

Review

Blue Water Visitor Monitoring Potential: A Literature Review and Alternative Proposal

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Abstract: This review presents a summary of existing visitor monitoring methods and relevant studies in land and marine-based areas, with a focus on the application to unique aquatic settings. Various opportunities and challenges exist with respect to the use of each method in different marine settings. These methods differ in terms of the complexity, costs, level of accuracy, and detailed information they provide. Furthermore, the feasibility of applying these methods also depends on the site attributes of a marine area. Since each marine area varies in geographical scale and environmental and social conditions, some methods will be more appropriate or perform more successfully than others in a particular location. Therefore, the consideration of these methods should be part of a proposed alternative process, focused on adaptive monitoring that scales to address visitor ebbs and flows in these aquatic areas. The proposed alternative seeks to develop consensus around quantitative goals for visitor monitoring and estimating techniques in marine settings, using a customizable mix of methods and techniques. This alternative effort progresses to subsequent tasks and discussions, and recommendations are made considering the feasibility and confidence of using these methods in particular marine settings and future pilot sites.

Keywords: visitor monitoring; marine protected areas; adaptive management; mixed methods; site-specific planning



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1. Introduction

The United States includes over 600,000 square miles of underwater parks designated as National Marine Sanctuaries (NMS) and over 132,000 square miles of lands within the National Park System (NPS). These significant areas serve as a bridge to natural resource exploration, education, recreation, and tourism, and offer many other ecosystem services for both U.S. citizens and foreign visitors alike. Visitors to these areas number in the hundreds of millions each year and account for significant economic production within, and adjacent to, these areas. Despite the popularity and importance of these areas, a knowledge gap exists with respect to visitation and use in aquatic, coastal, and marine areas. Their geographic locations and large spatial areas result in unique challenges when counting visitors, especially when data collection must be cost-effective. Marine sanctuaries and parks inherently have porous borders, and unlimited access points make counting to arrive at accurate visitation estimates a challenging approach. While federal land managing agencies have been estimating and reporting recreational use and visitation for many years, an effective visitor use monitoring system has not yet been systematically developed or applied to marine areas such as National Marine Sanctuaries. We seek to address this gap with a review of various approaches that can be employed to estimate visitation in natural

resource settings in general, and coastal-marine areas in particular, as well as opportunities and challenges associated with the research and management of visitor use and impact in these special areas.

Understanding visitation to a marine sanctuary or park is one of the first steps to accurately estimating associated benefits and economic contributions. Visitor use can be profoundly productive in terms of economic activity. Many studies have documented the linkage between visitor use and economic gain for particular areas. For example, Leeworthy et al. (2018) [1] reported trip expenditure information, economic contributions, and the spatial intensity of use by visitors to the Outer Coast of Washington. A 2016 study conducted by the Department of Commerce determined the gross value of recreational fishing and boating to be approximately \$38 billion [2]. Concurrently, the National Marine Sanctuary (NMS) System is estimated to provide \$8 billion in economic activity each year. The National Park Service (NPS) also provides the public with a rare combination of recreational, educational, and scenic opportunities in coastal-marine areas. The value of all NPS lands, waters, and historic sites is estimated to be \$62 billion [3]. Water-focused National Parks make up approximately 33% of the per-household total economic value, with nature-focused and history-focused National Parks comprising 37.5% and 29.5%, respectively [3]. Together, these figures demonstrate the ability of NMS and NPS resources to attract visitors and serve as primary economic drivers. Therefore, a better understanding of visitor use patterns and motivations would certainly increase the capacity for economic growth and sustainability of valuable ecosystem services in other aquatic resource areas.

The following literature review presents an inventory and review of the visitor monitoring literature and methods with respect to natural and marine settings worldwide, thereby providing resource managers with a consolidated resource to assist them in selecting methods best suited for their specific monitoring needs. The inventory includes a table and discussion of methods for both the counting of visitation and reporting and analysis of such visitation data. This is coupled with a comprehensive literature review of research methods which may best fit the application to desired visitor monitoring in marine areas. By following this coupled approach, we may best define which methods are generally available and specifically applicable to the NMS system.

Monitoring can be defined as the repeated measurement of specific phenomena or conditions over time [4]. Visitor use monitoring in natural areas involves assessing the amount of use, as well as social conditions. Determining the amount of use, use trends, characteristics of use and users, and qualities of the experience (e.g., opportunities for privacy and solitude) can provide important information for managers. Counts of visitors are used for many purposes in a variety of environments and situations. Simple presence-or-absence information suffices for studying spatial and temporal patterns of use, but reliable measures of total use levels are needed to track changes in biological or social conditions. Information on the specific locations and intensity of use can also provide an important “early warning” of locations of potential visitor resource impact and of times and places where the visitor density is suggestive of crowding, conflict, and other issues. We provide an overview of three principal categories of methods for monitoring visitor use in a variety of land and marine areas, including (1) self-counting, (2) direct-counting, and (3) indirect-counting methods. These methods have been used concurrently to maximize the accuracy and validity of visitation estimates [5].

2. Prevailing Visitor Monitoring Methods

2.1. Self-Counting

Information obtained through self-counting methods is provided by the visitor. Examples of self-counting methods include voluntary visitor registration, agency-issued permits, and self-issued permits. Self-registration methods may be the most pragmatic in areas where access is limited or the area of interest is too large for a more focal counting method [6]. In this sense, marine areas can effectively utilize self-counting methods as long as they account for inaccuracy associated with noncompliance.

Voluntary visitor registration has been used in wilderness and backcountry areas. Registration stations are installed at entry points and visitors are asked to complete a short form when entering or leaving the area. A problem with this method, however, is that not all people register, resulting in differential detection rates for various user types and understated levels of use [7]. A further limitation of these data is the lack of detailed descriptive information, such as perceptions, behaviors, and motivations, among others [8].

Mandatory permit methods have generally been employed where the amount of use is controlled to keep visitation levels from exceeding social and biological carrying capacities [9]. Permits are often required on rivers, in many National Park backcountry areas, and to a lesser extent in Forest Service wilderness and primitive areas. Registered permits may yield general information on the recreational activity, group size and composition, time of day entering the area, season, weather, and access point.

2.2. Direct Counting

Direct-counting methods entail one or more methods whereby information on numbers of visitors, and visitor characteristics and behaviors, are observed first-hand or by direct contact with visitors. Methods include direct observation census and sample counts; manually operated ground-level or aerial photography; direct aerial observation; interviews; and mail, phone, and internet surveys.

Random direct observation of backcountry visitors was perhaps the first monitoring method implemented in the field, and was commonly used in backcountry settings before mechanical devices were developed in the late 1960s [9]. In these settings, sampling designs that account for temporal use fluctuations (e.g., day of the week, weekend or holiday, and season) can render direct field sampling a practical method for obtaining accurate use estimates. This method is best suited for developed sites such as campgrounds [10,11], scenic overlooks, and wayside parks [11,12], or municipal recreation settings [13].

If an area has specific access points or methods, direct counts of individual visits, hours, and overnight stays may be possible using the quantity of visitors via those specific access points or methods [14]. For example, a recreational area may only allow access through ticket sales at particular gates or may only be accessible via a guided tour, which would allow counting based upon ticket or tour sales. These methods have been used in many areas to obtain not only visitor counts, [15–17], but also socio-demographic changes in visitor use (e.g., [18]), visitor use in protected areas (e.g., [19]), and evaluations of user recreation fees in the U.S. Forest Service (e.g., [20–22]).

Within a visitor area, counting by trained human observers may go beyond basic information on the abundance or density of visitors. Additional information, such as spatial and behavioral use, may provide a deeper understanding of visitor use indicators [23]. McKenzie and Cohen (2006) [24] developed the System for Observing Play and Recreation in Communities (SOPARC) as a method of observing and calculating visitor activity using synoptic sampling. The System for Observing Play and Recreation in Natural Areas (SOPARNA) extends this model to natural areas, such as campsites and more open landscapes [25]. Both of these methods rely on trained observers monitoring a specified target area for activity and proper coding of individual activity to create a more complete picture of overall visitor activity via extrapolation. A similar method known as behavior mapping uses the objective observation of visitor use across a defined space [26]. In this method, an observer uses a scan from left to right and records all information about visitors they see, such as the location, activity, and other relevant variables. This method also holds promise for using georeferenced visitor information to help inform and define the spatial arrangement and design of natural area features [26]. These methods may be modified for both human and automated sampling to include not only human observation and counting, but also the use of game cameras, trail counters, and other methods described in the following sections [19,27–29].

Survey sampling is another method of estimating dispersed visitor use levels. Visitor survey methods have been employed to assess visitor characteristics, human dimensions

(e.g., attitudes, norms, and preferences), and use patterns in a variety of natural settings. Survey methods are often used in combination with direct observation methods. This approach was applied to the Lower Salmon River in Idaho to ascertain the number of visitors, visitor distribution, preferences, and opinions [30]. The approach is attractive because it may be applicable to other similar areas with minor modification, and provides the desired information at a minimal cost [31–33]. In the marine setting, Loomis and others [34] gained a representative understanding of use patterns of resident and non-resident scuba divers, snorkelers, and recreational anglers in the Florida Keys. Their research examined stakeholder groups' interactions with coral reef environments, individual and collective values, norms of behavior, levels of specialization (a measure of how central a coral-reef-associated activity is to a person's life), perceived crowding, satisfaction, resource conflict, and attitudes. Samples of scuba divers, snorkelers, and recreational anglers were identified through in-person intercepts during a 13-month period, which were designed to collect names and addresses for a mail questionnaire. Users were surveyed in the near-shore, mid-channel, and reef margin/fore-reef zones. On-water intercepts targeted private boat owners or visitors who had rented a boat for the day and fished on or around coral reefs. Similar studies were conducted in Dry Tortugas National Park and Buck Island Reef National Monument [35,36]. A myriad of other visitor counting and monitoring efforts have been undertaken. For the sake of brevity, not all of these are discussed in this manuscript.

3. Contemporary Visitor Monitoring

3.1. Aerial Surveys

The utility of aerial surveys for counting recreational users in aquatic areas has been previously detailed with fishery-specific applications and favored as a method which covers large areas in relatively short periods of time [37]. While seemingly cursory in their ability to count visitors, specific details, such as the boat type [38] and angler effort [39], may also be gathered using aerial surveys. More contemporary research has shown promise with respect to the even greater detail of aerial survey data pertaining to recreational perceptions and spatial dynamics.

Smallwood et al. [40] assessed patterns of recreational use in large marine parks in Australia. In their study, 34 temporally stratified flights conducted over a 12-month period were used to obtain visitor data. All vessels and people were geo-referenced and where possible, their activities were recorded, providing data which illustrated dramatic expansions and contractions in recreational use. In their findings, not only did the spatial extent of use expand in the peak visitor season (April–October), but the density of use correspondingly increased. High densities of recreational activity in the park's waters were accompanied by increased numbers of vehicles, camps, boat trailers, and boats on the adjacent shoreline. Aerial surveys were found to be an effective method for rapidly obtaining recreational data with a high spatial accuracy.

Reed-Anderson et al. [41] conducted aerial surveys of boat usage in 99 stratified random lakes, sampling midday on weekdays in summer in order to assess baseline boater usage as it related to lake variables. They found that a mixture of landscape and social attributes correlated with the boat density, as more boaters were found on large lakes with more developed boating facilities and higher perceptions of fishing quality [41]. Aerial surveys remain a suitable option for visitor monitoring in certain cases, but the relatively high costs of operation may be prohibitive in some contexts.

3.2. Photography and Video

Photography has been used to derive visitor counts [42] and spatial and temporal data (visitation numbers by season or time of day, and numbers in given areas), and classify visitor behavior, and has been used in conjunction with other methods, such as visitor surveys [6,43]. Camera recordings through both images and video can provide detailed and accurate information with respect to visitor counts and characteristics. In 2015, research in support of the U.S. Forest Service National Visitor Use Monitoring Program (NVUM)

developed new methods for data collection associated with visitor use by employing wildlife (game) cameras at sites throughout Region 6 National Forests [44]. Using the Game Camera Plotwatcher PRO, the methodology was tested in the national forests of Oregon, Washington, and Brazil [44,45]. Cameras can be used to collect data pertaining to visitor use, vehicle use, and the social carrying capacity [46]. Using cameras, when compared to other monitoring methods, can reduce the financial costs of data collection at sites with low visitor use. In addition, cameras can provide richer and more reliable data than other visitor use monitoring equipment (e.g., infra-red or pneumatic road counters), as described in the upcoming sections. The use of cameras might also reduce human safety risks associated with drive times and time spent alone in remote areas in forests. In marine areas, the use of stationary cameras is reliant on mounting locations, such as buoys, mooring pylons, or other semi-permanent structures, which are not always easily accessible.

Cessford and Muhar [42] describe both the advantages and disadvantages of these methods and conclude that camera recordings have one of the highest overall coverage capacities of all methods reviewed. This flexibility and utility does come with costs of equipment, setup, training for data summarization, and analysis, and the initial need to calibrate visual estimates with actual field observations. Field observers and video observations may yield high levels of agreement (−0.9% to 1.4% difference) through low and high levels of visitor use when only collecting overall visitor counts [47].

However, it is possible to exceed field observer capabilities in some circumstances given the amount of visitors or variables being observed and collected. Arnberger et al. [43] (2005) compared video monitoring and human counts for user numbers, user types, and group sizes. No significant differences emerged between human observer counts and video counts with regard to the total number of visitors at a low level of use, but at a high levels of use (>120 people per hectare), field observers reported 20% less use than video interpreters. This difference is logical based upon field observers' temporal capabilities and may lend itself to the greater application of image and video capture in very high density use areas.

Remote, time-lapse cameras have broad scientific use in wildlife research [48] and are becoming more popular within fishery research as a method for estimating the angler effort ([40,49–51]. To estimate the angling effort, Greenberg and Godin [52] (2013) used time-lapse remote field cameras that captured hourly images of lakes in British Columbia over long time periods of weeks or months. The cameras were affixed to landscape features (e.g., trees) at one or more strategic locations surrounding a lake. Each digital image provided data on the lake identification, time and date the image was captured, environmental conditions, and angler/boat counts. Estimates of the angling effort were calculated from the raw data and calibrated against existing creel and aerial survey results. This provided a ratio or correction factor of the number of anglers seen by the camera to the total number of anglers on the lake at one time. To mitigate various workflow problems, Greenberg and Godin [52] (2013) developed a free image analysis software tool called Timelapse (<http://saul.cpsc.ucalgary.ca/timelapse>). The authors concluded that this approach is suitable for monitoring remote and/or hard-to-access lakes, and for capturing daily and seasonal effort trends. Camera data can be used alone or combined with additional data to produce a more accurate view of the angling effort over time. In remote areas where traditional creel surveys are difficult to carry out, camera surveys capture angler densities and allow harvest estimates when combined with brief interviews [53]. These applications hold promise for marine sanctuaries and other large areas, but must carefully consider long range distance and time capabilities in order to adequately capture visitors across the full extent of the study/use area.

3.3. Social Media

Social media has typically been considered a supplementary source for visitor use information. Social media sources such as Flickr photographs are inexpensive, making it easier and less costly to study visitation at remote sites. Such photographs are linked to online user profiles, allowing researchers to further investigate where visitors are located.

Wood et al. [54] (2013) studied the relationship between Flickr photographs at over 800 recreation sites around the world and found a significant correlation between visitation rates measured by the photos and by standard reporting methods. Uploaded photos are geo-tagged with the geographical coordinates of where the image was taken, and also include the date of when the image was taken. All metadata for public photos are accessible via the Flickr Application Programming Interface (<https://www.flickr.com/services/api/>).

Sessions et al. [55] (2016) assessed the validity of using crowd-sourced photos from Flickr to estimate the number of visitors to a National Park in a given month, and to infer information about their travel habits and recreational preferences. Monthly photo-user-days were computed with the InVEST software package. The data were compared to empirical data collected by the National Park Service Visitor Use Statistics. In their results, the majority of statistical models, fit per park, produced visitor estimates that fell within the range of observed counts by the National Park Service.

It is important to consider that each measurement technique for counting visitors involves sampling error and biases that cause it to vary from the true population of visitors. The Flickr data are biased by the popularity of the website, which varies by year; geography; and user groups. Accordingly, using social media to estimate visitation may yield a sample of slightly different subsets of the visitor population.

3.4. Counting Devices

The devices used to make indirect counts of visitors can include pressure plate and photoelectric trail counters, photo-graphic equipment, and electronic or pneumatic vehicle counters. Electronic and pneumatic-tube-type vehicle counters have been used to assess visitor use in backcountry areas with dispersed use, and developed areas accessed by roads, such as campgrounds, scenic overlooks, and boat docks. Such counting devices, coupled with direct counts of the number of visitors, have been used to estimate visitation. Until recently, the U.S. Forest Service used both pneumatic and infra-red counting devices as part of their National Visitor Use Monitoring Program. Both types of counters have 24-h timers to regulate counts per day. The pneumatic-tube device (e.g., K-Hill Signal Company, Inc.) counts the number of vehicles entering or exiting a particular location. Specifically, the device counts every axle that crosses it, but the face of the counter shows a “1” after two axles cross it. This is an automatic setting used because most vehicles are two axles. The traffic counter must be installed properly and must be calibrated before using it.

Infra-red counters (e.g., TrailMaster 1500 Active Infrared Trail Monitor) function in a similar way, counting anything that passes through the beam between the transmitter and receiver. Infrared energy is emitted from the transmitter in short pulses and is detected by the receiver. The receiver registers a count when the infrared beam is interrupted by the presence of a physical object, such as a human being. The TrailMaster 1550 model stores up to 16,000 pass-by events, with each recorded event containing a date and time stamp accurate to the minute. Both the receiver and transmitter must be vertically aligned for the system to give reliable results. For example, the transmitter and receiver can be strapped to trees on either side of the spot being monitored.

Pettebone et al. [56] (2013) used a TRAFx active infrared monitor (Canmore, Canada) and an Eco-Counter automated counter (Lannion, France) to collect trail use level data in Yosemite National Park. The TRAFx monitor system is comprised of a single infrared scope connected to a small memory unit. The monitor registers a count when the scope detects the infrared signature of a warm moving object (i.e., a passing hiker), and collects continuous data. The Eco-Counter monitoring system detects and quantifies the direction of a hiker’s travel, in addition to overall hiker counts. The direction of hiker travel was estimated using the data from the Eco-Counter. The direction of travel needs to be estimated because the number of visitor arrivals at a location is used as a proxy for the total number of visitors in an area.

As automated infrared monitors have become a popular tool for estimating visitor use levels in national parks and protected natural areas, it is important to note that there are

counting errors associated with all automated counters. Therefore, procedures are often required to convert raw counter data into accurate estimates of recreational use. Pettebone et al. [57] (2010) assessed the performance (i.e., degree of error) of automated trail traffic counters and documented procedures to correct counting errors associated with their use for measuring visitor use in Yosemite National Park. A series of statistical procedures were used to calibrate raw monitor data to produce accurate estimates of visitor use at each of the study sites. Direct observations of visitor use were compared to counts collected by automated visitor monitor equipment (TrailMaster 1550 active infrared monitors). The results of the study suggested a strong statistical relationship between observation-based visitor counts and monitor counts, which further supports confidence in the use of monitors for estimating recreational use in national parks and protected natural areas. However, researchers and managers who choose to apply automated counters to estimate visitor use should also provide personnel to collect direct observations. Otherwise, automated counters that are not calibrated cannot be used as a proxy for visitor use estimates. The use of multiple types of observations can also address the technical limitations of employing automated counters. Automated visitor counters do not discriminate between different types of users (or objects or animals). For example, visitor counts can be skewed by wildlife passing through a monitor's detection range.

3.5. Proxy Counts and Multipliers

There are many times when, and locations where, visitors enter a site in a manner where direct or automated counting systems cannot always be used. Parks with "porous" boundaries or extremely remote areas require alternative approaches for estimating visitation and may include counts with expansion multipliers or sampled counts. The proxy count method uses a count of something other than visits that can be converted into a reasonable estimate of visitation, or an alternative measure that is statistically correlated with visitation. All proxies require some adjustment to convert the proxy count into a visit count.

Agencies such as the National Park Service and U.S. Forest Service commonly employ a variety of detection technologies and estimation methods using proxy counts, statistical relationships, or constants to estimate visitor use and provide continuous counts throughout the year. For example, rather than attempting to count each individual visit, parks may employ standard traffic monitoring technology to count and then convert vehicle counts into recreation or non-recreation visits using persons-per-vehicle multipliers [14]. The same procedure can be employed for visitors arriving by bus, boat, aircraft, canoe/kayak, motorcycle, or other modes of transportation. Large or unstaffed campgrounds, where counting individual stays each night would be impractical, use counts of campground sites occupied (from permits or daily observations) with persons-per-site multipliers. Employing an expansion multiplier allows parks to estimate all park visitations from a single count. Furthermore, the addition of proxy information can reduce variation in visitation estimates, thereby reducing the sample sizes required to make accurate estimates [58].

In situations where individual visit or proxy counts cannot be used efficiently, managers can rely on statistical relationships between counted and uncounted areas. Statistical relationships between measured and unmeasured areas are often employed when a park has many entrances or if visitation in a remote area has a strong statistical relationship with an area that can be measured. For example, instead of covering every entrance with a traffic monitoring system (as described in the previous section), a park may monitor traffic at representative locations and use statistical relationships to estimate areas not covered by equipment. Using multiple sources of data and multiple pathways of visitation adds complexity to statistically modeling visitation across regions, but may be achievable in the proper settings [59].

3.6. GPS and Phone Data

GPS visitor tracking allows for a direct measure of visitor spatial patterns, including the use density and distribution. Identifying this type of information is particularly important for parks and protected areas because the distribution and density of visitor use influence the biophysical and experiential impacts. The results of GPS visitor tracking can inform managers on strategies for zoning activities, reducing conflict between resource protection and open access goals.

Researchers have incorporated spatially-related social data in parks and protected areas to describe the value that visitors attribute to specific sites [60–62], to understand where visitors actually travel [8,63,64], to identify and examine the quantity and timing of use [65,66], and to determine the suitability of landscapes and related resources for recreation [67,68]. GPS visitor tracking has been used in Yosemite National Park, Rocky Mountain National Park, and the Teton Range to measure the frequency, timing, and intensity of use [8]. Beeco et al. [64] (2014) used GPS tracking of visitor use and recreation suitability mapping to compare and contrast actual visitor travel patterns with mapped preferences for natural resource features.

Although GPS-based tracking methods have helped researchers to understand the spatial-temporal dimensions of visitor behavior, few studies have been able to capture the seasonal and spatial variability for an extended period of time due to limited sample sizes and short data collection periods. A common practice in GPS tracking studies is to hand out a GPS device to participants, which has several disadvantages, such as high equipment investment costs, concerns regarding the retrieval of units, and possible effects on human spatial behavior due to participants' awareness of the device. Researchers have also noted that the limited battery life and data storage of tracking devices represent a difficulty in using GPS-based methods to track visitor behavior within backcountry settings or multi-day trips [69].

The development of GPS-based mobile technology and applications is advancing the ways in which researchers can overcome some of the aforementioned obstacles. Accurate and rich spatial-temporal data can be extracted from mobile devices (i.e., smartphones) to accurately track visitor movement across time and space. Due to the widespread use of smartphones, user-activated GPS-based mobile applications and software can track users' real outdoor activities and generate accurate time and location information [70,71].

There is a large amount of time stamped geographical information available on the hard drives of mobile operators, which can be used in geographical and other relevant studies. Passive mobile positioning data are automatically stored in the memory of mobile operators in the form of log files at the time of any outgoing call or texting activity [72]. For billing purposes, when a mobile device is used, the mobile phone operators store the data about the mobile device, including the identification code, location, type of event, day and hour, service, duration of the connection, etc. [73]. Those records are called Call Detail Records. The accuracy of spatial location information depends on the structure of the mobile tower network. Passive mobile positioning data have been used in demographic research describing the spatial and temporal mobility of people in urban settings [74,75] and patterns in tourism [72]. Additionally, all mobile phones have a subscriber identity module, commonly known as a SIM card. A SIM card communicates with a mobile phone network through mobile phone towers. Every time a SIM card calls, the mobile phone network database records which tower connects the call. This database allows each SIM card's position to be followed over time with the accuracy of the mobile phone towers' coverage areas. Coverage areas vary from approximately 1 to 100 km² [72].

3.7. Acoustics, Buoys, and Drones

Traditional in situ monitoring techniques rely on either a single autonomous surface vehicle (ASV) or a fixed network of sensors. However, neither existing technology is suitable or efficient for robust monitoring and tracking in large marine environments. The development of new designs of ASVs are beginning to offer robotic innovations in

environmental monitoring. For example, the Chesapeake Bay Interpretive Buoy System is a smart, stationary buoy designed by the National Oceanic and Atmospheric Administration (NOAA) to monitor various environmental features related to the water quality, oceanography, and meteorology (<http://buoybay.noaa.gov/>). While buoys such as these are stationary, researchers are also designing mobile buoys. Zoss et al. [76] (2018) designed, constructed, and tested a large distributed system of ASVs in the form of self-propelled buoys capable of operating in open waters. The authors suggested that their multi-robot system offers a new metric for quantifying effective coverage and monitoring of coastal-marine environments.

The use of drones, also called unoccupied aircraft systems (UASs) or unmanned aerial vehicles/systems (UAVs), in marine science and conservation is growing rapidly. Drones operate under radiofrequencies and pre-programmed GPS-guided flight scripts that provide near-real-time data on the people, processes, and landscapes they survey, including inaccessible areas [77,78]. Data can be collected directly by individual researchers under a greater array of weather conditions and with a centimeter-scale spatial resolution. The timing of surveys and spatial coverage are user defined, which allows for efficient, on-demand sampling across multiple scales. This flexibility allows researchers to conduct studies that identify causal processes. Drones present great opportunities for enhancing conservation and management tasks [79], including both legal and illegal fishing, unreported and unregulated fishing [80], and mapping and monitoring coastal-marine areas [78,81]. Drones have been used to monitor and map fish nursery grounds, seagrass in coastal ecosystems of Cape Lookout National Seashore, and maritime archaeological sites and infrastructure [78]. Drone mapping was conducted for the Ghost Fleet of Mallows Bay in support of a nomination to be listed as a U.S. National Marine Sanctuary.

Drones are frequently being used to assess the abundance and density of marine organisms, including seabirds [82], dugongs [83], sea turtles [84], and sharks and rays [85]. In some cases, these assessments are done using relatively large fixed-wing drones with a flight endurance of more than 15 h [83], whereas others focus on smaller regions and use small drones [84]. Multirotor drones are also employed for these purposes [85], often for nearshore regions due to the limited flight times of most multirotor drones. Bathymetric surveys in shallow water habitats are capable of using UAVs and have notable potential for use in areas where the coastal physiography inhibits the use of vessels to accomplish surveys [86].

Studies have compared traditional counting methods with new drone-based approaches. For example, Johnston et al. [87] (2017) compared grey seal (*Halichoerus grypus*) colony counts collected by small fixed-wing drones with data collected by an occupied Twin Otter aircraft. They concluded that drone-based imagery was as good as, if not better than, that produced through the traditional method, and that drone counts of seals were reliable for population assessment purposes. Hodgson et al. [88] (2018) also support this conclusion, suggesting that drone-based counts may provide better data. Physical habitat assessment variables were found to be closely correlated when measured on the ground and with a UAV flown at heights varying from 30 to 120 m above the ground [89]. The potential for visitor monitoring is amplified when one considers the versatility of the imagery capabilities of UAVs. Sensors may be used on UAVs which collect normal imagery (RGB lens), near-infrared (NIR) light, 3D point clouds, digital elevation and surface models (DEM/DSM), and light detection and ranging (LiDAR) models, among others. The precision of these spectral tools can be quite specific and has been demonstrated in forestry applications [90,91], as well as fine-scale riverine habitat assessment [89,92].

Multimodal or cross-domain systems are continuously being developed and used for both land- and marine-based missions. For instance, Weisler et al. [93] (2017) have developed a cross-domain fixed-wing drone that can fly over ocean areas for visual surveys, and then land in the water and dive below the surface to conduct submerged observations. An advanced system such as this has the potential to collect a variety of human and oceanic data in one flight.

There are many challenges when using drones to study humans in marine systems, including obvious ethical and legal limitations associated with privacy and safety concerns. To fly drones in the United States, researchers need to get clearance (e.g., 14 CFR part 107 or Section 44807 Exemption) from the Federal Aviation Authority, which bans the commercial use of drones in U.S. airspace, including for academic research. Other challenges are more technological or financial limitations. Basic, off-the-shelf drones can cost less than \$1000, but a programmable model equipped with high-resolution imaging systems can cost at least \$20,000 to \$50,000. The availability of small, low-cost, easy-to-operate consumer drones has the potential to greatly increase the capability of coastal resource managers to continuously monitor both wildlife and human activities in large marine areas [94].

3.8. Vessel Monitoring Systems

In remote aquatic areas where direct observation, even across long ranges, is not possible, advanced technologies which rely on satellite signal transmissions may offer utility. One such example is the vessel monitoring system (VMS), which consists of a National Marine Fisheries Service (NMFS)-type-approved VMS transmitter that automatically determines a vessel's position and transmits that position to an NMFS-approved communications service provider. A communications service provider receives the transmission and relays it to NMFS. Used for commercial fishing vessels in the U.S. Exclusive Economic Zone (EEZ), VMS is a satellite surveillance system which can monitor the location and movement of vessels. Certain vessels are required to carry on-board GPS transceiver units, which relay information via satellite at certain intervals of activity. The information sent generally includes vessel identification and the time, date, and location, and is mapped and displayed in a database available to enforcement officials. Each vessel typically sends position reports once an hour, but increases intervals when the vessel is approaching an environmentally-sensitive area. Alerts can be sent to the VMS technicians and other personnel when a particular vessel location might require additional inquiry or contact with the vessel operator.

The VMS program currently monitors more than 4000 vessels, making it the largest national VMS fleet in the world [95]. The system operates 24 h a day, 7 days a week, with near-perfect accuracy. The VMS program is comprised of five regions within NOAA's Fisheries Service, which include the Northeast Region, Northwest Region, Pacific Islands Region, Southeast Region, and Alaska Region. For instance, in the Pacific Coast groundfish fishery, the position data are primarily used to monitor fishing activity relative to closed areas. In the Northwest Region, three types of vessels are required to have a VMS: (1) Any vessel registered for use with a limited entry endorsed permit (i.e., not a Mothership (MS) permit) that fishes in state or federal waters 0–200 nm offshore of the states of Washington, Oregon, or California; (2) any vessel that uses non-groundfish trawl gear to fish in the EEZ; or (3) any vessel that uses open access gear (e.g., long lines, traps, etc.) to take and retain, or possess groundfish in the EEZ or land groundfish taken in the EEZ.

Research using VMS data to estimate the fishing effort has been conducted since at least 1998, when the adoption of VMS became more widespread (see the review by Lee et al. from 2010 [96]). Using variation in data, such as the speed and location, researchers often attempt to identify the fishing effort spatially. However, the methodologies used are specific to the research questions and standardization of using VMS data is needed and has begun to become developed [96]. The continued use of VMS data in contemporary fishery research highlights its utility. Watson and Haynie [97] (2016) identified approximately 30,000 trips made by vessels that targeted walleye pollock (*Gadus chalcogrammus*) in the Eastern Bering Sea from 2008 to 2014 using VMS and landings data. Gonzalez-Mirelis et al. [98] (2014) used vessel monitoring system data to map the distribution of prawn trawling and calculate the fishing intensity in a marine protected area in Sweden. The combination of accurate location data with activity data may be very useful for measuring visitation in aquatic environments, especially those with defined borders, such as marine protected areas.

Another system which monitors vessels remotely is the Automatic Identification System (AIS). It is both a ship-to-ship and ship-to-shore system designed primarily for safety of navigation and used similarly throughout the world. AIS has been in use since 2001, with requirements for certain size vessels pertaining to Safety of Life At Sea (SOLAS) as of 1 July 2002. Information such as the tonnage, speed, and bearing are typically included in transmissions as AIS transceivers are typically attached to shipboard electronic charting systems. These data make AIS a useful tool for communicating additional information for mariners and shore side authorities. McGillivray et al. [99] (2009) discussed the use of AIS technology that was implemented in ship traffic transit areas of the Stellwagen Bank National Marine Sanctuary to minimize ship interactions with endangered whales. While this technology is currently required on larger vessels, it is becoming more commonly employed on all vessel types and sizes. This system shows promise for the remote detection of vessels with location and additional real-time attributes, which may be beneficial to counting visitation within certain boundaries.

4. Applications in Marine Areas and an Alternative Proposal

A number of studies have examined visitor use in a variety of marine areas, including National Parks and Monuments; National Marine Sanctuaries; and marine reserves in Florida, U.S. Virgin Islands, Hawaii, Guam, American Samoa, and the Northern Mariana Islands. Studies in the Dry Tortugas National Park and Buck Island Reef National Monument obtained a representative sample of scuba divers and snorkelers, providing baseline data on visitors' knowledge of park resources and ecosystem conditions, their perceptions of threats to ecosystem health, and their duty to act responsibly as recreational users [35,36]. This information assisted park managers in assessing recreational impacts, visitor satisfaction and enjoyment, and how to communicate stewardship messages to visitors and the public at large. Studies in the Western Pacific interviewed and conducted both internet and mail surveys with commercial, recreational, and subsistence fishermen on their perceptions of procedural justice, fairness, and the management of marine protected areas [33]. These marine protected areas included areas that were already established, newly designated, and proposed.

In Australia, Castley et al. [100] (2009) developed a framework that integrates visitor monitoring and evaluation within adaptive management cycles to improve management responses in Australia's marine protected areas. The framework uses existing management processes, where possible, for focusing monitoring efforts and selecting appropriate ecological indicators. This focus is achieved through a process of the prioritization of natural assets used by visitors, or those likely to be impacted by visitor use. The framework follows a hierarchical, sequential, adaptive cycle of identifying natural asset values and their vulnerability and use by visitors to derive appropriate indicators for monitoring.

Wardell and Moore [101] (2005) have provided an overview of visitor use studies in marine protected areas of Australia. Total annual visitor numbers are collected using mechanical vehicle counters and electronic MetroCount vehicle classification units, pedestrian counters, observation counts, entry fees, camping fees, permits, registration logbooks, commercial tour operators, and aerial photos in Western Australia. MetroCount classifiers and observation counts data are entered into the Visitor Information and Statistics Program (VISTAT) databases. Entries are made into fields for each data collection method, such as MetroCount data and observation data. The average number of passengers per vehicle is also entered into the system and the database then automatically calculates the total number of visits for the park or recreation site. For example, vehicle classifier data are multiplied by a vehicle occupancy rate calculated for each vehicle type. Data from the vehicle classifiers are entered each month and split into vehicle types. For each vehicle class, the average vehicle occupancy rate is calculated for each season (peak, low, or shoulder), and this process must be carried out for all vehicle counting units. VISTAT databases automatically sum individual park figures to provide the total number of visits across each district, region, etc.

Research on visitation in Brazil is a relatively new concept [19], with much of the visitation research taking place in federally managed settings. The US Forest Service International Programs (USFS-IP) and US Agency for International Development (USAID) developed a partnership that allowed for standardized visitor monitoring pilot studies in selected protected areas. Under this partnership, several public use training courses were held with staff from Brazil's National Park Service (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio)). The training related to visitor counting resulted in a "Normative Instruction", which presented the guidelines for monitoring visitation and highlighted different methodologies to be used in Brazil's visitor counting projects [102]. The Normative Instruction outlined a method for monitoring the number of visits for the institutional planning and management of public use of all federal protected areas (e.g., national forests, national parks, wildlife preserves, etc.) that have visitation for recreational, sporting, educational, cultural, or religious purposes.

In Brazilian coastal areas, there are a few examples of visitor counting. One of these is Fernando de Noronha Archipelago, located 545 km off the coast and Brazil's northeastern capital of Pernambuco (Recife). Noronha is one of Brazil's premier coastal and beach natural settings, and visitor use on much of the island is managed by a concessionaire (Econoronha). Visitor counting is achieved through counts of entrance fees, and multiplied by the number of days of stay [102,103]. At Jericoacoara National Park, which is a coastal protected area located in the state of Ceará, visitation estimates are used. The average length of stay for visitors in lodging facilities in the village of Jericoacoara is 3.7 days and 357,536 visitors per year, with total annual visitation estimated to be 1,322,883 recreation days. These data are provided to ICMBio by the Jericoacoara Business Council. Furthermore, at Pirajubaé Marine Extractive Reserve (another type of protected area in Brazil), the number of visitors is reported by the local community.

In the Amazon region of Brazil, the Tapajos National Forest makes use of a gate and sign-in system and infrequent survey research [103,104], and in the state of Parana, the Campos Gerais National Park only makes use of infrequent survey research [105]. Visitation monitoring varies greatly across Brazil's protected areas, and visitation counting is still being standardized across ICMBio protected areas. Nonetheless, ICMBio resource managers are in fact following best practices of more developed protected area systems, such as those of the United States and the European Union [106].

Alternative Proposal

Choosing an efficient and reasonably accurate method for estimating visitor use in large marine areas is a challenging task. Estimation methods that control for primary sources of bias can be expensive or logistically prohibitive. Adopting these methods requires a substantial investment on the part of the resource management agency. On the other hand, methods that are relatively inexpensive and easy to administer can yield unreliable data. Basing management decisions on questionable data could result in an undesirable mix of hidden costs and management problems. While there are no clean and easy solutions, there are four key requirements that must be met in most situations: (1) The method must generate reliable and accurate estimates of visitation counts; (2) the method must be efficient for the given monitoring area, with respect to time, logistics, and costs; (3) the method should provide valid and reliable information on the type and purpose of visitor trips; and (4) the method should generate visitation data in categories and/or segments that are applicable to the protected area attributes and managing agency requirements.

The methods presented in this review vary in terms of the complexity, costs, level of accuracy, and detailed information they provide. A summary of these methods is provided in Table 1, thereby providing resource managers with a consolidated resource to assist them in selecting methods best suited for their specific monitoring needs. For each method, the table summarizes the principal means of collecting data, the type of use data (i.e., activity, date, group size, etc.), the type of visitor data (i.e., information on

human dimensions, behavior, etc.), the costs to administrators (low, moderate, or high), and the costs to visitors (low, moderate, or high) (Table 1). In determining costs to visitors, we assumed that costs are highest when freedom of choice and action are compromised by regulations and restraints to the visitor's experience. Although it is difficult to define costs to administrators, particularly in dollar terms, some general assessments for each method are given based on the budgetary requirements, ease of application, and validity of findings. As collaborative efforts progress to subsequent tasks within a specific visitor monitoring framework, recommendations should be made on the feasibility of using each method in marine settings and at potential counting sites.

An alternative proposal to traditional and contemporary visitor counting methods that considers feasible methods at the site scale using specific attributes allows a generalized structure, but specific application, for visitor definitions in aquatic settings (Figure 1). Such a proposal builds upon local knowledge of the setting and seeks to address weaknesses of monitoring while building upon existing strengths. Within the alternative framework, iterative phases allow the adaptive creation and modification of sampling methods that may be applicable to the visitor counting goals at a given aquatic site. Due to the complexities surrounding aquatic protected areas discussed throughout this review, a framework which follows iterative phases and includes input from experts with localized knowledge of the area of interest is recommended. Additionally, because all described visitor counting methods come with limitations that may be exacerbated in aquatic applications, reliance on a single method is typically discouraged. The availability of data may be the primary driver of the method's feasibility, which further emphasizes the importance of building local expert knowledge in the visitor monitoring process. Experts with knowledge of the area of interest may be critical in helping facilitate data sources that can be analyzed for visitor information or contacts. Once methods are finalized for application to a given aquatic area of study, it is also important to assess the quality of data produced by each method, as it relates to visitor information. For example, imagery taken from a satellite or drone may provide exact spatial data, but lack a temporal resolution beyond the moment of image capture. Automated vessel identification data may provide the spatial and temporal resolution of vessel traffic, but may not contain information about the number of people aboard the vessel or the specific activity being conducted within a protected area. Therefore, the strengths and weaknesses of each data source should be aligned in order to create the most comprehensive data collection approach that is specific and useful for the setting and resources available for monitoring.

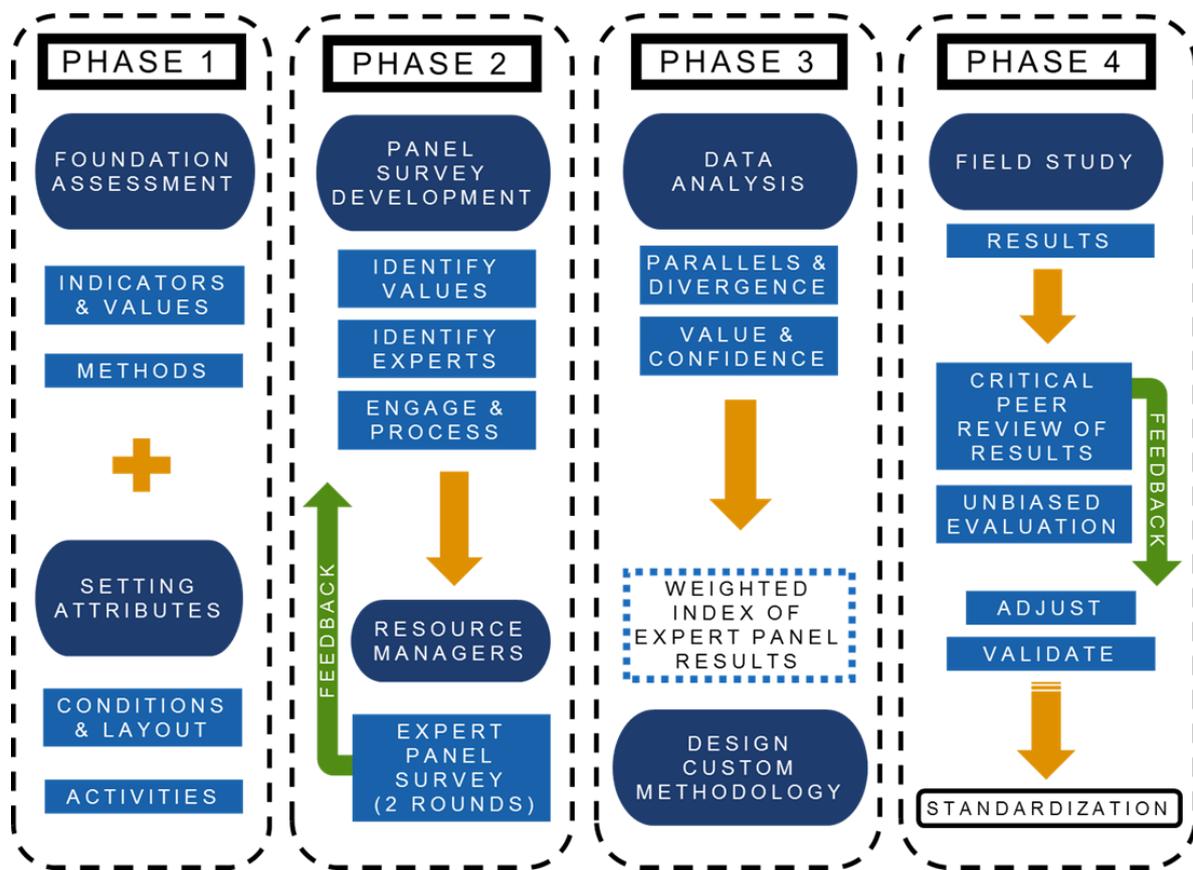


Figure 1. Conceptual diagram of a visitor monitoring process that can be applied to aquatic protected areas. This process is adopted from the work of Burns et al. [107] (2020), which outlines the process as it can be applied to National Marine Sanctuary sites within the U.S. The process covers four phases, from foundational assessment to application to field study and data collection. Critically, the incorporation of expert panel input and analysis of potential methods is included with the option to generate feedback and adapt to changing visitor monitoring demands.

Table 1. Reviewed visitor monitoring methods as applicable to aquatic protected areas. Categories should be weighed for comparison as they relate to the context of the aquatic area that requires visitor monitoring. Methods vary from simple to complex. Means of obtaining data may be variable, depending on the chosen method. Types of use and visitor data should be defined by the protected area and prioritized for management activities. Sources of bias/error should be minimized and controlled for as much as possible in visitation monitoring plans. Costs to administrators may be related to the budget, time, personnel, application, and data processing/validity. Costs to visitors may include imposition on the visitor experience, time constraints, and privacy concerns related to data collection methods. Category criteria should be weighted in any decisions that lead to a full monitoring plan, as certain criteria may hold a higher weight than others in specific site contexts.

Method	Principal Means of Obtaining Data	Type of Use Data	Type of Visitor Data	Sources of Bias/Error	Costs to Administrators	Costs to Visitors
Voluntary Self-Registration	Registration at station or office	Activity, length of stay, group size, travel mode, date	General demographics and behavior	Inaccurate information reported	Low	Low
Mandatory Permits Self-Registration	Online, station or office, visitor center	Activity, length of stay, group size, travel mode, date	General demographics and behavior	Inaccurate information reported	Moderate: Issuing and enforcement	Moderate: must obtain before use
Random Direct Field Observation	Obtrusive/unobtrusive observation	Activity, group size, travel mode, date	None. Requires additional survey methods	Unobserved and/or incorrect observations, double counting, use fluctuations	Moderate: staff on sampling days, design difficulties	Low-Moderate: onsite contract
Convenient Direct Field Observation	Obtrusive/unobtrusive observation	Activity, group size, travel mode, date	None. Requires additional survey methods	Disproportionate sampling, unobserved and/or incorrect observations	Low: staff make observations at convenience	Low-Moderate: observed onsite
Mail or Internet Survey	Random sample of users by mail/online	Detailed info on use, activity, visit	Detailed info on human dimensions and behavior	Inadequate sampling, low response rates, inaccurate info	Moderate: study design, implementation	Low: contact is off-site
Onsite Survey	Random sample surveyed or interviewed onsite	Moderate info on use, activity, visit	Moderate info on human dimensions and behavior	Inadequate sampling, low response rates, inaccurate info	Moderate-High: study design, implementation, staff onsite	High: imposes time constraints
Cordon Sampling	Visitors surveyed at check point on access routes when exiting	Activity, length of stay, group size, travel mode, date	Moderate info on human dimensions and behavior	Unobserved access points, double counting, use fluctuations	High: staff onsite sampling	Moderate-High: imposes time constraints

Table 1. Cont.

Method	Principal Means of Obtaining Data	Type of Use Data	Type of Visitor Data	Sources of Bias/Error	Costs to Administrators	Costs to Visitors
Aerial Observation	Tallies recorded during random flight transects	Spatial and temporal use density	None, requires additional survey methods	Inadequate flight transects, incorrect observations, visual obstructions	High: pilots, observers, flight costs	Low: No contact with visitors
Time-lapse or triggered photography	Data extracted from photos	Activity, time spent in location, group size, date	None, requires additional survey methods	Unobserved access, equipment failure, double counting, resolution	Moderate: equipment costs, installation, analysis	Moderate: privacy concerns
Video	Data extracted from videos	Activity, time spent in location, group size, date	None, requires additional survey methods	Unobserved access, equipment failure, double counting, resolution	Moderate: equipment costs, installation, analysis	Moderate: privacy concerns
Automated Visitor Counters	Total use recorded by counters	Number of visits	None, requires additional survey methods	Unobserved access, equipment failure, double counting	Low-Moderate: equipment and upkeep costs	Low: no interference
Electrical Traffic Counter	Total counts of vehicles entering or exiting	Vehicle counts, travel mode, date	None, requires additional survey methods	Unobserved access, equipment failure, double counting, inaccurate counts	Low-Moderate: equipment and upkeep costs	Low: no interference
GPS	GPS units or other required hardware	Spatial and temporal use, movement	None, requires additional survey methods	Equipment failure, positional error	Moderate-High: equipment costs	High: privacy concerns
Acoustics, buoys, and drones	Satellite technology, sensors, cameras	Spatial and temporal use, movement	None, requires additional survey methods	Equipment failure, spatial resolution, inaccuracy	High: equipment costs	High: privacy concerns
Vessel monitoring system	Satellite technology, locations	Spatial and temporal use, movement	None, requires additional survey methods	Equipment failure	High: equipment costs, data acquisition	High: privacy concerns

5. Conclusions

The review presented here is meant to capture existing visitor monitoring methods that are commonly used in terrestrial settings, and offer explanations of additional methods that are well-suited for application to marine and other aquatic settings. Additionally, an alternative proposal is illustrated, which seeks to select methods that offer the most utility for the context of a specific aquatic visitor monitoring project. High quality visitor monitoring may produce data that are essential in defining both the ecological and economic dynamics of aquatic protected areas. In such aquatic areas, the limitations of single visitor monitoring methods may be exacerbated by the challenges of the setting and thus, a combination of methods is proposed for obtaining the greatest level of monitoring coverage. It is important to consider the type of data obtained and not only the coverage of data across time and space, as the richness of the data may offer a higher or lower value for a given method in a specific context. Finally, it is important to consider the costs of methods for the administration of monitoring, but also for the visitors themselves. Data collection methods that may cover broad aquatic areas (e.g., aerial imaging or drone flights) may also incur higher costs to visitors with respect to disruption of their activities and/or privacy and should be weighed accordingly before adoption in a sampling plan. Following iterative steps that allow for the adaptation of sampling plans as site contexts and constraints are clarified will allow the best optimization among tradeoffs for visitor monitoring in such aquatic protected areas.

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