National Park Service
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Natural Resource Stewardship and Science

Sea Otter Monitoring Protocol for Glacier Bay National Park, Alaska

Version SO-2017.1

Natural Resource Report NPS/SEAN/NRR—2018/1762

ON THIS PAGE
Sea otters resting near Boulder Island in Glacier Bay National Park and Preserve.
NPS/JAMIE WOMBLE; USFWS Permit # MA14762C-0.

ON THE COVER
Sea otters resting in kelp near Ripple Cove in Glacier Bay National Park and Preserve.
NPS/JAMIE WOMBLE; USFWS Permit # MA14762C-0.

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Revision Tracking

Every SEAN protocol component is assigned a specific formal version identifier to distinguish its content from earlier work. The identifier for sea otter monitoring protocol packages follows the form SO-YYYY.V, where YYYY is the year the majority of rewriting occurred and V is a sequence number used to distinguish a protocol if more than one version is published in a year.

The version identifier is stamped on every product created under a protocol, including the individual rows in datasets. It is possible for database objects to contain values acquired under multiple protocol versions. Users should be aware that records within the same table may reflect somewhat different definitions or methodologies, but these are precisely documented in the protocol package that corresponds to the protocol identifier in each row.

This protocol narrative component is designated as version SO-2017.1 Protocol packages consist of narrative, data quality standards statement, and standard operating procedure (SOP) documents. The full set of specific documents operational at a particular span of time is organized and available at https://irma.nps.gov/DataStore/Reference/Profile/2240453.

All edits and amendments made to this narrative document are recorded in the table below. Users of this protocol should notify the Project Leader/Manager of any recommended edits or changes. The Project Leader (following SOP 11) will periodically review and incorporate suggested changes as necessary, record these changes in the revision history log, and modify the date and version number on the title page of this document to reflect the new edition.

Revision History Log

Previous Protocol ID	Revision Date	Revised By	Changes Made	New Protocol ID
–	September 2018	Jamie Womble	Initial version	SO-2017.1

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Executive Summary

Sea otters (*Enhydra lutris kenyoni*) are an apex consumer in the North Pacific Ocean and are known to influence and structure nearshore marine communities. Sea otters were extirpated from southeastern Alaska prior to 1911 due to the commercial fur trade; however, approximately 400 sea otters were reintroduced to southeastern Alaska in the 1960s. By 1988, sea otters had expanded into lower Glacier Bay and the U.S. Geological Survey (USGS) began aerial survey monitoring efforts to monitor the colonization, distribution, and abundance of sea otters; these efforts continued through 2012. Currently, sea otters are one of the most abundant marine mammals in the park.

In 2015, sea otters were identified as a vital sign by the National Park Service's Southeast Alaska Network (SEAN) Monitoring Program due to their role as a keystone species in the nearshore marine ecosystem. The primary objectives of the monitoring program are to use contemporary field and analytical methods to monitor the abundance and spatial distribution of sea otters in Glacier Bay. A spatio-temporal statistical model representing current knowledge of sea otter abundance and distribution, including underlying ecological processes governing colonization dynamics in Glacier Bay, was constructed using multiple sources of data collected on sea otters between 1993 and 2012 and will accommodate future data to be collected via aerial photographic surveys. Specifically, a partial differential equation that incorporates knowledge of sea otter ecology and behavior including habitat preferences, maximum growth rates, and observations of sea otters was developed and embedded within a Bayesian hierarchical framework to accommodate uncertainty in the data collection process, the ecological process, and the model parameters. Development and testing of a new monitoring design and field methods were initiated in 2016 with a suite of objectives aimed at improving the safety of aerial surveys, the reliability of abundance and distribution information for informing park managers, and general program sustainability. Contemporary methods for obtaining digital imagery and counting sea otters from the imagery were developed to replace prior observer-based methods. Aerial photographic surveys will be conducted and digital imagery will be archived as a permanent record enabling independent verification of counts of sea otters and quantification of habitat covariates. New methods for estimating availability at the time of sampling utilize replicate counts, from repeated images of a group of sea otters, within an N-mixture model framework to estimate detection probability.

The new monitoring design implements an iterative optimal dynamic sampling scheme to increase sampling efficiency, providing the most information from the data that can be collected affordably. The spatio-temporal model will be used to generate forecasts of sea otter abundance and associated uncertainty for subsequent monitoring periods. Forecasts then will be used as a template to select a set of survey transects that minimize the uncertainty in model-based forecasts of predicted abundance of sea otters. Optimal survey designs will be updated following each year data are collected and, therefore, are dynamic through time. A set of random transects also will be selected to supplement, validate, and compare abundance estimates of sea otters among sampling approaches. Reallocation of effort among survey types will be considered in the future as another means to optimize program performance and efficiency.

The combination of using (1) aerial photographs for collecting data, (2) advanced and flexible statistical models that incorporate our understanding of the ecological system, permitting rigorous estimates of occupancy, abundance, and colonization dynamics, and (3) a sampling framework that explicitly links our statistical model and future data to be collected, will improve monitoring efficiency, and our ecological understanding of sea otters in Glacier Bay.

The following protocol describes the rationale, methods, processes, and staff responsibilities for monitoring the abundance and spatial distribution of sea otters within Glacier Bay in southeastern Alaska. A series of related Standard Operating Procedures (SOPs) detail specific implementation instructions for survey design, field implementation, data analysis, data management, and reporting. Resulting data and report products will be available online through the NPS Data Store.

Acknowledgments

The development of this protocol was funded by the NPS Inventory & Monitoring Program Southeast Alaska Network (SEAN), Southwest Alaska Network (SWAN), and the Glacier Bay Marine Management Fund. The protocol has benefitted greatly from discussions with Mevin Hooten (United States Geological Survey (USGS), Colorado State University), George Esslinger, Dan Esler, Dan Monson (USGS-Alaska Science Center), Heather Coletti (SWAN), Michelle Kissling (United States Fish & Wildlife Survey (USFWS), Erin Moreland, John Jansen, Katie Sweeney, and Lowell Fritz (National Marine Fisheries Service-Marine Mammal Laboratory; NMFS-MML). We appreciate the assistance of Nina Chambers (NPS) with document formatting and copy editing. Research and monitoring was conducted under U.S. Fish & Wildlife Service Scientific Research Permit #MA14762C-0 and NPS Scientific Research Permit GLBA -2016-SCI-022.

1 Background and Objectives

1.1 Introduction

Sea otters (*Enhydra lutris kenyoni*) are considered a keystone species in the nearshore marine environment due to their influence on community structure and associated trophic responses (Estes and Palmisano 1974). Since 1988, sea otters have rapidly colonized Glacier Bay and now are one of the most abundant marine mammals. Sea otters were selected as a vital sign by the SEAN vital signs monitoring program in 2015, with the primary objectives of monitoring the spatial distribution and abundance of sea otters in Glacier Bay to assess patterns of population colonization and expansion while providing reliable data to inform management decisions that may affect sea otters and the nearshore environment.

Protocol development was initiated in 2016 to develop and test a rigorous statistical framework, efficient sampling design, and new aerial photographic survey methods for monitoring sea otter abundance and spatial distribution. A dynamic spatio-temporal model of sea otter abundance and distribution was developed to incorporate multiple data sources and account for multiple sources of uncertainty (Williams et al. 2017a). New methods were developed for estimating availability using replicate counts of sea otters from repeat aerial digital photography (Williams et al. 2017b). Optimization routines were incorporated to improve efficiency and performance with available funding and monitoring assets (Williams et al. 2018). The results of these efforts form the foundation of the following protocol for monitoring the abundance and spatial distribution of sea otters in Glacier Bay.

Subsequent sections provide additional information on sea otter ecology and status, rationale for the new monitoring program, specific monitoring objectives, staff roles and responsibilities, descriptions of field and analytical procedures, and an accompanying data management framework. In addition to this protocol narrative, detailed implementation procedures can be found in a series of associated SOPs.

1.2 Sea Otter Range, Habitat, and Status

Sea otters are the smallest marine mammal and a member of the subfamily (Lutrinae), which is part of the family Mustelidae. Sea otters occupy the nearshore waters of the North Pacific Ocean, historically ranging from Hokkaido, Japan through coastal regions of the Russian Far East, and the Pacific coastal areas from Alaska to Baja California. In Alaska, sea otters occupy a geographically extensive range from approximately 172ºE to 130ºW (over 3,500 km east to west) and 51ºN to 61ºN (over 1,000 km from south to north; Figure 1.1; Kenyon 1969). Sea otters spend the majority of their life cycle within the nearshore zone and forage primarily on intertidal and subtidal invertebrates. The food web in the nearshore zone can be complex with a large proportion of energy sources resulting from benthic-based primary production (Duggins et al. 1989).

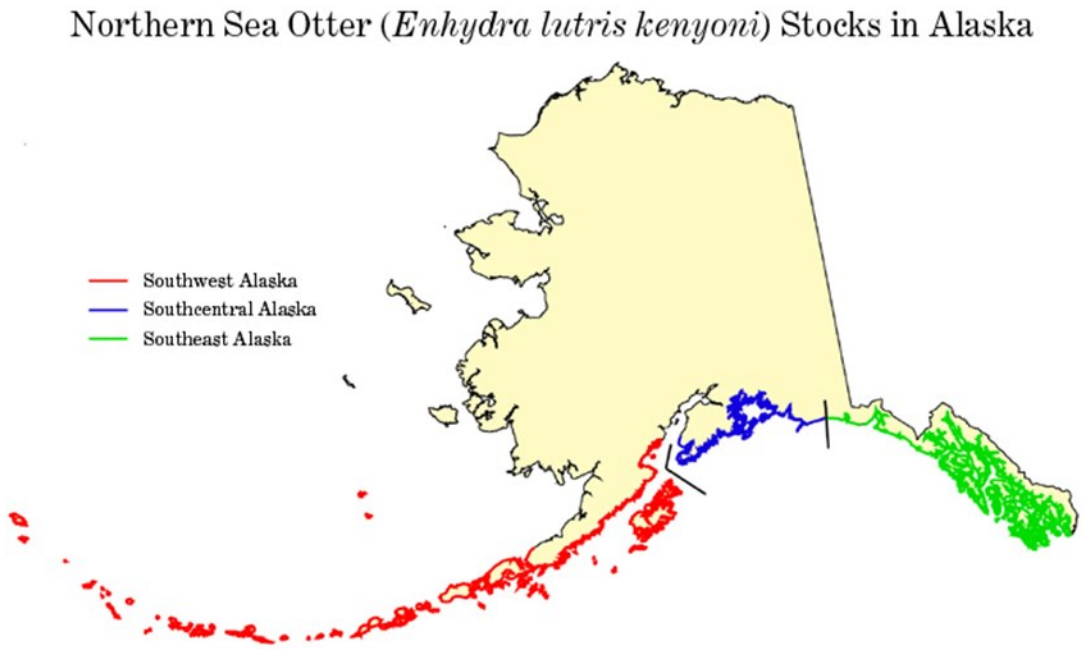


Figure 1.1. Approximate sea otter distribution and range in Alaska. Each sea otter stock is identified by a unique color (from U.S. Fish and Wildlife Service).

The U.S. Fish and Wildlife Service (USFWS) is the federal agency responsible for maintaining sea otter populations. Currently, sea otters are managed as three stocks (Southeast, Southcentral, and Southwest) in Alaska. In 2005, due to dramatic declines, sea otters in southwest Alaska were listed as threatened under the Endangered Species Act (ESA). Sea otters are also protected under the Marine Mammal Protection Act of 1972, which prohibits “take” of all marine mammals. However, subsistence harvest by coastal Alaska Natives is generally permitted under the Marine Mammal Protection Act. Currently, Glacier Bay is the only area in Alaska where subsistence harvest of sea otters is not permitted.

From about 1750 through 1911, the world-wide sea otter population was reduced dramatically by commercial harvest by the Russian and Russian/American fur trades. Although substantial uncertainty exists, the estimated number of sea otters before the commercial harvest began ranged from 150,000 to 300,000. Harvest peaked at the turn of the 19th century with an average of 15,000 otters harvested per year. By the late 1890s, due to scarcity, harvest was effectively ended. By 1911, it is estimated that only 13 colonies remained in western Alaska, California, and Haida Gwaii in British Columbia (Lensink 1962, Kenyon 1969).

Given the near extirpation of sea otters throughout much of their range, the International Fur Seal Treaty Act of 1911 was enacted with the objective of restricting hunting of commercially valuable fur-bearing resources, including sea otters and fur seals (*Callorhinus ursinsus*). After commercial harvesting was curtailed, the few remaining sea otter colonies began to recover, with the majority of remnant colonies distributed near the northern limits of their range, with the exception of a small colony in central California (Kenyon 1969).

Beginning in the 1950s, efforts were initiated to recover sea otters throughout much of their historical range along the Pacific coast of North America with translocations of sea otters from Amchitka in the central Aleutian Islands to several areas including the Pribilof Islands, Attu Island, Prince William Sound, British Columbia, Washington, Oregon, and southeastern Alaska (Kenyon 1969).

The translocation of sea otters to southeastern Alaska was the largest with approximately 413 individuals. The reintroduced population increased an average of 18% annually in the decades following translocation. However, divergent trends began to emerge within southeastern Alaska (SEAK). The annual rates of change declined to approximately 3% in northern SEAK and 7% in southern SEAK. (Esslinger and Bodkin 2009, USFWS 2014). In contrast, in Glacier Bay, which was colonized around 1988, sea otters expanded rapidly (Esslinger et al. 2013, 2015) and by 2016, sea otters were found throughout much of the bay.

1.3 Rationale for Establishing a Monitoring Program for Sea Otters

Long-term monitoring of the spatial distribution and abundance of sea otters in Glacier Bay has been justified and prioritized for a number of reasons.

(1) Sea otters are recognized as an apex or keystone species due to their ability to limit prey populations and influence nearshore marine community structure. The effects of sea otter predation in nearshore communities are well-documented in rocky substrate habitats in the North Pacific Ocean (Estes and Palmisano 1974). The top-down influences on nearshore prey species include maintaining a more diverse nearshore ecosystem. There is also interest in understanding the potential top-down effects and bottom-up responses in Glacier Bay where unconsolidated sediments are more common.

(2) Sea otters recently (around 1988) colonized and expanded into much of Glacier Bay and currently are one of the most abundant marine mammals in the park. From 1988 to 2012, the USGS and Glacier Bay National Park and Preserve (GLBA) maintained a research and monitoring effort quantifying the abundance of sea otters, foraging behavior of sea otters, and benthic invertebrate communities to study the role that colonizing sea otters play in structuring nearshore marine communities in Glacier Bay (Estes and Duggins 1995, Donnellan et al. 2002, Bodkin et al. 2007, Esslinger et al. 2013, Weitzman et al. 2013). Prior efforts provide baseline data and a solid foundation for the development of new approaches for monitoring sea otters in Glacier Bay and a framework that incorporates a contemporary model-based design and digital aerial photographs.

(3) The founding legislation and purpose statement of GLBA is “to protect the dynamic tidewater glacial landscape and associated natural successional processes for science and discovery in a wilderness setting.” Specifically, “Glacier Bay National Park and Preserve protects a natural biophysical landscape that is continually changing through large-scale natural disturbance followed by the biological succession of plants and animals, and accompanied by an evolving physical environment” (Glacier Bay National Park and Preserve Foundation Statement 2010). The ongoing colonization of Glacier Bay by sea otters offers a unique opportunity to study succession in the nearshore marine ecosystem. Quantifying and understanding the colonization, spatial distribution, and abundance of sea otters in Glacier Bay will be important for understanding top-down and bottom-up processes in the nearshore marine communities.

(4) The development of a robust quantitative framework for monitoring sea otters will be important for evaluating population status, spatial distribution, and abundance within Glacier Bay and contributing to Alaska-wide estimates of abundance of sea otters by informing the USFWS stock assessments for sea otters in Alaska, which are required under the Marine Mammal Protection Act of 1972.

(5) Sea otters also are designated as a vital sign in Kenai Fjords National Park and Katmai National Park and Preserve and monitored by the SWAN (Coletti al. 2016). Monitoring sea otters across Alaska parks provides the opportunity to contribute to a broader understanding of the species status and ecology.

(6) Sea otters are highly susceptible to injury from marine contaminants and oil spills given their nearshore distribution, diet, and small home ranges (Lipscomb et al. 1993, 1994, Rebar et al. 1995, Monson et al. 2011), thus understanding the spatial distribution and abundance of sea otters in Glacier Bay will provide important baseline data.

1.4 Description of Study Area in Glacier Bay National Park

Glacier Bay is a tidewater glacier fjord in southeastern Alaska that constitutes a part of GLBA (Figure 1.2). Distinct oceanographic and circulation patterns (Etherington et al. 2007, Hill et al. 2009), resulting from rapid and repeated advances and retreats of tidewater glaciers over the past 225 years (Field 1947, Hall et al. 1995), have led to high levels of primary productivity and abundant forage fish (Etherington et al. 2007, Robards et al. 2003).

Figure 1.2. Map of Glacier Bay National Park and Preserve (GLBA) in Alaska.

Glacier Bay is part of a Biosphere Reserve and World Heritage Site, encompassing over 242,811 hectares (600,000 acres) of marine waters. While the park was not created solely to protect marine mammals, it functionally serves as one of the largest marine mammal protected areas in the world with regulations intended to minimize threats to marine mammals and sustain a healthy ecosystem for their conservation (Womble and Gende 2013). There is a long history of monitoring marine mammals in Glacier Bay including species such as harbor seals (*Phoca vitulina richardii*), Steller sea lions (*Eumetopias jubatus*), humpback whales (*Megaptera novaeangliae*), and sea otters (Mathews and Pendleton 2006, Womble et al. 2009, 2010, Mathews et al. 2011, Esslinger et al. 2013, Gabriele et al. 2017). Collectively these studies provide a foundation for understanding long-term trends in abundance and distribution of these species of conservation concern and also provide important information for assessing potential impacts to these populations.

1.5 Background and History of Sea Otter Monitoring

This protocol focuses on implementing a quantitative framework to estimate the spatial distribution and abundance of sea otters in Glacier Bay. In Alaska, numerous methods have been used to count sea otters including vessel surveys and aerial surveys (e.g., Udevitz et al. 1995, Bodkin and Udevitz 1999, Burn and Doroff 2005). This project builds upon historical research and monitoring efforts to quantify sea otter abundance, foraging behavior, and nearshore communities in Glacier Bay (Estes and Duggins 1995, Bodkin et al. 2007, Esslinger et al. 2013, Weitzman 2013).

1.6 Sea Otter Population Monitoring Measurable Objectives

Sea otters were selected as a vital sign by the SEAN Monitoring Program in 2015. Sea otters are a subtidal benthic forager and play a key functional role in the nearshore food web of Glacier Bay. The primary objectives are to monitor the spatial distribution and abundance of sea otters in Glacier Bay to assess patterns of population colonization and expansion while providing reliable information that can be used to inform management decisions that may affect sea otters and the nearshore food web.

Specific monitoring objectives include:

(1) monitor the abundance and spatial distribution of sea otters in Glacier Bay;

(2) utilize a dynamic spatio-temporal model and flexible statistical framework that can account for multiple sources of uncertainty and accommodate multiple data types and that results in an iteratively refined model using survey results as a primary means to advance ecological learning;

(3) implement optimal dynamic survey designs to increase sampling efficiency to maximize program sustainability, increase safety, and improve the precision of parameter estimates; and

(4) provide reliable quantitative information regarding the spatial distribution and abundance of sea otters to assess the status of sea otters in Glacier Bay, inform Alaska-wide stock assessments by USFWS, and inform decisions regarding management actions that may have the potential to impact sea otters and the nearshore environment.

2 Study Design

2.1 Optimal Dynamic Sampling Designs and Rationale

Between 1993 and 2012 the USGS developed and implemented a design-based survey (*sensu* Cochran 1977, Thompson 2012) to collect data on sea otter abundance in Glacier Bay (Bodkin and Udevitz 1999). Design-based surveys provide robust, unbiased estimates of abundance, and appropriate confidence intervals to characterize uncertainty due to sampling error. The design-based survey used by the USGS provided relatively precise estimates of abundance of sea otters in Glacier Bay between 1999 and 2006 (Figure 2.1). However, by 2012, sea otters had become much more widespread and abundant, in estimates with large confidence intervals, ranging from approximately 4,000-12,000 sea otters (Esslinger et al. 2013, 2015; Figure 2.1).

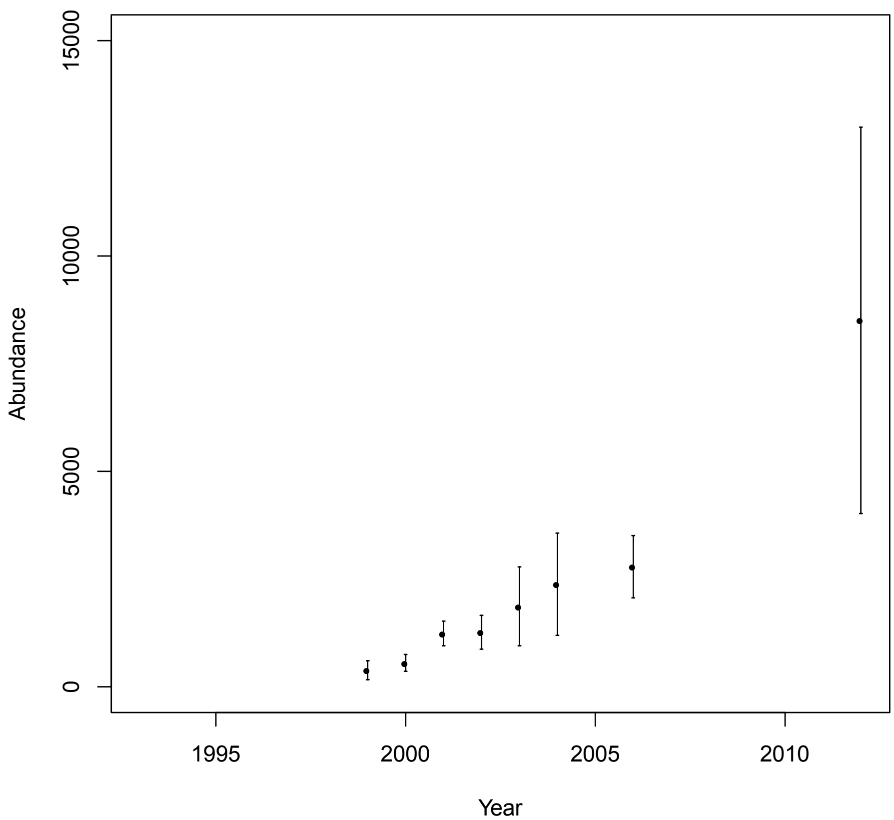


Figure 2.1. Design-based estimates of sea otter abundance in Glacier Bay, calculated from data collected by U.S. Geological Survey between 1999 and 2012.

Further, although design-based surveys provide robust, unbiased estimates of abundance, the data often fail to capture essential spatio-temporal variability of an ecological process; information important for the etiology of community response and ecosystem change due to the reintroduction of sea otters (Williams et al. 2018). Thus, a sampling design that provides precise and reliable estimates of abundance, distribution, and colonization dynamics is required for sea otter vital sign monitoring.

A dynamic survey design allows investigators to explicitly incorporate models of spatio-temporal processes that characterize the colonization dynamics of a spreading population. Dynamic sampling is concerned with selecting monitoring locations that optimally improve inference about a process of interest (e.g., abundance and distribution). Dynamic sampling designs incorporate data collected during previous surveys to inform optimal sampling locations for future surveys. Optimal dynamic sampling increases sampling efficiency by surveying the areas that will aid in inference the most. Optimal dynamic sampling designs are considerably more efficient than static sampling designs, allowing managers to obtain a greater understanding of the system with fewer resources (Wikle and Royle 1999, Hooten et al. 2012).

Dynamic sampling designs are conceptually straightforward (Figure 2.2), and analogous to adaptive resource management (Holling 1978). First, a dynamic spatio-temporal process is modeled using baseline data. Next, the model is used to make a statistical forecast. A statistical forecast is a procedure for making predictions about the future based on available data. The statistical forecast also includes estimates of uncertainty about the predictions. After a statistical forecast is made, the goal of an optimal dynamic design is to locate the set of spatial locations to survey that will provide the “best” information for improving future forecasts. “Best” is quantified with a design criterion that is optimized. The design criterion is often associated with minimizing prediction uncertainty, but could also include multi-model uncertainty, cost, or some combination of objectives (e.g., Williams and Kendall 2017). The design criterion maps actions (i.e., the potential designs that are being considered) and the statistical forecasts, to a number that represents some benefit (or cost) associated with each potential design and the predicted future state of nature (Williams and Hooten 2016). The optimal survey design is the design that maximizes the benefit (or minimizes the cost) represented by the design criterion. New data are then collected using the optimal design, and the statistical model is refit using the new data. This entire process (i.e., Figure 2.2) is repeated through time, updating our ecological understanding by reducing uncertainty in our statistical model.

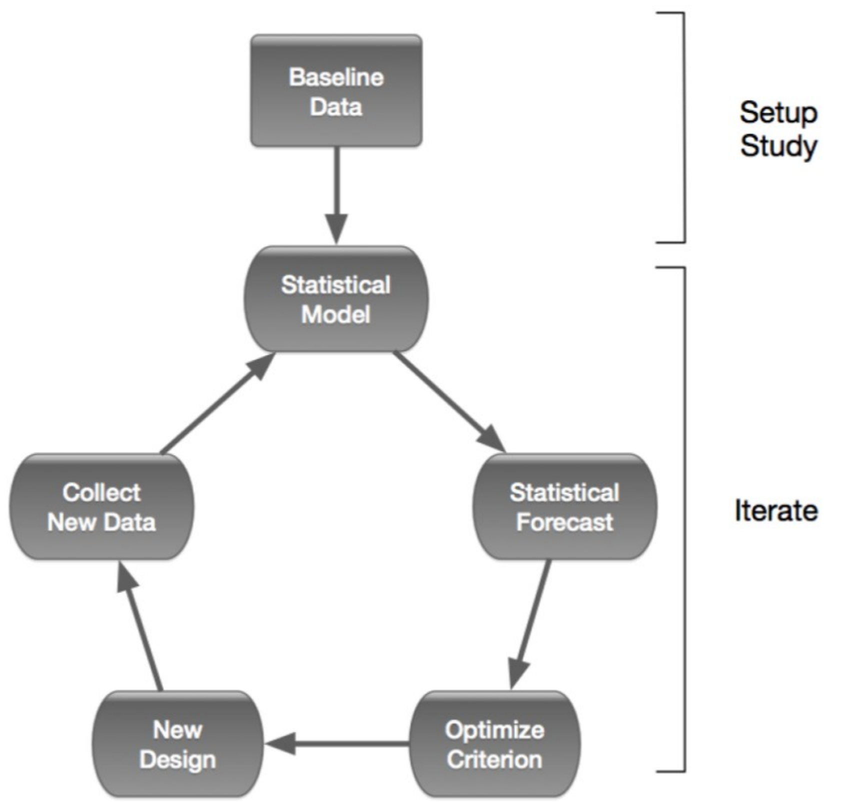


Figure 2.2. Schematic of optimal dynamic sampling. First, baseline data are used to fit a statistical model. Next the statistical model is used to make a forecast. After the forecast is made, potential designs are evaluated based on an optimization criterion. The design that optimizes the design criterion is optimal. After the optimal design is selected, new data are collected and the model is re-fit using the new data. The cycle then repeats through time, improving our model, and hence our understanding of the ecological system.

Hybrid sampling designs combine traditional sampling techniques (e.g., design-based surveys) with dynamic designs to identify an optimal dynamic sampling design (e.g., Hooten et al. 2009). Hybrid sampling is advantageous when fully dynamic designs are prohibitively computationally intensive due to the space of possible sampling designs being large, or when survey effort varies in time (e.g., due to changing operating budgets), and investigators must choose to add sample locations when additional funding is available, or alternatively, remove sample locations as funding becomes more restrictive (e.g., Hooten et al. 2012). Hybrid designs leverage the advantages of traditional, design-based approaches, with the advantages of an optimal dynamic sampling design.

Spreading populations are ideal candidates for optimal dynamic designs or hybrid designs because they have significant spatio-temporal interactions. Additionally, the spatio-temporal processes that regulate population spread are usually of ecological interest (e.g., processes that influence species invasions, re-establishment of apex predators). Optimal dynamic designs maximize the efficiency in learning about these spatio-temporal processes.

2.2 Survey Design Considerations

Survey design considerations are characterized by Figure 2.2, and include baseline data, a statistical model that will be used to make a forecast of sea otter distribution and abundance using the baseline data, and a design criterion that quantifies the utility of sampling each site, with respect to survey objectives. A summary of design consideration choices is provided in Table 2.1

Table 2.1. Summary of design considerations for optimal dynamic survey design.

Component	Description
Baseline data	Three data sources including: 1. Design-based surveys in 1999-2004, 2006, and 2012. 2. Intensive sample units in 1999-2004, 2006, and 2012. 3. Distributional surveys in 1993, 1995-1998, 2005, 2009, and 2010.
Statistical model	A dynamic spatio-temporal statistical model described in Williams et al. (2017a).
Statistical forecast	Forecast of abundance and uncertainty to future monitoring period to identify optimal sampling areas.
Optimization criterion	Minimize uncertainty in forecasted abundance. Design criterion described in detail in Williams et al. (2018).
New design	Combination of: 1. Transects that minimize the optimization criterion 2. Random transects 3. Optimal abundance flight

2.2.1 Baseline Data

Sea otter data collected by the USGS between 1993 and 2012 (Esslinger et al. 2013, 2015) provide an excellent source of baseline data to develop a statistical model for characterizing occupancy, abundance, and colonization dynamics (Williams et al. 2017a). Ancillary baseline data include distributional surveys conducted by the USGS in 1993-1998, 2004, 2005, 2006, 2009, and 2010, and a data set for estimating detection probability during these aerial surveys.

The design-based survey consisted of a probabilistic aerial survey method described in detail in Bodkin and Udevitz (1999). Briefly, this survey consisted of one observer in an airplane flying pre-determined linear transects across Glacier Bay. Transects were placed systematically across Glacier Bay with a random initial transect location. Transects were stratified based on two criteria, seafloor depth and distance from the shore. Areas with depths <40 m received a higher sampling effort than areas with depth >40 m, and areas closer to the shoreline received higher sampling effort. Transects were flown in years 1999-2004, 2006, and 2012. Transects were 400 m wide, indicated by strut marks on the aircraft, flown at velocity 29 m/sec, and at a height of 91 m. Observers searched for and located groups of ≥ 1 sea otters within transects and subsequently counted individuals within groups.

Sea otter distribution surveys were conducted in Glacier Bay by one or more observers in a fixed-wing aircraft. In an attempt to survey all shoreline habitat <40 m in depth, swaths were flown parallel to the shoreline at an altitude of 152 m during calm sea conditions. Distribution surveys were flown in 1993-1998, 2004, 2005, 2006, 2009, and 2010 (Williams et al. 2017a). Sea otter counts and flight tracks were recorded on nautical charts and later digitized in ArcGIS (ESRI, Redlands, CA).

The design-based survey observation methods undercounted sea otters due to imperfect detection (e.g., diving sea otters are often uncounted). To estimate detection probability, additional data were collected in intensive search units (ISUs). ISUs were a randomly selected subset of 469 units from the design-based survey. ISU data were collected each year the design-based surveys occurred. At these 469 sites, after a group of sea otters was detected and counted using the procedures from the design-based survey, five concentric circles were flown around groups so observers could obtain precise counts of abundance within the group. The concentric circles were flown in 3.6 minutes; a time chosen based on the aerobic dive limit of sea otters (Thometz et al. 2015; so diving sea otters could be included in the counts when they resurfaced).

2.2.2 Statistical Model

Williams et al. (2017a) developed a spatio-temporal occupancy abundance model for characterizing colonization dynamics, and Williams et al. (2018) rigorously implemented the model to the baseline sea otter data described above. For this application we used the model from Williams et al. (2018) and forecast population spread into the future. As future data are collected, the model will be refit to the new data, and revised as necessary. A full description of the model and directions to implement and update the model are reported in SOP 9. The model was developed in a Bayesian hierarchical framework, permitting us to estimate uncertainty in the data collection process, the ecological process, and model parameters. A model-based sampling design differs from classic, designed-based estimation. Design-based sampling is often concerned with obtaining independent and unbiased estimates of annual abundance. In design-based sampling, power analyses are often conducted to determine the number of transects to be sampled annually, number of survey years necessary to conduct trend analyses, etc., to obtain useful levels of precision in abundance estimates. In model-based sampling, a model is developed to represent the process of interest, and sampling is conducted to resolve key uncertainties in the model to improve inference and model prediction. The model is then assessed based on how well it predicts the observed data using various model-checking procedures (Conn et al. 2018). The model-based approach is advantageous in that we can leverage multiple data sources, incorporate spatial and temporal structure in the data, account for multiple levels of uncertainty, and make spatial interpolations and temporal forecasts of ecological processes. In principle, classic power analyses that examine the multiple-objective trade-off problem of decreasing cost and maximizing precision can also be conducted in a model-based sampling procedure. However, computation might be prohibitive. Our approach focused on the different optimization problem of maximizing precision, conditional on a fixed budget.

2.2.3 Design Criterion

A design criterion based on minimizing prediction uncertainty of the total expected abundance was selected. That is, we want to minimize

$$q_d = \frac{1}{K}\sum_{k=1}^{K}\left(u_{total,T+1,d}^{(k)} - \frac{1}{K}\sum_{k=1}^{K}u_{total,T+1,d}^{(k)}\right)^2$$

where $k=1,\ldots,K$ corresponds to the k^{th} MCMC iteration, $\boldsymbol{q_d}$ *is* the value of the design criterion for a specific design ***d,*** $u_{\text{total},T+1,\text{d}}$ is the sum of the forecasted process in time *T+1* across Glacier Bay*,* estimated using real data, $\mathbf{y}_1, \ldots, \mathbf{y}_T$, *and* future data $\mathbf{y}_{T+1,d}$. Future data are unavailable prior to the survey. Lacking such data, multiple imputation is used (Rubin 1996, Hooten et al. 2017, Scharf et al. 2017). The document SOP 10 provides a complete description of the design criterion, and directions for finding the optimal design. Additionally, Williams et al. (2018) rigorously describes optimizing sampling designs for sea otters based on this design criterion.

2.3 Survey Design

The sea otter survey design consists of up to three types of sampling, and therefore is a hybrid approach (e.g., Hooten et al. 2009). The sampling types include: (1) selecting a random sample of transects, (2) selecting an optimized sample of transects by minimizing model-based prediction variance, described in the previous section, and (3) selecting an optimized survey route by maximizing the predicted abundance of sea otters observed during the flight. The data from each sampling type will be combined cohesively in our model to produce one estimate of abundance (see Williams et al. 2017a for details of how multiple data sources can be combined to generate a posterior distribution of estimated abundance). Each of these survey types is described below in more detail. Initially, without informative prior information on how to distribute sampling effort among sample types and sampling frequency, we distributed effort equally across each sampling type, and each sampling type is to be conducted every year. Effort allocation (both among sampling types and sampling frequency) will be re-assessed after sufficient data have been collected to evaluate the properties of each sampling type. We predicted that it will take approximately 7 years of annual data collection to permit evaluation of the properties of each sampling type. Seven years was chosen because it is approximately how many years of data that are available from each of the design-based and distributional surveys. Annual data collection will provide a rich data set that will permit examining trade-offs between abundance estimates and sampling frequency that we will use in future analyses to optimally identify sampling frequency. Furthermore, recent evidence suggests the sea otter population in Glacier Bay is approaching (or at) carrying capacity (Williams et al., *In review*). Thus, collecting data annually during this period will provide valuable insight into regulating mechanisms of the sea otter population in Glacier Bay. After this seven-year period, we will calculate the optimal effort allocation among sampling types and optimal temporal frequency of data collection. This framework is flexible and can be adjusted annually to meet budgetary constraints so that any combination of these survey types could be conducted each year. Additionally, subsequent to data being collected from each of these survey types, the data can be used to examine the efficacy of the survey types, so that future monitoring can be based on the amount of information gained per unit effort of each survey type. Detailed documentation of the site selection procedure and computation methods for selecting sites are provided in SOP 10.

2.3.1 Random Transects

The first survey type is a random sample of transects. Random transects are a type of probabilistic, design-based survey, and therefore have desirable characteristics (unbiased estimates of abundance) and are widely used for wildlife surveys. To select random transects, we first identified a survey area (Figure 2.3). In 2017, the survey area was 68 km x 56 km, and omitted parts of the arms of Glacier Bay. In 2018, we expanded the survey area to include all of Glacier Bay (72 km x 60 km), including the arms. After the survey area was selected, it was partitioned into a grid with 400 m x 400 m cells. The cell size was chosen because previous data were collected at a range of 400 m, and for computational tractability (smaller cell sizes were not computationally feasible). Then rows of the grid (representing the transects) are randomly selected. The number of transects (n_{rt}) selected can vary depending on available funding. Initially, 20 transects were chosen for the first sampling year (i.e., 2017) based on the number of transects that could be flown given a flight-time restriction of 4 hours, with 1.5 hours of travel between the Juneau origin and Glacier Bay (Figure 2.3). New random transects are selected each year the survey is conducted.

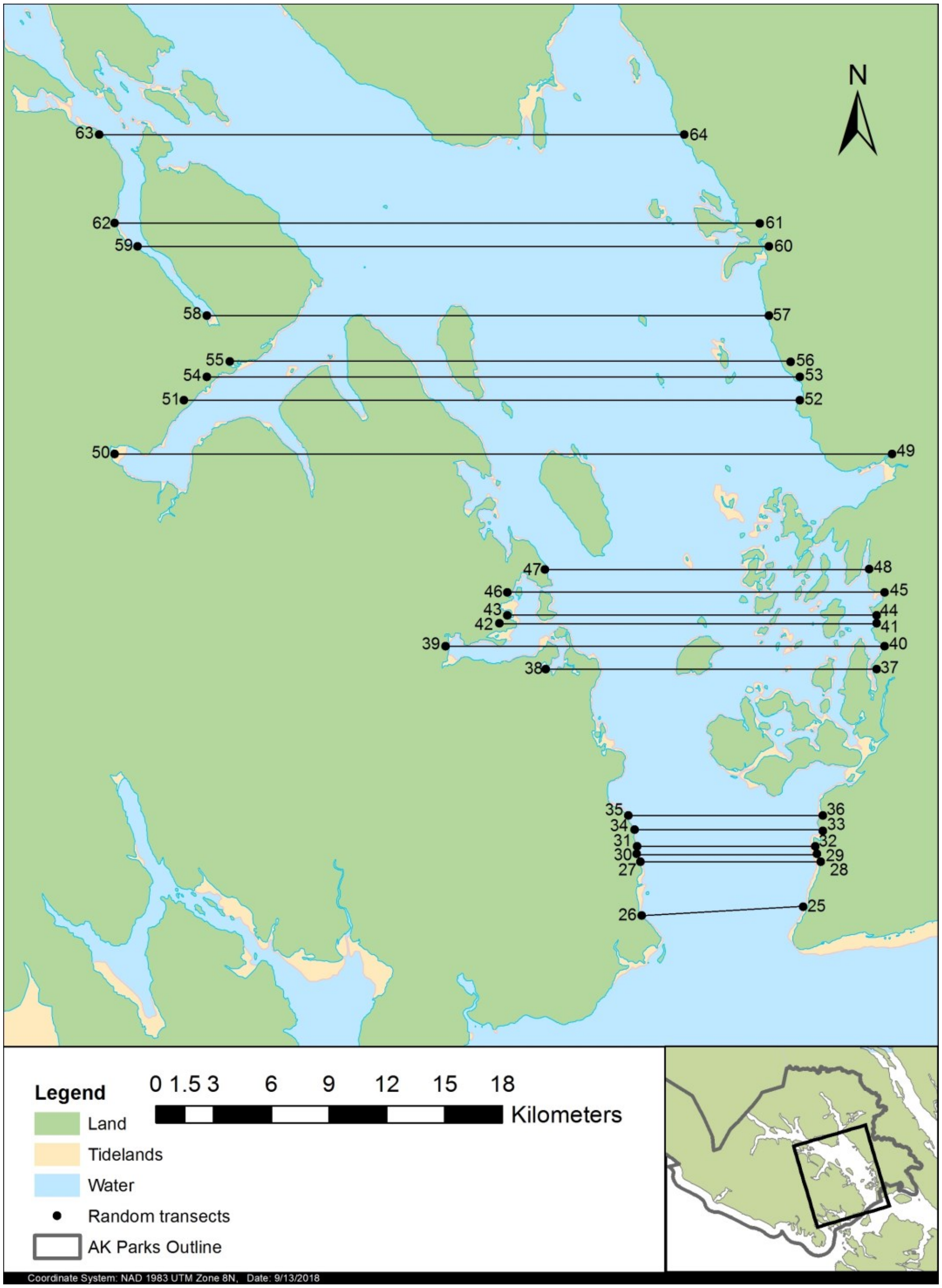


Figure 2.3. Examples of locations of n_{rt} = 20 randomly selected transects along which aerial photographic surveys are flown.

2.3.2 Optimal Transects

The second survey type is an optimized sample of transects that minimize a design criterion that represents objectives of the SEAN monitoring program. Specifically, the design criterion is the posterior prediction uncertainty described above; transects are selected such that the optimal transects minimize the variance in our model-based predictions of sea otter abundance and distribution. The design criterion can be updated to meet any changing objectives of the SEAN monitoring program.

To select the optimal transects, we first condition on the random transects that were selected in 2.3.1. That is, to avoid redundancy in the type of information collected between the random transects and the optimal transects, the attributes of the random locations are documented, and the optimal transects account for the information already collected in the random transects. To select the optimal set of n_{opt} transects, we first consider a large number of potential designs m (e.g., m=64 potential designs, where 64 was chosen based on the number of computation cores we could access using a cloud computing service), where each potential design was the set of n_{rt} and n_{opt} transects, and each design of n_{opt} was different from all other designs. For each of the m potential designs, we estimated the design criterion (e.g., prediction uncertainty), and then selected the design that minimized the design criterion. For reference, we call this the *optimal random design*.

To further optimize the optimal random design, we use an exchange algorithm. The exchange algorithm works by first exchanging Transect 1 in the optimal random design, with neighboring transects (first the transect above it, then the transect below it). After one transect is exchanged, we estimate the design criterion of the model using the exchanged transect instead of the original transect. If the design criterion is improved using the exchanged transect, the exchanged transect is kept, and the original transect is removed. This process is then conducted for transects 2,…,n_{opt} , and repeated again for transects 1,…, n_{opt} until no further exchanges improve the design criterion. The remaining transects are the optimal design (Figure 2.4).

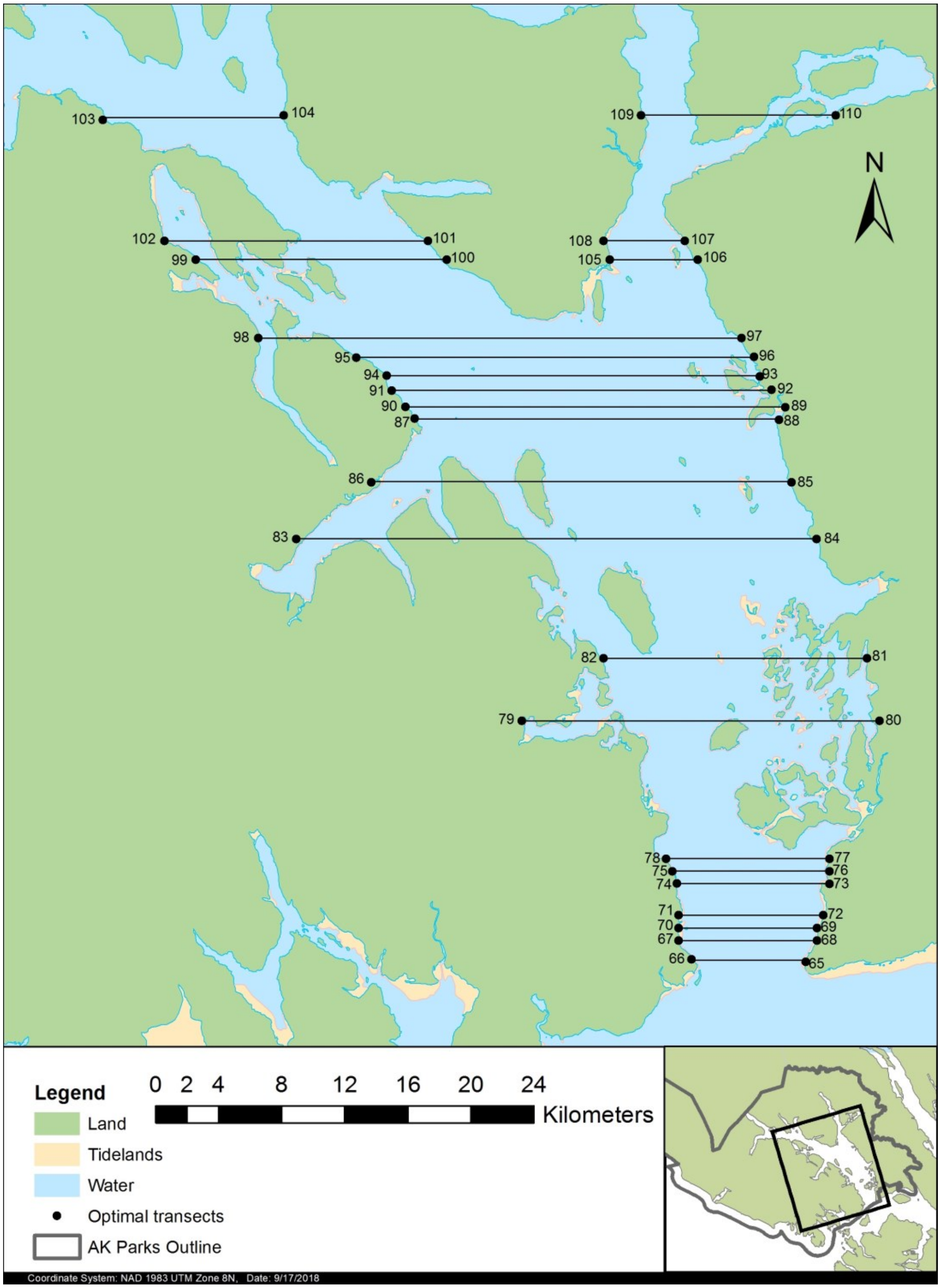


Figure 2.4. Examples of locations of n_{opt} = 20 optimal transects along which aerial photographic surveys are flown. Optimal transects are selected by optimizing a sample of transects by minimizing model-based prediction variance in model-based predictions of sea otter abundance.

2.3.3 Optimal Abundance Transects

The third sampling type is a model-based method that is analogous to stratification in the design-based sampling framework. That is, we want to sample more intensively in areas where sea otters are more likely to occur. To select the optimal survey route for sampling areas where sea otters are likely to be, we use a model-based forecast of sea otter abundance for the upcoming sampling year. We then identify the optimal flight route for visiting areas that were forecasted to have the most sea otters (Figure 2.5). For example, in 2017, 35 transects were conducted and each transect was 6 km in length and allowed for the ability to cover small patches of high predictive abundance.

After data are collected from each of these surveys, we can examine the gain in information obtained from each sampling type, and further optimize sampling for future years. Further, we can assess the amount of sampling effort that will be required in future years (potentially reducing the amount of survey days and effort) by comparing the precision of model parameters from a model fit to the full data set that was collected to a model fit to a restricted data set, where some transects are omitted, representing less sampling effort. Increased precision in model parameters helps to identify the effect size and significance level of each parameter in our model. Thus, by comparing the precision of model parameters from a model fit to the full data set that was collected to a model fit to a restricted data set, we are effectively conducting a power analysis among the differing survey types. Optimal dynamic surveys are aimed at identifying the survey design that most increases parameter precision. Thus, optimal dynamic survey designs are analogous to power analyses that are commonly used in phenomenological statistical models.

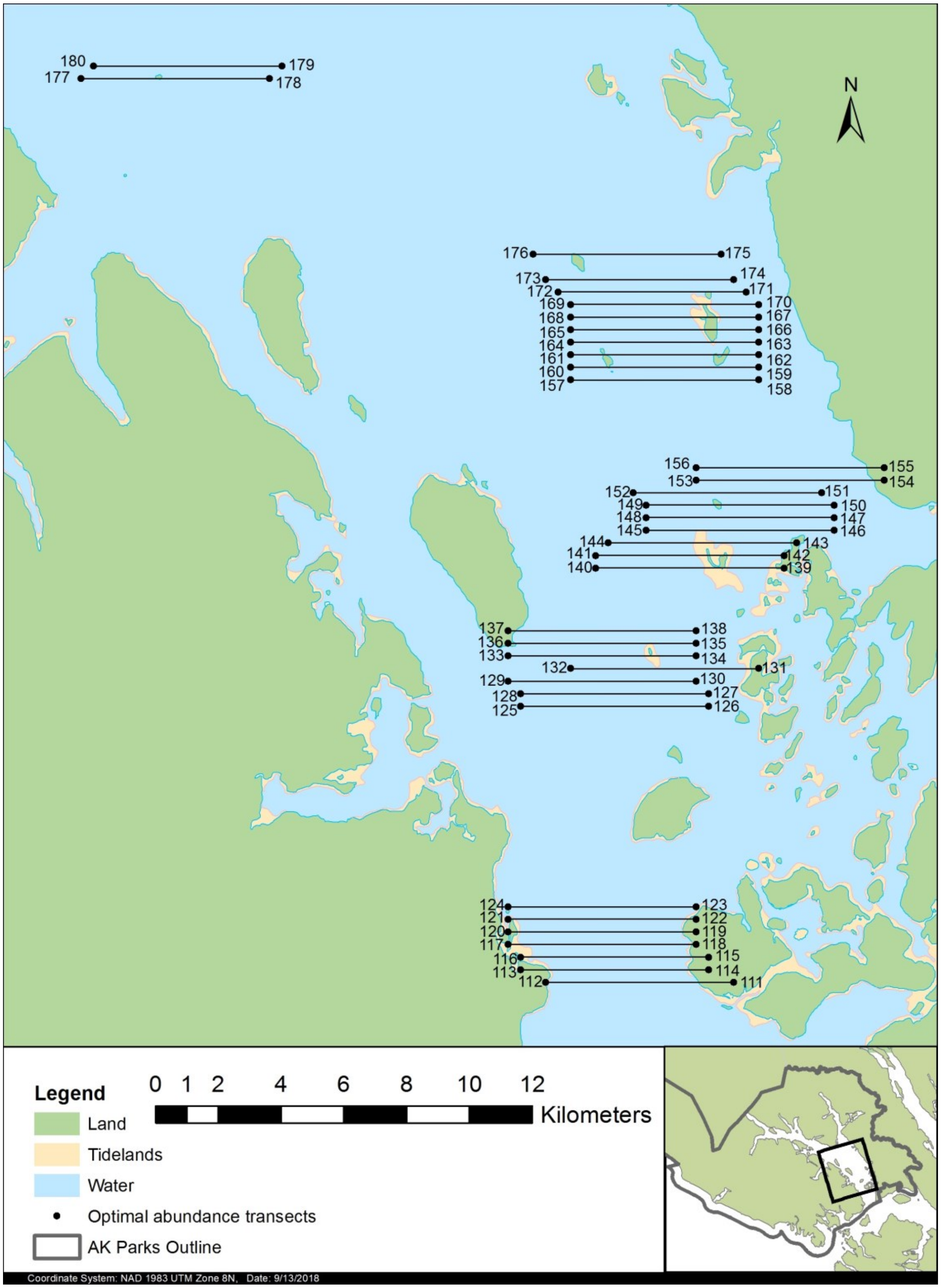


Figure 2.5. Examples of locations of optimal abundance transects along which aerial photographic surveys are flown. Optimal abundance transects are selected by optimizing a survey route by maximizing the predicted abundance of sea otters observed during previous surveys.

2.4 Aerial Photographs

Aerial photographic surveys are an important tool for estimating distribution and abundance of wildlife populations (Buckland et al. 2012). However, undercounting animals from aircraft presents an estimation problem with aerial surveys, including aerial photographic surveys (Graham and Bell 1969, Caughley 1974). Animals are undercounted because they are not available to be counted (e.g., underwater; termed *availability bias*), or observers miss animals that are available to be counted (termed *perception bias*; Marsh and Sinclair 1989). Aerial images improve perception bias, but not necessarily availability bias (Leonard and Fish1974, Gibbs et al. 1988, Bayliss and Yeomans 1990, Frederick et al. 2003). For example, sea otters are highly likely to be detected in images if they are at the surface of the water, but animals may be diving beneath the surface of the water and unavailable to be photographed (Figure 2.6).

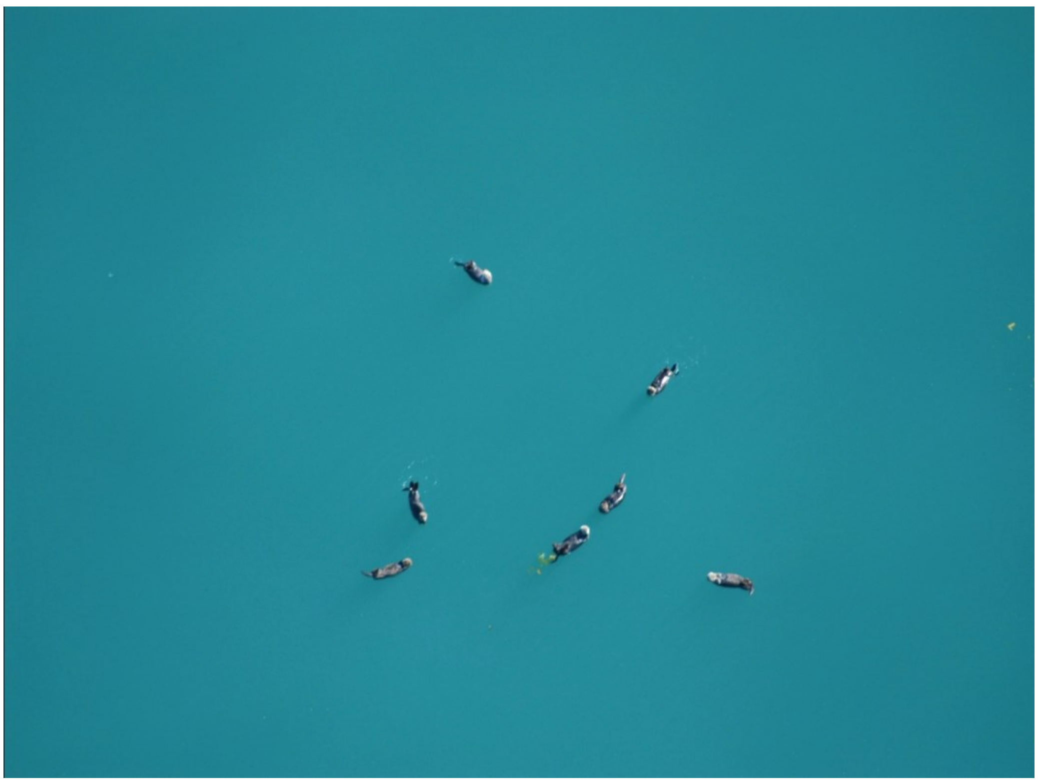


Figure 2.6. Aerial photograph of sea otters in Glacier Bay National Park. Sea otters on the surface of the water have a high probability of being counted, but sea otters underwater might not be counted.

Until recently, methods for estimating availability using aerial images alone have not been available, and auxiliary information usually has been required to estimate absolute abundance (Williams et al. 2017b). Auxiliary information includes activity budgets or time spent diving underwater, estimated from telemetry devices including VHF transmitters, satellite-linked transmitters, or time-depth recorders (Bechet et al. 2004, Harvey and Goley 2011, Lonergan et al. 2013).

A new method for estimating availability is to take multiple images of a group of otters, and use the replicated images within an *N*-mixture model framework to estimate detection probability (Williams et al. 2017b). The *N*-mixture model is advantageous in that it does not rely on data auxiliary to aerial images. Data required to fit *N*-mixture models can be collected from a single aircraft and individual animals do not need to be uniquely identified. Williams et al. (2017b) demonstrated the utility of this approach by first applying the framework to simulated data. A pilot study that assessed our ability to collect temporally replicated images of spatially referenced sites containing sea otters was conducted.

Aerial photographic images can provide several advantages over observer-based methods. Aerial photographic images provide a permanent record that is available for independent verification (Buckland et al. 2012), they can be used for automated detection (Conn et al. 2014, Seymour et al. 2017), and also allow for quantification of habitat covariates (McNabb et al. 2016). Photographic sampling methods also can be extended to unmanned aerial systems (UASs), which are relatively new platforms that can be used to quantify wildlife and their habitats (Hodgson et al. 2013, Moreland et al. 2015, Sweeney et al. 2015).

The combination of using (1) aerial photographs for collecting data, (2) advanced and flexible statistical models that incorporate our understanding of the ecological system, permitting rigorous estimates of occupancy, abundance, and colonization dynamics, and (3) a sampling framework that explicitly links our statistical model and future data to be collected, will ultimately improve monitoring efficiency, and our ecological understanding of sea otters in Glacier Bay.

3 Field Methods for Sea Otter Aerial Photographic Surveys

3.1 Field Season Preparation

Before the start of field operations, all flights are procured and scheduled, the pilot and plane are verified to have current Department of the Interior (DOI)-NPS certifications, all field personnel are made current in aviation training, all equipment used for data collection is tested and verified to be in good working order. See SOP 1 for a summary of experience and training required of personnel. See SOP 2 for detailed instructions on planning aerial survey flights.

- **Permitting Requirements (USFWS):** A scientific research permit issued by the USFWS is required to conduct research activities, including aerial surveys, on sea otters. The USFWS permit authorizes "take" of sea otters, a protected species, for scientific purposes. Sea otter population monitoring in Glacier Bay is currently conducted under USFWS Permit issued to Jamie N. Womble. The number of "takes" of sea otters are reported annually to USFWS. A USFWS permit application may take more than twelve months to be processed once a completed application has been submitted to USFWS, so any modification or applications needs to be submitted at least 12 months in advance of when the research activities are expected to take place. The current permit (USFWS-MA14762C-0) is valid through 31 May 2022.

- **Permitting Requirements (NPS):** A research permit issued by GLBA also is required to conduct sea otter population monitoring in GLBA. The current permit (GLBA-2016-SCI-0022) is valid through 31 December 2021. NPS permit application review may take about three months.

- **Survey Aircraft:** Aerial photographic surveys of sea otters require that the aircraft has a belly port through which a camera can be mounted and aimed for the collection of digital images. A de Havilland Canada DHC-2 Beaver on floats is currently the preferred platform and is available locally for charter in Juneau, Alaska. There may be other suitable aircraft (including unmanned aerial vehicles), but the primary constraint is that the survey platform must have a belly port where a digital camera can be mounted.

- **Procurement of Aircraft:** Aerial surveys need to be procured using the most current procurement procedures identified by NPS. An estimate of flight hours, cost per flight hour, and vendor must be submitted at least two months in advance to the GLBA Aviation Safety Officer. A survey flight should not take place until a task order/contract has been issued by an NPS contracting officer. NPS regulations regarding flight procurement change frequently so it is imperative to work closely with the GLBA Aviation Manager and the DOI-NPS Alaska Region contracting officer to ensure that flights are procured properly.

- **Survey Pilot:** A pilot with extensive experience conducting wildlife surveys is necessary to fly the surveys successfully and safely. In addition, a pilot with knowledge of the Glacier Bay survey area, weather conditions, flight hazards, aerial photography, and plane maintenance is important. The pilot must hold current DOI certifications and carding for the specified plane and operation to be conducted.

- **Primary Observer/Wildlife Biologist/Camera Operator:** A primary observer that has extensive experience conducting aerial photographic surveys and observing marine mammals such as sea otters or pinnipeds from an aircraft is necessary to complete the surveys successfully. The current primary observer, Jamie Womble, NPS Wildlife Biologist, has over 17 years of experience conducting aerial surveys and observations of pinnipeds (harbor seals, Steller sea lions) and other marine mammals in Glacier Bay and throughout Alaska.

- **Second Observer**: The second observer performs camera set up, makes mandatory check-in calls, maintains a watch for other aircraft in the survey area to avoid collision, and assists with observations.

- **Aviation Training:** All observers that participate in aerial surveys are required to have current DOI aviation safety training. Water Ditching and Survival (A-312), although currently not mandatory for these surveys, is highly recommended. These certifications must be current. Consult the Interagency Aviation Training website for the most up to date training requirements (https://www.iat.gov/).

- **Flight Following:** Flight plans are filed with the NPS Alaska Regional Communication Center prior to each survey and NPS protocols for flight following are observed (see SOP 3).

- **Safety Equipment:** A list of safety equipment that is carried along on aerial surveys is provided in SOP 2.

- **Personal Gear:** A list of personal gear and clothing that is used for aerial surveys can be found in SOP 2.

3.2 Aerial Photographic Surveys and Data Acquisition

3.2.1 Survey Platform and Personnel for Surveys

Aerial surveys for sea otters are conducted from a single-engine high-winged float-equipped aircraft (Figure 3.1; see SOP 2). Personnel requirements for aerial surveys include an experienced pilot that has current DOI-NPS certifications. Given the intricacy associated with survey design, it is highly recommended to conduct all surveys in a period using the same pilot.

Figure 3.1. Aircraft (de Havilland Canada DHC-2 Beaver) used for sea otter aerial surveys in Glacier Bay National Park and Preserve. Left to right: Louise Taylor-Thomas (NPS Ecologist), Avery Gast (Pilot), and Jamie Womble (NPS Wildlife Biologist).

One primary observer, the Project Leader, is required to oversee all aspects of the aerial survey mission from start to finish including safety, logistics, camera set-up, triggering the automatic timer and camera during the survey, and ensuring the GPS is calibrated for altitude and is collecting the tracklog. Setting up the camera in the plane before the survey typically takes approximately one hour, depending on experience (see SOP 5).

The primary observer must be seated in the back seat (2^{nd} row of the aircraft) to trigger the timer that is attached to the camera. A second observer (seated in the co-pilot seat) is extremely useful as they can assist with sea otter observations, maintain watch for other aircraft (to avoid possible collision), and conduct mandatory check-in calls that are required at intervals throughout the flight. Although there may be space in the aircraft for a total of four passengers, ideally the mission can be best and most efficiently accomplished with two observers (primary, second) and the pilot.

3.2.2 Data Acquisition: Digital Photographs and GPS Tracklog

Aerial photographic surveys of sea otters are conducted from a single-engine high-winged, float-equipped aircraft. The aircraft is flown at 213-250 m altitude at 157-166 km/hr. Digital photographic images of sea otters are taken directly under the plane using a vertically-aimed digital camera (currently Nikon D810, 36.3 megapixel) with an 85 mm focal length lens (currently Zeiss F/1.4

ZF.2). The camera is attached to a tripod head and mounted to a plywood platform that is secured in the belly porthole of the aircraft (Figure 3.2; see SOP 5). A digital timer, which triggers the shutter release, is attached to the camera and operated by the primary observer.

Figure 3.2. Digital camera mounted on tripod head and attached to custom-made plywood frame and secured in the belly of the aircraft. Plywood frame is secured to plane using cargo straps.

An onboard GPS, with an external antenna, is used to record a tracklog of plane position (latitude, longitude, altitude). It is critical to synchronize the time on the GPS and camera before each survey so the images can be accurately geolocated (see SOP 4). Each digital image (7,360 x 4,912 pixel JPG) covers approximately 90 m x 60 m at the surface of the water with an approximate 1.23 cm pixel resolution.

3.2.3 In-field Data Management for Aerial Surveys

In-field data quality assurance processes are limited to ensuring that both the camera and GPS are working properly and collecting data at the appropriate intervals. It is also important to ensure that prior to the start of the survey that the compact memory flash card (256 MB) has been formatted and that camera and GPS batteries are fully charged.

3.2.4 Post-survey Operations

Immediately after the survey is completed the digital images and GPS tracklog are downloaded, renamed, geocoded, and saved to the National Park Service Indian Point Server for archiving and storage. Downloading and renaming procedures are detailed in SOP 6. All images are reviewed, organized, and renamed using ACDSee (ACD Systems, Inc., Bellevue, Washington; see SOP 6). The latitude, longitude, and altitude from the tracklog are then written to the EXIF headers of each digital image to embed the location data into each image permanently using RoboGEO (Pretek, Inc. Christiana, Tennessee; see SOP 7). Images are imported into CountThings (Dynamic Ventures, Inc., Cupertino, California), a custom counting program. An experienced observer marks each sea otter in the image (see SOP 8). The total number of otters per image along with attribute data from each digital image including date, time, latitude, longitude, and altitude are exported from CountThings into a CSV (comma separated values) file.

4 Data Management: Product Creation, Acceptance, Reporting, and Archiving

4.1 Data and Information Essential to this Sea Otter Monitoring Program

Figure 4.1 provides a top level summary of the data and information used by this program as it flows from source to recipient. The central circle represents the set of monitoring program processes used in gathering data and disseminating resulting data and information. The rectangles are entities that provide data, receive data, or do both. For example, GPS UNITS is a source of tracklog data used to specify the location for each photo. PARK MANAGERS is the recipient of briefs, reports, and recommendations coming out of the monitoring processes. NPS DATA STORE is the recipient of final data products as well as the source of these for others.

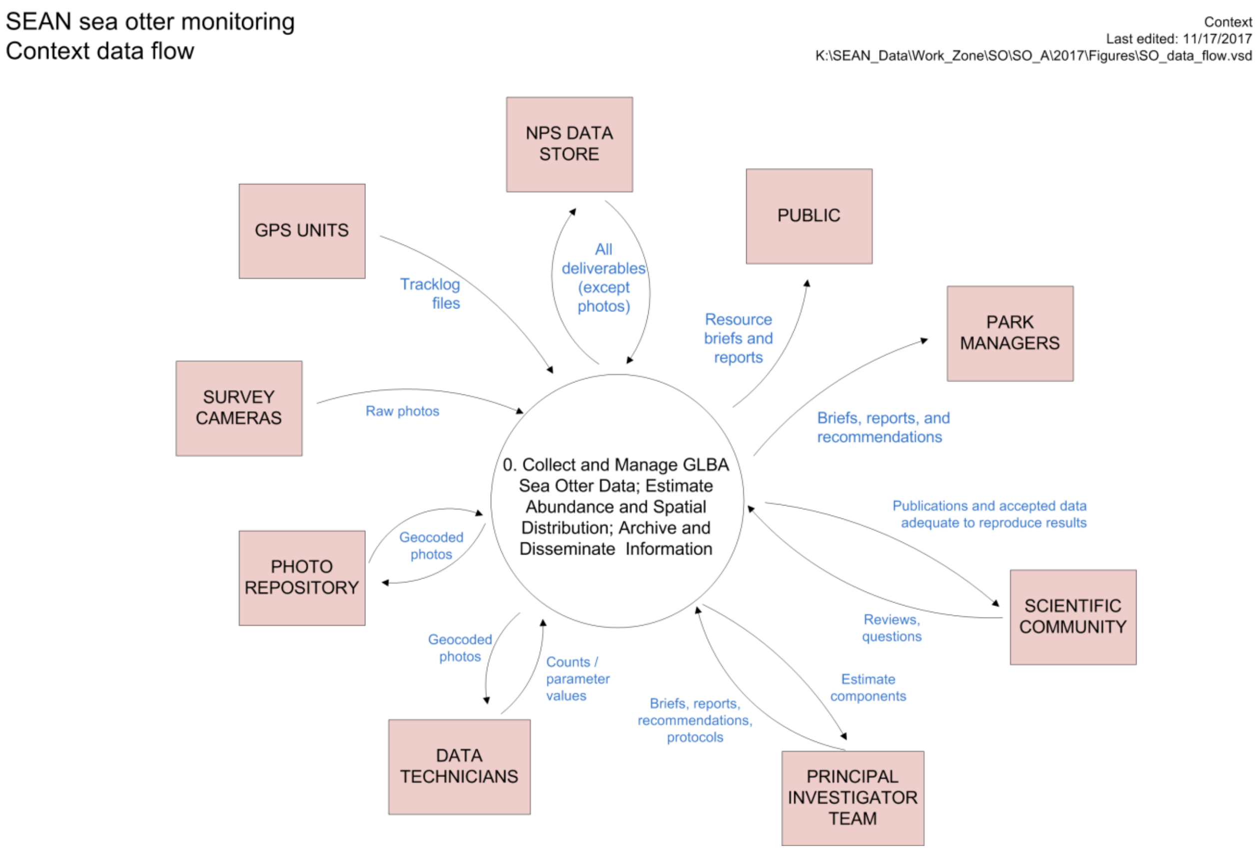


Figure 4.1. Context level data flow of the sea otter monitoring program.

4.2 Creating Data and Information Products

From the data flow we identified ten formal deliverable products, summarized in Table 4.1. These include data products, detailed metadata products required so users may properly interpret the data, and associated NPS reports. The deliverables were chosen so that the research community may effectively make use of the data over the long term, without relying on future availability of key personnel or other agency resources.

Table 4.1. The SEAN information deliverables (A–J) provided by the sea otter monitoring program.

Deliverable Title	Description	Provided to Customers as	Frequency Produced	SOP
SO_A: Protocol package consisting of Narrative, DQS, and SOP Set	The document package defining this sea otter monitoring program. Protocol Narrative and Data Quality Standards (DQS) are published as NRR reports. SOP Sets are housed in Data Store using reference type "SOP". Each component of the package is always stamped with a unique version identifier.	PDF documents	New documents as needed, but always prior to each field season	11
SO_B: Resource brief	Report summarizing the state of the resource suitable for use by interpretive staff.	PDF file	When requested	12
SO_C: Geocoded photos	Aerial survey photos with embedded date, time, latitude, longitude, and altitude.	JPEG files with EXIF data	Once per survey effort	13
SO_D: Count data from images	CSV files containing counts of sea otters from digital imagery and covariates derived from SO_C photos. The complete data set may span multiple CSVs to make management simpler for technicians. All resulting CSVs are zipped into a single package for dissemination.	ZIP package	Once per survey effort	14
SO_E: Tracklogs	GPX files containing date, time, latitude, longitude, and altitude recorded along transects during aerial surveys. Each aerial survey results in one or more GPX files. All GPXs for a survey effort are zipped into a single package for dissemination.	ZIP package	Once per survey effort	15
SO_F: Annual Summary Brief	Summary of sea otter abundance and spatial distribution estimates based on the current survey.	PDF file	Once per survey effort	16
SO_G: Periodic abundance report	Analysis of sea otter abundance and population status over multi-year periods as well as evaluation of monitoring program performance in the form of an NRR publication.	PDF file	When new estimates become available	17
SO_H Field notes	Images of written notes recorded during aerial surveys documenting flight characteristics and exceptions.	PDF file	Once per survey effort	18

Note: "Survey effort" refers to all field and office processes executed to develop population and distribution estimates at a particular time, such as the 2017 survey effort. This is distinct from "aerial survey" which denotes an airplane flight used to gather field data, such as the aerial survey done on 17 July 2018.

Table 4.1 (continued). The SEAN information deliverables (A–J) provided by the sea otter monitoring program.

Deliverable Title	Description	Provided to Customers as	Frequency Produced	SOP
SO_I Count data used to estimate availability	CSV files containing counts of sea otters from overlapping digital imagery used to estimate availability. The complete data set may span multiple CSVs to make management simpler for technicians. All resulting CSVs are zipped into a single package for dissemination.	ZIP package	Once per survey effort	19
SO_J Bathymetry layer package	ESRI "layer package" of Glacier Bay bathymetry that is used as a boundary layer for restricting movement of sea otters to marine environments and for limiting inference to Glacier Bay. Covariates including depth, distance to shore, slope of ocean floor, and shoreline complexity are derived from the bathymetry package. This information is expected to be static over the life of the program.	ESRI LPK file	Once at the onset of the monitoring program	20

Note: "Survey effort" refers to all field and office processes executed to develop population and distribution estimates at a particular time, such as the 2017 survey effort. This is distinct from "aerial survey" which denotes an airplane flight used to gather field data, such as the aerial survey done on 17 July 2018.

Table 4.1 includes a column referencing the appropriate SOP to use in building each deliverable. Individual SOPs present the detailed algorithms used for creating each product. Each SOP also contains a data dictionary section specifying the full technical definition of its deliverable and data flow diagrams that illustrate where underlying data come from, what processes are applied to them, where they are stored, and who is responsible for managing each of them.

Technical content includes, among other things, specific quality control criteria that must be met by each deliverable in order to be considered valid. Until a deliverable is formally accepted as valid, it will not be installed in the authoritative repository from which it gets disseminated. Validity, in this context, means that the content fully meets documented technical criteria; it does not refer to accuracy/precision of measurements nor of the suitability of data to be used for a specific purpose.

The authoritative repository used by all these deliverables is the NPS Data Store. Permanent archiving, disaster recovery, and public accessibility of the deliverables are accomplished through the enterprise facilities built into the Data Store. Versions of deliverables from other sources are not authoritative.

4.3 Quality Control and Acceptance

The preferred method for accepting deliverables employs three roles: Builder, Validator, and Acceptor. These roles may be filled by staff as circumstances require, but to realize the best quality levels it is most desirable that the Builder of a product be a different person than the Validator of the product. Under expected staffing one possible assignment scheme could have Data Technician be Builder, Data Manager be Validator, and Project Leader be Acceptor.

The Builder creates a deliverable product by following the steps specified for it in individual deliverable SOPs referenced in Table 4.1. Note that all deliverables undergo acceptance, regardless of whether they are tabular data or some other kind of information—formal content is not disseminated *ad hoc*, it must first be accepted by someone in the monitoring program. When complete, the Builder submits the product (which is always in the form of a computer file) to the Validator for formal quality assessment. In the event the submission fails validation, the Builder reviews the exception findings provided by the Validator, rebuilds a corrected deliverable, and submits this for validation. The steps and roles are depicted in flowchart style in Figure 4.2.

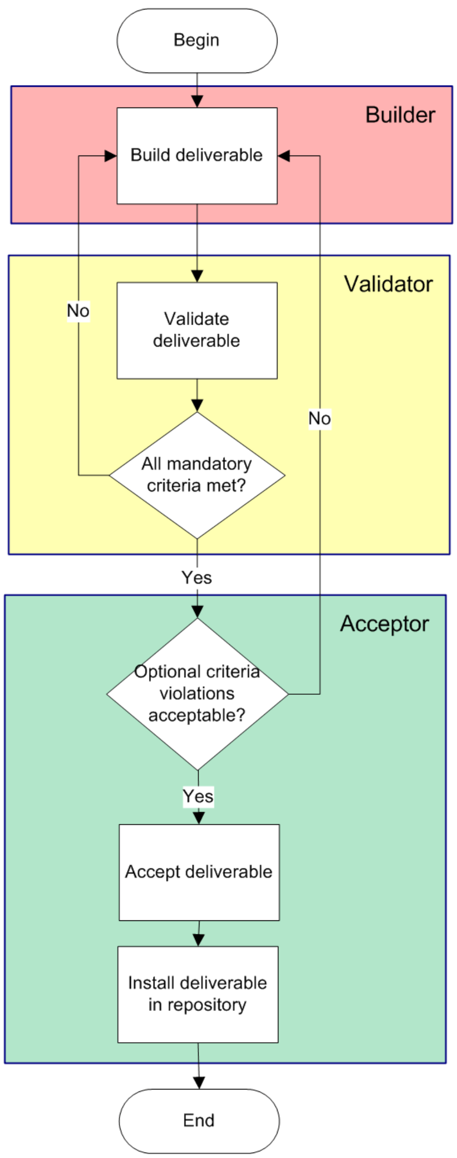


Figure 4.2. Tasks and user roles required by the acceptance process.

The Validator accepts product submissions from the Builder and evaluates their quality according to the criteria specified in the product's SOP. The Validator then reports to the other team members by email, documenting any quality exceptions encountered. Most deliverables have both mandatory criteria and optional criteria specified in their data dictionary. Mandatory criteria violations are so serious as to require the deliverable submission be rejected *in toto*. For example, a deliverable specified as being a PDF file type that internally has a spreadsheet XLSX format would typically violate mandatory criteria. Optional criteria suggest possible quality issues are present that should be reviewed before considering issuing acceptance. For example, parameters falling outside the expected domain yet flagged as excellent quality or values missing from important fields are often addressed in optional criteria.

The Acceptor reviews the validation report for submissions that have passed all mandatory criteria. Optional criteria violations are considered and, if corrections are possible, the Acceptor returns the candidate to the Builder for revision and resubmission to the Validator. If all optional criteria are met or if optional criteria violations are not correctable, then the Acceptor attests that the deliverable's quality level meets the written quality standards by adding a sentence to that effect in the Notes section of the appropriate repository reference. The Acceptor then authorizes the Data Manager to install the accepted product into the authoritative repository from which it will be disseminated. If the Acceptor judges content within a submission falls into the "sensitive" category, redaction is accomplished by withholding permissions on the holding in Data Store from all except those authorized to see such items. Sensitivity is determined following the written guidance provided by the Chief of the Inventory and Monitoring Division, currently dated February 26, 2018. Final determination is pending but, since sea otters are not currently threatened or endangered in Glacier Bay, it is unlikely data and information regarding them will be judged sensitive.

If an accepted deliverable in the repository is subsequently found to have errors, a new corrected version of accepted data may be produced. The method is the same as that used for generating the deliverable from scratch. After acceptance, the new file is uploaded to Data Store and marked as the latest version. (Note that earlier versions are always retained: it is not possible to delete content once posted to Data Store.)

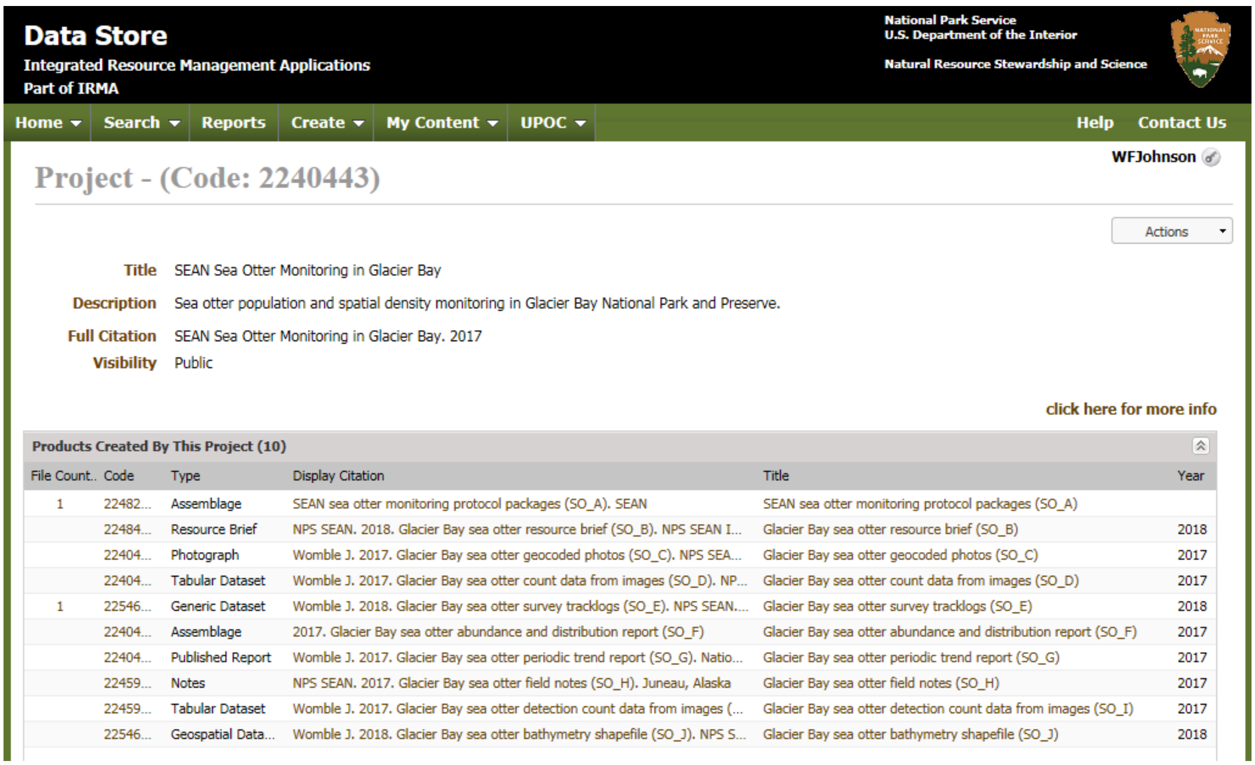
4.4 Reporting Data and Information

Three formal reports are outcomes of this program. The SO_A Protocol Package is published as a combination of natural resource reports (NRR) and multiple individual SOPs. The SO_F Annual Summary Brief is published as a Natural Resource Data Series (NRDS) report. The SO_G Periodic trend report is an NRR. The analyses and methods used for formulating these reports are detailed in their associated SOPs (listed in Table 4.1). One informal report, SO_B, is a periodically revised Resource Brief summarizing the state of the resource.

Another six deliverables described in Table 4.1 are quality controlled and retained in Data Store. These involve original data underlying the analyses. They are included as a basis for reproducing and/or expanding on our results.

All formally accepted deliverables are installed in the NPS Data Store repository (https://irma.nps.gov/DataStore/). Data Store is a facility that provides for robust retention of our products as well as web dissemination facilities for both the internal NPS staff and the public. One Data Store PROJECT reference is maintained for sea otter vital sign monitoring (Figure 4.3). An individual PRODUCT reference is created for each deliverable. The product reference type and permission/protection level to use for each of the deliverables is specified in its associated SOP. Accepted deliverables are uploaded to Data Store as holding files of the corresponding product reference (Figure 4.4).

This structure permits users to go to the project and navigate through every permanent item the monitoring program has created. It also provides the mechanism to ensure all products will persist in complete documented form after their originators have departed the project.



File Count..	Code	Type	Display Citation	Title	Year
1	22482...	Assemblage	SEAN sea otter monitoring protocol packages (SO_A). SEAN	SEAN sea otter monitoring protocol packages (SO_A)	
	22484...	Resource Brief	NPS SEAN. 2018. Glacier Bay sea otter resource brief (SO_B). NPS SEAN I...	Glacier Bay sea otter resource brief (SO_B)	2018
	22404...	Photograph	Womble J. 2017. Glacier Bay sea otter geocoded photos (SO_C). NPS SEA...	Glacier Bay sea otter geocoded photos (SO_C)	2017
	22404...	Tabular Dataset	Womble J. 2017. Glacier Bay sea otter count data from images (SO_D). NP...	Glacier Bay sea otter count data from images (SO_D)	2017
1	22546...	Generic Dataset	Womble J. 2018. Glacier Bay sea otter survey tracklogs (SO_E). NPS SEAN....	Glacier Bay sea otter survey tracklogs (SO_E)	2018
	22404...	Assemblage	2017. Glacier Bay sea otter abundance and distribution report (SO_F)	Glacier Bay sea otter abundance and distribution report (SO_F)	2017
	22404...	Published Report	Womble J. 2017. Glacier Bay sea otter periodic trend report (SO_G). Natio...	Glacier Bay sea otter periodic trend report (SO_G)	2017
	22459...	Notes	NPS SEAN. 2017. Glacier Bay sea otter field notes (SO_H). Juneau, Alaska	Glacier Bay sea otter field notes (SO_H)	2017
	22459...	Tabular Dataset	Womble J. 2017. Glacier Bay sea otter detection count data from images (...	Glacier Bay sea otter detection count data from images (SO_I)	2017
	22546...	Geospatial Data...	Womble J. 2018. Glacier Bay sea otter bathymetry shapefile (SO_J). NPS S...	Glacier Bay sea otter bathymetry shapefile (SO_J)	2018

Figure 4.3. Example Data Store project reference, having links to all formal deliverables produced by the monitoring program.

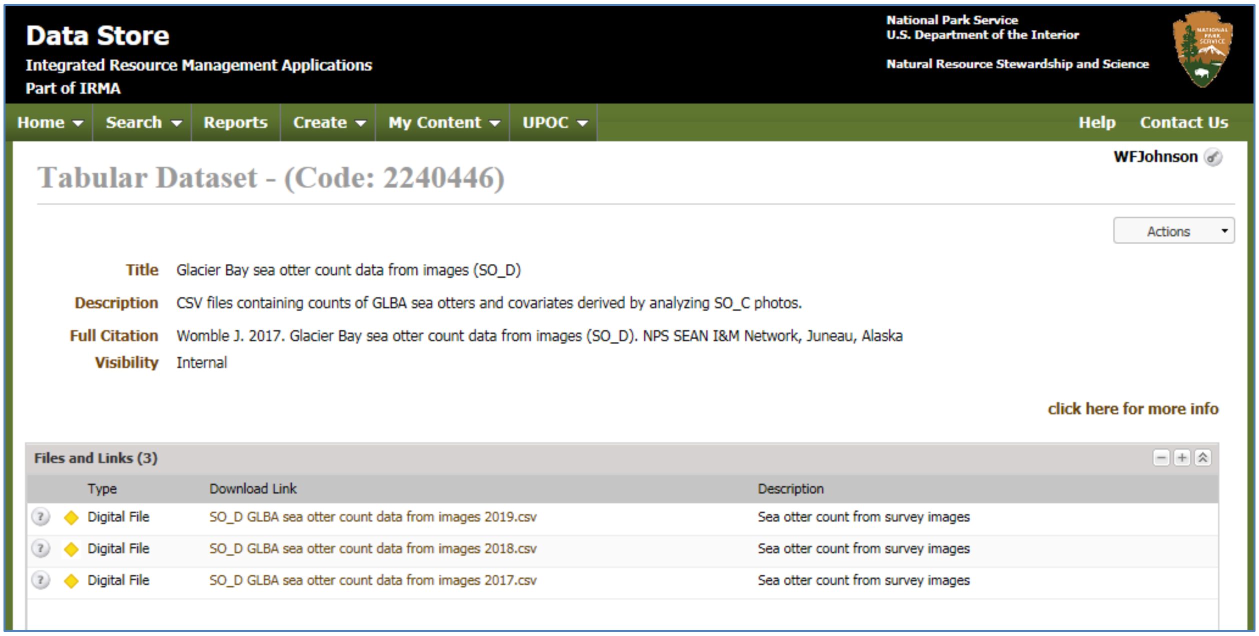


Figure 4.4. Example Data Store deliverable reference having links to all downloadable files for the particular deliverable.

4.5 Product Archiving

Permanent archiving and disaster recovery of all deliverables is accomplished through the enterprise facilities employed by the national NPS Data Store repository. No action is required on the part of the monitoring staff.

4.6 Scheduling Deliverable Production

A set of prerequisites must be completed before most deliverables can be generated. That is, creating some deliverables may depend on prior acceptance of other deliverables, which in turn may have their own dependencies. Figure 4.5 illustrates the typical order used in creating the products. Due to the numerous circumstances and exceptions one may encounter while operating the monitoring program, it may be necessary to revise the order of execution *ad hoc* under the direction of the Project Leader. Any substantive permanent variations to processing order, however, must be formalized in future protocol package revisions (SOP 11).

BEFORE ANY SURVEY EFFORT IS DONE BY THE PROGRAM

Deliverable	Comment
SO_A Protocol package	Narrative and Data Quality Standards (DQS) / QAP change rarely. SOPs may be frequently updated in order to reflect current process details.
SO_J Bathymetry layer package	Likely to be static for the duration of monitoring program.

AFTER COMPLETING ALL AERIAL SURVEYS FOR THE CURRENT EFFORT

Deliverable	Comment
SO_E Tracklogs	Required in order to geocode photos.
SO_C Geocoded photos	Cannot be generated until after SO_E tracklogs product has been formally accepted.
SO_D Count data from images	Derived from the accepted SO_C photo set.
SO_I Detection count data	Derived from the accepted SO_C photo set.
SO_F Annual Summary Brief	SO_D must first be accepted. It is the basis of population estimate sections of the report.
SO_H Field notes	Not dependent on other deliverables.

OCCASIONALLY, AFTER COMPLETION OF SEVERAL SURVEY EFFORTS

Deliverable	Comment
SO_B Resource brief	Should be generated when annual abundance and distribution reports reflect significant new information.
SO_G Periodic trend report	The least frequently produced deliverable, needed only after significant new trend information has been generated.

Figure 4.5. Expected order of deliverable production. Due to the nature of processes used by the sea otter monitoring program, there is little opportunity to vary from this schedule.

5 Personnel Roles, Responsibilities, and Training

Personnel roles and responsibilities are split into office and field components. The Project Leader, Data Manager, Data Technician, and Statistician collaborate to implement protocol procedures.

5.1 Project Leader

The Project Leader has lead responsibility for project implementation from start to finish, which includes multiple roles. The Project Leader has the ultimate authority for when to begin, suspend, or end surveys during field operations. The duties and roles of the Project Leader are diverse and are listed below.

Duties of Project Leader (presently Jamie Womble, GLBA)

- Complete field season preparations including equipment acquisition and preparation, keeping permits current, aviation contracting, scheduling surveys, and ensuring all safety and training activities (SOP 1) occur.
- Conduct aerial photographic surveys and collect imagery following protocol procedures and in compliance with DOI Aviation Safety standards.
- Supervise image processing by Data Technician and collaborate with Statistician to complete data analysis.
- Collaborate with the network Data Manager to ensure that data and information products meet specified quality standards, fit prescribed form and content, and are archived and disseminated in a timely fashion. Accept final data and information products and authorize dissemination.
- Update SOPs as defined in SOP 11.
- Prepare reports and manuscripts to be submitted to peer-reviewed journals and NPS publications.
- Recommend initiation of protocol revision cycle to Program Manager when needed.

Training Needed for Project Leader

- Extensive experience conducting aerial surveys of sea otters, pinnipeds, or other cryptic wildlife species in the marine environment.
- Advanced or graduate-level training in wildlife ecology and in the use of GIS, R, and digital imagery.
- Advanced or graduate-level training in statistical methods and study design.
- Knowledge of sea otter biology and ecology.

- Extensive knowledge and familiarity with the geography of the study area and study sites in Glacier Bay.
- Current training and certifications in Aviation Safety, Operational Leadership, Water Ditching and Survival.

5.2 Data Technician

The Data Technician is supervised by the Project Leader and the primary duties of this position are to assist with processing and counting the digital imagery from aerial surveys and data entry and verification. The data technician also assists with and participates in aerial surveys as the secondary observer.

Duties of Data Technician (presently Louise Taylor-Thomas, GLBA)

- Perform data processing, entry, and verification of photo content using ACDSee Photo Software, CountThings, and RoboGEO.
- Serve as secondary observer during aerial surveys, conduct equipment set-up, data collection, and ensure that check-in calls are made.
- Work closely with Project Leader and Data Manager to address data processing questions, data validation, and other issues.
- Assist in preparation of data files, data deliverables, protocol, and information products.

Training Needed for Data Technician

- Previous experience conducting aerial surveys of sea otters or other marine mammals.
- Undergraduate or graduate-level degree in biology, environmental sciences, statistics, or GIS.
- Training and certifications in Aviation Safety, Operational Leadership, Water Ditching and Survival.

5.3 Data Manager

The Data Manager is supervised by the SEAN Program Manager and coordinates closely with the Project Leader to produce a rigorously defined set of information deliverables of the highest quality.

Duties of Data Manger (presently Bill Johnson, SEAN)

- Perform quality control processes and other tasks required to produce data deliverables specified in Table 4.1 according to rules listed in associated SOPs.
- Archive data products and metadata in designated repositories, primarily NPS Data Store.
- Track deliverable progress to meet production deadlines.

- Coordinate deliverable updates so that repositories continue to contain the best available project data.
- Provide the resulting products and documentation to NPS Inventory and Monitoring Division (IMD) websites.
- Contribute to protocol package update cycles.

Training Needed for Data Manager

- Regular updates on how to perform data management functions under the continually shifting NPS Inventory and Monitoring Division technology landscape.

5.4 SEAN Program Manager

The Program Manager oversees the project to ensure that it meets NPS Inventory and Monitoring Division standards and complies with the expectations of the SEAN Board of Directors.

Duties of SEAN Program Manager (presently Mike Bower, SEAN)

- Oversee project budget and annual work plan as a component of the SEAN vital signs monitoring program.
- Supervise Project Leader and Data Manager.
- Review and approve annual and trend reports and briefings.
- Oversee, coordinate, and approve protocol revisions.

5.5 Aircraft Pilot

The Aircraft Pilot works for NPS or an aviation vendor that is contracted by NPS for aerial survey flights.

Duties of Aircraft Pilot (OAS Carded Pilot)

- Ensure that aircraft is prepared and maintained for aerial surveys.
- Communicate with Project Leader regarding suitability of the environmental conditions for the survey.
- Ensure proper fuel management during surveys.
- Carry out surveys following DOI-NPS Aviation Safety standards.

Training Needed for Aircraft Pilot

- Previous extensive experience (recommended 15+ years) conducting wildlife surveys in southeastern Alaska.

- DOI-NPS certifications (for both pilot and plane); note that Pilot must be carded specifically for these types of missions.

5.6 Statistician

The Statistician collaborates with the Project Leader to complete abundance estimation of sea otters.

Duties of Statistician (presently Perry Williams, University of Nevada Reno)

- Work with Project Leader to generate estimates of abundance and spatial distribution.
- Provide and update code for abundance estimation and analysis.
- Optimize study design by selecting prioritized transects.

Training Needed for Statistician

- Advanced and graduate-level training in sampling theory, spatial statistics, Bayesian models, and optimization methods.

6 Operational Requirements

6.1 Annual Workload and Field Schedule

The field season includes aerial photographic surveys of sea otters during July.

- January: Verify all required permits and certifications are current.
- January–April: Generate transects that are to be flown for the year. Transects should be mapped and reviewed by Project Leader and Statistician before implementation. Determine whether a protocol package revision is needed; if yes, then execute SOP 11.
- March–April: Submit contracting paperwork to NPS Alaska Region contracting officer to request flight time. Contact flight vendors to secure dates for aerial surveys.
- April: Assemble field items listed in SOP 5 checklists. Ensure that all equipment is working. Renew satellite phone subscription with provider.
- July: Conduct aerial surveys. Allow for 1 month to complete survey effort, depending on weather.
- July–March: Data product creation-through-acceptance cycle is performed covering the year's survey effort.
- July–September: Ensure tracklogs are properly downloaded and formally accepted (SOP 15). Ensure that all data photos are properly downloaded, archived, properly named, and georeferenced from survey (SOP 6, SOP 7).
- September –March: Data Technician counts sea otters in images and provides count data in CSV files for analysis.
- November–December: Report annual takes of sea otter to USFWS to maintain compliance with USFWS Research Permit.
- October–May: Estimate abundance and spatial distribution of sea otters and prepare deliverables.

6.2 Facility and Equipment Needs

- Aircraft with porthole for camera
- GPS with external antenna (Garmin 276Cx)
- Camera (Nikon D810, 36 megapixel)
- Camera lens (Zeiss 85 mm)
- Binoculars (Swarovski 10 X 50)

- Tracking Device (Delorme inReach Explorer)
- Satellite Phone with headset connector (Iridium phone, Flightcell Pro)
- Laptop computer with capacity to deal with digital imagery
- Portable Hard Drives (2TB)
- Data processing and archive facilities on the SEAN network

6.3 Startup Costs and Budget Considerations

Startup costs have already been borne by the SEAN, SWAN, and the Glacier Bay Marine Management Fund which funded expert assistance with model development, re-analysis of historical sea otter data collected by USGS, development of analytical framework for estimating abundance and spatial distribution of sea otters, and development of optimization routines for survey design through a Cooperative Ecosystem Studies Unit (CESU) Task Agreement (P15AC00953/CSURM-312; $200,000 for FY16-FY17) agreement with Colorado State University. Given that survey design and the protocol are complete, recurring operational costs are relatively minimal.

Annual costs include SEAN staff time (4.0 months GS-11 Project Leader, 2.5 months GS-7/9data technician), aircraft charters ($15,000-$17,000 per year), travel expenses (approximately $1,000 per year), approximately $1,000 per year in consumable supplies (e.g., batteries, SD cards) and replacement of broken or lost equipment (e.g., GPS units, binoculars, etc.). Approximately two weeks of park housing may be needed each year, otherwise these travel costs would increase considerably. Annual reporting may benefit from contracting an external statistician. Scope, cost, and procurement method for this assistance will be determined based on needs at the time.

6.4 Protocol Revision Process

This protocol may be updated or revised as new knowledge, technologies, equipment, and methods become available. Revisions will balance the advantages of new techniques with possible disadvantages associated with disrupting data continuity.

All revisions require review for clarity and technical soundness. Small changes to the existing protocol documents (i.e., formatting, simple clarification of existing content, small changes in the task schedule or project budget, or general updates to information management handling SOPs) may be reviewed in-house by project cooperators and NPS staff. Changes to data collection, analysis techniques, or sampling design will trigger an external peer review to be coordinated by the NPS.

Every effort will be made to ensure that complete, accepted protocol revisions are applied before the start of each new sampling effort. However, revisions may be required during an active sampling effort in order to remedy an identified safety deficiency, a significant issue regarding data quality, or a breakdown in field operations.

The protocol package is a formally prescribed set of documents identified as deliverable SO_A. The required processes to use in revising components of the protocol package are detailed in SOP 11.

7 Other Considerations

7.1 Data Management Changes

Due to the dynamic nature of information technology, any detailed set of tasks and specifications regarding data management is inherently ephemeral so these are deliberately addressed in sections of SOPs rather than in other documents in the protocol package. The SOP structure is designed to support ongoing updates. Because data specifications, processing methods, and content occasionally get redefined in SOPs over a monitoring program's life, it is essential that each SOP Set always be given a unique identifier and this identifier be stamped in individual data and information products to document the exact methods and quality criteria used to create them. This is essential in order for researchers to properly interpret the deliverables over the long term.

7.2 Information Gaps and Future Research

Future research that would complement the existing protocol includes the development of methods and algorithms for automated detection of sea otters in aerial photographs (Conn et al. 2014, Seymour et al. 2017) which would provide for a more efficient data post-processing routine. In addition, it would be useful to investigate the utility of using data from time-depth recorders or other telemetry devices to estimate the proportion of time that sea otters are available to be photographed at the surface to refine estimates of detection (e.g. Simpkins et al. 2003, Harvey and Goley 2011, Lonergan et al. 2014). Finally, the development and implementation of surveys using UASs, will be important for reducing risk associated with manned aerial surveys (Moreland et al. 2015, Sweeney et al. 2015).

This protocol presents a contemporary analytical framework and photographic methods for estimating the abundance and distribution of sea otters in Glacier Bay. In the future, an ecological model of the nearshore food web using a similar Bayesian hierarchical approach should be developed to serve as the foundation for understanding the ecological role of sea otters in Glacier Bay and the integration of diverse ecological information in nearshore food webs. Such a model would allow for the integration of multiple data sources from the nearshore food web in Glacier Bay including the distribution and abundance of sea otters, intertidal and subtidal prey resources, and oceanography.

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