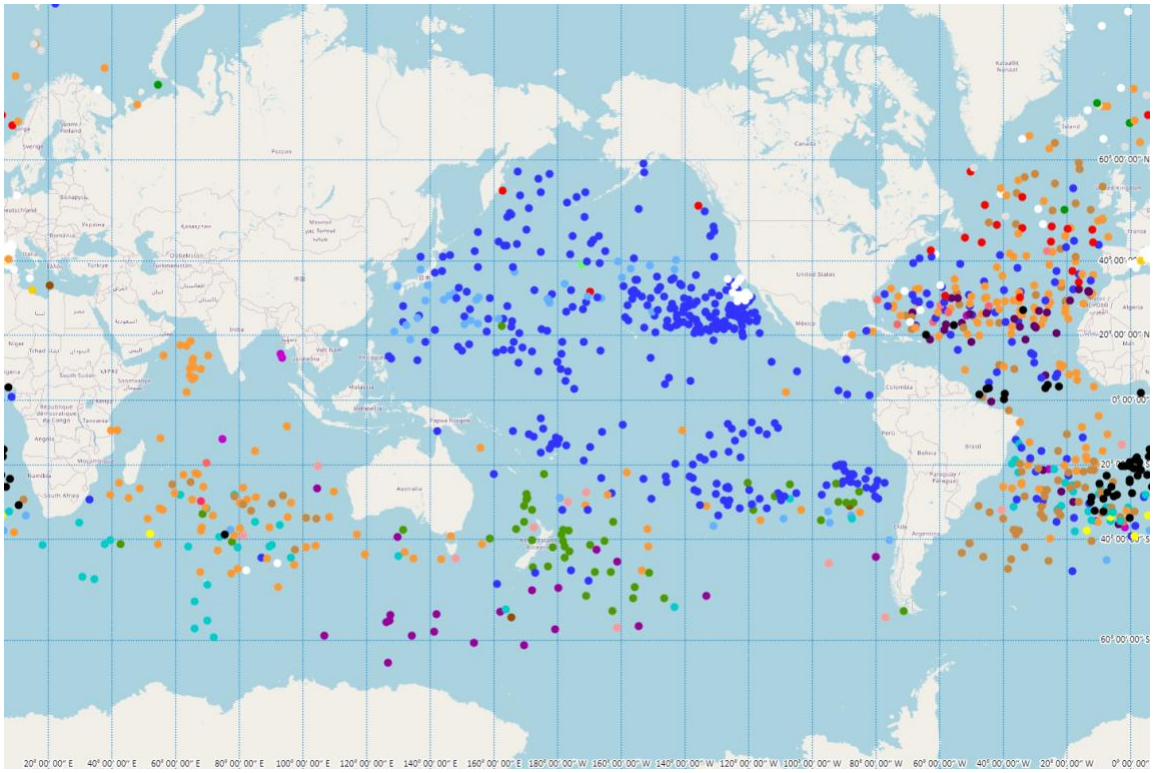
Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

NATIONAL MARINE SANCTUARIES CONSERVATION SERIES

Understanding Research-Based Pollution in National Marine Sanctuaries

Scoping Project for New Ocean-Biodegradable Plastic Developments



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Cover photo: Map of the locations of active ocean drifters in the NOAA Global Drifter Program as of June 13, 2023. Image: NOAA Atlantic Oceanographic and Meteorological Laboratory, 2023

About the National Marine Sanctuaries Conservation Series

The Office of National Marine Sanctuaries, part of the National Oceanic and Atmospheric Administration, serves as the trustee for a system of underwater parks encompassing more than 620,000 square miles of ocean and Great Lakes waters. The 15 national marine sanctuaries and two marine national monuments within the National Marine Sanctuary System represent areas of America's ocean and Great Lakes environment that are of special national significance. Within their waters, giant humpback whales breed and calve their young, coral colonies flourish, and shipwrecks tell stories of our nation's maritime history. Habitats include beautiful coral reefs, lush kelp forests, whale migration corridors, spectacular deep-sea canyons, and underwater archaeological sites. These special places also provide homes to thousands of unique or endangered species and are important to America's cultural heritage. Sites range in size from less than one square mile to almost 583,000 square miles. They serve as natural classrooms and cherished recreational spots and are home to valuable commercial industries.

Because of considerable differences in settings, resources, and threats, each national marine sanctuary has a tailored management plan. Conservation, education, research, monitoring, and enforcement programs vary accordingly. The integration of these programs is fundamental to marine protected area management. The National Marine Sanctuaries Conservation Series reflects and supports this integration by providing a forum for publication and discussion of the complex issues currently facing the National Marine Sanctuary System. Topics of published reports vary substantially and may include descriptions of educational programs, discussions on resource management issues, and results of scientific or historical research and monitoring projects. The series facilitates integration of natural sciences, socioeconomic and social sciences, education, and policy development to accomplish the diverse needs of NOAA's resource protection mandate. All publications are available on the Office of National Marine Sanctuaries website.

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Report Availability

Electronic copies of this report may be downloaded from the Office of National Marine Sanctuaries website.

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Abstract

Although research and monitoring equipment is vital to our understanding of marine ecosystems, a growing number of expendable ocean instrumentation continues to contribute to our ocean's plastic pollution. Informally known as the "ocean internet of things," this rapidly expanding web of interconnected, and often disposable, monitoring equipment has presented a growing problem within national marine sanctuaries as research and conservation efforts clash. In order to understand the level of plastic pollution generated through unretrieved scientific instrumentation in West Coast national marine sanctuaries, the sanctuary research permit database was used to conduct a meta-analysis on the amount of plastic deposited. Instrumentation deposit hotspots and instrument use cases were estimated from permit application data between 2013 and 2023. Additionally, reporting rate and gear recovery rates were estimated from the data provided in final permit reports from projects that used scientific sensors. This study aims to help reduce microplastic and plastic pollution within sanctuary boundaries by identifying possible marine equipment prospects for ocean-biodegradable plastic alternatives. It also aims to raise awareness about the amount of plastic pollution generated from research activities and to inform future national marine sanctuary permit policies regarding non-degradable marine deposits.

Key Words

marine debris, plastic discharges, marine deposits, ocean-biodegradable plastic, expendable scientific instrumentation, national marine sanctuary permits, OSPREY database, expendable scientific equipment, ocean plastic

Chapter 1: Introduction

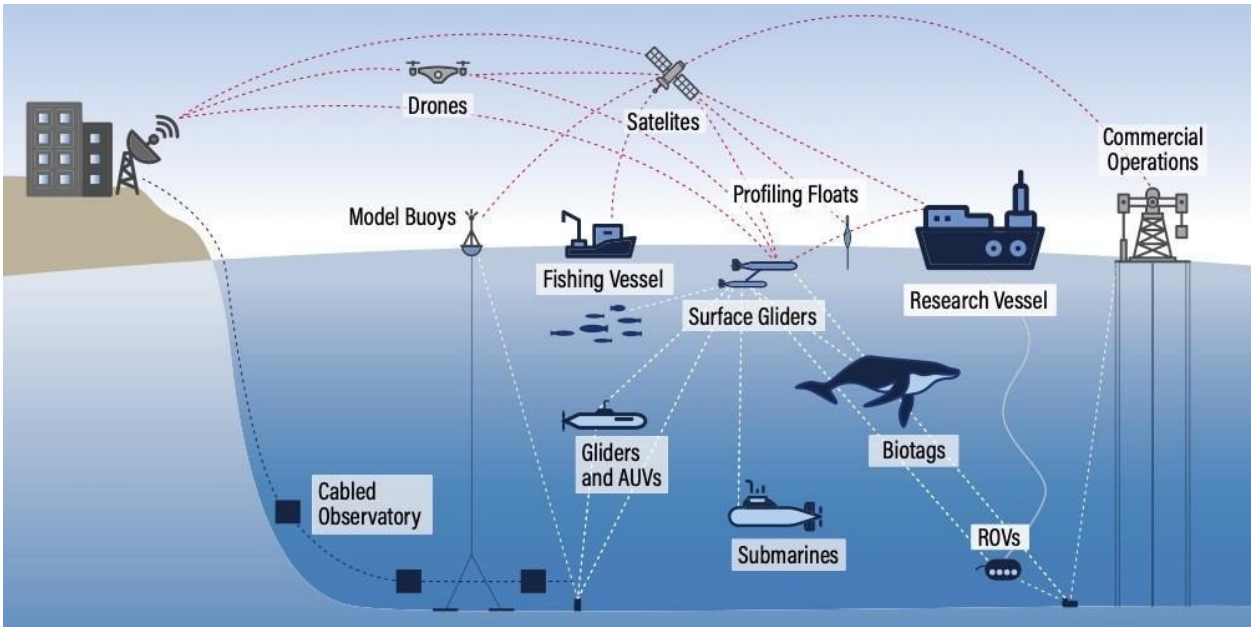

Figure 1.1. An Ocean Internet of Underwater Things: A depiction of how scientific marine data is sourced from a web of interconnected research equipment. Image: Leape et al., 2020[1]

The National Marine Sanctuaries Act protects marine areas with extraordinary ecological, educational, scientific, historic, and cultural qualities that give them national significance. One of the key protections for sanctuaries is the prohibition of marine discharges, or in other words, human deposits of synthetic material into the sanctuary. All West Coast national marine sanctuaries also prohibit the abandonment of any structure, material, or other matter on or in the submerged lands of the sanctuary, unless it meets certain criteria as outlined in National Marine Sanctuary Program regulations (15 C.F.R. part 922). Under these regulations, sanctuaries have permitting authority over all activities that further sanctuary management goals, including research activities.

Research plays an instrumental role within national marine sanctuaries, as it is crucial to understanding marine ecosystems and informing management strategies and policies designed to conserve sanctuary resources. Research activities rely on a growing amount of scientific instrumentation with varying lifespans and use cases. This web of interconnected scientific equipment has recently begun to be referred to as the Ocean Internet of Underwater Things (Bello & Zeadally, 2022). Although the growth of this web has contributed to the progress of science, it has become a concern. While discharges and deposits are regulated within national marine sanctuaries, there has been limited information on the cumulative impacts of permitted deposited gear associated with research and scientific monitoring activities. In this study, we addressed this data gap by examining discharges and deposits in West Coast national marine sanctuaries resulting from permitted research activities. Scientific and research-related

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instrument deposits were estimated by completing a systematic review of the Office of National Marine Sanctuaries Online Sanctuary Permitting, Reporting, and Evaluation System (OSPREY) database, which contains all national marine sanctuary permit records and their associated documentation.

The goal of this study is to inform future policy by identifying suitable expendable and commonly unretrieved scientific instruments as initial targets for newly developed ocean-biodegradable plastics. The substitution of traditional plastics with one that is ocean-biodegradable in unretrievable instrumentation is expected to limit the cumulative impact of research by effectively reducing plastic buildup within sanctuaries. Current ocean-biodegradable plastics are able to completely degrade much faster than traditional counterparts, and unlike traditional plastics, do not generate microplastic byproducts (Hankermeyer & Tjeerdema, 1999; Rajan et al., 2017).

The Permitting Process

When an individual wishes to conduct an activity within a national marine sanctuary that is prohibited by regulation, such as fieldwork that involves marine discharges, a permit is required (15 CFR § 922.30–922.37). Applicants must complete and submit a National Marine Sanctuaries Permit Application to the corresponding sanctuary permit coordinator, who then evaluates and recommends approval to the sanctuary superintendent if the proposed activity aligns with sanctuary goals and meets review criteria. As part of the application, applicants describe the proposed project, including goals, methods, duration, and the rationale as to why it is necessary to conduct the activity within a national marine sanctuary (as opposed to elsewhere). Additionally, the applicant must state the expected direct (e.g., abandonment of an anchor) and indirect (e.g., creating an artificial settling plate in a sandy bottom area) effects of the project, and also explain how any possible negative effects are outweighed by the project's overall contribution to the protection of sanctuary resources. Lastly, as part of the application requirements, each applicant that is awarded a permit typically must submit annual reports as well as a final report shortly after the culmination of the permitting period. These reports give a brief overview of the project, the data collected, and a summary of all fieldwork conducted. They should also include a list of all gear deployed and whether it was successfully recovered, lost, or abandoned.

When an application is submitted to a permit coordinator, it is assigned a permit ID, and a unique record is opened in the OSPREY database. This record is then continually updated with any additional information from the permit applicant, including permit reports. Thus, given that OSPREY contains a record of nearly all permitted research activities conducted, it is an invaluable tool for assessing the cumulative impacts of research within national marine sanctuaries.

Chapter 2: Methods

Study Scope

Over 500 permits pertaining to Cordell Bank (CBNMS), Greater Farallones (GFNMS), Monterey Bay (MBNMS), Olympic Coast (OCNMS), and Channel Islands (CINMS) national marine sanctuaries from January 2013 through March 2023 were evaluated (Figure 1.2.). Each permit record was categorized to determine permit use cases, primarily focusing on those that permitted marine discharges or deposits with the goal of identifying expendable and commonly used or lost scientific instruments from the permit application data. Additionally, the recovery rates of scientific sensors were estimated from the permit final reports.

Study Site

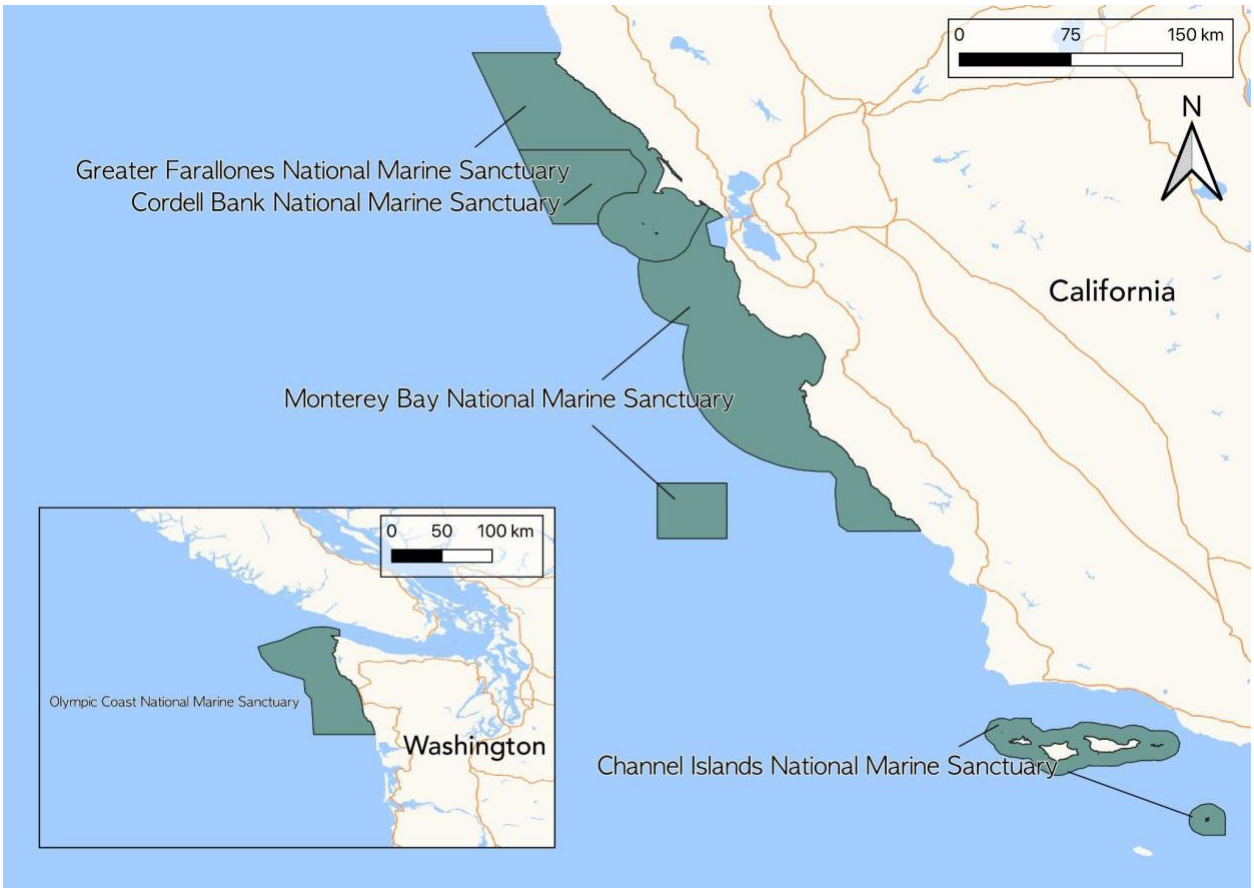

Figure 2.1. Map of the five West Coast national marine sanctuaries for which permits were evaluated.

West Coast national marine sanctuaries were collectively chosen for this pilot study due to the ongoing field testing of ocean-biodegradable plastics at CINMS, MBNMS, and OCNMS. The testing of the ocean-biodegradable plastic under real-world conditions will ensure its viability and degradability within these environments.

Permit Classification and Evaluation

Issued Permits vs. Permit Records

The OSPREY database contains 608 entries pertaining to permit and permit amendment applications between January 2013 and March 2023 for the West Coast national marine sanctuaries. This includes both applications that resulted in a permit being awarded as well as records of permit applications that did not result in an issued permit due to the application being incomplete, denied, or withdrawn. The administrative rights to delete permits are assigned to the national permit coordinator. Therefore, site permit coordinators must request permit records to be deleted when necessary. If records are not deleted, this results in "false" entries for which there is no work associated with a permit record. Some false entries are identified with a permit status of "N/A" or by a permit record being marked as closed. Some possible reasons for the flagging of these records as N/A or closed include miscommunication between permit coordinators and researchers, lack of funding for the project, lack of necessary permits from another issuing agency, or a permit application being submitted when no permit is actually needed to conduct the project (i.e., the proposed project does not involve an otherwise prohibited activity). Cancellation of the project or flagging for deletion of the entry shortly after the creation of its permit record appear to be the most common causes of false records. This is a key distinction from other issued permits that, due to extenuating circumstances, such as adverse weather or the COVID-19 pandemic, resulted in no work being carried out during the permitting period. As opposed to a false record, when fieldwork is not conducted under an issued permit, it is reported by the permit holder in a final report following the same procedure as if the work had been completed. In the final report for these types of permits, the permit holder often explains why the fieldwork could not be completed and may denote the desire to re-apply for another permit at a later date.

All permit records that did not result in an issued permit—including false entries and incomplete, denied, or withdrawn applications—were excluded from this study as they did not have fieldwork associated with them. This resulted in a total of 546 permit records, each corresponding to an issued permit or permit amendment, being evaluated and classified as part of this study. For classification purposes, permit amendments were treated as unique permits given that they each have a unique record, as permit holders are required to submit a separate application for permit amendments.

To avoid double counting discharges between permits and respective permit amendments, only permit records or permit amendment records that permitted a discharge were classified within the discharges category. For instance, if permit X allowed for a discharge but the amendment X-A1 only warranted a timeframe extension for the previously deployed instruments, then only the original permit X would be classified under the discharges category. If the amendment had allowed for an increase in the number of units discharged, then it would be classified under the discharges category in addition to the original permit.

Permit Categories

Given the large number and variety of permits, it was important to develop a robust classification system to allow for subsets of the database to be analyzed without excluding

relevant data. In this study, we were primarily interested in getting a better understanding of the quantity and types of expendable sensors, non-expendable sensors, and tags permitted (Figure 2.2). This led to the categorization of permits into five broad categories:

1. Non-discharge permits
2. Expendable sensor discharge permits
3. Non-expendable sensor discharge permits
4. Tag discharge permits
5. Non-sensor discharge permits

While these simple permit categories would be ideal for our analyses, there was significant overlap between them. To avoid double counting permits, four additional categories were created to account for permits that allowed for several discharge types and would otherwise fall under more than one category. These were:

6. Non-expendable and expendable sensor permits
   This category involves overlap between categories 2 and 3. In other words, these permits allowed for the discharge of expendable as well as non-expendable sensors (e.g., an acoustic receiver [non-expendable] and a sonobuoy [expendable]).
7. Expendable sensor and tag permits
   This category involves overlap between categories 2 and 4. In other words, these permits allowed for the discharge of expendable sensors as well as tags (e.g., a sonobuoy [expendable] and an acoustic tag).
8. Non-expendable sensor and tag permits
   This category involves overlap between categories 3 and 4. In other words, these permits allowed for the discharge of non-expendable sensors and tags (e.g., an acoustic receiver [non-expendable] and a dive monitoring tag).
9. Expendable, nonexpendable, and tag permits
   This category involves overlap between categories 2, 3, and 4. In other words, these permits allowed for the discharge of expendable and non-expendable sensors as well as tags (e.g., acoustic receivers [non-expendable], sonobuoys [expendable], and dive monitoring tags all under one permit).

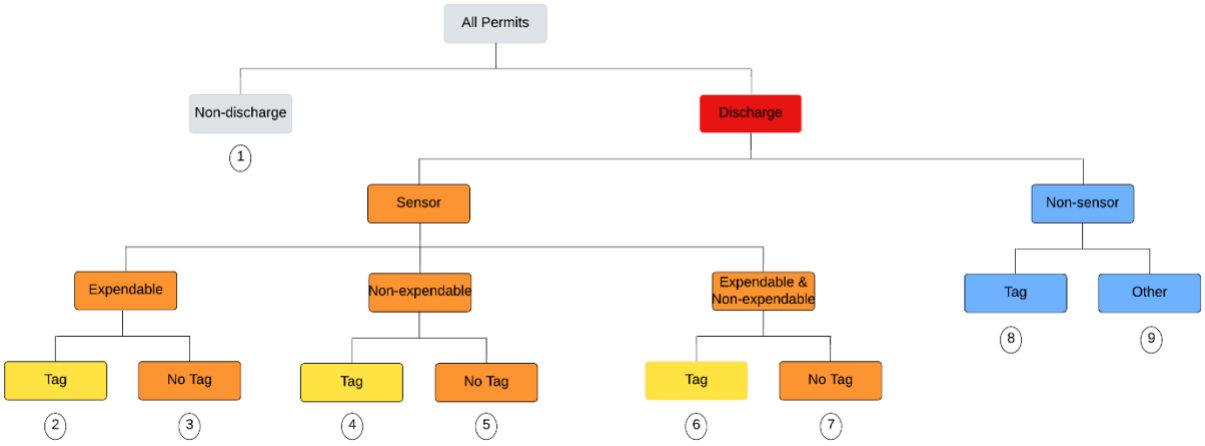

Figure 2.2. Flowchart of the permit classification process. Permits were sorted based on the type of discharge permitted which resulted in nine permit categories. Circled numbers correspond to these categories: 1. Permits that do not authorize discharges; 2. Permits for the discharge of expendable sensors and tags; 3. Permits for the discharge of expendable sensors; 4. Permits for the discharge of non-expendable sensors and tags; 5. Permits for the discharge of non-expendable sensors; 6. Permits for the discharge of expendable sensors, non-expendable sensors, and tags; 7. Permits for the discharge of both expendable and non-expendable sensors; 8. Permits for the discharge of tags (without any sensors); 9. Permits for the discharge of other non-sensor equipment.

Non-Discharge Permits

For the purposes of this study, discharges were defined as scientific objects with prolonged subsurface exposure without diver intervention, apart from autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs). ROVs are not considered discharges because their operation requires a tether to a research vessel, which facilitates recovery in case of motor or electronic failure. Although AUVs are considered discharges for permitting purposes, they were excluded from the discharges categories of this study. This is because there have been no expendable (single-use) ROVs or AUVs permitted for use within West Coast national marine sanctuaries during the study period and, to the best of our knowledge, all non-expendable ROVs and AUVs deployed in the sanctuaries have been successfully recovered. We also do not anticipate a decrease in the rate of recovery of these units given their robust communication capabilities, onboard tracking equipment, and high price tag. Thus, ROVs and AUVs fall outside of our target scope of identifying commonly unretrieved and expendable scientific instrumentation.

The non-discharges category includes permits that do not allow for the discharge of scientific equipment, such as traps, sensors, tags, settlement plates, or other gear. Given that this study aimed to assess plastic discharges, the non-discharges category was not classified or quantified further. However, based on our observations, the permits in the non-discharge category of this study primarily dealt with activities such as AUV, ROV, vessel, and aerial surveys. Future research is needed to gain a more comprehensive understanding of the cumulative effects of this type of research in sanctuaries. While the activities encompassed in non-discharge permits might present a low risk of generating marine debris, they may be associated with other negative impacts, such as disturbances to wildlife as a result of increased noise or light pollution.

Expendable Sensor Permits

In this study, scientific sensors were classified using the National Institute of Standards and Technology (n.d.) definition of "a device that produces a voltage or current output that is representative of some physical property being measured (e.g., speed, temperature, flow)." Scientific sensors were evaluated separately from other marine plastic discharges to assess the recovery rates of instrumentation and identify targets for ocean-biodegradable plastic. Scientific sensors yield high promise for ocean-biodegradable bioplastic implementation due to the high cost of their internal components, such as electronics or radio equipment. Relative to the cost of the entire instrument, changing the external housing and other plastic components to ocean-biodegradable plastic would not have a significant impact on the instrument's total manufacturing cost. The expendable sensors category includes permits for single-use sensors and sensors not designed to be recovered.

Non-Expendable Sensor Permits

The non-expendable sensors category includes permits for scientific sensors that are designed to be recovered or reused. They contain archival data that is of high value to scientists and the sensors themselves can be prohibitively expensive to replace. For instance, VR2W acoustic receivers can cost upwards of $1,200 per unit and have a battery life of 15 months. However, when the batteries are replaced, each sensor is expected to last for several years. Other non-expendable sensors, such as temperature loggers, can be more affordable, but their recovery is still necessary to offload the data, which highly incentivizes their retrieval.

Tag Permits

Animal-borne sensors or "tags" were considered separately from other scientific sensors. While these fall under the technical definition of a sensor, the wide range of applications for tags and the vastly different types of tags warranted a separate category. There is also a key distinction between the way tags and other non-expendable sensors are permitted. Due to the nature of animal-borne sensors, tags rely on the successful capture of target species for tag deployment. Thus, the number of deployed tags has the potential to be less than the permitted amount due to variables such as not encountering sufficient individuals of the target species. This also leads to permits for the tagging of animals during opportunistic encounters.

Non-Sensor Discharge Permits

Permits that were classified as non-sensor deal with the discharge of all equipment that falls outside of the definition of a sensor. For instance, a permit that allows for the discharge of different types of fishing traps that are not measuring any environmental variables would be classified as a non-sensor permit. Other examples include permits for transect markers embedded in the substrate and settlement plates used for recruitment studies.

Assessment of Permitting Trends

Of the 546 permits and permit amendments analyzed as part of this study, 339 did not involve discharges into the sanctuary (other than AUVs and ROVs), which equates to roughly 62.1% of all permits (Figure 2.3). The other 37.9% of permits involved different kinds of discharges, with 55 permits involving the discharge of scientific instrumentation other than sensors, 13 involving the discharge of expendable scientific sensors, 104 involving the discharge of non-expendable scientific sensors, five involving the discharge of both expendable and non-expendable sensors, 25 involving the discharge of tags, and five involving the discharge of tags and sensors (one for tags and expendable sensors; one for tags, expendable sensors, and non-expendable sensors; and three for tags and non-expendable sensors).

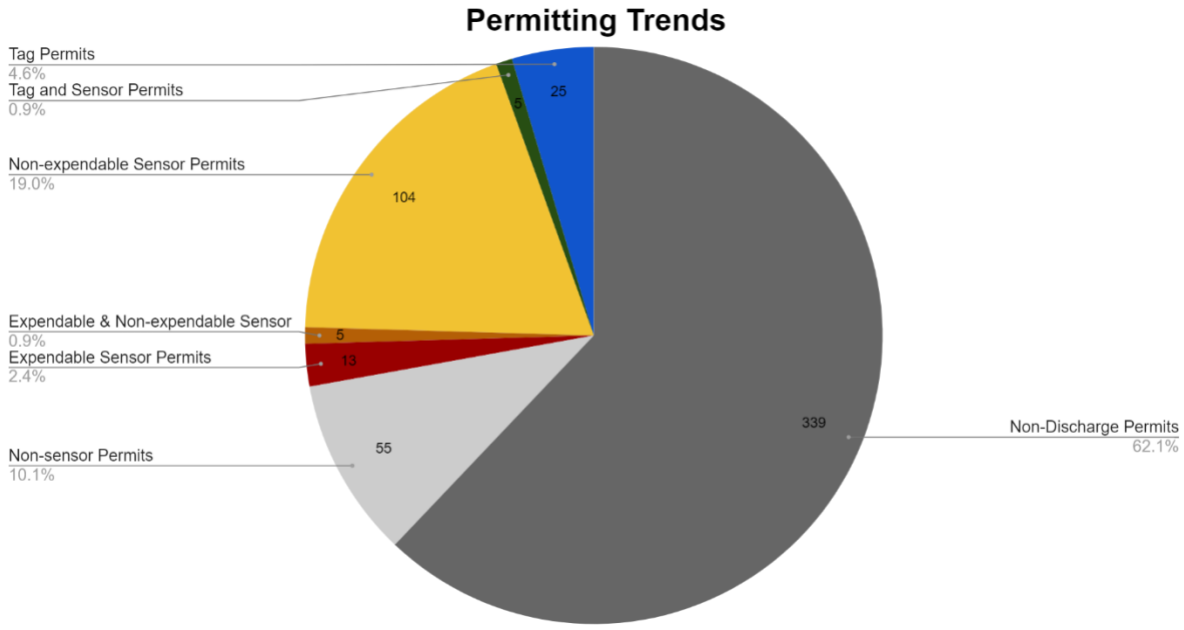

Figure 2.3. Permitting trends for West Coast national marine sanctuaries from 2013–2023. Permits were classified by the type of discharge permitted.

Expendable Sensors

Expendable sensors were the primary interest for this study, as their disposable nature makes them an ideal target for ocean-biodegradable plastic implementation. There were four kinds of expendable sensors permitted for West Coast national marine sanctuaries from 2013–2023 (Figure 2.4):

- ***Expendable bathythermograph (XBT)*** – Probes used to measure temperature as they fall throughout the water column. The data are primarily used for multibeam sonar, water column studies, and seafloor mapping operations. Once the temperature profiles are complete, XBTs are not recovered and remain on the ocean floor (Lockheed Martin, 2013).
    - Permits considered as part of this study allowed for the discharge of approximately 935 XBTs. These included 518 from multi-sanctuary projects

managed by the Office of National Marine Sanctuaries (MULTI permits), 216 from CINMS, 80 from OCNMS, 86 from MBNMS, 25 from CBNMS, and 10 from GFNMS.

- ***Sonobuoys*** – Expendable recording devices with an omnidirectional hydrophone capable of estimating the direction of the sound of interest. Within national marine sanctuaries, these are primarily used for cetacean studies when conditions are unfavorable for other recording equipment (Rankin et al., 2019). Outside of sanctuaries, these are commonly used by the Navy for detecting submarines (Sonobuoy TechSystems, n.d.).
    - Some permits for educational purposes require that the sonobuoys be recovered. However, these are still considered expendable because the majority of permitted sonobuoys are not intended to be recovered, and even when recovered, sonobuoys are non-reusable.
    - Permits considered as part of this study allowed for the discharge of approximately 127 sonobuoys. These included 60 from MULTI permits, 65 from OCNMS, and 2 from MBNMS.
- ***Dropsondes*** – Expendable probes deployed from an aircraft that collect GPS and atmospheric data on their descent (Earth Observing Laboratory, 2023).
    - Permits considered as part of this study allowed for the discharge of 12 dropsondes in OCNMS.
- ***Expendable Mobile Anti-Submarine Training Target (EMATT)*** – Navy expendable mobile underwater acoustic sources are expendable anti-submarine training targets used by air and surface anti-submarine warfare platforms (Naval Sea Systems Command Office of Corporate Communication, 2021).
    - It is important to note that EMATTs permitted for use within national marine sanctuaries were programmed to fail outside of sanctuary borders (by the time their batteries were depleted, they should be outside of the sanctuary). However, they are still of concern to sanctuaries, as unretrieved EMATTs may eventually drift back into sanctuary waters as marine debris.
    - Permits considered as part of this study allowed for the discharge of approximately 12 EMATTs within MBNMS.

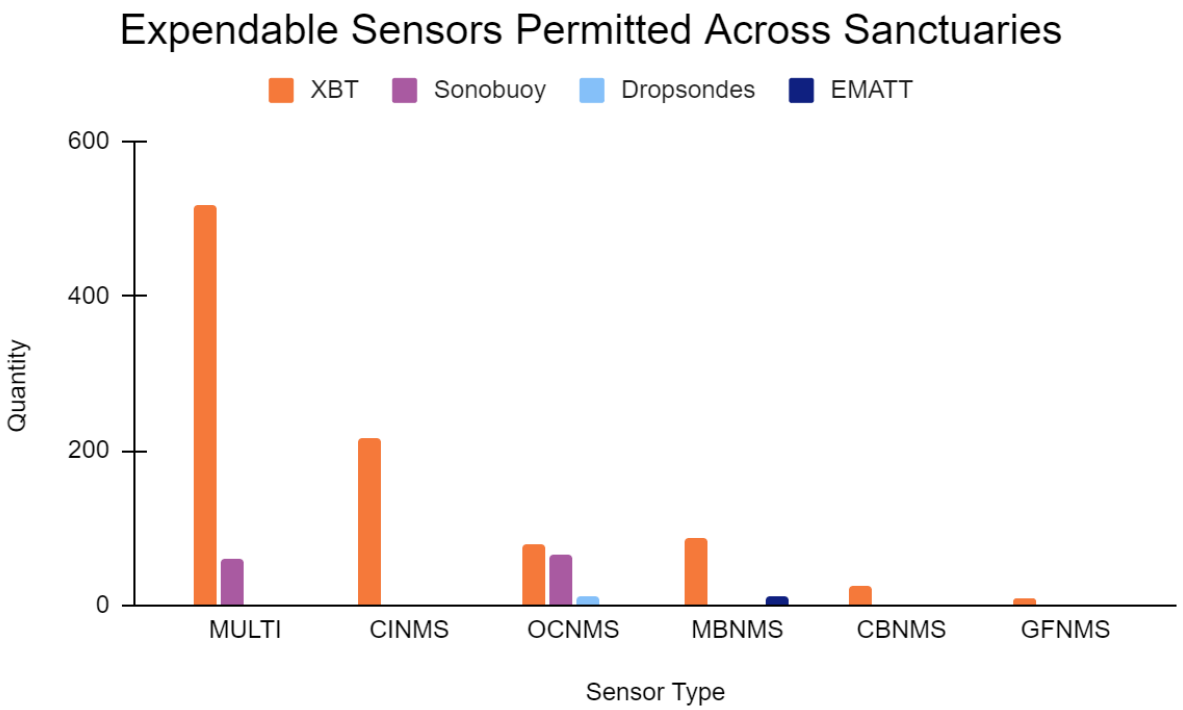

Figure 2.4. The number of expendable sensors (XBTs, sonobuoys, dropsondes, and EMATTs) permitted across West Coast national marine sanctuaries. MULTI refers to permits that are issued for multiple sanctuaries and managed by the Office of National Marine Sanctuaries.

Tags

Projects associated with the approximately 30 permits that allowed for the discharge of tags used a diversity of marine instruments. While the permits rarely included model numbers, the tag descriptions within each permit allowed for their classification into 19 distinct categories: acoustic (494), advanced dive behavior (ADB; 56), archival acoustic (25), biologging camera tags (10), biologging clamp tags (21), dart/bar tags (184), dive monitoring (DM; 25), e-flipper tags (150), electric pop-up MiniPAT (12), flipper tags (618), floy mark-recapture tags (30), low impact minimally percutaneous electronic transmitter (LIMPET; 10), passive integrated transponder (PIT; 330), pop-up archival transmitting tags (PAT; also known as pop-up satellite tags) (427), PVC ID tags (20), satellite-linked (10), smart position and temperature transmitting tags (SPOT; 60), suction-cup tags (390), and VHF radio transmitter tags (157). Figure 2.5 illustrates the distribution of permits for each type of tag across West Coast sanctuary sites.

The tags have a wide range of monitoring and transmission technologies that make each of them well-suited for studying a particular species. While not all tags are intended for recovery, many larger marine tags (like the ones used on cetaceans) rely on recovery for data download or have satellite technologies that allow for recovery. Other expendable tags, such as a wide number of acoustic tags, are often small and placed within animals (by ingestion or incision) or by directly attaching them to their skin. Thus, while tags present a large part of marine research, they do not pose an ideal target for initial ocean-biodegradable plastic implementation, at least until more toxicology and animal safety research can be conducted.

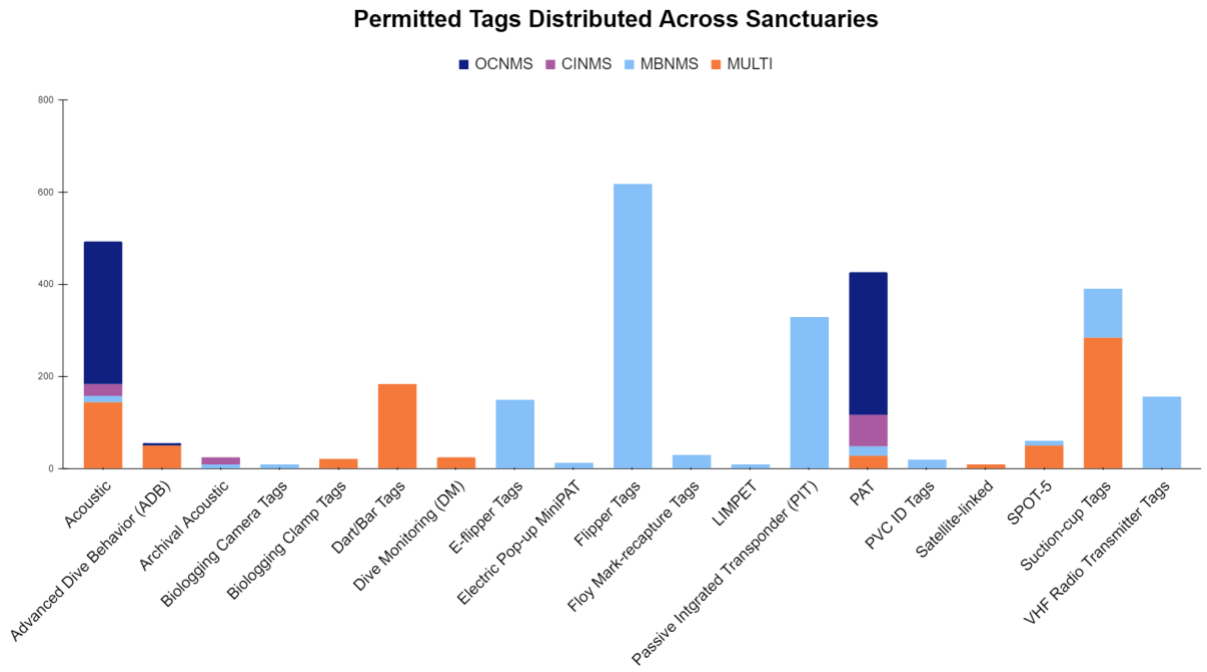

Figure 2.5. Permitted tags types by national marine sanctuary. While no tags were permitted through CBNMS or GFNMS, tagging operations may have taken place at these sanctuaries through MULTI research permits.

Reporting Shortfalls

One of the conditions for the issuance of a national marine sanctuary permit is the submission of a report shortly after the permit period ends, usually within one year. One of the goals of this study was to assess the rates of equipment retrieval based on the final report information. While the majority of permit holders did submit a report, these were not standardized, and many lacked the details necessary to adequately address whether or not equipment was lost. For instance, while some reports go as far as submitting preliminary data and detailed boat logs, some failed to even mention field operations entirely or some components of them. This was observed more commonly in permits that allowed for several types of discharges, where the permit holder provided extensive information about the deployment of one type but failed to mention the other. To enhance the Office of National Marine Sanctuaries' ability to assess the cumulative impacts of research activities, the format of final permit reports and the way they are entered into OSPREY should be standardized.

More concerningly, over 30% of permit holders for non-expendable sensors did not submit a final report. The failure of permit holders to comply with national marine sanctuary policies greatly limits the Office of National Marine Sanctuaries' ability to adequately assess the cumulative impacts of research. This is of concern, as eight out of 64 completed permitted projects for which a final report was submitted showed some level of gear loss (Figure 2.6), which raises concerns regarding how much gear loss may go unreported. While it is unlikely that every overdue report corresponds to operations where gear was lost, it presents a large data gap that could contain a disproportionately large amount of lost or unrecovered instrumentation.

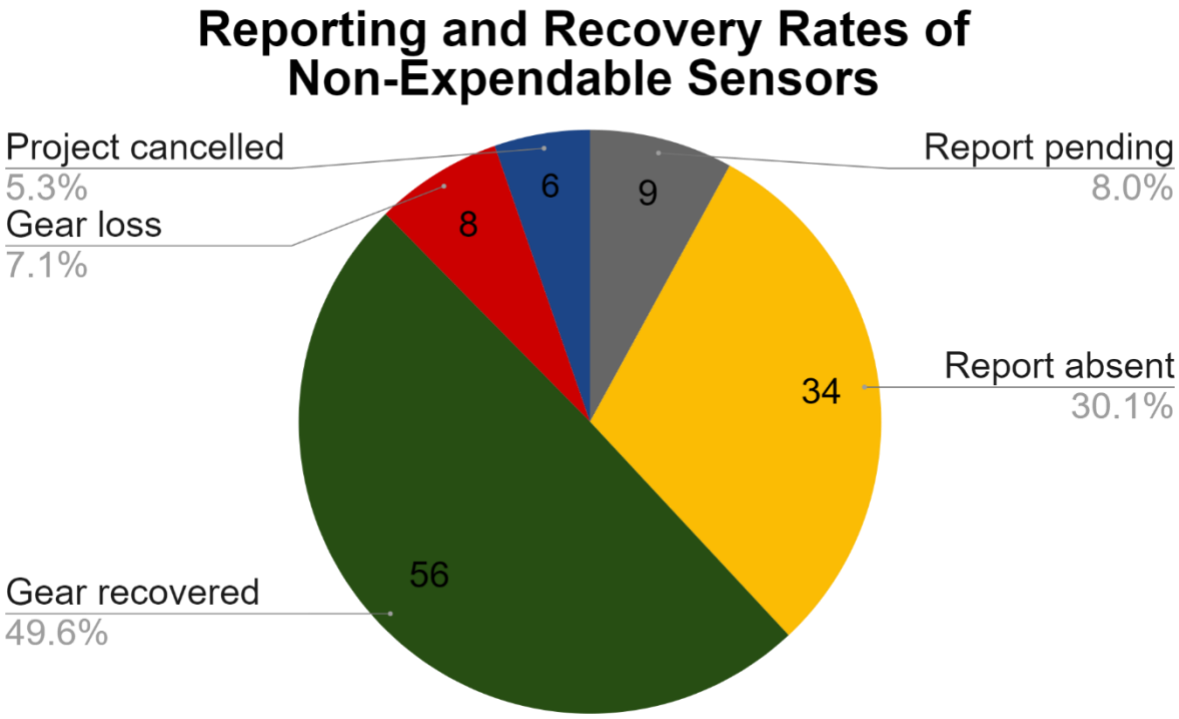

Figure 2.6. Recovery rates for non-expendable sensors based on permit final report information. For the 113 non-expendable sensor permits, only 70 final reports were submitted, with 56 indicating that all discharged gear was recovered, six indicating that the project was canceled due to extenuating circumstances (primarily the COVID-19 pandemic), and eight indicating at least some loss of equipment. While nine permits did not have a final report due (as permits were still active or in a grace period), 34 non-expendable sensor permit holders failed to submit a final report.

Table 2.1. Non-expendable sensor permit final report status by national marine sanctuary. Report received refers to permits compliant with all required report documentation, reports overdue refers to permits for which a report was required but has not been received, and report pending/project canceled refers to permits for which a report was not due as the permit remains active or the project was terminated.

Sanctuary	Total Number of Non-Expendable Permits	Report Received	Report Overdue	Report Pending/ Project Canceled
CBNMS	2	0	2	0
MULTI	12	7	3	2
CINMS	11	3	8	0
GFNMS	14	7	5	2
OCNMS	25	12	11	2
MBNMS	49	35	5	9
Total	113	64	34	15

Permitted vs. Discharged

The amount of instrumentation permitted represents the absolute maximum that may be discharged by permit holders. From the permit final reports available, it was apparent that for non-expendable sensors, the amount permitted translates roughly to the amount discharged. However, this was not the case for expendable sensor permits. According to permit coordinators at CINMS and MBNMS, expendable instrumentation such as XBTs and sonobuoys (which comprise the majority of expendable deposits) were essentially permitted on a "potentially highest number to be deployed" basis. Essentially, these are typically used in large projects with lengthy field operations, but the deployment of the instruments depends on a variety of environmental conditions that may impact data clarity. Depending on the quality of the reading of the initial instrument, additional instrument deployments may be required to obtain a sufficient reading. As with all other permits, these are only issued if the value of the research to sanctuary management outweighs the negative environmental impacts, even in the case that all permitted instruments are discharged. The criteria used to weigh this decision are outlined in the National Marine Sanctuaries Act and National Marine Sanctuary Program regulations (15 C.F.R. part 922). While this presents an ideal compromise between resource protection and research, it also presents a challenge when assessing the cumulative impacts of scientific activities.

Unfortunately, the quality of reports varied greatly, making it difficult to adequately estimate the amount of expendable instrumentation discharged into sanctuaries. Out of 20 permits issued for expendable instruments, six permit holders did not submit a report; five of these pertained to XBT operations. While some permit reports provided coordinates and dates for every instrument discharged, some focused on other aspects of the fieldwork and failed to mention expendable (e.g., XBT) activity altogether. Additionally, some multi-year permits with yearly budgeted XBTs only submitted some of the required yearly reports, introducing uncertainty regarding whether the permitted XBTs for the missing report years were deployed. Similarly, some MULTI permits allowed for expendable deposits within several sanctuaries, but the reports did not address all permitted locations. Due to the shortcomings of the permit report data, we used the permitted amount of instrumentation when evaluating the accumulation of research-based plastic within West Coast sanctuaries. The use of permitted instrumentation as a proxy for expendable marine deposits is further supported by the fact that around half of the permits for expendable sensors for which a report was received reported full utilization of the permitted number of expendable sensors.

Chapter 3:
Challenges and Future Implications

Permit Database

One of the biggest challenges throughout this study was the lack of consistency between permit applications and records, both in terms of how they were written and how they were entered into the OSPREY permit database. Currently, there are major differences in the way permit data are entered from sanctuary to sanctuary. While all sanctuaries provide all of the information necessary, some provide information that is inadequate or incompatible with data analysis and programming tools. This makes comparing permits from different sanctuaries more time-consuming, as comparable information can be located in different fields, often with slight variations in terminology (e.g., multiple names for the same piece of equipment). While the OSPREY database contains a wealth of information that is key to sanctuary management, the standardization of information in the database would make this resource even more valuable.

One way the database could be improved is through the implementation of drop-down categories. This would allow for the standardization of activity names and easy quantification of permitted activities. With clearly tracked events, the system could also autogenerate a supplemental report form for permit holders to fill out regarding the status of the specific number of activities in a "checklist/fill-in-the-blank" format. This would be beneficial for compliance tracking as it would lighten the burden on permit coordinators and streamline the process for permit holders by outlining clear report expectations.

Ocean-Biodegradable Plastic Implementation

In conjunction with Nereid Biomaterials, CINMS is currently field testing a new biodegradable plastic that is designed to completely degrade in the ocean into carbon dioxide and water without any negative environmental byproducts. While degradation tests under different conditions are still taking place, the lifespan of these instruments (once they hit the ocean) is estimated to be anywhere from two years to eight years depending on the additives in the plastic and the environmental conditions. This makes the new ocean-biodegradable plastic a great candidate for implementation in XBTs, sonobuoys, EMATTs, and dropsondes, as the working lifespan for all of these instruments is well below that range. These instruments usually serve their purpose within a few hours of deployment and they all contain substantial plastic components.

Non-expendable sensors with a short lifespan could also be candidates for the use of ocean-biodegradable plastic. These are sensors that, although they are reusable and recovered, end up either in a landfill or left in the ocean within a few years, having either exhausted their batteries or worn out. One such example is temperature loggers. While permit records don't always indicate the specific type of temperature loggers used in a project, these sensors are widely used, with over 150 permitted within sanctuaries (HOBO TidBiTs are the most widely used). While these loggers are resilient and come in models with replaceable batteries, some users prefer units with integrated batteries, which are less prone to flooding and have a greater depth rating.

The plastic housings used to attach these loggers to the substrate are typically used for around five years (lifespan of sensor), making them ideal candidates for ocean-biodegradable alternatives.

Another area worth exploring for potential biodegradable plastic implementation is ocean surface drifters. These are relatively novel pieces of equipment that are used in a range of applications from mapping ocean currents and collecting wave data to predicting the spread of an oil spill. Depending on the use case, these can either be expendable or recoverable. In West Coast national marine sanctuaries, 31 surface drifters were deployed within the last 10 years, all intended for recovery. While not all reports were received, at least one drifter was lost. The risk of loss associated with free-floating objects, combined with the typically short lifespan of drifters, makes them an ideal target for bioplastic implementation. Drifters also present a prime opportunity for NOAA to lead the way in terms of widescale implementation of biodegradable plastic in research equipment, as NOAA plays a key role in maintaining the Global Drifter Array, a fleet of 1,070 drifters (as of July 2023) providing worldwide oceanographic data. While the data collected by the array provide critical information for weather predictions and our understanding of ocean currents, it comes at a cost to the environment. The program has a current drifter death rate of around 970 deaths per 1,250 drifters each year. Essentially this means that to sustain the array, around 1,000 new drifters must be deployed annually, and given that these are scattered around the globe, defunct drifters can only be retrieved if they run into a boat or wash ashore. The average age of failure for the drifters is around 312 days. The short lifespan combined with their high rate of failure and mass production makes these drifters an ideal target for ocean-biodegradable plastic implementation.

The use of biodegradable alternatives to traditional expendable sensors within sanctuary waters would help further management objectives, as this approach would reduce the amount of marine debris generated through research. Marine debris has been recently found to be a significant threat to national marine sanctuaries and has been identified as an area for active improvement in both the CINMS and MBNMS management plans. With ever-increasing evidence of the negative environmental impacts of plastics and microplastics within our ocean (Issac & Kandasubramanian, 2021; Lim, 2021), along with the growing variety and use of oceanographic research and monitoring equipment, it is imperative to employ all tools available to reduce plastic pollution.

There is a rapidly growing awareness of the vast problem of plastic pollution in the ocean and its wide variety of sources. Thus, it may be easy to overlook or underestimate the contribution of seemingly small sectors like ocean research. Note, however, that the U.S. Navy ordered over 126,000 sonobuoys in 2022 alone, and has procured over 30,000 EMATTs (U.S. Department of Defense, 2022). Additionally, NOAA estimates that about 16,000 XBTs are deployed each year worldwide, none of which are recovered (Goni et al., n.d.). Thus, all of these instruments present a growing plastic pollution threat, drifting into and out of national marine sanctuaries as marine debris. Promoting biodegradable plastics in scientific equipment in national marine sanctuaries can influence researchers elsewhere. Moreover, by demonstrating the benefits of ocean-biodegradable alternatives, sanctuaries can leverage their stature in ocean conservation to encourage further development and widespread adoption of sustainable plastics and more environmentally friendly practices.

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