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Examining the Potential of Electronic Monitoring to Augment Protected Species Bycatch Data Collection

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Main photo: EM camera system on a fishing vessel. Photo credit: Brett Alger, NOAA Fisheries.

Bottom left photo: Entangled whale tail. Photo credit: NOAA Fisheries. Image taken under NOAA MMHSRP permit # 932-1905.

Bottom center photo: Foul hooked giant manta ray. Photo credit: Bethany Augliere, Marine Megafauna Foundation.

Bottom right photo: Sea turtle. Photo credit: NOAA Fisheries Pacific Islands Fisheries Science Center. PIFSC MTBAP Permit # 21260

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Abstract

Most electronic monitoring (EM) programs in the United States were developed with a primary focus on objectives related to monitoring target catch and discards of finfish. However, electronic data collection for improving science-based management and for monitoring bycatch of protected species is very possible given the broader capabilities of technology. EM is growing in the U.S. at a modest pace, creating an opportunity to increase collection of critical data types used for estimating bycatch and developing bycatch reduction measures. EM has the potential to improve monitoring of protected species bycatch and interactions, and help evaluate the effectiveness of bycatch mitigation measures. The U.S. currently has four pilot programs, five programs under development, and nine fully operational EM programs in federal fisheries, and of these, less than one quarter focus on primarily collecting data on protected species to support new or refine existing management measures. The goal of this project was to identify opportunities to enhance monitoring of protected resources bycatch in each region—and discuss the appropriate electronic or other monitoring mechanisms that could help collect additional monitoring data. By comparing the gear types, bycatch species, and data collection opportunities across regions, we were able to identify possible national monitoring priorities with the potential to improve protected species bycatch estimates in multiple regions of the U.S., as resources allow. For example, regions lack robust data on the interaction rates of sea turtles, whales, dolphins, and porpoises in gillnet fisheries. This analysis may assist the agency in setting or developing monitoring priorities within and/or across regions that improve protected species bycatch monitoring, such as novel research and technology applications that could identify where and when protected species bycatch events are occurring. Before a new EM program is developed or an existing program is expanded, protected species data currently collected by human observers should be assessed, and any potential loss of critical protected species data streams should be evaluated. Electronic technologies could be identified and considered in order to collect useful information on protected species interactions in fisheries where traditional observer programs are not as feasible, such as vessels that cannot accommodate an observer. These results could help guide the design and data collection priorities for EM and electronic reporting (ER) programs, as well as funding priorities for grants that support innovation in fisheries-dependent data monitoring for protected resources.

Introduction

Electronic technologies (ET) are becoming more prevalent in fisheries around the world for collecting fisheries-dependent data, driven by constrained budgets and increased data demands. Fishery managers, scientists, and stakeholders are exploring how global position systems (GPS), electronic reporting (ER), video cameras, gear sensors, technologies for human observers, and other tools can improve the collection and integration of fishery-dependent data. While most existing electronic monitoring (EM) programs in the U.S. were developed in collaboration with fishers with objectives related to finfish, the broader applicability of electronic data collection has become apparent. Applying these technologies can facilitate more timely, accurate, cost effective, and accessible fisheries-dependent data collection. For resource managers of protected species (including threatened, endangered, and protected marine mammals, sea turtles, seabirds, and federally-listed sharks/finfish/invertebrates), EM could improve monitoring of protected species bycatch and interactions and help evaluate the effectiveness of existing bycatch mitigation measures. Additionally, EM could inform safe handling procedures as well as provide critical information used to develop new mitigation measures. Recent work has shown that EM can be particularly effective for monitoring large bycatch species (Moncrief-Cox et al. 2020).

Currently, the data required for estimating protected species bycatch are primarily provided by observer programs. Observers aboard fishing vessels record information on the condition of protected species bycatch (such as the extent of injuries and disposition at release), species and size of the bycaught animal, gear type, capture location, and environmental conditions, and collect tissue samples to aid in species/stock identification and support other research (e.g., stable isotope, contaminants, and hormone analyses). Data on the number of interactions between a particular species and fishery from a representative sample of hauls or trips (or some other relative measure of fishing effort) can be extrapolated to the unobserved portion of the fishery using logbook or other data (Karp et al. 2011). However, if observer coverage is too low or nonexistent due to limited resources for monitoring, and/or sampling designs are not appropriate, protected species bycatch estimates may be biased. In addition, when bycatch events are rare, extrapolations using ratio estimators may systematically under- or overestimate bycatch. There are multiple federal and state fisheries with no data on protected species bycatch levels, and so obtaining some information on interaction rates could help managers focus monitoring efforts and refine conservation or management measures designed to reduce bycatch and mortality/serious injury of these species. Therefore, fishery managers and scientists are looking for new tools to expand data collection and improve protected species bycatch estimates.

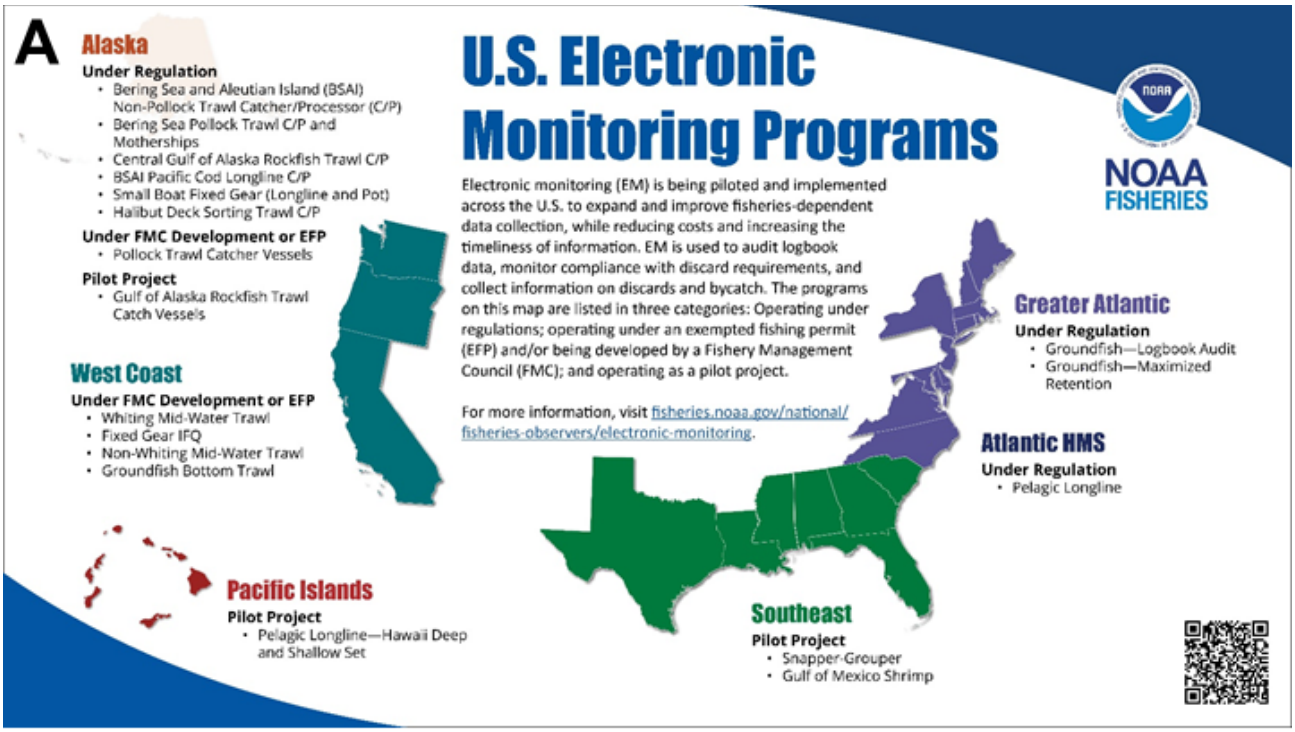
A previous report reviewed the efficacy of EM in monitoring protected species interactions in commercial fisheries (Pierre 2018). Results showed that EM can be effective in monitoring captures of a range of protected species, entanglements in fishing gear, handling of captured species, life status, and discarded catch (McElderry et al. 2011, Hosken et al. 2016, NOAA 2016, Bartholomew et al. 2018, Pierre 2018). Individual species identification was possible in many instances, e.g., for bycatch of seabirds and pinnipeds (Bartholomew et al. 2018, Glemarec et al. 2020). However, monitoring seabird interactions with trawl warps and third wires

was less successful with EM (McElderry et al. 2011). While there were many EM trials or pilot programs collecting information on protected species interactions, there were fewer operational programs (Pierre 2018).

The United States currently has nine fully operational EM programs in federal fisheries, five programs under development, and four pilot programs (Figure 1), and of these, less than one quarter of them have a primary focus of collecting data on protected species to support new or refine existing management measures. Since 2017, the number of vessels participating in each of these EM program types has generally increased and/or remained stable (Figure 1).

For this exercise within NOAA Fisheries, we examined existing regional protected species bycatch data collection programs and discussed possible regional priorities for collecting additional monitoring data to potentially improve bycatch estimation, if these programs could be expanded in the future. These priorities and data collection opportunities are based on experience with methods and coverage levels before 2021. As those methods and coverage levels vary, the priorities and data collection opportunities may change. While EM is a promising mechanism for capitalizing on some of these data collection opportunities, we also consider other monitoring mechanisms that may be more appropriate (e.g., increased observer coverage, additional surveys, or vessel monitoring systems (VMS)). Aligning these priorities with EM technologies could result in amended video review protocols and data quality standards to support additional data collection that could assist in protected species recovery and conservation. In 2020, the NOAA Fisheries Protected Resources Board[1] recommended identifying priority fisheries with protected species bycatch for EM applications (Box 1). This collaborative effort presents an opportunity to identify protected species bycatch priorities and data collection improvements and discuss the appropriate monitoring mechanism(s) that could help collect additional protected species bycatch data, with input from regional experts in protected species issues and EM. The results could help guide the design and data collection priorities for EM and ER programs, including the potential that existing programs could be adjusted to improve protected species bycatch estimates.

[1] This Board includes protected resources leadership from regional offices, science centers, the Office of Protected Resources, and the Office of Science and Technology.



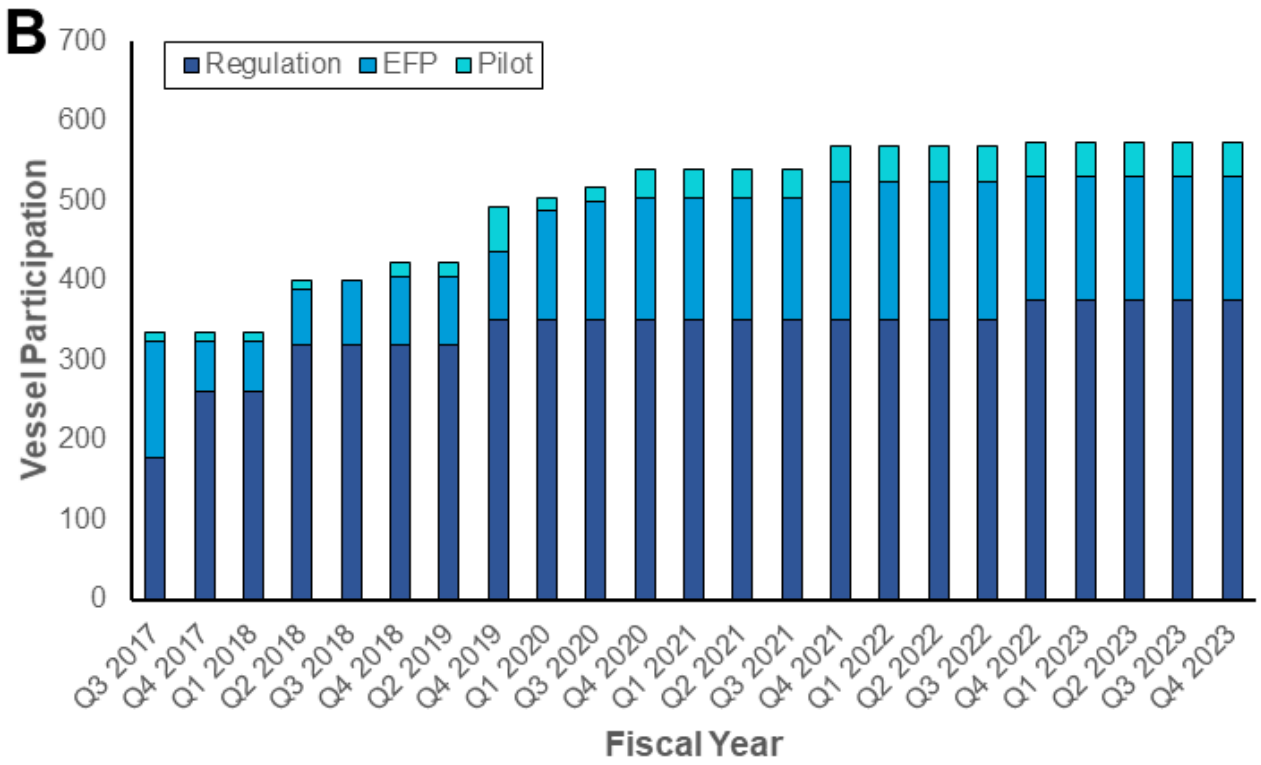


Figure 1: *Map of U.S. Electronic Monitoring Programs, including programs operating under regulations, operating under an exempted fishing permit (EFP) and/or being developed by a Fishery Management Council (FMC), and pilot projects (**A**). Total vessel participation in U.S. pilot, EFP, and regulated (operational) EM programs, updated through quarter four of fiscal year 2023 (**B**).*

Box 1: Protected Resources Board Recommendation

Each region (regional office and science center pair) will identify a list of priorities (specific fisheries and protected species) for protected species electronic monitoring and data collection, including both existing and potentially new programs. The Office of Protected Resources representative to the Electronic Technologies (ET) Working Group will provide these priorities to the National ET Coordinator to incorporate into various funding opportunities (ET, Fisheries Information System, etc.). Once priorities have been identified, each region should incorporate these into the relevant regional ET implementation plans when updated.

Methods

We contacted protected resources staff and EM experts (hereafter regional experts) in each of the five NOAA Fisheries regions (Figure 1) to schedule initial meetings on this project. Some regional experts invited additional staff to these meetings, and regional attendance ranged from two to 14 individuals. All participants were provided with a written description of this project, including background information, examples of protected species bycatch data collection opportunities and possible EM solutions, and brief guidance on prioritizing bycatch data collection in the identified fisheries (see below). In addition, a brief summary of the project was presented during initial meetings with each region.

Examples of how EM could potentially augment protected species bycatch data collection

- Electronic monitoring could be useful for verifying the effectiveness of safe handling, resuscitation, and release requirements for sea turtles incidentally caught in pelagic longline fisheries. Video footage could be used to verify that regulations are appropriate and effective (50 CFR 223.206(d)(1)).
- Fisheries with primarily small boats could benefit from EM coverage, because these boats typically do not have space to accommodate observers. In these fisheries, EM could collect additional data on unobservable vessels, such as some coastal gillnet fisheries vessels (Glemarec et al. 2020). EM could provide valuable information on bycatch presence/absence, bycatch species composition, fine-scale fishing effort data, and ultimately increase the precision of bycatch estimates.
- With ongoing climate change, many species are shifting their ranges and distributions (Hazen et al. 2013), potentially leading to more overlap with fishing activities. Additional VMS data, which provide real-time vessel position reporting, may be helpful for characterizing the spatial extent of these interactions.
- In trawl fisheries, protected species may get injured by fishing gear without being transported to the surface (i.e., unobserved bycatch). EM programs could potentially address this issue by including a camera mounted inside trawl nets (Jaiteh et al. 2014).

Brief guidance on prioritizing fisheries with protected species bycatch data collection opportunities

Prioritization criteria can be separated into two broad categories: biological and logistical. Biological criteria include protected species status, such as species with small population sizes, low reproductive potential, and high vulnerability to local and global stressors (including declines in prey availability, climate change, etc.). Generally, protected species with a more vulnerable status (e.g., listed as endangered rather than threatened) would be higher priorities for additional monitoring. The magnitude and severity of protected species bycatch in a fishery also influences the priority level. Fisheries with high or unknown levels of protected species bycatch would be higher priority, as would fisheries with protected species interactions that are likely to result in mortality (e.g., high on-board and post-release mortality of sea turtles bycaught in trawl gear due to decompression sickness (Parga et al. 2020)).

Logistical criteria include the feasibility of applying EM in a particular gear type (such as trawl vs. longline) and under certain fishing conditions (such as night fishing). Certain gear types are more conducive to EM. For example, one study found that EM was more accurate in a longline fishery than a gillnet fishery (Emery et al. 2019). While this section on prioritization criteria was shared during initial meetings with each region, regional experts ultimately determined the priorities for their respective region.

Questions for Regional Experts

Following a brief presentation of the project goals, examples of ways EM could potentially augment protected species bycatch data collection, and prioritization guidance, regional experts were presented with the list of questions below. These questions served as a starting point for initial discussion and also guided the development of response documents containing details on high priority protected species bycatch data collection opportunities and overlap with EM applications in each region.

1) What are your high priority fisheries with protected species bycatch where current data collection programs (regardless of the tool used) are not providing enough information to evaluate bycatch? Why are these your top priorities?
2) Table 1 shows the EM programs in your region. What are your top three protected species priorities in fisheries covered by these programs?
3) For the high priority fisheries identified in the first question, what protected species may be potential candidates for EM data collection? Other types of data collection (e.g., ER)?
4) For each fishery/protected species pairing, what specific data types could improve the statistical reliability of bycatch estimates? Example data types include, but are not limited to: presence/absence, species identifications, types of interactions and disposition at release (hooked, entangled, mortality), spatiotemporal coverage, and higher resolution fishing effort.
5) Is there a monitoring mechanism you recommend to collect those data? Mechanisms can include logbooks, VMS, electronic monitoring (including cameras and gear sensors), more observer coverage, species distribution maps, etc.
6) Are there fisheries in your region with an observer program that may be better monitored by EM, either in part or in full?

Table 1: *Current EM programs in U.S. fisheries and all known bycatch species categories that interact with each fishery. Note that the EM programs in these fisheries are not necessarily designed to collect data on all the bycatch species listed. F/I = fish/invertebrate, MM = marine mammal, ST = sea turtle, SB = seabird.*

EM Program	Type	Region	Bycatch Species Category*	Gear Type
Bering Sea and Aleutian Island (BSAI) Non-Pollock Trawl Catcher/Processor (C/P)	Operational	Alaska	F/I, SB, MM	Otter trawl bottom
Bering Sea Pollock Trawl C/P and Motherships	Operational	Alaska	F/I, MM, SB	Otter trawl midwater
Central Gulf of Alaska Rockfish Trawl C/P	Operational	Alaska	F/I, MM, SB	Otter trawl bottom, Otter trawl midwater
BSAI Pacific Cod Longline C/P	Operational	Alaska	F/I, MM, SB	Bottom longline
Small Boat Fixed Gear (Longline and Pot)	Operational	Alaska	F/I, MM, SB	Bottom longline, Pot
Halibut Deck Sorting Trawl C/P	Operational	Alaska	F/I, SB	Trawl
Pollock Trawl Catcher Vessels	Under Development	Alaska	F/I, MM, SB	Otter trawl midwater
Whiting Mid-Water Trawl	Under Development	West Coast	F/I, MM, SB	Otter trawl midwater
Fixed Gear IFQ	Under Development	West Coast	F/I, MM, SB	Bottom longline, Pots and traps
Non-Whiting Mid-Water Trawl	Under Development	West Coast	F/I, MM, SB	Otter trawl midwater
Groundfish Bottom Trawl	Under Development	West Coast	F/I, MM, SB	Otter trawl bottom
Nearshore Rockfish	Pilot	West Coast	F/I, MM, SB	Combined gears
Pelagic Longline - Hawaii Deep and Shallow Set	Pilot	Pacific Islands	F/I, MM, ST, SB	Pelagic longline
Snapper-Grouper	Pilot	Southeast	F/I, ST	Bottom longline, vertical line
Gulf of Mexico Shrimp	Pilot	Southeast	F/I, MM, ST	Otter trawls

EM Program	Type	Region	Bycatch Species Category*	Gear Type
Pelagic Longline	Operational	Atlantic HMS	F/I, MM, ST, SB	Pelagic longline
Northeast Multispecies	MREM: Operational (under EFP) Audit: Operational (under EFP Fishing Year 2016-2020; under regulation Fishing Year 2021-Present)	Greater Atlantic	F/I, MM, SB, ST	Gillnet, Otter trawl, Bottom longline, Scottish seine, Hand line
Herring Mid-Water Trawl	Operational (under EFP)	Greater Atlantic	F/I, MM	Otter trawl midwater
Northern Gulf of Maine Scallop	Pilot	Greater Atlantic	*Pre-implementation phase*	
Northeast Multispecies For-Hire	Pilot	Greater Atlantic	F/I, ST	Hook and line

**Data extracted from the U.S. National Bycatch Report First Edition Update 3 (Benaka et al. 2019), including updates from regional experts for this report.*

Results

Regional responses to the questions were reviewed and compared, and similar data collection opportunities across regions were identified. The high priority fisheries with protected species bycatch data collection opportunities generally fall into two categories: data collection opportunities without restrictions on the recommended type of monitoring mechanism (Appendix Table 1), and data collection opportunities in existing EM programs that could potentially be filled with modifications to the EM program (Appendix Table 2). Regional responses for both of these categories are summarized and compared below.

This project was not an exhaustive survey of ways existing protected species bycatch data could be improved, or a review of observer coverage gaps in U.S. fisheries. Rather, the results presented here describe the highest priorities identified by regional experts involved in this study in early/mid 2021, rather than a comprehensive list of priorities. Some U.S. EM programs are still in early phases of development and are expected to be dynamic as they transition into mature programs.

Similar monitoring priorities across regions for augmenting protected species bycatch data collection (regardless of the type of recommended monitoring mechanism)

State fisheries make up 42 percent of the high priority fisheries with protected species bycatch data collection opportunities that could benefit from additional monitoring, excluding fisheries that are part of existing EM programs. One priority from the Greater Atlantic operates in both federal and state waters and was excluded from this calculation. It is important to note that each listed priority provided by the regions often does not correspond to a single specific fishery. For example, one of the Alaska region's top priorities includes all state components of fisheries that operate in both state and federal waters.

Regional experts were asked to identify their top priority bycaught protected species that could benefit from additional monitoring, regardless of the monitoring mechanism that would be used. These high priority species were aggregated into larger species categories to aid in summarizing responses. For each high priority fishery, regional experts typically listed more than one protected species or general species category (such as elasmobranchs or marine mammals, see Appendix Table 1) that could benefit from additional monitoring. When pooling results across regions, the majority of high priority protected species were marine mammals, followed by sea turtles and elasmobranchs (Figure 2). The most frequently listed individual species as high priorities for additional monitoring were loggerhead sea turtles and giant manta rays (Appendix Table 1). Each of these species were listed under seven separate priority fisheries. Interestingly, regional experts also listed the high priority bycatch species as 'unknown' in seven different fisheries, pointing to crucial areas where more data are needed (Figure 2). Of these seven listed fisheries with unknown bycatch species and levels, four are state fisheries. Obtaining more data on leatherback turtles (n=6 high priorities) and humpback whales (n=5 high priorities) were also listed frequently as top priorities (Appendix Table 1). Other species may become priorities for additional monitoring if there are changes in human observer coverage or new information becomes available.

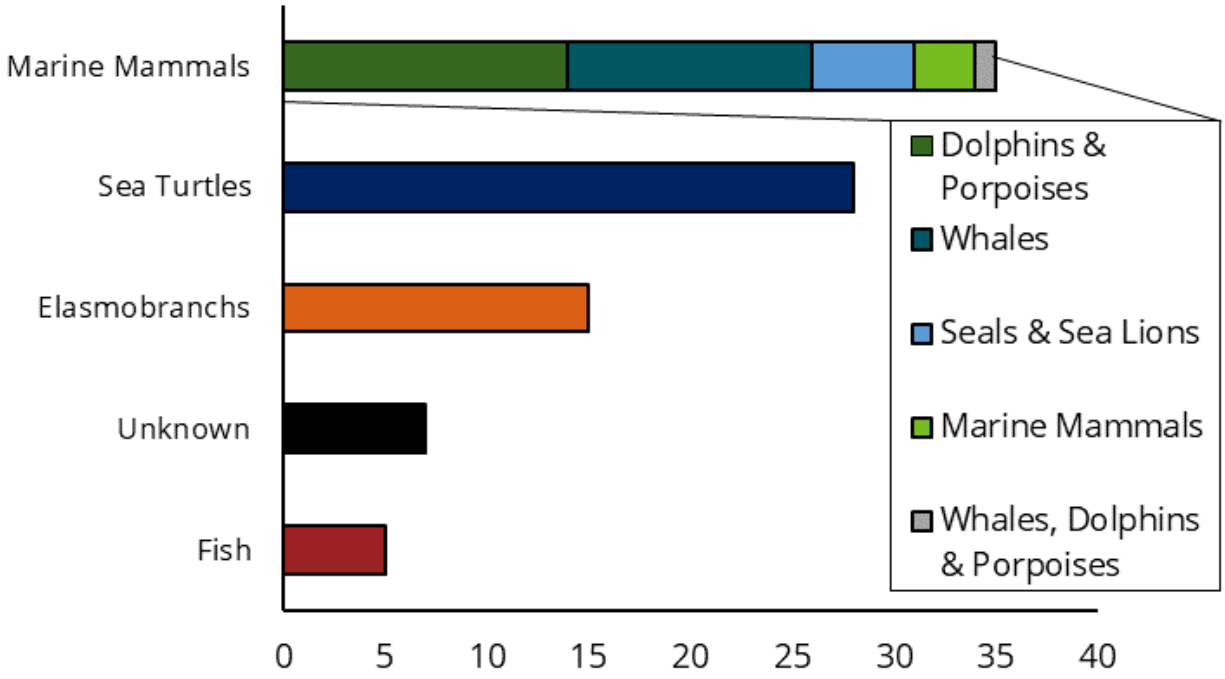


Figure 2: *The frequency of species in higher level species categories listed as top priorities for additional monitoring. Note that some categories are more general based on the taxonomic specificity of the regional responses; see Appendix Table 1 for additional details.*

Gillnet fisheries are the most common gear type prioritized for data collection (Figure 3). The Greater Atlantic, West Coast, Alaska, and Southeast all listed at least one gillnet fishery as a top priority. The high priority species in these gillnet fisheries were mostly sea turtles, followed by whales, dolphins, and porpoises (Figure 4). The most common protected species bycatch data collection opportunities in gillnet fisheries include lack of data on bycatch events and interaction rates (Figure 4). Additional observer coverage was recommended for some of these fisheries. EM may be useful for collecting data on interactions (for example, by increasing overall monitoring coverage) and fishing effort, particularly in situations when vessels are too small to carry observers (as in the Southeast and southern Mid-Atlantic gillnet fisheries). However, other data types such as biological samples can only be collected by human observers.

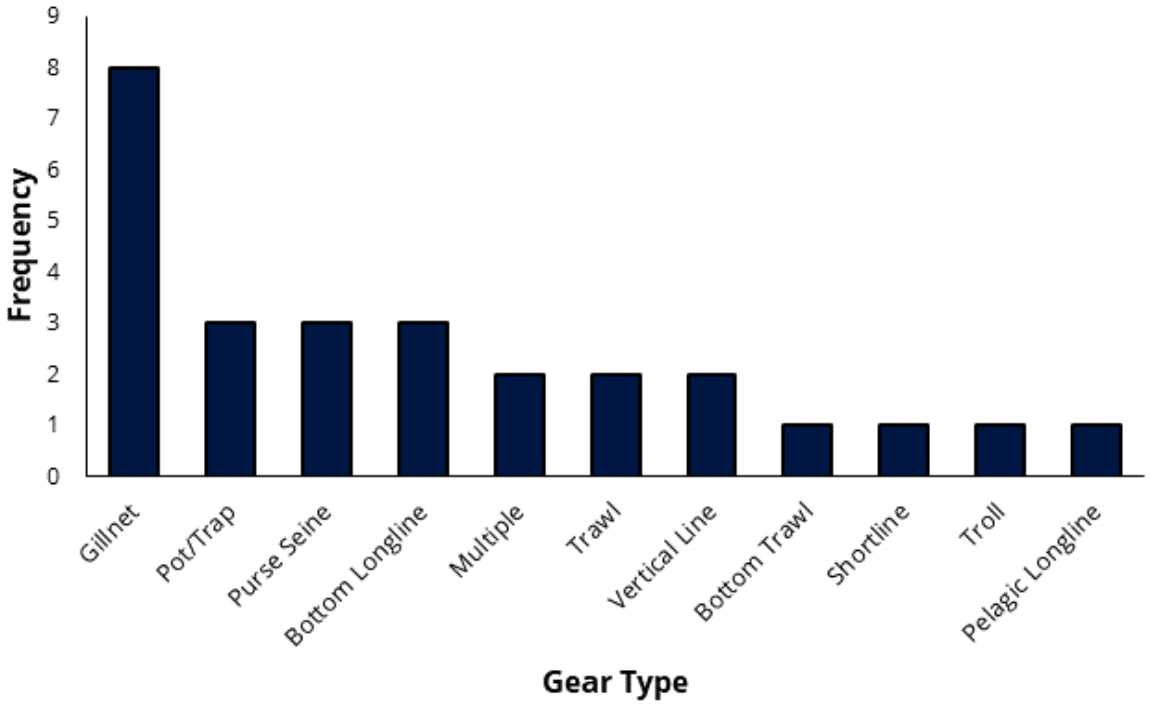


Figure 3: *The number of regional high priorities corresponding to different fishing gear types. See Appendix Table 1 for additional details.*

Both pot/trap fisheries and purse seine fisheries are listed in three regional high priorities (Figure 3). The Greater Atlantic, West Coast, and Alaska each listed one pot/trap fishery as a high priority. The high priority species that could benefit from additional monitoring in these fisheries were either sea turtles or whales (Figure 5). The data collection opportunities associated with these fisheries include lack of robust data on interaction rates, release condition, fishing effort, and extent of injury (e.g., non-serious injury, serious injury, or mortality). More specifically, there is a lack of information on entanglements in vertical lines from pots and traps that occur when the fishing vessel is absent; the entanglements are unobserved because whales can swim off with the gear. Because suspected entanglements occur when pots/traps are unattended, the addition of vessel-mounted camera systems for collecting information on entanglements and other interactions was not recommended. Potential avenues for collecting these additional data include hosting a broader discussion where regional experts can brainstorm novel solutions. Other electronic tools such as accelerometers may be able to better track locations of buoys.

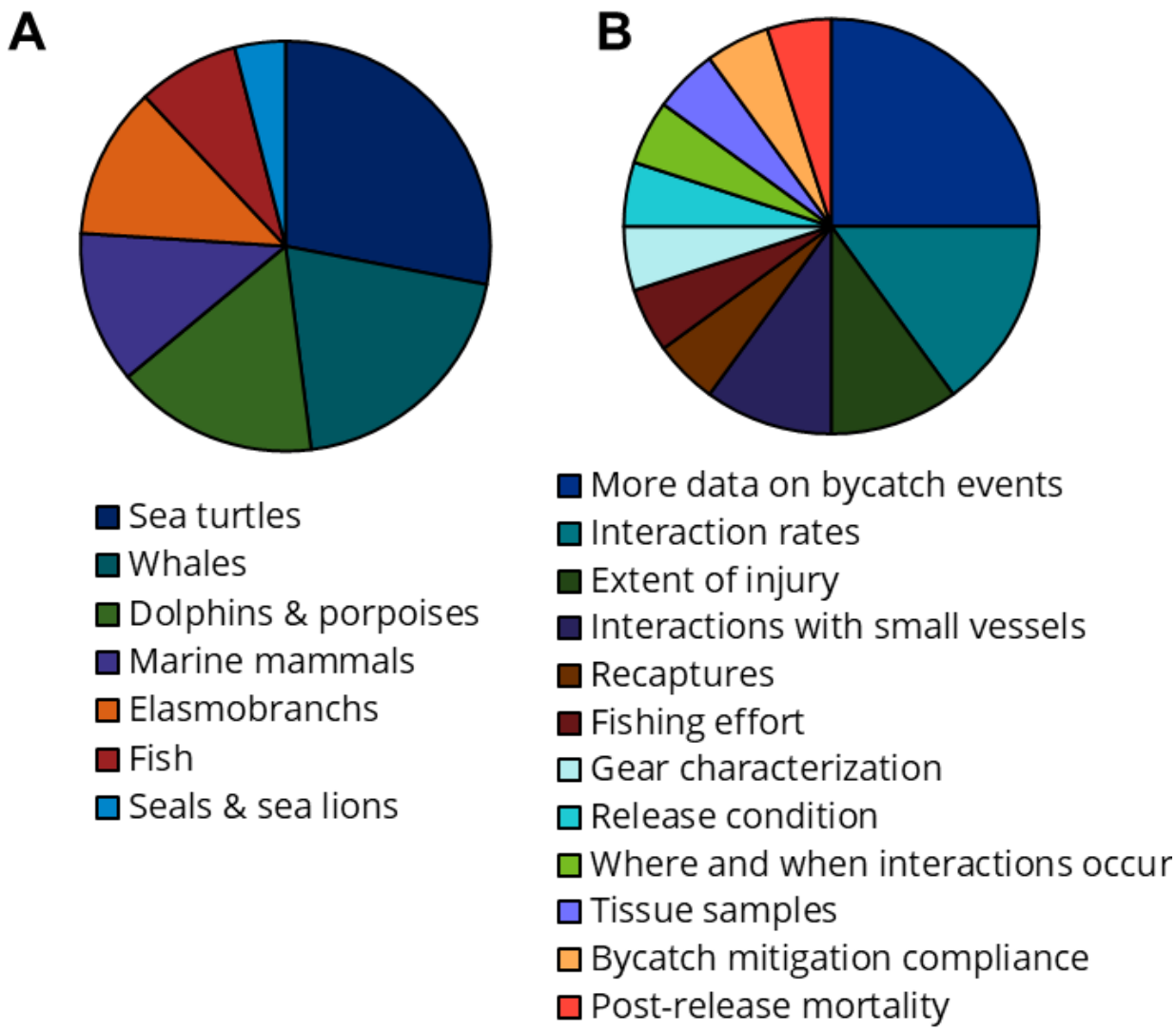


Figure 4: *The proportion of regional high priorities in gillnet fisheries separated by species category (**A**) and data type (**B**).*

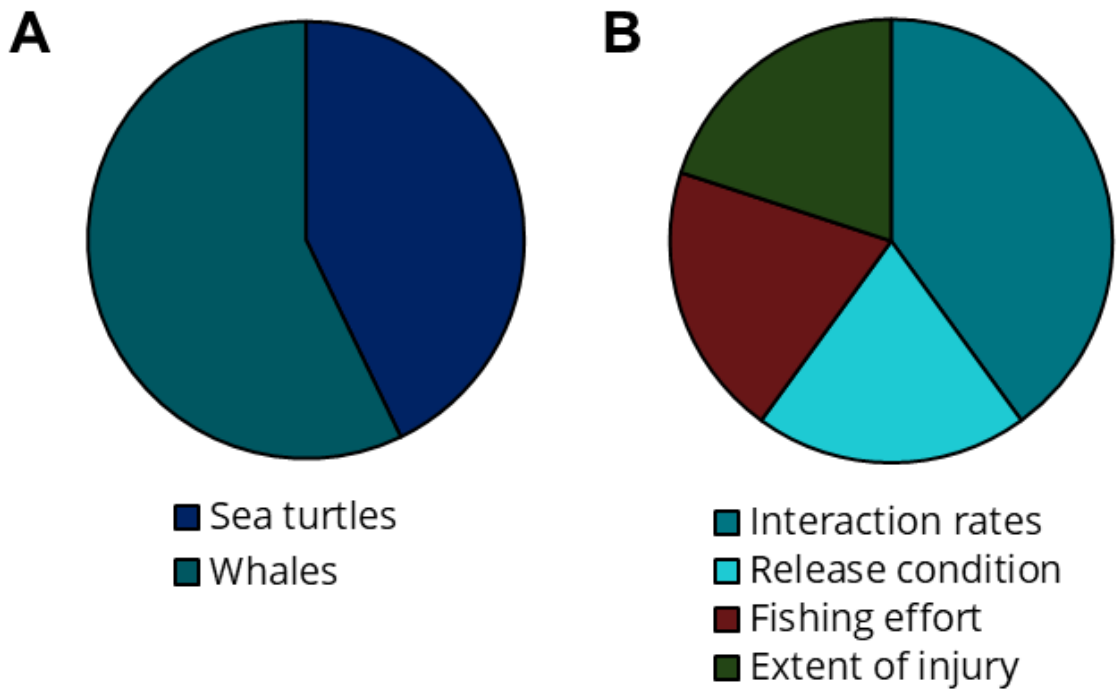


Figure 5: *The proportion of regional high priorities in pot/trap fisheries separated by species category (**A**) and data type (**B**).*

The Pacific Islands, Alaska, and Southeast listed purse seine fisheries as high priorities. The high priority species impacted by these purse seine fisheries were mainly elasmobranchs and sea turtles (Figure 6). The two most common data collection opportunities in purse seine fisheries were a lack of data on species identification and the extent of injury (Figure 6). Different EM applications, potentially in combination with human observers, were recommended to improve protected species monitoring in purse seine fisheries. One potential EM application to address unobserved fishery interactions was noted by the Pacific Islands regional experts. In their high priority purse seine fishery, protected species interactions that occur underwater near fish aggregation devices (FADs) are not observed. EM in the form of underwater cameras/monitoring systems that can capture protected species interactions with FADs was recommended as a potential tool to collect these additional data.

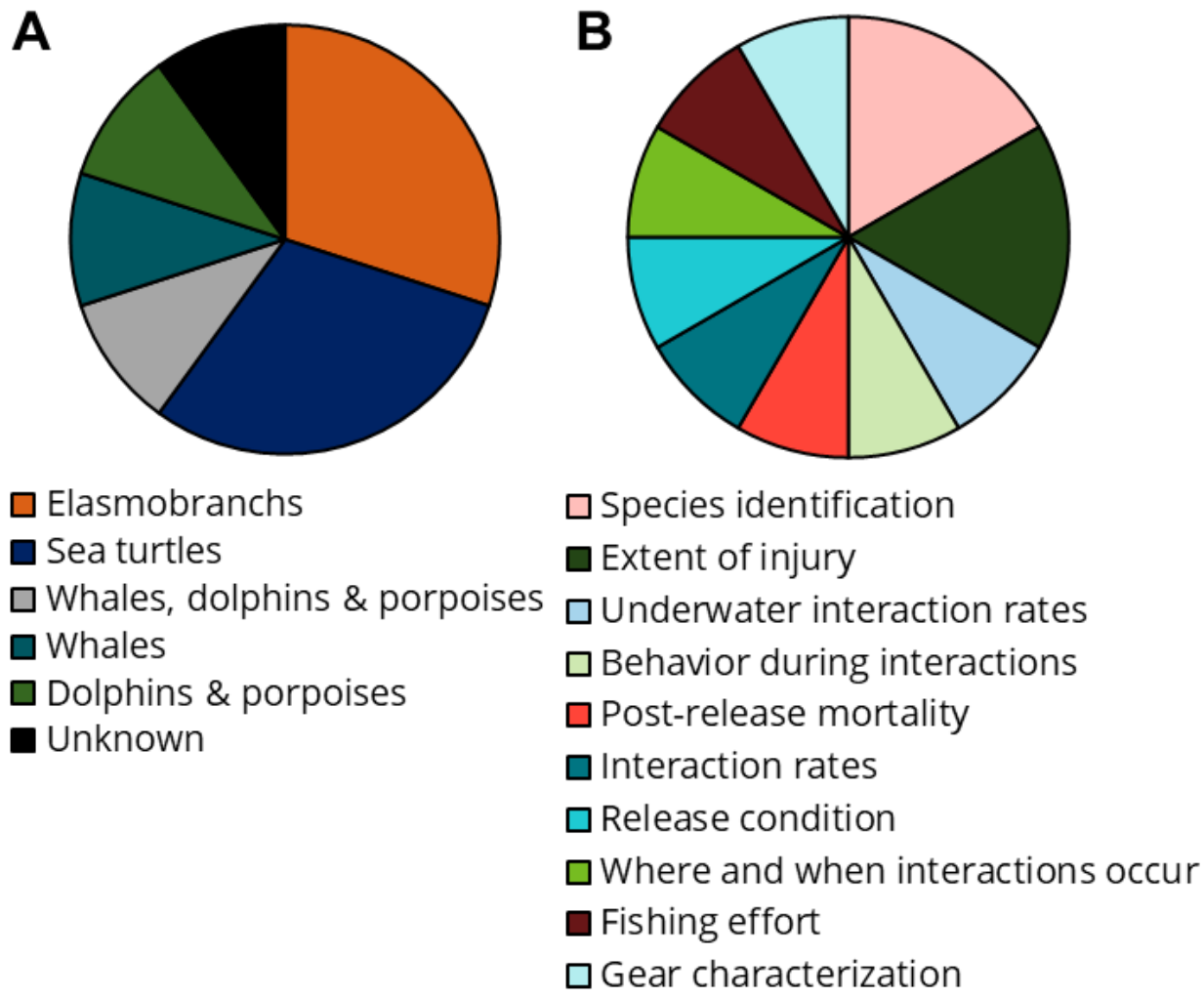


Figure 6: *The proportion of regional high priorities in purse seine fisheries separated by species category (**A**) and data type (**B**).*

It should be noted that our methods of identifying national priorities by comparing the frequency of regional high priorities corresponding to different fishing gear types may mask specific priorities within a given region. For example, while the Southeast identified gillnet fisheries in its list of top priorities, Southeast shrimp trawls were identified as its highest priority overall (Appendix Table 1).

Potential expansions to existing EM programs

Regional experts were also asked to identify high priority protected species that could benefit from additional monitoring in any existing EM programs in their regions (including programs under development and in the pilot phase). Regional responses are summarized in Table 2, and more detailed responses can be found in Appendix Table 2. Overall, bycatch estimation for 14 fisheries with existing EM programs (out of 20 total existing EM programs, Figure 1A) could benefit from additional statistically reliable information on protected species bycatch. Results show different scenarios where EM was and was not recommended for collecting these high priority protected species bycatch data.

Three regions recommended potentially adding more cameras to vessels in order to better monitor protected species interactions in existing EM programs (Table 2). In the Greater Atlantic, a developing EM program with existing observer coverage focuses on sampling fish discards and quota monitoring. Protected species (e.g., marine mammal, sea turtle) interactions may be missed when animals fall out of the net and observers are not actively observing the hauling of the gear. Additional cameras aimed at the nets during haulback on gillnet vessels carrying observers (who are focused on fish sampling) could potentially address this issue. Because EM cannot collect biological samples, measurements, and other important information, EM is generally not a replacement for observers. Still, cameras can supplement existing fisheries monitoring, either when observers are not able to watch all aspects of the operation or when funding, vessel size, or other constraints prohibit the deployment of human observers.

For the West Coast Groundfish EM program, regional experts highlighted a desire to analyze the type and quality of protected species bycatch data that can be collected using EM. Current onboard EM systems may need to be adjusted if they are to be adapted to better collect protected species bycatch data (including the addition of cameras, or changing camera angles in order to capture particular bycatch events and/or handling and release). The Southeast experts also noted that the effectiveness of safe handling and release requirements for protected species, as well as assessments of post-release mortality suffer from a lack of robust data. These data could potentially be collected by modifying camera views or adding cameras so that all protected species interactions are documented. Post-release mortality could be assessed by reviewing data collected by the cameras on the condition of the animal and/or amount of gear left on the animal post-release.

The regional experts from the Pacific Islands specified that protected species bycatch data could be improved by expanding EM in their existing monitoring program. Their current pilot pelagic longline EM program focuses on both fish and protected species monitoring. For this program, robust data are lacking on species identification, injury location, and interaction rates (Table 2). Some modifications to the EM system and catch handling procedures were recommended in a previous study that could improve protected species data collection (Carnes et al. 2019). The authors indicated that data collection could be improved by adding higher resolution cameras, recording video during gear setting to capture data on seabird interactions, and modifying handling methods of large protected species brought alongside the vessel to improve capturing the event on camera. If the existing EM design were modified to improve protected species data collection, the program could be expanded to additional vessels and more data could be collected to assess whether data collection protocols are adequate for estimating protected species bycatch.

Finally, the regional experts from Alaska consistently stressed the importance of the diverse protected species data streams collected by human observers, and their concern that a transition to increased EM deployment (and decreased human observer effort) could result in substantial data loss. In Alaska, four EM programs operate alongside human observer coverage, where marine mammal bycatch monitoring is conducted by an observer (Appendix Table 2). The EM systems in these programs are focused on enforcement of catch sorting, species retained/discarded, and salmon bycatch sorting. The fisheries observers monitor marine mammal bycatch by collecting morphometric data, close up images for species/stock/sex identification, and tissue samples. Because of this design, regional respondents did not

recommend EM as a replacement for observers in existing EM programs in the future, and instead recommended maintaining the current hybrid approach. However, they did stress the utility of using EM in unobserved fisheries to collect marine mammal bycatch data.

The Greater Atlantic region also expressed concerns about data loss if human observers were to be replaced by EM. In this region, the collection of information on marine mammal and other protected species interactions from EM data is not authorized, as it is not a component of the Northeast Multispecies At-Sea Monitoring (ASM) Program developed by the New England Fishery Management Council. Therefore, the Northeast Multispecies EM Program is not designed to supplement at-sea monitors or traditional fisheries observers in the fisheries covered by this program.

Table 2: *Summary of regional responses collected in 2021 describing high priority protected species bycatch data collection opportunities in existing EM programs.*

Region	Number of EM Programs (from responses)	Protected Species Bycatch Data Collection Opportunities	EM Potential
Greater Atlantic	3 Operational (under EFP)* *1 Program was implemented under regulation for Fishing Year 2021 (beginning May 1, 2021)	For some species, there is insufficient spatio-temporal coverage. Under some observer protocols, marine mammals may fall out of the gear during the haul and are subsequently missed by observers. This results in potentially biased marine mammal bycatch rates. The EM systems are not designed to meet any marine mammal bycatch monitoring requirements.	**Add EM:** The EM system could be modified to add cameras directed at viewing the hauler on gillnet vessels when traditional observers on board the same vessel have other duties to attend to. EM systems could also be useful if funding, vessel size, or other constraints preclude human at-sea monitors or observers.
West Coast	1 Under Development	An analysis of the type/quality of data that can be gathered on PR interactions using EM could be useful; this analysis could compare what data would be lost from replacing and/or supplementing observers with EM data.	**Add EM:** Additional cameras could be deployed to capture where observation and handling of large whales and other protected resources may occur.

Region	Number of EM Programs (from responses)	Protected Species Bycatch Data Collection Opportunities	EM Potential
Pacific Islands	1 Pilot	This pilot pelagic longline EM program focuses on both fish and protected species (Carnes et al. 2019). Interactions often occur at night and at a distance from a vessel; could use improved data on species identification, injury location, interaction rates, geographic/oceanographic data, size, genetic samples, and post-release mortality metrics.	**Expand EM:** The current program could be expanded to additional vessels to increase monitoring coverage and collect more data on protected species interactions.
Alaska	5 Operational; 1 Under Development	Four EM programs operate alongside observer coverage, where marine mammal bycatch monitoring is conducted by an observer (Appendix Table 2). Observers collect morphometric data, close up images for identification and sex, and tissue samples from marine mammals. For the remaining two programs, EM systems are generally designed to collect different data streams. The EM systems are not designed to meet any marine mammal bycatch monitoring requirements. In the Small Boat Fixed Gear program, the cameras do not capture horizon view and will not capture protected species interactions that occur at a distance from the vessel. In the Pollock trawl EM program (exempted fishing permit, or EFP), EM only captures interaction events involving marine mammals entangled and brought aboard the vessel, brought onto the trawl deck, or interactions occurring at the stern of the vessel. The loss of at-sea observers in this program could lead to a loss of morphometric information and tissue samples.	**Maintain Hybrid Observer/EM:** The present approach of deploying both observers and EM systems should be maintained in the existing EM programs. However, new EM-only programs may be useful to collect marine mammal interaction data in fisheries that are unobserved. EM could capture images of marine mammals caught in trawl nets and boarded. If at-sea observers are not deployed, could evaluate what data could be collected by fishers.

Region	Number of EM Programs (from responses)	Protected Species Bycatch Data Collection Opportunities	EM Potential
Southeast	2 Pilot; 1 Operational EM; 1 Operational ER	More data could be collected on bycatch events, post-release mortality, and the effectiveness of safe handling and release requirements. Lack of robust data to estimate protected species bycatch.	**Add EM:** Verify optimal placement of camera view so that all interactions (including protected species) are documented. An analysis of the usefulness of self-reported protected species bycatch data is lacking (e.g., from ER programs).

Conclusions and Recommendations

In this study, we collected responses to survey questions in 2021 from both protected species and EM experts to describe their high priority protected species bycatch data collection opportunities in each of the five NOAA Fisheries regions. By comparing the gear types, bycatch species, and data collection opportunities across regions, we were able to identify possible national monitoring priorities with the potential to improve the statistical reliability of protected species bycatch estimates in multiple regions (Table 3). Multiple regions listed gillnet fisheries as high priorities for additional monitoring opportunities, as resources allow; this makes sense because gillnetting can result in high levels of bycatch for sea turtles and marine mammals, and most of the bycatch results in mortality from drowning. Because of the rarity of protected species bycatch events, the costs of increased monitoring can be challenging or even prohibitive. Novel research applications that can reduce the costs of monitoring protected species interactions in gillnet fisheries could be particularly beneficial. For example, developing computer vision, machine learning, and artificial intelligence applications to process large amounts of video footage and identify protected species interactions could substantially increase monitoring efficiency. Similar technological applications to automate fish catch and bycatch monitoring on commercial fishing vessels are currently in development (Khokher et al. 2021).

Table 3: *Potential national monitoring and research priorities identified in the present study.*

Recommendations
● Prioritize projects across regions that could improve protected species bycatch monitoring, such as novel research and technology applications that could identify where and when protected species bycatch events are occurring. ● Protected species data collected by human observers should be assessed, and any potential loss of critical protected species data streams should be evaluated before a new EM program is developed or an existing program is expanded, resulting in replacement of human observers with EM. ● Identify technologies that could be leveraged to collect useful information on protected species interactions in fisheries where traditional observer programs are not as feasible, such as monitoring underwater interactions with protected species.

Adding sensors to track fishing gear

A promising area of research identified in this study includes investigating how to leverage existing technologies - potentially including accelerometers, satellite tags, and other sensors - or develop new technologies to monitor fishing gear when the vessel is absent (e.g., as in pot/trap fisheries). Better monitoring of fishing gear location could lead to an improved understanding of where and when protected species bycatch events are occurring, and how patterns may change in the future. Accelerometers record acceleration vectors and have been used to successfully record behavioral stress responses of sharks hooked in fishing gear (Gallagher et al. 2017). To our knowledge, accelerometers have yet to be applied to monitor the movement of set fishing gear, although recent advancements in integrated smart sensors are promising. One such novel technology is the Farallon Buoy (Blue Ocean Gear[2]), which includes sensors for measuring GPS, acceleration, velocity, depth, and water temperature. This smart buoy system was previously tested by two vessels in the Bering Sea and Aleutian Islands crab fisheries, where participants were able to capture data on the behavior of unattended buoys (case study[3]). Results from research projects testing applications of these advanced technologies could improve monitoring of fishing gear location over time, including derelict fishing gear that can continue entangling protected species for years beyond original deployment. As more gear location data is collected, we may be able to identify when buoys are moving against ocean currents, potentially as a result of an entangled, swimming animal.

In addition to better monitoring gear location, sensors on fishing gear can potentially be used to improve data on fishing effort. The results from this study revealed that additional data on fishing effort could improve high priority protected species bycatch estimates and better enable NOAA Fisheries to identify changes in fishing methods that could increase future bycatch levels (Appendix Table 1). Ongoing research in the bottom longline shark fishery to explore how gear sensors may be used to monitor soak times could provide a way to increase data collection on fishing effort (Miller et al. in prep). While this advancement in EM could be beneficial for producing better estimates of protected species bycatch, fish bycatch estimates and catch per unit effort data could be enhanced as well. More accurate data on fishing effort could thereby

[2] Blue Ocean Gear, 2022. [Available at: https://www.blueoceangear.com/]

[3] Blue Ocean Gear, 2022. Case Study: Time Saved is Money Saved and in the Bering Sea, Knowing Where to Find Gear Quickly is Priceless. [Available at: https://www.blueoceangear.com/casestudy]

improve stock assessments and provide better information for managing fish and protected species stocks.

A third application for new sensors on fishing gear could be capturing information on unseen bycatch. For example, there is some evidence that bycaught marine mammals may sometimes disappear from gillnets before being observed, especially if the soak time is long and the animal decomposes and/or is depredated. Accelerometers or other sensors could help quantify the portion of lethal or nonlethal bycatch events that are not otherwise observable, via designed and controlled experiments (Warden and Murray 2011).

We also found that additional monitoring of protected species interactions in purse seine fisheries was a high priority for three regions, should additional monitoring opportunities become available. Previous work comparing the effectiveness of EM and human observers in estimating bycatch in tropical tuna purse seine fisheries revealed that EM tended to underestimate the number of shark bycatch events (Ruiz et al. 2015, Briand et al. 2018). EM was also unable to identify many bycatch events to the species level. Because accurate data on species identification and interaction type is important for appropriately estimating bycatch levels, we recommend increased observer coverage to collect these additional data in purse seine fisheries presently, as resources allow.

Ensuring continued collection of biological samples and other data types collected by human observers

As new EM programs are developed and existing EM programs make refinements, it is important to look at all of the existing data collected in a fishery and better understand the tradeoffs of deploying different tools, such as replacing human observers with EM. EM is growing in the U.S. at a modest pace (Figure 1), so there is an opportunity before EM expands faster and further to ensure we do not lose critical data collected by observers. Observers collect biological samples (critical for correct species/stock identification of some protected species), detailed photos/videos (aid in identifying individuals), the amount/type/position of gear on entangled animals (required to assess injuries in accordance with the NOAA Fisheries Process for Distinguishing Serious from Non-Serious Injury of Marine Mammals[4] and the Process For Post-Interaction Mortality Determinations Of Sea Turtles Bycaught In Trawl, Net, And Pot/Trap Fisheries[5]), and opportunistic sightings (inform species distributions and habitat use). Further, observers are trained to mark dead animals that are discarded to prevent double-counting. Before a new EM program is developed or an existing program is expanded resulting in replacement of human observers with EM, the protected species data collected by observers should be assessed, and any potential loss of critical protected species data streams should be evaluated.

[4] NMFS. 2012. Process for Distinguishing Serious from Non-Serious Injury of Marine Mammals. NMFS Policy Directive 02-238. NMFS, Protected Resources. 4 p. [Available at https://media.fisheries.noaa.gov/dam-migration/02-238.pdf]

[5] NMFS, 2022. Process For Post-Interaction Mortality Determinations Of Sea Turtles Bycaught In Trawl, Net, And Pot/Trap Fisheries. NMFS Procedure 02-110-21. NMFS, Protected Resources. 22 p. [Available at: https://media.fisheries.noaa.gov/2022-03/02-110-21_renewal_March%202022_kdr_0.pdf]

In their responses, the experts from the Alaska region suggested that managers should consider if there are specific data types that observers currently collect that fishers could collect while operating an EM system. This could provide a potential way to expand EM while mitigating the potential loss of data currently collected by observers. There may be some information, such as close-up images of dead marine mammals or length information, that could be straightforward for fishers to collect. As more vessels participate in EM programs, processes could be put in place for ensuring the continued collection and access to crucial protected species bycatch data. For example, in the Alaska pollock trawl EM program, fishers may choose to use EM instead of human observers under an EFP, resulting in potential loss of morphometric information and tissue samples. In 2019, around 40 percent of the vessels (47 vessels out of 116 total) in the pollock trawl fishery participated in the EM program through the EFP (Alaska Region Electronic Technologies Implementation Plan, 2021). The North Pacific Fishery Management Council has begun analyses[6] to implement a regulated trawl EM program by January 2024, which may result in some data loss (such as tissue samples) for some protected species if contingency plans are not developed. A similar data loss could occur in the Northeast Multispecies fishery if fishers choose EM over human observers to fulfill the monitoring requirement. Further, any limitations on the use of EM video for collecting data on protected species bycatch combined with increasing use of EM (and decreasing use of human observers) have the potential to create data gaps.

Adding EM to augment existing observer programs

Protected species interactions and other rare bycatch events can be costly to monitor with human observers in many fisheries, and it is difficult to deploy observers in fisheries with relatively small vessels. EM/ET could be leveraged in these situations to collect useful information on protected species interactions when traditional observer coverage is not cost-effective or observer deployment is not feasible. For example, assessments of bycatch from Southeast gillnet fisheries (including those in North Carolina and the Gulf of Mexico) with vessels too small to carry observers could benefit from EM, particularly in those fisheries that have never been observed. Additionally, camera-based EM systems may be able to capture information when an observer is not on deck, or not able to view an event when they are on deck (e.g., off the stern of a vessel).

In the Pacific Islands, protected species interactions can occur underwater near FADs, but those interactions are not detectable by human observers. The development of underwater cameras/monitoring systems could be explored as a means to determine unobserved mortality and site fidelity/usage of ESA-listed species (such as giant manta rays, oceanic whitetip sharks, and leatherback sea turtles) at FADs (Appendix Table 1). Underwater cameras have been successfully used to monitor protected species bycatch inside actively fishing trawl nets (Jaiteh

[6] North Pacific Fisheries Management Council, 2022. Integrating Electronic Monitoring on Pollock Catcher Vessels using Pelagic Trawl Gear and Tender Vessels in the North Pacific Observer Program. NPFMC. 195 p. [Available at: https://meetings.npfmc.org/CommentReview/DownloadFile?p=51d917fa-1a0a-487f-9b57-df020dfbab91.pdf&fileName=C4%20Trawl%20EM%20Initial%20Review%20Analysis%20.pdf]

et al. 2014) as well as to monitor individual sea turtle and shark behavior (Hayes et al. 2017, Brena et al. 2018). Future studies could build upon these previous underwater monitoring applications to estimate protected species bycatch at FADs. Bycatch of protected species is likely occurring in many unmonitored fisheries, and even if EM cannot provide all of the data that human observers collect (e.g., bycatch rates, biological samples for identifying stock/species), it could provide useful information to focus future management efforts. Additionally, video footage of protected species bycatch events is helpful for developing mitigation measures to reduce bycatch, and if that is not possible, to reduce post-release mortality. Note that the costs incurred by leveraging EM (such as for additional cameras, more video review, and higher costs for the fishery associated with handling protected resources in a way that facilitates data collection) to collect additional protected species bycatch data may not be lower than the cost of deploying human observers.

Lastly, EM can be used to augment existing observer data collection by expanding sample sizes and spatiotemporal coverage. Multiple regions highlighted the potential benefits of improved coverage and recommended using EM to help collect some of these data on relatively rare protected species bycatch events. However, as detailed in a forthcoming technical memo on integrating EM into fish stock assessments (Peterson et al. in prep), combining data streams is not a straightforward process, especially for use in stock assessment models. The authors note that engagement with the stock assessment community early in the development of the EM program can ensure that well-defined monitoring objectives are identified, and each data type that is collected can be fully incorporated into fish stock assessment analyses. These recommendations also apply to stock assessments for protected species; marine mammal and sea turtle assessment scientists could also be included in discussions of integrating observer and EM data to provide the best available science for natural resource management.

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Appendices

Appendix Table 1

Summary of regional experts' high priority fisheries with protected species bycatch data collection opportunities with no restrictions on the recommended monitoring mechanism. This table does not include priorities in existing EM programs. Note that this is not an exhaustive list of observer coverage gaps in U.S. fisheries.

Fishery Description	Protected Species	Data Collection Opportunity	Monitoring Recommendation
Northeast			
Federal water gillnet fisheries using mesh ≥ 7 inches in winter months of Nov-Feb from Chincoteague VA to Long Island	All Atlantic sturgeon DPSs but primarily the New York Bight DPS	Number of interactions, apparent mortality, and whether fish are being repeatedly captured (e.g., is fishing effort occuring in a sturgeon aggregation area)	More observer coverage for a period of time (e.g., a specific number of winter seasons).
State water gillnet fisheries south of Cape Cod, MA (all mesh sizes, but mesh ≥ 7 inches are higher priority)	Sea turtles (green, Kemp's, leatherback, loggerhead), Atlantic sturgeon (all DPSs possible but most likely New York Bight DPS)	Effort and gear characterizations, interaction rates, and condition/disposition at release	Observer coverage, electronic monitoring if shown to be effective for protected species monitoring in gillnets (there are concerns about missing interactions (e.g., if turtle falls out of net before it is brought on board)).
Pot/Trap (federal and state waters)	Sea turtles (leatherback, loggerhead)	Interaction rates and condition/disposition at release for both state and federal components of the fishery	Could be helpful to have a discussion on what might be most effective here to get information on interactions.
State water bottom trawl fisheries	Sea turtles (green, Kemp's, leatherback, loggerhead)	Effort and gear characterizations, interaction rates, and condition/disposition at release	Observer coverage, potentially EM
North Carolina coastal gillnet fishery (not internal state waters).	Northern and Southern NC Estuarine bottlenose dolphin stocks. Both have low population sizes, are strategic & depleted stocks	<u>*Can be resolved with EM*</u>: Spatio temporal coverage; increased sample size; sampling the small vessel fleet. <u>*Can't be resolved with EM*</u>: Biopsy samples from incidental bycatch	EM - to increase sample size and improve consistent annual spatial/temporal coverage across the NC coastline, but particularly in the region south of Cape Lookout down to the NC/SC border. Logbooks may be required to collect haul by

Fishery Description	Protected Species	Data Collection Opportunity	Monitoring Recommendation
	and are subject to a Take Reduction Team and Plan.	events to reduce uncertainty in assigning takes to individual stocks.	haul data on fishing practices. In addition, EM could not collect biological samples from dolphins that have drowned or retrieve whole animals for subsequent necropsy. Likely would include human observers on a portion of EM trips in the pilot phase of an EM program to validate data collection and quality.
West Coast			
WCR State managed Dungeness crab fisheries	ESA-listed humpback and blue whales, leatherback sea turtles	Details on fishery operation; specifically effort monitoring to facilitate risk assessment and co-occurrence modeling for whales and sea turtles.	Electronic monitoring (solar loggers, VMS, etc.; w/o cameras) of fishing effort; could also be used to facilitate development of other gear modifications that include pop-up gear systems. Efforts could be focused on areas/times when/where entanglement risks are highest.
WCR gillnet fisheries – CA large mesh drift gillnet (DGN) fishery	Numerous marine mammal species including ESA-listed whales, sea turtles, sharks/rays	Bycatch estimates generated from observed vessels could be improved/validated with data from unobservable and/or unobserved vessels. Compliance with take reduction plan measures (pingers) could be monitored with EM.	Camera monitoring for PR species.
WCR gillnet fisheries – CA State small mesh DGN and set gillnet	Numerous marine mammal species including ESA-listed whales, sea turtles, sharks/rays	Consistency of coverage and production of solid PR bycatch estimates for many PR species and potentially other species of interest	Camera monitoring for PR species; electronic monitoring for effort (solar loggers, VMS, electronic logbooks, etc.)
WCR gillnet fisheries – WA salmon drift gillnets	Risk for numerous marine mammal species including ESA-listed whales, harbor porpoise	Production of solid bycatch estimates for PR species: including harbor porpoise, which have relatively high stranding rates including signs of fisheries interactions.	Camera monitoring for PR species

Fishery Description	Protected Species	Data Collection Opportunity	Monitoring Recommendation
Pacific Islands			
Purse Seine	Giant manta rays, oceanic whitetip sharks, leatherback sea turtles (and other turtle species), large cetaceans	Protected species interactions that occur underwater near FADs are not observed. Observer data is not detailed enough for characterizing behavior during fishery interactions and injuries, species identification. Post-release mortality is unknown for most ESA-listed species.	EM; development of underwater cameras/monitoring for FADs to attempt to determine unobserved mortality, site fidelity/usage of ESA-listed species at FADs; improved species identification; and post release mortality studies such as satellite tagging. EM might be able to add additional spatial data, as well as species ID and video of the set and to provide better data on protected species interactions prior to or during the set (EM can augment observer data). Genetic sampling. Observer training.
All state-managed fisheries in Hawaii.	Sea turtles, oceanic whitetip sharks, Hawaiian monk seals, and the Main Hawaiian Islands Insular stock of FKWs (MHI IFKW)	Lack of bycatch data for all fisheries and all species. Interactions with protected species are typically not self-reported and little to no mitigation exists. There is no monitoring of protected species bycatch in state-managed (recreational, subsistence, and commercial) fisheries. Fishing effort, what species interact with state-managed fisheries, interaction rates and type (i.e., was it a mortality, serious injury, or non-serious injury), geographic location, species ID and stock, description of the animal that includes size.	A fishing permit program would be an important first step. Self-reporting forms (protected species field on commercial reporting forms; reporting forms for recreational fishing); recreational fishing permits; observers, creel surveys; EM/VMS data; FAD underwater monitoring.
[State] Hawaii-based shortline	Currently unknown, possibly insular false killer whales, elasmobranchs, and others.		Possibly EM, although this could require extensive work with the state and fishers to establish; improved record keeping and reporting
[State] Troll (as well as palu-ahi and handline, but troll as a priority)	Pantropical spotted dolphins, others unknown, possibly false killer whales, oceanic whitetip sharks, and others		Possibly EM, although this could require extensive work with the state and fishers to establish; improved record keeping and reporting as a first step.

Fishery Description	Protected Species	Data Collection Opportunity	Monitoring Recommendation
[State] Coastal hook and line, gillnet, spearfishing, crab traps	Green and hawksbill sea turtles, Hawaiian monk seal, others as of yet unknown		Recreational fishing permits, improved record keeping and self-reporting, Incidental Take Permit application and Conservation Plan currently in process, subsequently any type of monitoring system could be useful.
Alaska			
State commercial salmon gillnet fisheries (Highest Priority: southeast Alaska salmon gillnet fishery, gillnet fishery in Cook Inlet)	Harbor porpoise, Cook Inlet beluga whales, Steller sea lions (eastern and western DPS), humpback whales (Hawaii and Mexico DPS)	Observer data on these fisheries are rare, badly outdated, or nonexistent, but when observer data are available, they demonstrate that there are levels of bycatch of harbor porpoise that are near to or greater than the Potential Biological Removal (PBR) for the impacted harbor porpoise stock.	A focused, science-based observer program with a survey design to evaluate the level of marine mammal bycatch in selected state fisheries. We are open to discussing ways to collect the data we need using EM.
Single-pot gear in Alaska (crab, shrimp, Pacific cod, octopus, etc.)	Humpback whales (Hawaii, Mexico, and Western DPS), bowhead whales	When pots are individually set, it decreases our ability to detect large whale entanglement. Single pots are generally light enough that large whales entangled in them remain mobile and swim away with the gear. Because these fisheries are untended, the absence of a pot when retrieving gear generally leaves no indication for the fisherman, observer, or EM reviewers as to why that pot went missing. More data on interaction frequencies and outcomes from entanglements could be beneficial. Traditional observer programs focus on the gear retrieval, but we don't have ways of tracking gear that goes	While traditional camera-based EM designs would not be suitable for monitoring single-pot fisheries for protected species data, there are other tools such as accelerometers or automatic identification systems (AIS) that may be able to better track buoy lines and identify possible entanglements. Using AIS to understand either where pots are set, or where pots go after being lost, could be useful.

Fishery Description	Protected Species	Data Collection Opportunity	Monitoring Recommendation
		missing or have ways to determine if the gear loss could have been due to an entanglement.	
State component of fisheries that operate in both state and federal waters	Steller sea lions - western US, humpback whale - western North Pacific, killer whale - GOA/AI/BS transient. Other species that could be observed as bycatch include harbor porpoise, harbor seals, and Northern fur seals.	Bycatch of marine mammals in these state fisheries is unknown and could be of concern, particularly for those state fisheries that overlap significantly with areas of high marine mammal density. More data on interactions could be beneficial.	We recommend a focused, science-based observer program with a survey design to evaluate the level of marine mammal bycatch in selected state fisheries. We are open to discussing ways to collect the data we need using EM.
Longline fisheries that are subject to whale depredation (e.g. halibut and sablefish bottom longline fisheries)	Sperm and killer whales	We know that these interactions are leading to entanglements, however, more information on the outcomes of these events (serious injury and/or mortality) could be beneficial.	We do not know of a way to effectively monitor this fishery for marine mammal serious injuries or mortalities using EM, but are open to discussing approaches that have worked for other similar fisheries. We could develop a project to understand the likely outcome of serious injury/mortality events that occur incidental to these fisheries.
Herring and salmon purse seines in southeast Alaska	Humpback whales (Hawaii and Mexico DPS)	These fisheries are currently unobserved. More data on interactions could be beneficial.	EM systems may allow for an effective way to account for incidental capture. Further, EM systems that allow vessel operators to monitor video feed in real time may even help reduce captures.

Fishery Description	Protected Species	Data Collection Opportunity	Monitoring Recommendation
Southeast (Fleets ranked from highest to lowest priority for this region)			
GOM and South Atlantic federal shrimp otter trawl fisheries	Sea turtles (Kemp's ridleys, loggerheads, and greens most frequent but other species too) (See Babcock et al. 2018); also elasmobranchs (sawfish, giant manta rays); dolphins (caught in nets and in lazy lines); and Atlantic sturgeon (albeit rarely) (See NMFS 2021)	For all species, bycatch estimates are hindered by low coverage and effort data problems, particularly in the Atlantic (e.g., accurate information about the number of hours fished could be beneficial); for dolphins there are additional species/stock ID issues; post-release survival and species ID for sea turtles, giant manta ray and smalltooth sawfish	Would still like more traditional observer coverage, but adequate coverage associated with that method is cost-prohibitive so EM coverage (cameras) could be considered, too.
GOM and South Atlantic State-water trawl fisheries (otter, skimmer, others)	Sea turtles, Atlantic and Gulf sturgeon, sawfish, dolphins, giant manta ray	With TEDs required in some skimmers now and potentially more in the future, routine observer/ bycatch monitoring of these could be beneficial	Observer coverage and EM
Southeast Gillnet (North Carolina and GOM)	Sea turtles, giant manta rays, bottlenose dolphins	Post release survival data could be particularly beneficial	EM would improve coverage especially on vessels too small to carry observers. Attempted to test but significant industry pushback
Menhaden Purse Seine (state water)	Bottlenose dolphins; sea turtles; giant manta ray, unknown	Species identification, types of interactions, condition at release, spatiotemporal coverage, fishing effort, gear characterization	EM proof of concept pending (testing cameras, drones, human observers on alternative platforms)
Reef Fish Bottom Longline	Loggerhead sea turtles, dolphins, giant manta rays. Unknown if interacting with marine mammals but concerns about Bryde's whales.	Better CPUEs, data on the overlap of effort and Rice's whales	Combination of observers and EM; expansion of work by Mote Marine Lab

Fishery Description	Protected Species	Data Collection Opportunity	Monitoring Recommendation
Shark Bottom longline	Leatherback and loggerhead sea turtles, smalltooth sawfish	Post release survival rates	Satellite tagging to estimate post release survival
Non-HMS Dolphin Wahoo Pelagic Longline	Unknown but suspected to be similar to HMS pll	Species identification, types of interactions, condition at release, spatiotemporal coverage, fishing effort, gear characterization (All of the above)	Observer coverage
Commercial reef fish fisheries vertical line	Loggerhead sea turtles, giant manta ray	Species identification, types of interactions, condition at release, spatiotemporal coverage, fishing effort, gear characterization (All of the above); better observed CPUEs (more accurate, precise, and less biased)	Increased observer coverage
Commercial snapper-grouper fisheries vertical line	None documented	Species identification, types of interactions, condition at release, spatiotemporal coverage, fishing effort, gear characterization (All of the above)	Observer coverage

Appendix Table 2

High priority protected species that are bycaught in fisheries with existing EM programs. In the Northeast and Southeast, all protected species (not just high priority species) that may interact with the gear type used in the fishery were listed.

EM Program	Type	Gear	High Priority Protected Species Bycaught	Monitoring Program (outside of EM)	Protected Species Bycatch Data Collection Opportunities	Potential EM Modifications to Monitor Protected Species Bycatch
Northeast						
Northeast Multispecies (Commercial Fishery)	MREM: Operational (under EFP) Audit: Operational (under EFP Fishing Year 2016-2020; under regulation Fishing Year 2021-Present)	Gillnet, bottom otter trawl, bottom longline, handline (jig).	Sea turtles, harbor porpoise, gray seals, harbor seals, harp seals, offshore bottlenose dolphins, Risso's dolphins, white-sided dolphins, common dolphins, pilot whales, minke whales, humpback whales.	NEFOP, ASM	For some species, there is sufficient monitoring by human observers; for other species the precision of bycatch estimates is worse than the target CV. Also, there is a large discrepancy in the sampling type for the gillnet fleet. Greater than 90% of observer coverage is 'Complete' coverage where the focus is on the sampling of fish discards. This contrasts with 'Limited' coverage that is dedicated to observing for marine mammal interactions due to 'fall outs' that are missed when observers are not actively observing the hauling of all the gear back on to the vessel. The consequence of this differential coverage is potentially biased marine mammal bycatch rates.	The precision of bycatch estimates could be improved if sufficient EM footage is available and reviewed to capture rare events. Additional requirements could include species-level identifications, cameras that can see gillnets as they are being hauled in from the water, and making the data available for the development of bycatch estimates. The problem of missed 'fall outs' could potentially be resolved with EM technology if cameras were arranged/directed to view the nets during haulback on gillnet vessels. Currently that is not the case because the present EM program was developed for monitoring fish discards and quota monitoring.

EM Program	Type	Gear	High Priority Protected Species Bycaught	Monitoring Program (outside of EM)	Protected Species Bycatch Data Collection Opportunities	Potential EM Modifications to Monitor Protected Species Bycatch
Herring	Operational (under EFP)	Midwater trawl (EM program may also include herring purse seine and bottom trawl vessels)	Harbor porpoise, gray seals, harbor seals, harp seals, offshore bottlenose dolphins, Risso's dolphins, white-sided dolphins, common dolphins, pilot whales. Midwater trawl gear interacts with marine mammals at a much lower frequency compared gillnet and bottom trawl gear. Most observed purse seine interactions result in live release, non-serious injuries (e.g. pinnipeds), but not always.	NEFOP	Unknown	Unknown

EM Program	Type	Gear	High Priority Protected Species Bycaught	Monitoring Program (outside of EM)	Protected Species Bycatch Data Collection Opportunities	Potential EM Modifications to Monitor Protected Species Bycatch
West Coast						
Current Groundfish EM programs	Under Development	Bottom trawl	ESA-listed humpback whales and other marine mammals, sea turtles	Human observer coverage traditionally has been relatively high, but under EM program, human coverage is being supplemented with EM in large portions of fishery	Additional evaluation of the type/quality of data that can be gathered from PR interactions as EM is being implemented could be useful as these programs move forward independent from deployment of human observers.	Deployment of cameras/protocols in consideration of where observation and handling of large whales and other PR may occur
Pacific Islands						
Hawaii-based longline fishery (Hawaii Deep-Set Longline)	Pilot	Longline	Leatherback sea turtles, False killer whales (particularly insular stock), Giant manta rays Additional species: Oceanic whitetip shark, Olive ridley, loggerhead & green sea turtles, rough tooth dolphin, Risso's dolphins, other blackfish, Black-footed albatross, Laysan albatross, and other seabirds	current observer coverage in longline and purse seine fisheries	80% of the fleet is not monitored by observers. Many interactions occur at night and at a distance from the vessel, so there are often issues with identifying the species and/or injury location, interaction rates, geographic/oceanographic data, size, and genetic samples. There is also a large data collection opportunity concerning post-release mortality metrics for most species. Fisheries interacting with the species; hooking location on body (e.g., lip, jaw)	Expand EM in longline fishery to focus on protected species interactions, and EM data review systems; post release mortality studies, such as satellite tagging. Increased observer coverage and training is recommended for some species. EM to focus on protected species bycatch could provide expanded data on interaction rates, species ID, crew handling, and condition at release (EM can augment observer data). Genetic sampling.

EM Program	Type	Gear	High Priority Protected Species Bycaught	Monitoring Program (outside of EM)	Protected Species Bycatch Data Collection Opportunities	Potential EM Modifications to Monitor Protected Species Bycatch
Alaska						
Bering Sea and Aleutian Islands (BSAI) non-pollock trawl catcher/ processor (C/P)	Operational	Otter trawl bottom	western Steller sea lions, western humpback whales, killer whales	This suite of fisheries have full observer coverage and the EM systems are designed to assist the observer in ensuring that they have unfettered access to sample unsorted catch. Cameras are used to view fish-holding bins and on the trawl deck.	EM on these vessels are not designed to meet any marine mammal bycatch monitoring requirements because marine mammal bycatch monitoring is conducted by an observer.	EM could capture additional images of marine mammals caught in a trawl net and landed, although observers would need to collect morphometric data, close-up images for identification and sex, and tissue samples.
Bering Sea pollock trawl catcher/ processor and motherships	Operational	Otter trawl midwater	western Steller sea lions	This fishery has full observer coverage and the objective of EM on these vessels is to monitor areas where salmon bycatch sorting occurs. Therefore, these camera systems are generally below deck, focused on the catch sorting line and on bins in which salmon are stored until samples can be collected.	EM on these vessels does not meet any marine mammal bycatch monitoring requirements because marine mammal bycatch monitoring is conducted by an observer.	****(These suggestions apply to all AK fisheries, particularly Cat II)**** Consider whether there are things that observers collect now that we could require the fishermen to collect in conjunction with an EM program (e.g. skin samples, picture of dead marine mammal, length information, etc).

EM Program	Type	Gear	High Priority Protected Species Bycaught	Monitoring Program (outside of EM)	Protected Species Bycatch Data Collection Opportunities	Potential EM Modifications to Monitor Protected Species Bycatch
Central Gulf of Alaska rockfish trawl catcher/ processor	Operational	Otter trawl bottom, Otter trawl midwater		EM systems on these vessels mirror the design used by the BSAI non-pollock trawl C/Ps described above.	Because this is a Category III fishery, it is a low priority from a marine mammal bycatch perspective.	
BSAI C/P Longline (BSAI Pacific Cod Longline C/P)	Operational		Killer whales, GOA/AI/BS transient	These vessels carry at least one observer at all times. EM systems are focused on the in-line electronic scale with the objective of ensuring that all Pacific cod brought on board are weighed.	EM on these vessels does not meet any marine mammal bycatch monitoring requirements because marine mammal bycatch monitoring is conducted by an observer.	
Small boat fixed gear (longline and pot; unclear how this maps to the LOF)	Operational	Bottom longline, Pot		EM on these vessels is designed for catch accounting and catch disposition (retained or discarded).	Current EM designs do not capture horizon view and will not capture protected species interactions that occur at a distance from the vessel. The loss of at-sea observers leads to a loss of morphometric information and tissue samples.	

EM Program	Type	Gear	High Priority Protected Species Bycaught	Monitoring Program (outside of EM)	Protected Species Bycatch Data Collection Opportunities	Potential EM Modifications to Monitor Protected Species Bycatch
Pollock trawl catcher vessels (BSAI pollock trawl is Cat II; GOA pollock trawl is Cat III).	Exempted Fishing Permit/Under Development	Otter trawl midwater		The objective of EM is to capture rare instances of catch discard and verify operator reports of discard.	EM on these vessels includes deck and horizon cameras which capture marine mammal bycatch events (including entanglements, mortality, and serious injury) on board the vessel, brought onto the trawl deck, or at the stern of the vessel during gear hauling. EM cameras could allow for an unobstructed view of interactions at the stern of the vessel through the horizon view camera. The ability to capture views of the stern during gear hauling is something that human observers currently do not have for safety reasons. However, protected species interactions that occur at a distance from the vessel will likely not be captured. These EM systems replace at-sea observers, and there may be a loss of morphometric information and tissue samples if contingency plans are not developed.	

EM Program	Type	Gear	High Priority Protected Species Bycaught	Monitoring Program (outside of EM)	Protected Species Bycatch Data Collection Opportunities	Potential EM Modifications to Monitor Protected Species Bycatch
Southeast						
Shrimp	EM Pilot	Otter trawl	Smalltooth sawfish, Giant Manta Rays, Sea turtles, Sturgeon, Dolphins	Electronic Logbooks, Shrimp Observer Program,	Protected resources interaction rates and condition/disposition at release; no post-release mortality estimates for manta ray.	Through increased physical observer coverage coupled with comprehensive EM, accomplished through extensive discussions with the Shrimp industry and 3rd party EM vendors.
Highly Migratory Species (HMS) Pelagic Longline	EM Required	Pelagic longline	Leatherback and loggerhead sea turtles, marine mammals, scalloped hammerheads, pilot whales, sperm whales (rare), oceanic whitetip sharks, giant manta ray	VMS, PLOP, PL Logbook	Verification of the effectiveness of safe handling and release requirements; Post release survival rates; 8% observer coverage	Work through hurdles towards collaboration with HMS on their EM; verify optimal placement of camera view so that all interactions are documented. The current EM requirement is not used for protected species bycatch monitoring, but could be.
Reef Fish	EM Pilot	Longline (bottom) and vertical line	Sea turtles, giant manta ray	VMS, Reef Fish Observer Program, Coastal Logbook, Supplement	Interaction rates and condition/disposition at release	EM modifications are possible.
Southeast For- Hire Electronic Reporting Program	ER Required	Vertical line	Sea turtles		Monitoring insufficient to evaluate protected species bycatch	Uncertain; need to evaluate if/how self-reported protected species bycatch data would be used.