Better Utilizing VMS Data to Enhance Fisheries."

[68] Orofino et al., 2023

[69] "33 CFR §164.46 -- Automatic Identification System.," § Title 33, Chapter I, Subchapter P, Part 164, accessed August 30, 2023, https://www.ecfr.gov/current/title-33/part-164/section-164.46.

[70] Orofino et al., 2023

vessels, satellites, or receivers on land. Signals will bounce from vessel to vessel until they reach a land-receiver. This means if a vessel is not near any other vessels there could be gaps in coverage[71] [72]. Some fishermen have begun to use inexpensive AIS devices to track their fishing gear, however using AIS in this way is still considered illegal as it could interfere with vessel safety[73] [74]. Some researchers and organizations, such as Global Fishing Watch, have used vessel tracks produced by AIS data to model fishing effort. However, because AIS devices are not required on all vessels, and can be easily turned off by fishermen, they are not a very reliable method for monitoring fleets[75] [76].

Electronic Logbooks

Electronic logbooks (elogs) are applications based on mobile devices like smartphones or tablets. Elogs can record important data like trap drop locations, catch, effort, and discards[77]. They can also function similar to a data logger in that they can passively record spatial data and transmit once in range[78]. Elogs provide a range of granularity, and depending on the approach, can allow for fishery monitoring in almost real time[79]. In theory, devices are efficient for fishermen and managers and provide direct benefits in terms of logging data, data transfer, and data processing[80]. However, they can interrupt the workflow of a fishing trip and act as an inconvenience to the fast-paced environment on a vessel if using a self-reported, detailed catch log. An interview with a D. Crab fisherman[81] revealed that electronic logbooks may have issues in real-time applications. As a result, it might be more feasible to look at elogs in a passive recording context, similar to data loggers.

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[71] Shepperson et al., 2018
[72] Orofino et al., 2023
[73] He & Surronen, 2018
[74] "Public Notice-- FCC Enforcement Advisory" (Federal Communications Commission, November 28, 2018), https://docs.wixstatic.com/ugd/b66831_0b229258568848beb1e7334f7e05826c.pdf.
[75] Kroodsma et al., 2018
[76] Shepperson et alk., 2018
[77] TNC, 2023
[78] Huff McGonigal Personal Communication
[79] DM Lowman et al., "Fisheries Monitoring Roadmap," 2013.
[80] Lowman et al.
[81] Dick Ogg Personal Communication

GPS Plotters

GPS plotters are commonplace on every boat in the D. crab fishery[82]. They are used as part of the vessel's navigation system to display their location on top of a map. CDFW is currently allowing fishermen to provide GPS plotter records to comply with the new 1/min ping rate monitoring requirement[83]. However, plotters are unlikely to be accepted moving forward because these devices are quite easy to tamper with and don't have the capacity for automatic data transmission meaning records are often physically mailed into the CDFW officer, or otherwise difficult to process.

Technology Type	Example Tools	Costs	Key considerations for feasibility in meeting management data needs
GPS Data Logger	Pelagic Data System (PDS), Particle Industries-TrackerOne	**Equipment costs:** $200 - $3,000 [84] **Subscription costs:** $20 - $60 per month (varies with business model)[85]	Data loggers can provide vessel location at high ping rates for a relatively inexpensive cost. They automatically send data to fisheries managers and can support integrations with hydraulic sensors. **For these reasons, data loggers are being seriously considered for the vessel monitoring program.**
AIS	ICOM, Raymarine, McMurdo	**Equipment costs:** $700 - $3,500 [86] **Subscription costs:** $0	AIS is used primarily to avoid vessel collision. Although the majority of D. crab vessels have AIS installed, the ping rate is not constant, and the device can be easily turned off. AIS data is not confidential which is a concern with D. crab being a derby fishery. **AIS is not being considered as a viable option for the vessel monitoring program.**

[82] Dick Ogg Personal Communication
[83] California Department of Fish and Wildlife, "Compliance Guide for the California Commercial Dungeness Crab Fishery Electronic Monitoring Program."
[84] Appendix 1
[85] Appendix 1
[86] Orofino et al., 2023

Technology Type	Example Tools	Costs	Key considerations for feasibility in meeting management data needs
VMS (federally type-approved)	Skymate m1600, Woodshole Triton, Network Innovations Sailor VMS Gold	**Equipment costs:** $3,000 - $5,000[87] **Subscription costs:** $50/month; costs increase with ping rate[88]	Since VMS is a subset of data logger technology, they have many of the same capabilities, however because VMS is federally managed it is not practical for CDFW management needs. **VMS is not being considered for the vessel monitoring program.**
Electronic Logbooks	Teem Fish Monitoring, Small Pelagics, Bluefin Data, Harbor Light Software	**Equipment costs:** N/A **Subscription costs:** ~$300/year (varies greatly with vendor)[89]	Electronic logbooks are manually filled out by fishermen either during or after a fishing trip. Data collected can include fished areas, location of traps, and fishing effort. Although electronic logbook records can be falsified by fishermen, they provide a good way of verifying other vessel monitoring systems. **Electronic logbooks could meet RAMP data needs.**
GPS Plotters	NA	NA	GPS plotters are used onboard to show a vessel's route on a map in real time. Location data from fishing trips cannot be automatically sent to fishery managers, and the devices are easily tampered with. **GPS plotters are not considered able to meet RAMP data needs.**

TABLE 6: SUMMARY OF ALL VESSEL MONITORING TOOLS DEFINED IN THIS SECTION. SPECIAL ATTENTION IS GIVEN TO THE FEASIBILITY OF TECHNOLOGY FOR USE IN THE D. CRAB VESSEL MONITORING PROGRAM.

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87 Orofino et al., 2023

88 Lowman et al., 2013

89 Gway Kirchner, Shonene Scott, and Jena Carter, "Investigating the Potential for an Electronic Logbook for Oregon's Commercial Dungeness Crab Fishery," *The Nature Conservancy*, 2021.

Fishing Gear Monitoring Technologies

Hydraulic Sensors

Hydraulic sensors are used in conjunction with other monitoring technologies, such as electronic monitoring or data loggers, to indicate when a vessel's hydraulic system is operated. This could be used as a proxy for understanding duration and location of fishing activity as the hydraulic system is used to deploy and haul fishing gear, however hydraulic activity alone is not enough to prove fishing activity occurred[90], so lack valuable insights for effort tracking and enforcement. In the Groundfish fishery electronic monitoring incorporates hydraulic sensors to determine when to start recording footage of nets being deployed or hauled (see figure 3)[91]. Hydraulic systems can be used for non-fishing related activities onboard, such as dropping anchor or operating generators, because of this the hydraulic sensors should not be used without other corroborating data such as video footage or GPS location/speed. Additionally, hydraulic sensors would need to be tested within the context of the D. crab fishery to determine exactly what information they can reliably provide. Some case studies have shown that hydraulic sensors have been explored for vessel monitoring in other circumstances but were not pursued, which may indicate they experienced challenges in implementing them[92].

FIGURE 3: HYDRAULIC SENSOR (CIRCLED) INSTALLED ON GROUNDFISH VESSEL. PHOTO CREDIT: CHLOE SWICK

Gear Tracking Technologies

There are a variety of gear tracking technologies on the market and ready for use for marine fishing gear. The technology can be broken down into three main types: Radio Frequency Identification (RFID) tags, AIS transponders, and radio/satellite buoys. RFID tags can be read by specific RFID readers at ranges up to 240 meters and are a fully developed technology

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[90] "GPS Data Loggers as a Low-Cost Alternative to Vessel Monitoring Systems (AK)."

[91] "Regulatory Impact Review and Final Regulatory Flexibility Analysis for the Regulatory Amendment to the Pacific Coast Groundfish Fishery Management Plan to Implement an Electronic Monitoring Program," n.d.

[92] SIFIDS Report Sections 2A and 2B, 2021

that has been tested in crab fishery cases[93]. Hybrid tags with GPS integration also exist, which transmit their GPS signals to a central base[94]. Devices can also track temperature and salinity data around traps, which can provide useful insights to fishermen about ocean conditions that correlate with higher catch. Class B AIS transponders (the buoy unit) offer integration with already existing systems onboard through extra transponders and make use of an extremely long range and well-developed satellite network. However, using AIS transponders for gear tracking is currently illegal as it can interfere with vessel safety as they transmit on the same frequency as other vessels and can appear as vessels on monitors[95]. Radio and satellite buoys can be on the more expensive side but can connect over very large distances and have selective call modes that increase security. For a detailed accounting of the different gear tracking technologies see Table 7. These technologies also increase efficiency for fishers by reducing gear loss and recovery time, but due to the sheer scale of the gear used on each boat, even low-cost equipment may be impractical.

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[93] Tore Syversen and Jørgen Vollstad, "Application of Radio Frequency Identification Tags for Marking of Fish Gillnets and Crab Pots: Trials in the Norwegian Sea and the Barents Sea, Norway," *Fisheries Research* 259 (March 2023): 106557, https://doi.org/10.1016/j.fishres.2022.106557.
[94] Jen-Han Yang et al., "Monitoring Coastal Aquaculture Devices in Taiwan with the Radio Frequency Identification Combination System," *GIScience & Remote Sensing* 59, no. 1 (December 31, 2022): 96–110, https://doi.org/10.1080/15481603.2021.2016241.
[95] "Public Notice-- FCC Enforcement Advisory."

Tech Type	Example Tools/technological readiness	Description/ capabilities	Costs	Pros/Cons
Radio frequency identification tags (RFID)	RFID tags GPS/RFID hybrid tags Ready to be rolled out, pilots in Taiwan and Norway (used to tag longlines or fishing platforms and track location)	RFID tags allow for remote reading of tags in ranges from 14 cm - 240 m. Broadcasts a radio signal from the tag to a reader onboard.[96]	$30 - $90[97]	**PROS:** • Can be read from a long distance • Allows for ID when buoys are underwater **CONS:** • Can be tampered with by tag removal
AIS Transponders on Buoys	Established AIS technology providers in onboard technology	Using existing AIS transponders (not transceivers) to broadcast location to existing AIS devices onboard	$50 - $200[98]	**PROS:** • Uses existing AIS infrastructure on boats **CONS:** • Location can be seen by other fishermen • Currently not approved by FCC

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[96] Pingguo He and Petri Suuronen, "Gear Tracking - Google Drive," *Marine Pollution Bulletin* 129, no. 1 (2018): 253–61.

[97] Yang et al., "Monitoring Coastal Aquaculture Devices in Taiwan with the Radio Frequency Identification Combination System."

[98] Michael Crowley, "Using AIS Net Buoys? FCC Fines up to $19k per Day," National Fishermen, 2018, https://www.nationalfisherman.com/national-international/using-ais-net-buoys-fcc-fines-up-to-19k-per-day; "Wholesale Ais Buoy For Your Marine Activities - Alibaba.Com," Retailer, Alibaba.com, accessed August 21, 2023, https://www.alibaba.com/showroom/ais-buoy.html.https://www.alibaba.com/showroom/ais-buoy.htmlCrowley, "Using AIS Net Buoys?"; "Wholesale Ais Buoy For Your Marine Activities - Alibaba.Com."

Tech Type	Example Tools/technological readiness	Description/ capabilities	Costs	Pros/Cons
Radio Buoys	Blue Ocean Gear; hybrid transmission technology	Constant transmission or selective transmission. can also transmit information like GPS position or temperature	$1,000 - $1,500[99] [100]	**PROS:** • Provide long distance, constant transmission that can be picked up with onboard equipment • Sel-call buoys can be used to address security concerns (only pings when prompted) **CONS:** • Requires new reader equipment onboard • Expensive

TABLE 7: ACCOUNTING OF THE COSTS, TECHNOLOGICAL READINESS, AND PROS AND CONS OF VARIOUS GEAR TRACKING DEVICES. THESE GEAR TRACKING DEVICES CAN PROVIDE BENEFITS TO FISHERMEN BY ALLOWING THEM TO SPEND LESS TIME SEARCHING FOR OR RECOVERING GEAR, BUT ALSO CAN PROVIDE VALUABLE INSIGHTS FOR MANAGEMENT AND ENFORCEMENT.

[99] https://whitewaterfishingsupply.com/collections/gear-tracking-equipment
[100] https://www.blueoceangear.com/howitworks

Data Processing and Analysis/Role of Modeling

Any data produced by the vessel monitoring systems described in this section will need to be processed in some way to make the data actionable. A review of relevant literature found that developing models to interpret data can be an effective way to estimate fishing effort in trap fisheries from vessel location monitoring tools. These models, at their most basic, implement a speed filter to identify different vessel activities such as steaming, deploying gear, or hauling gear[101]. Some researchers include data from other vessel sensors, smartphone apps, or landing receipts to develop their models and to identify trap hauls[102]. In the D. crab fishery, deploying gear is often done at similar speeds to hauling, so it is unclear if speed filters alone would be able to clearly define fishing events; the integration of data from other vessel sensors presents an opportunity to create better models that could potentially define individual trap drop locations. Testing different technological integrations would reveal what offers the most critical information in developing the model and what level of specificity in fishing effort could be predicted. For example, the integration of hydraulic sensors could be used to corroborate fishing activity indicated by speed filters. Care should be taken to prove the utility of any additional integrations before requiring their use. To develop accurate speed filters and ground-truth a fishing activity model in the D. crab fishery it will be helpful to first develop a training dataset. This can be done using onboard observers, or utilizing the groundfish fleet monitored with EM. In our review, we did find numerous proofs of concept of developing fishing activity models, but little adoption by managers, like the case of the Atlantic States Marine Fisheries Commission (ASMFC).

Framework for Approach Evaluation

This analysis evaluates the potential technologies, and technology pairings, as to how well they can provide high confidence co-occurrence data for the RAMP and enforcement, with minimal cost and complexity for fishermen and CDFW. By analyzing the potential for these technologies to be used synergistically, we increase the potential gains, while minimizing

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[101] Nuno Sales Henriques et al., "An Approach to Map and Quantify the Fishing Effort of Polyvalent Passive Gear Fishing Fleets Using Geospatial Data," *ICES Journal of Marine Science*, June 14, 2023, https://doi.org/10.1093/icesjms/fsad092; David A. Kroodsma et al., "Tracking the Global Footprint of Fisheries," *Science* 359, no. 6378 (February 23, 2018): 904–8, https://doi.org/10.1126/science.aao5646; Mendo et al., "Identifying Fishing Grounds from Vessel Tracks."

[102] Feist et al., 2021; Galotto-Tébar et al., 2022

costs and disadvantages. Important considerations for evaluating these technologies include: **1.) Data Granularity, 2.) Costs, and 3.) Complexities.**

Data Granularity:

- *Ability to provide data on location of fishing activity/gear.* This is the most important consideration for preventing whale entanglements as it informs whale-fishing activity co-occurrence maps. All of the technologies described above have some potential to provide data on the distribution of fishing activity, however the granularity and certainty of the data varies greatly from aggregate fishing areas to locations of individual traps.
- *Ability to provide data that contributes to enforcement objectives.* Enforcement measures are important for ensuring the success of fisheries management programs. Considering how and if data can be used by CDFW enforcement for prosecuting against fishing in closed areas helps in determining the overall value of the technology.

Costs:

- *Monetary costs.* Costs are broken up into those paid by CDFW (includes initial device purchase and data analysis/storage costs) and those paid by the fishermen (includes replacement device fees, installation fees, subscriptions if applicable, and device maintenance).
- *Human capital costs.* Key questions include how much time investment will the maintenance and operation of this technology require and who will be providing this time investment. For CDFW the time investment includes time spent analyzing and organizing data. For fishermen the time investment includes time spent operating and maintaining the equipment or technology.

Complexities:

- *Vulnerabilities.* Key weakness of the technology that drives its ultimate success or incompatibility with the vessel monitoring program. These include malfunction potential, tamper-ability concerns, indicator lights, or data misrepresentation.
- *Data Confidentiality.* It is extremely detrimental for fishermen to have the location of their traps shared during D. crab season, and trap data would have to be collected anonymously in the aggregate to comply with state law. Whether data collected by the technology will be kept confidential between managers and fishermen is an important consideration in improving compliance and cooperation.

Results

Individual technologies can have data gaps when it comes to fulfilling data objectives like aggregate distribution of fishing activity or vessel-specific data for enforcement; by combining technologies these weaknesses can be mitigated, and their strengths amplified.

We have decided to primarily evaluate data loggers and elogs due to our conclusions in Table 6 and the Vessel Tracking Technologies Section. These technologies both utilize modeling to make the data actionable. Hydraulic sensor integrations with data loggers and elogs are also analyzed for their potential to improve data collection.

DATA GRANULARITY

Ability to provide data on the location of fishing gear:

- Data loggers are able to provide vessel location data at a certain ping rate for the duration of the fishing trip; to make this data actionable, models need to, at a minimum, impose speed filters that provide an idea of aggregate fishing effort (steaming, hauling, etc.).
- Elogs can provide vessel location, trap location, and fishing effort data. However, since elogs are housed on smart devices, like tablets or phones, the data is less reliable due to being self-reported.
- Hydraulic sensors can't be used on their own but can be used in conjunction with data loggers and elogs to verify and provide context to the data they provide. Hydraulic sensors record every instance of a vessel's hydraulic system being used, which can indicate hauling, but may also indicate other vessel activity[103].

Ability to provide data that contributes to enforcement objectives:

- Data loggers can automatically record and transmit GPS pings, which could be used by enforcement to ensure compliance with closed zones or depth restrictions if models prove effective at distinguishing fishing from transit activity. Integration of additional monitoring tools or sensors may be able to provide a more detailed picture of the vessel's activity i.e., are they moving through a closed zone or actively fishing?
- Some Elogbooks can also record GPS pings and more detailed, self-reported information about fishing activity, which enforcement could use to check vessel

[103] Geoff Bettencourt and Dick Ogg Personal Communication

compliance. However, due to elog catch data being self-reported, enforcement may also desire additional levels of verification through independent data collection like data loggers to get a better picture of activity.
- Both technologies could provide data that would assist enforcement officers in monitoring compliance with management actions. The addition of hydraulic sensors, and/or advanced models could provide a more detailed and substantiated understanding of the vessel's activity; however, our research found sparse examples. Further research is required for enforcement capabilities, as this analysis mainly focuses on management needs.

COSTS

Monetary costs:

- Data loggers have a high initial investment, with two major ranges. Cheaper devices that just record and transmit timestamped location data are $200-$400, while more expensive devices with more developed communication capabilities[104] are $1300 - $3000.
- The other main cost item is the data plan. These plans are very variable, and more detailed information is available in Appendix 1.
  - The main pricing structure is a subscription model, with a flat fee for a period of access, charged monthly, annually, or per fishing season.
  - CDFW is seeking use of existing grant funds to purchase the physical device on behalf of fishermen, but fishermen would be responsible for paying for the data plan fees and any subsequent devices.
- Elogbooks have limited costs to industry, as most in the form of free apps that can be downloaded to a mobile device.
  - Some vendors may require a subscription fee (usually around $300/year) for more functional elogs, but others are entirely free for fishermen, like Bluefin Data. They may come with a small data management cost to the state.
- Hydraulic sensors usually cost around $260 per sensor. It is not clear who would be responsible for purchase of sensors, but fishermen would likely be considered responsible for maintaining them.

[104] These capabilities include two-way comms, a wifi network, or SMS messaging. See Appendix 1

- There are also costs associated with developing and testing models to analyze this data. Sometimes these are additional payments to a data logger vendor for analytics in a web portal, or models can be developed from scratch.

Human capital costs:

- The main human capital costs associated with data loggers for fishermen are installation time, with minor upkeep. After that, the ideal situation is the device sitting on the boat and recording passively, with no active maintenance from fishers. It is important to note that there is variation within data loggers in complexity of installation (see Appendix).
- Elogbooks have much higher human capital costs for fishermen, as not only is there time associated with setup and training, but it also adds another thing to manage in an already hectic and fast-paced fishery. Elogs require a lot of active involvement for fishers, and as a result, can impede workflow or lead to inaccurate reporting due to rushing.
- Hydraulic sensors passively record and transmits without any involvement from a fisher, outside of initial installation and any maintenance.
- The main human capital cost to CDFW comes from any regulatory processes to implement a program and from data processing and management needs. These models are scalable, and increased investment provides finer data. There additional costs for CDFW associated with regulation, contract writing, and constructing infrastructure to manage and analyze log data.

COMPLEXITY

Vulnerabilities:

- The main vulnerabilities of data loggers lie in tamper-ability and malfunction potential/maintenance requirements.
    - Tamper-ability: The device has minor tamper-ability concerns and depends on the device. There are vendors who do not let fishers change the ping rate or turn off the device, but it’s possible that fishers could find a way to turn the physical device off (or physically remove it).
    - Malfunctions: Some vendors don’t have mechanisms on physical devices to indicate whether the device is receiving power or transmitting data, which can lead to a fisherman being considered non-compliant with regulations and to incomplete information in the RAMP program. Some solar devices may not be

able to remain powered in persistent cloud and fog conditions, but usually have backup batteries for this case.

- Elogbook data suffers from inefficiency and tamper-ability.
    - Streamlined Elogbook may be considered tedious by fishermen who currently are not required to operate a logbook while fishing D. crab. While touted as efficient, going from no logbooks to elogbooks is different from modernizing an existing paper log system. In a fast-paced environment, this can severely interrupt workflow.
    - Because elogs take away time from fishing, fishers can rush to fill in data or fill everything at the end of a trip, which can lead to errors in reporting and general low confidence in data accuracy.
- As mentioned above, hydraulic sensors have not been proven to indicate trap hauling behavior exclusively and reliably, as hydraulic systems are used for much more than just hauling traps and can malfunction to further misconstrue fishing activity. Further testing is required to see if these technologies can be used to verify model insights.

Data Confidentiality:

- Across all/most vendors, data logger data and associated chain of custody is entirely confidential and encrypted regardless of transmission method and can be accessed through a secure web portal with credentials. Depending on the vendor, fishers may not be able to access their vessel location data. Here, CDFW controls the flow of data, and also decides what to report.
- Elog data follows with data logger data – fishers can usually access their data through a web portal, and management has access to all of it. Transmissions are usually encrypted through the same mechanisms as cellular data loggers and have the regular data protections associated with traditional phone plans. Here, fishermen control the flow of data through reporting, and decide what to report.
- Hydraulic sensor data would typically be integrated with one of the above approaches and relayed through one of the two above channels, and as a result, is also secure.

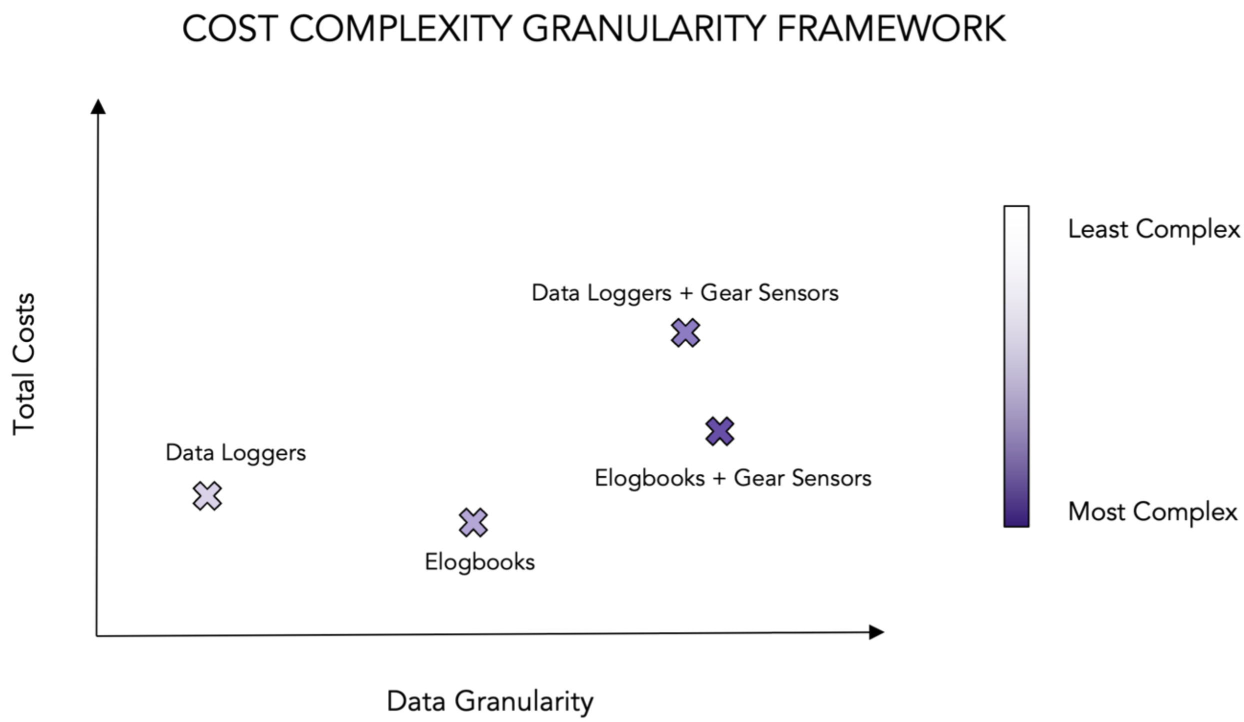

FIGURE 4: ILLUSTRATION OF RELATIVE COSTS, DATA GRANULARITY, AND COMPLEXITY ASSOCIATED WITH DIFFERENT MONITORING METHODS AND COMBINATIONS OF METHODS. WE ASSUME THAT MODELING WILL BE USED IN SOME CAPACITY FOR ALL OF THESE APPROACHES. THE AMOUNT OF AUTOMATION AND INSIGHTS DEPENDS GREATLY ON THE INVOLVEMENT AND TYPE OF MODELING USED, SO THIS FIGURE REPRESENTS THE RELATIVE RELATIONSHIPS BETWEEN THESE APPROACHES.

Discussion

1. Cost tradeoffs: In our research, we found that all technologies have cost tradeoffs between monetary and human capital costs. It's important to consider which of these costs is more important to the parties involved, and how these tradeoffs affect the fishery at large in terms of accurate vessel monitoring.

2. Importance of combinations: To account for the weaknesses of different technologies have to be used together. The increase in inputs makes analysis easier, as the dataset is more robust.

3. Minimize complexity / emphasize fishermen accessibility: At the end of the day, the people who will end up interfacing with these technologies the most are fishermen. Making sure that they can operate this technology and know it is working properly

ensures accurate and consistent data and optimizes enforcement actions by minimizing false leads.

FIGURE 5: PHOTOGRAPH OF REPORT AUTHORS WITH GEOFF BETTENCOURT, D. CRAB FISHERMAN, ON HIS FISHING BOAT IN HALFMOON BAY, CA. THROUGH CONVERSATIONS WITH FISHERMEN WE WERE ABLE TO GAIN A BETTER UNDERSTANDING OF THE APPLICABILITY OF THIS TECHNOLOGY ON A REAL FISHING BOAT, AND THE KEY CONSIDERATIONS FISHERMEN HAVE WHEN INTEGRATING NEW TECHNOLOGY INTO THEIR OPERATION.

PHOTO CREDIT: JENN HUMBERSTONE

4. Importance of synergy with existing technology on fishing boats: In looking at these technologies, it's important to find systems that work with existing technology on fishing boats and integrate with these systems. Fishermen have the tech set up to meet their needs, so it's unlikely these technologies will pose additional benefits to them. Tech doesn't have to integrate seamlessly but should at least eliminate redundancy or require little active involvement.

5. Clearly defining management goals: More specific management goals are needed to accurately navigate the tradeoffs between these different approaches. In order to justify the additional costs of incorporating more equipment or utilizing specific technologies over others, the benefits need to be clearly assessed relative to very specific data needs.

6. In general, data collected from these approaches in enforcement applications, can also lead to false prosecutions if sensors are misfired, the data logger malfunctioned, or if elogs were filled out incorrectly. Testing these models on diverse sources of data can eliminate a majority of this error, and especially testing within the Dungeness Crab Fishery.

Appendix

The below table breaks down 12 different brands of data loggers by different characteristics, which can be divided into four main groups:

1.) **Basic information** details the device's ability to meet regulatory and reporting needs, as well as its data efficiency (see rows 9 and 10).
   a. These rows indicate if the vessel can automatically adjust ping rate to minimize pings when a vessel is docked.
2.) **User responsibilities** focus on operating the device and the fishermen's perspective, with focus on power source (rows 13-16) and reporting indicators (rows 18-20) to make sure fishermen know that a device is on and transmitting before they leave.
3.) **Data transmission and access** details how the data is transmitted, but also the backend analytics portion. In rows 34 and 35 the different ways data is accessed and analyzed are detailed.
4.) **Cost information** talks about both monetary costs (rows 38-40) and cost drivers and availability.

These 12 data loggers were selected for analysis because they have all been tested on the US West and East Coasts. These data were derived from a combination of case study review, vendor interviews/market research, and literature review. Blank cells indicate the information was not readily available in the literature/online, and we were unable to contact the manufacturer.

Company	Archipelago	CLS	CLS	Skymate	SnapIT Group	Succorfish	Rock7	Pelagic Data Systems	Particle Industries	Viatrax	Network Innovations	Anchor Labs BlackBox Lite
Device	LIME	Nemo	Triton		SolarVMS	SC2	Rockfleets	VTS	Particle OneTracker	Boat Command	hiSky Smartellite Dynamic Ku terminal	
BASIC UNIT INFORMATION												
Waterproof rating/ruggedness	IP65			IP67		IP67	IP68	IP68		IP66	IP67	
Tested for ability to detect fishing activity (vs transit)- and how/which fisheries?	yes	yes (SSF's worldwide)		no		yes	yes	yes		lobster fisheries east coast		
Can do 1 min ping rate?	yes	yes	yes	no		yes	yes	yes		yes	yes	
Can accommodate hydraulic sensors now or in the future?	yes	no	yes	in dev		unknown	yes	unknown		yes	yes	
data transmitted w/ gps implied	speed/heading	speed/heading	speed/heading	speed/heading		speed/heading	speed/heading	speed/heading		speed	speed/heading	
Power Down in Port? Other Capabilities?	no	unknown	unknown	yes		unknown	yes	yes		24 hr reports in port		
Is there any automatic reduction in ping rate or other change when the vessel isn't moving?	no	unknown	unknown	yes		unknown	yes	yes		yes		
USER RESPONSIBILITIES												
Power Source?	external wiring	internal battery	external wiring	external	internal battery	external wiring + internal battery	external wiring + internal battery	Internal solar powered battery		external wiring + internal battery	external wiring	
Hard Wire	yes	no	yes	yes	no	yes	yes	no		yes	yes	
Solar	no	yes	no	no	yes	no	no	yes		no	no	
Internal battery (how to charge? Replace?)	no	no	no	no	yes	yes	yes (power on boat)	yes		no	no	
On/Off or always on?								on/off				
How does user know unit is working?	logins	lights	lights	lights		lights	light on the side			lights on the side		
How does user know unit is gathering data and/or transmitting?	data feed	lights	unknown	lights		lights/portal	access the portal			indicator lights		
Will unit alert if malfunctioning/power loss etc?	no	lights	alarms	lights		lights	access the portal			yes (managers)		
Can users adjust ping rate?	yes (managers)	yes (managers)	yes (managers)	yes (managers)		no	yes (cloudloop)	no		yes (managers)		
DATA TRANSMISSION & ACCESS												
Transmission Rate? How quickly is data pushed from device to vendor?	near real time (possible, but increased error)	near real time	near real time	near real time		near real time	near real time	near real time		near-real time		
Ability to push data- via API?	☑	☑	unknown	☑		☑	☑	☑		☑		
How often can data be transmitted to PSMFC through an API?	bucket data from like 30 minutes	onboard data storage, transmits in range	depends on ping rate	recommended 5 min or greater due to ping		w/ ping rate	w/ ping rate	w/ ping rate		depends on coverage, pings can be up to 10 s		
How is data transmitted?												
Cellular	☑	☑	☑	☐	☐	☑	☑	☑	☐	☑	☐	☐
Satellite	☐	☑	☐	☑	☐	☑	☑	☐	☐	☐	☑	☐
Bluetooth	☐	☐	☐	☐	☐	☑	☑	☐	☐	☐	☐	☐
Wi Fi	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐
Serial/UART	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐
Other												
data platform? (data access for owners/fishermen?)	archipelago cloud that can push at diff intervals	web interface	web interface	available to anyone w/ credentials		web interface	yes, available to people to credentials	web interface		fisher access through phones		
confidentiality/data access and storage	fishers have access to data w/ the login (FLEET interface)	credentials	credentials	data is only available through web interface, stored internally		credentials, variable for company	all-encrypted, different access levels, data analytics	credentials		stored in their AWS servers, accessible to managers and individual fishers		
COST/SERVICE INFORMATION												
Unit cost	1299 (MSRP) + 264 pressure sensor	549	3000	~3000		300	1000-1100	200	205-325	200-300		
Service plan and possible structures	Monthly	Annually	Annually	Monthly		Annually	Monthly	Annually	Monthly	Annually		
Recurring Bill	69 / month 470 / annually 295* / fishing season	249	648	22-74		300	17	300	0	180		
Bundle price if user has other devices (VMS, EM etc)	yes			N/A								
Cost Drivers (e.g.,ping rate)	device			ping rate		integration, ping rate	device	API cost		ping rate + data processing		
Availability of units for purchase- when can they be shipped etc.	ASAP			on website						ready on website		
Customer Service provided by vendor?	yes									yes		

NOTES/Key Insights												
When it comes to cost structures specifically, the primary source of variability is transmission plans, see specific notes per vendor	emphasizes data efficiency			smaller solar device for 1000	never returned communications		cellular + Serial are optional add ons		unit cost depends on accessories bundle	aws	has integrations w/ e loggers	
Data access and storage, on the other hand, remain consistent across vendors. The general model involves each company storing the ping data on servers on their end, either through a cloud computing service or their own servers.	bulk pricing (package can go under 1000 depending on quantity)			pricing based on character limits (each ping is 20 characters, goes from 8000 to 50,000)			600 is for cellular + satellite		never returned comms	180 yearly is based off cases w/ variable ping rate (speed threshold)		
As a small aside, the vendors that we spoke to that sell a traditional VMS systems like Skymate or Woodshole as opposed to a data logger usually lack gear sensor integrations that CDFW is seeking currently, and in general seem less flexible when it comes to accommodating additions or modifications to support CDFW's unique data needs				don't sell physical products, have to look at authorized vendors			2 way communication					
							mentioned overlaying w/ whale locations inside the platform					
							credit system... (buy credits for incremental messages setup)					
							per vessel (traditional plan), credits scale w/ data sent, usually <14 cents per credit, different bundles'					

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Interviews

The following interviews with scientists, fisheries managers, and industry experts helped tremendously in improving our understanding of these technologies and methods and helped to inform the development of our analytic frameworks.

Brent Thomason; Account Manager l Ground Control

Chris Free; Quantitative Fisheries Ecologist l University of California, Santa Barbara

Craig Myers; Product Manager l Skymate

Darcy Bradley; Senior Ocean Scientist l The Nature Conservancy

Dick Ogg; Commercial Fishermen l Bodega Bay, California

Geoff Bettencourt; Commercial Fishermen l Halfmoon Bay, California

Gord Snell; President and CEO l Archipelago

Idan Shomroni; Director of Sales l hiSky

Josh Johnston; Product Manager l Viatrax

Lindsey Peavey-Reaves; West Coast Region Sanctuary Soundscape Monitoring Project Coordinator l NOAA Fisheries

Ryan Bartling; Senior Environmental Scientist Supervisor l California Department of Fish and Wildlife

Sylvie Giraud; Sales & Marketing l CLS

Trevor Joyce; Contractor with Ocean Associates, Inc. l Affiliated with NOAA Southwest Fisheries Science Center

Vienna Saccomanno; Senior Ocean Scientist l The Nature Conservancy