



Glacier Bay National Park and Preserve

Acoustic Resource Management Framework

NSNSD / Technical Assistance Request No. 2058



Cover Photo: A Dark-eyed Junco sings in Glacier Bay National Park, NPS photo.

Glacier Bay National Park and Preserve: Acoustic Resource Protection Framework

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Table of Contents

Introduction

Purpose

Soundscape Program Components

1. Research

An Ecological Paradigm of Acoustics

Measurement of the Acoustic Environment

Underwater Ambient Measurements

Terrestrial Ambient Measurements

Integrated Study of Underwater and Terrestrial Environments

Sampling

Spatial Sampling

Temporal Sampling

Project-Specific Sampling Locations

Acoustic Modelling

Underwater Acoustic Modelling

Terrestrial Acoustic Modelling

Geospatial Acoustic Modelling

Supporting Data

Source Data / Visitor Use Data

Bioacoustics Data

Social Science Data

Action Items

2. Management

Authorities

Science-based Management

Management Objectives

Indicators and Standards

Scale

**Contrast
Fidelity
Summary of Indicators**

Management Practices

**NPS Internal Practices
External Affairs**

3. Monitoring

**Prerequisites
Collecting Monitoring Data
Underwater
Terrestrial**

4. Communication

**Narrative
Communication Objectives**

Attachment 1: Review of Glacier Bay Foundation Statement

Attachment 2: Georeferencing Legacy Underwater Acoustics Metadata

Attachment 3: Glossary

Introduction

Glacier Bay National Park and Preserve (GBNPP) is a large wilderness park encompassing a pristine set of terrestrial and marine ecosystems within its 3.3 million acre boundary (Figure 1). GBNPP preserves one of the largest areas of federally protected marine ecosystems in Alaska and more than 2.7 million acres of designated wilderness, including marine wilderness. As such, GBNPP includes substantial areas of both terrestrial and underwater environments – a setting that is unique in the National Park Service (NPS). An array of rich and diverse natural sounds occur on park lands. In places, these sounds are free from the influence of inappropriate human-caused sound (i.e., noise). GBNPP is a globally significant marine and terrestrial sanctuary that continues to offer the opportunity for human immersion into remote wilderness that is rapidly disappearing in today's world. Comprehensive protection of both terrestrial and underwater acoustic environments align with purposes expressed in the core statutory documents that define GBNPP: the Antiquities Act and Presidential Proclamation 1733, NPS Organic Act, Wilderness Act, and Alaska National Interest Lands Conservation Act (ANILCA).

While a subset of visitors explore the park from the cockpit of a kayak, the vast majority of park visitors experience its wonders from the decks of large cruise ships. Some also visit via smaller motorized vessels or aircraft. The cumulative effect of motorized access introduces a significant amount of noise into the ecosystem. The addition of noise to the park's acoustic environment is a concern for terrestrial and marine wildlife as well as the preservation of wilderness character.

An important part of the NPS mission is to preserve or restore the natural soundscapes of parks and provide for enjoyable visitor experiences (NPS Management Policies 2006 § 4.9, § 6.3.7, § 6.3.4.3). The acoustic environment is the combination of all the physical acoustic resources in a given area as modified by the environment. Acoustic resources include natural sounds (such as water, wildlife, weather) and cultural and historic sounds (such as tribal ceremonies). Natural ambience is composed of the natural sound conditions in a park that exist in the absence of noise. The soundscape is defined here as the component of the acoustic environment that can be perceived and comprehended by humans. The character and quality of a park's soundscape influence visitors' perceptions and overall park experience.

Natural sounds occur within and beyond the range of sounds that humans can perceive, and can be transmitted through air, water, or solid materials. Some natural sounds in the natural acoustic environment are also part of the biological or physical resource components of the park, such that protection of the acoustic environment also constitutes protection of other resource values directly identified as necessary to the park's purpose.

Natural and cultural sounds are inherent components of *“the scenery and the natural and historic objects and the wild life”* protected by the NPS Organic Act. They are vital to the visitor experience of many parks and provide valuable indicators of the health of various ecosystems. Noise is a concern because it is capable of affecting ecological, recreational, cultural, or wilderness character resources, diminishing the ability of the NPS to accomplish its resource protection mission. This document provides an overview of key components for developing an integrated acoustic resource protection program at GBNPP.



Figure 1. Glacier Bay National Park and Preserve.

Purpose

The purpose of this framework is to identify strategies to research, manage, monitor, and communicate about terrestrial and underwater soundscapes in an integrated manner. The intent is not to produce a comprehensive management plan, nor a detailed and technical long-term monitoring plan. Instead, it synthesizes existing knowledge into a contemporary context, allowing the park to prioritize future action. Unlike most parks, considerable work on acoustics has already been conducted in the terrestrial and underwater environments of GBNPP. Therefore, this framework will also provide recommendations of ways to build on existing research and restoration efforts into the future.

This work was completed by the NPS Natural Sounds and Night Skies Division (NSNSD) in response to Technical Assistance Request #2058.

Soundscape Program Components

The following four program components will be the focus of this document:

- **Research** - Acoustic research has been conducted in Glacier Bay over the last 36 years, beginning with Malme et al. (1982). This framework will briefly review current understanding from these investigations and describe projects that would do the most to advance science-based management of terrestrial and underwater acoustic resources. It will describe the ecological paradigm of acoustics (Pijanowski et al. 2011, Kuhn 1970) as a conceptual basis for decision-making.
- **Management** - The understanding of acoustic condition in the park from previous, current, and future research should inform decision-making processes in the park. In this section, special attention is devoted to a discussion of acoustical indicators in advance of Glacier Bay's Wilderness Stewardship planning process.
- **Monitoring** - A successful monitoring program is goal-based. Such goals will influence the nature of inventory work and the metrics used in planning documents. NSNSD is developing an understanding of how changes in natural ambience affect the measurement of noise - an undertaking crucial to monitoring change. With its unique environment, Glacier Bay has the potential to shape NPS underwater monitoring methodologies and protocols.
- **Communication** - Opportunities and approaches to interpreting Glacier Bay's soundscape for a variety of audiences: visitors and the commercial carriers who bring them, NPS and partner staff, the media, the scientific community and the broader public will be discussed.

1. Research

An Ecological Paradigm of Acoustics

When Glacier Bay was established in 1925, the world was undergoing a shift in paradigm. The invention and proliferation of sound transducers (microphones and loudspeakers) was allowing humans to interact with sound outside of its original environment for the first time - ushering in a new era of observational research (Kuhn 1970). Early underwater transducers were first developed in 1917 for naval purposes (Wood 1965) and military researchers rapidly discovered that the ocean was not silent, but rich with sounds of life - an understanding that was readily used for tactical purposes (Johnson 1947). Gradually the sounds of life began to be studied in their own right, contributing to scientific understanding of animal behavior, communication, and movement. Inaugural research on the underwater acoustics of Glacier Bay was conducted 36 years ago by Charles Malme and his crew in response to government concerns over vessel noise impacts to humpback whales (Malme et al. 1982). When his team published data documenting the acoustic environment these animals lived in, knowingly or unknowingly they were among those pioneering the field of soundscape ecology (Pijanowski et al. 2011) within the larger domain of landscape ecology.

The original, broad definition of an ecosystem proposed by Sir Arthur Tansley plainly states, “*we cannot separate [organisms] from their special environment, with which they form one physical system*” (Tansley 1935). The ecological paradigm of acoustics conceptualizes all naturally-produced sources of sound at a location as part of such a physical system: the ecosystem process of energy flow. This includes both identifiable nearby natural sounds, such as whale song or glacial calving, as well as the diffuse collection of distant or faint sounds referred to as *natural ambient energy*, or natural ambience.

The types of data Malme collected in Glacier Bay suggest he was aware that natural ambience scales the space within which an organism can hear. Likewise, the impact of noise to an acoustic environment is dependent on the natural ambience (Moore 2012, Wickens 2002, Betchkal and Hoffman 2016). Therefore it is of primary importance that Glacier Bay’s soundscape program document natural ambient conditions in both underwater and terrestrial environments. The next section will discuss ambient data GBNPP has already collected.

Measurement of the Acoustic Environment

Calibrated sound pressure level measurements of Glacier Bay have been collected for both underwater and terrestrial environments. This section will consider each in turn.

Underwater Ambient Measurements

Sound recordings from hydrophones deployed in Bartlett Cove (Figure 2) represent the most complete record of the underwater ambient environment available to the park (Kipple 2002, Kipple and Gabriele

2003), but how generalizable these measurements are to other areas of the bay is unknown. Measurements at Bartlett Cove may be representative of conditions in the relatively shallow, open areas of the lower bay, but probably not of reflective/reverberant areas like the Sitakaday Narrows (Malme 1982) or inlets of the upper bay.

Other hydrophone deployments by researchers from the Cornell University Bioacoustics Research Program (in 2007), Scripps Institution of Oceanography (2012, 2013), and the Oregon State Bioacoustics Laboratory (2015, 2016) have documented areas of the lower and middle bay (Figure 2). Each project had different objectives, and thus varied instrumentation, sample lengths, and audio formats were used. For the Cornell samples, at least, the 12-bit sample depth may preclude an accurate quantification of natural ambient energy due to a high noise floor (Ponirakis, personal comm. 2017, Pohlmann 2005). Still, these records can be used to document ambient sound levels in many cases. It should be a priority of the park to glean ambient spectral sound pressure levels from all underwater acoustic data that have been collected in the park to date. This includes digitization of spectral sound pressure levels presented in Charles Malme's seminal 1982 report, paired with an assessment of instrument error for his analog measurement system. For the purposes of this framework, the first step of georeferencing Malme's sampling locations has been conducted (Figure 3). For a more technical description of this effort, please see *Attachment 2 - Georeferencing Legacy Underwater Acoustics Metadata*. Four of these legacy sampling locations are included in Figure 2 as suggestions for contemporary hydrophone deployments.

Glacier Bay: Underwater Acoustic Data

Extant and Proposed Hydrophone Deployments, 2000 - 2016

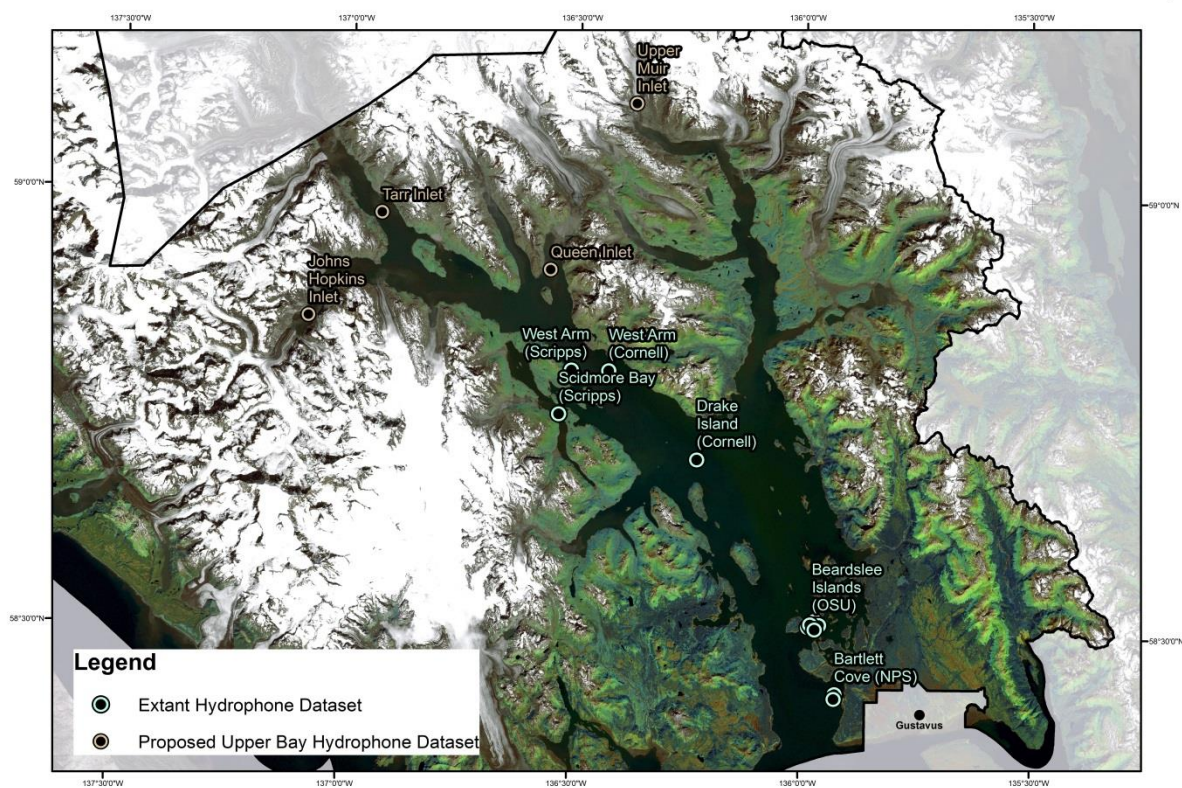


Figure 2. Locations of contemporary hydrophone deployments (2000 - 2016). Four locations previously sampled in upper Glacier Bay (see Figure 3, below) are included as a suggestion for future documentation of ambience.

Glacier Bay: Legacy data from Bolt, Beranek, and Newman report no. 4848

Calibrated spectral sound pressure levels taken 1981

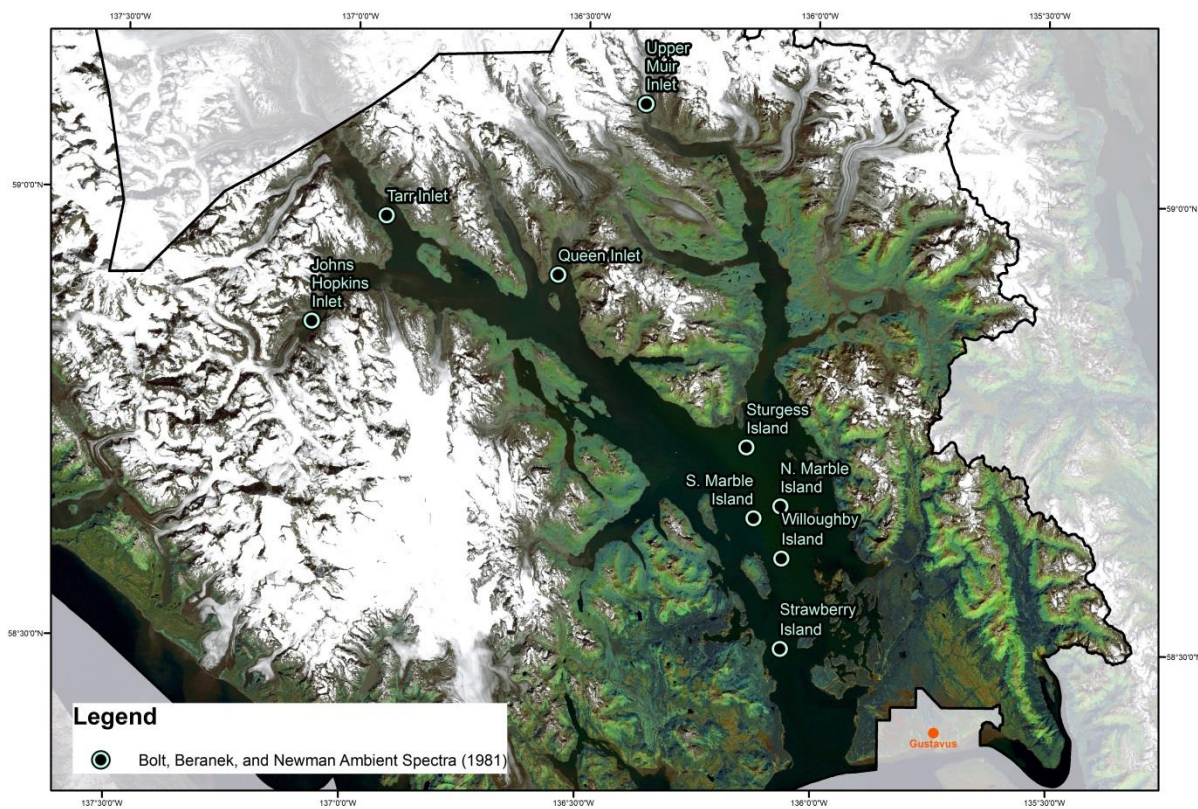


Figure 3. Georeferenced locations of underwater acoustic measurements reported in Bolt, Beranek, and Newman report no. 4848 (Malme et al. 1982).

Terrestrial Ambient Measurements

All acoustic records of the terrestrial environment of GBNPP have been collected as uncalibrated audio recordings from consumer-grade digital audio recorders (Lynch 2012). Subsequently these records were calibrated with an accuracy slightly outside of Type 2 measurement standards as per IEC 2002 (a tolerance of ± 1.4 dB.) These calibration methods were developed by NPS staff in conjunction with Colorado State University (Buxton et al. 2016, Mennitt and Fristrup 2012). The noise floor of these measurements is fairly consistent for the type of recording unit used thus far in GBNPP [Roland R05, firmware ver 1.03, ~ 27 decibels] but may be high enough as to preclude the quantification of ambient sound levels (Mennitt and McKenna, personal comm. 2017).

Ideal acoustic measurements in terrestrial environments, “*should be collected by calibrated sound level meters in 1 s, 1/3 octave bands (unweighted) paired with long-term audio recordings (such as MP3) archived with broad accessibility for computation of all metrics and comparative analyses. An excellent, low-budget alternative to include sound measurements in as many studies as possible is to use an MP3 recorder with a known relationship to a calibrated sound level meter*” (Barber et al. 2011). Currently

GBNPP has collected data via Barber's alternative recommendation. Valuable documents of human and wildlife behavior were gained by the park's initial work, but to improve future inventory efforts GBNPP should focus on documenting natural ambience as well.

Of the five sites sampled during the summer of 2011 (Figure 4), Rendu Inlet and Hutchins Bay were the most impacted by noise. In fact, the 2011 Rendu Inlet record has the greatest percentage of time with noise audible of any backcountry site sampled by the NPS in Alaska to date: 37.9% of the record. The median Alaskan backcountry site has noise audible 5% of the record. The median site in the Lower 48 has noise audible 28% of the record (Lynch et al 2011). These observations were confirmed by attended listening - where NPS observers spent time logging the sounds they heard *in situ*. By this approach areas such as Rendu Inlet, Queen Inlet, and John Hopkins Inlet were observed to have noise audible for 90 - 100% of daytime summer listening sessions. By contrast, such areas as Gloomy Knob, the Upper East Arm, or Muir Inlet were less impacted (10 - 35% of daytime listening sessions,) but these places still exceed typical conditions for most Alaskan parks.

Glacier Bay: Airborne Acoustic Data

Extant and Proposed Microphone Deployments, 2011 - 2016

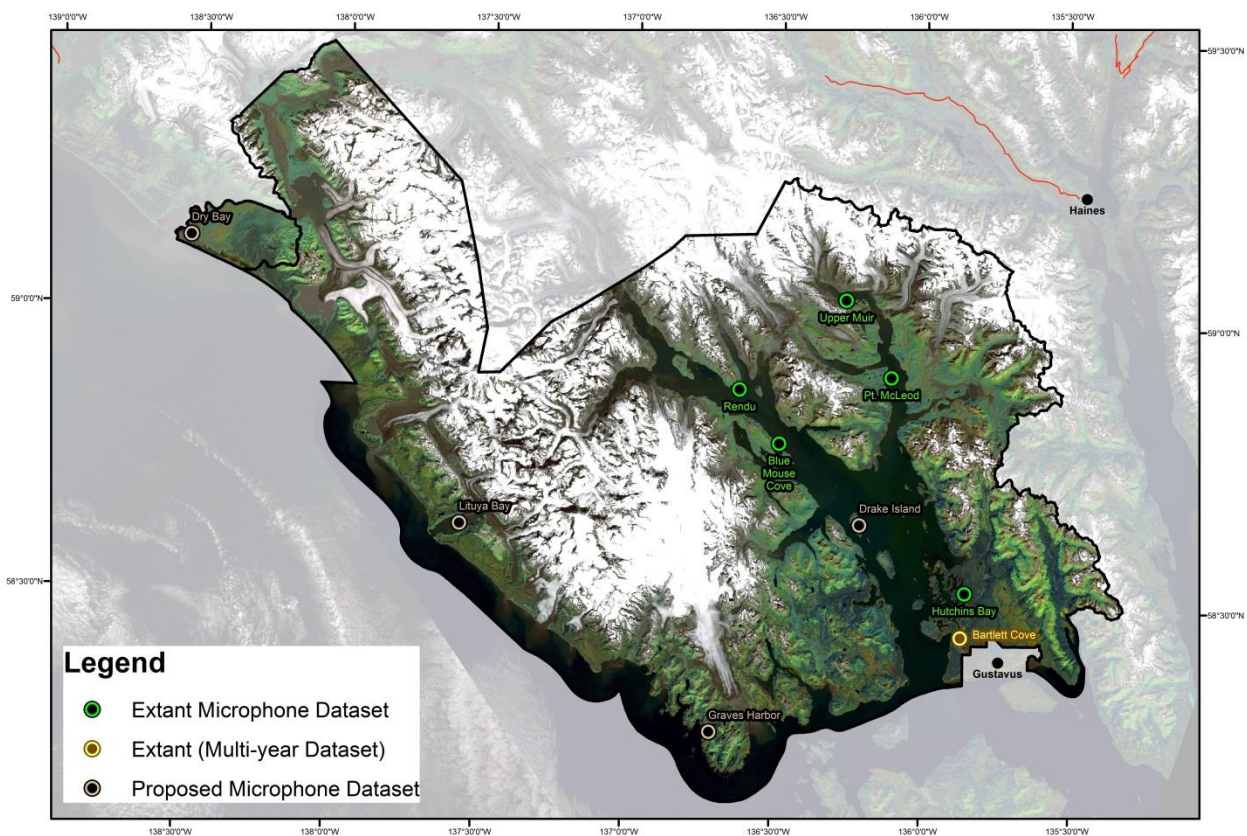


Figure 4. Locations of microphone deployments (2011 - 2016) that document spectral ambient conditions. Four additional locations derived from staff comments and the interest of spatial coverage are included as a suggestion for future documents of ambient condition.

Integrated Study of Underwater and Terrestrial Environments

During the original scoping of this document in 2009, Glacier Bay staff expressed interest in conducting research that involved simultaneous, spatially-paired measurements above and below the ocean surface. The primary reason to collect paired measurements would be to assess the effects of management action on both environments simultaneously. Several previous examples of this research strategy are available. In one study, researchers used a paired hydrophone and microphone on a floating platform to study the acoustics of small lakes (Kuehne et al. 2013). In another, the same type of recorder was mounted on pre-existing marine platforms in Florida Bay and was used to study cascading ecological effects of habitat restoration in the Everglades (McKenna et al. 2015).

Several concerns arise when contemplating paired data collection:

- 1) *Noise Floor*: As with any meaningful acoustics study, the dual-channel recorder must have a noise floor low enough to allow the quantification of natural ambient sound levels. (The park may submit a technical assistance request to NSNSD to provide noise floor measurements of potential instrumentation.)
- 2) *Wilderness*: What infrastructure is required for sampling in a paired fashion? Is it appropriate to the aesthetics/wilderness values of the bay? Will it be reasonable to deploy and maintain?
- 3) *Comparability*: Can pressures in underwater and terrestrial environments be meaningfully compared? What length of acoustic monitoring is necessary to achieve the goals of the paired recordings?

The last of these questions can be readily answered without project specificity. An excellent review exists explaining the comparison of spectral pressure energy in air/water using the units of Intensity Spectral Density ($W / m^2 Hz$) (Dahl et al. 2007). The units are arcane, however, and if the purpose of monitoring above and below water is simply to understand how a single management action benefits both environments no direct comparison is needed. Instead, both environments would be monitored separately.

Sampling

Most parks sample their acoustic environment with inventory and monitoring goals in mind. They attempt to sample in such a way that they can generalize conditions in a particular area and repeat the measurements at a different time to assess change. Broken into pieces, that involves:

- 1) *Spatial sampling*: Understanding how sound scales in space.
- 2) *Temporal sampling*: Understanding how long equipment must be deployed to obtain a meaningful representation of patterns in time.

Spatial Sampling

NPS Director's Order #47 calls for parks to collect inventory data on acoustic resources for use in planning. In the case where GBNPP is confronted with a tangible change in noise condition, spatial samples should be designed to best serve *effectiveness monitoring* or *adaptive management* (Reynolds et al. 2016). Such monitoring programs are noise source specific, with data only collected in the geographic extent of the action. Covariate data are also collected to document changes within the physical system. (See section *Research: Supporting Data*, below.) Ultimately such programs address whether the action was as effective or as detrimental as predicted.

Contrast this to *status and trends monitoring* (where the acoustic environment is characterized through time) or *threshold monitoring* (where changes in the acoustic environment trigger a specific management action.) Both are meant to alert the park to deteriorating conditions. Spatially they are best served by inventory data evenly spread over the park's geographic extent. Spreading out samples in space allows for a broader range of conditions to be observed, and reveals conditions that may be surprising (i.e., informative, Pierce 2012) to managers. Such insights are lost when only noisy, impacted locations are sampled. Alaska Region parks are anecdotally referred to as spectacularly quiet places. Spatially widespread inventory data provide a defensible administrative record to conserve them that way for the enjoyment of future generations.

Spatial sampling in acoustics is governed by a scaling law. Given the same source and environment, the area over which a source can be detected scales with its power as $A \propto P$. In other words, the power of a sound source and its audible extent over a landscape are proportional. Power is defined as the rate at which energy is dissipated by a sound source, with units of joules per second. Sound sources span a truly incredible range of powers: turbo jet engines dissipate on the order of 1×10^5 J/s while an animal breathing may dissipate only 1×10^{-9} J/s (Cowan 1993).

Sound spreads out over the landscape in a way that is *energy-scale invariant* (Pierce 1981, Rienstra and Hirschberg 2004). This means that one can reliably expect powerful sources to be detected over larger areas than less-powerful natural sources. As a consequence, a source of power P has a characteristic length scale, ℓ , corresponding to the largest diameter of its audible extent. Evenly placed sensors ℓ units apart will not detect the same source simultaneously (Figure 5).

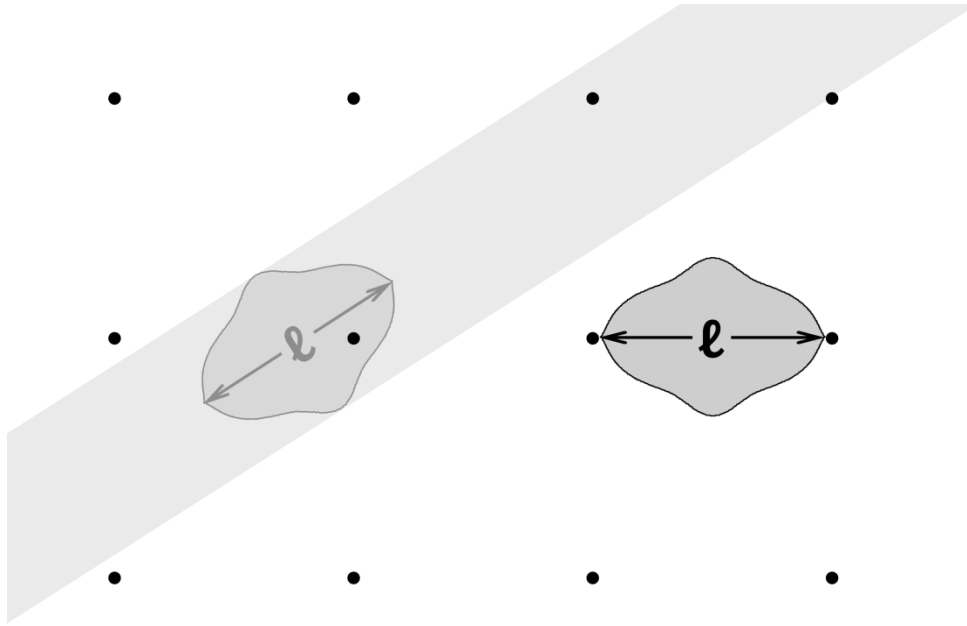


Figure 5. No two evenly spaced sensors ℓ units apart will detect a source footprint of characteristic length ℓ simultaneously.

Acoustic environments are an ensemble of sounds produced by sources across the energy scale – from mosquitos to jet engines. Thus, sensor spacing of an acoustic inventory will necessarily set limits on inference for specific sources. Sensors spaced at distances much greater than ℓ_{source} cannot be meaningfully interpolated and generalizations about the source beyond the local area should be avoided (Peterson and Parker 1998, Lovejoy et al. 1985). Sensors spaced at distances much smaller than ℓ_{source} are no longer spatially independent for that source. Two practical conclusions for large Alaska Region parks are derived from this:

1. Basic interpolation techniques are not effective for natural sound sources because of the sampling density required. If landscape-scale estimation of acoustic environments is desired, geospatial regression should be used instead (Mennitt et al. 2013).
2. Because of the increased distances sound propagates underwater, it follows that a hydrophone sensor network may require less sensor density than a terrestrial network to achieve inferential power.

To date, the only NPS unit to conduct a statistically robust random sample of the acoustic environment is Denali National Park and Preserve. Denali's inventory helped elucidate which sound metrics can be accurately interpolated at a 20-km scale (Betchkal and Hoffman 2016). Though important in informing future NPS sampling strategy, the project was relatively expensive and time-consuming. It is no surprise that every other project conducted by the NPS has utilized a sample of convenience. Most have been guided by the concept of *acoustical zones* (NPS 2013, Ch. 2). Sampling via acoustical zones relies on the assumption that similar landscapes will share similar natural acoustics. This approach has helped many parks collect baseline data within the practical realm of access-limited sampling.

To address some of the limitations of a convenience sampling approach, the park could sample using a method similar to a Generalized Random Tessellation Stratified (GRTS) design - which disperse samples in a statistically efficient manner. GRTS works by minimizing the variance in the area of polygons (called ‘Voronoi cells’) surrounding each point (Stevens and Olsen 2004). By relying on the underlying mathematics of GRTS, large national parks like GBNPP can conduct a spatially-balanced non-random sample while respecting access constraints. Such a design was tested for a soundscape inventory in Katmai National Park and Preserve, 2015-2017 (Fig 6). The process was as follows:

- 1) Generate an exhaustive list of accessible site locations.
- 2) Decide how many stations can be reasonably deployed during the initial time period. Deploy these initial stations to accessible locations as far apart as possible.
- 3) Create a Voronoi tessellation using the coordinates of the stations.
- 4) Pick the next iteration of samples by selecting accessible sites at either the edges or vertices of a Voronoi cell, prioritizing sites that reduce large cells towards the typical size of other cells (minimizing variability as per GRTS.) These will be deployed during the next time period.
- 5) Repeat steps 1-5 through time until the median size of the Voronoi cells is similar to or slightly larger than the detection area of the noise source at issue, *or* until funding/time constraints limit the inventory project.

In Katmai this technique proved flexible enough to include samples from a variety of landcover types, management zones, and other categories of interest. Access constraints in GBNPP may not allow for as much variability to be captured, and so other GIS layers may wish to be included for optimization. Such a discussion should take place in advance of acoustic inventory work.

Voronoi Sampling Case Study: *Katmai National Park and Preserve*

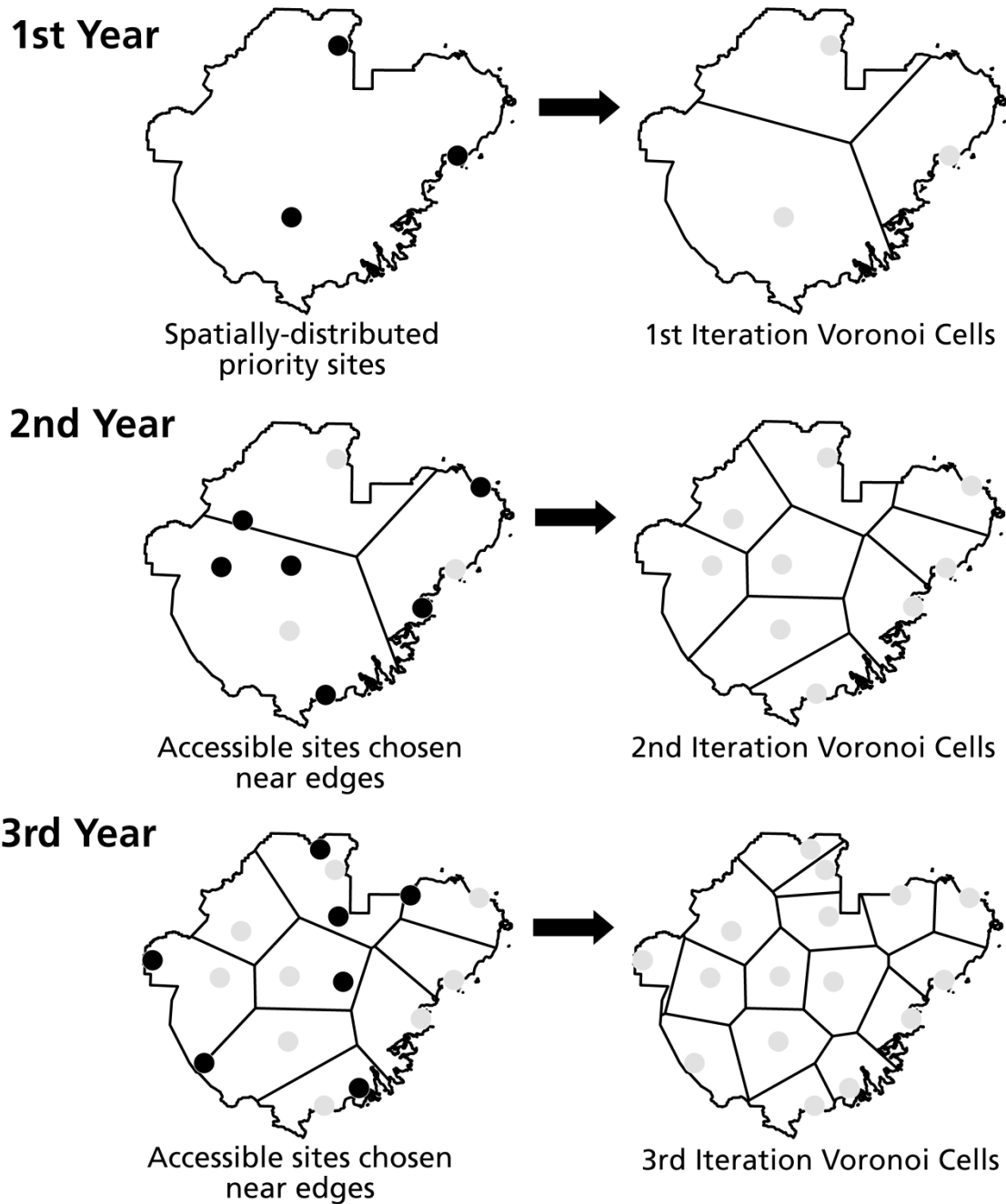


Figure 6. Voronoi sampling case study, Katmai National Park and Preserve. The diagram shows how Voronoi cells can help guide access-constrained sampling so that the final sample is spatially balanced. By the third iteration it is possible to see how variability in area around each site is minimized by this technique.

Finally, because earth science sensor networks (such as meteorological stations or seismometers) are rarely deployed with a design that satisfies the independent, identically distributed random sampling

(i.i.d.) assumption, there are a number of techniques available to decluster and treat such networks effectively (Dubois 2000, Doswell and Lasher-Trapp 1997, Sen 2009 § 5.4). Depending on the type of spatial generalizations the park would like to make, the i.i.d. assumption is probably minor in comparison to assumptions about spatial isotropy, considering the directional influence of the Gulf of Alaska, Fairweather Range, and Glacier Bay, itself.

Temporal Sampling

A standard NPS acoustic recording system logs one-second averages of pressure. Standard audio recorders log pressure values many thousands of times per second. Such measurements of pressure accumulate at a linear rate - a data storage consideration for sampling in remote locations (Pohlmann 2005). Conversely, observations of events within the data do not accumulate at a known, linear rate. Temporal sampling, then, involves balancing the maintenance effort of systems with the sampling effort required to capture an adequate number of acoustic samples (or noise events) necessary for statistical analysis.

Thus, an early problem for the NPS was to assess the temporal sampling effort required to accurately estimate the broadband sound pressure level (SPL) of an environment. Year-long data sets from six parks in the southwestern U.S. were subsampled which allowed NSNSD to determine that a 25-day sample would provide an estimate of the median SPL for a site within ± 3 dBA (Iyer 2005). In 2017 the Natural Sounds and Night Skies Division replicated this study with data collected by modern sound level meters in Alaska and found an incredible range of variation in sampling requirement, with sites requiring 31 ± 22 days to achieve the ± 3 dBA criterion (Betchkal 2017.) Multiple authors have reiterated that, if possible, the best approach is to sample the entire season or year of interest (Iyer 2005, Schomer et al 1979, Schomer and DeVor 1981). Thankfully, this prospect is much easier than it was even a decade ago due to advances in storage media and improved design of digital audio recorders.

Project-Specific Sampling Locations

A number of management-related sample locations were mentioned by GBNPP staff during the scoping phases of this document in 2009. For terrestrial research, these included interest in the effects of vessel noise on breeding birds (measured at South Marble Island for example) or studying the noise propagating into wilderness sites adjacent to motorized waters.

For the underwater sites, interest in protecting animals was a key driver of interest. Discussions in 2009 identified many areas for sampling: conditions affecting Kittlitz's murrelets in Tarr Inlet, humpback whales at Point Adolphus, and pinnipeds in the Beardslee Islands, John Hopkins Inlet, South Marble Island, Tarr Inlet, McBride Inlet, or Adams Inlet. Underwater sites were also proposed to show differences in motorized use: vessels in transit in the lower West Arm, and areas without motorized vessels (such as the Beardslee Islands) to assess how motorless waters are affected by sources outside of the closure. The viability of any of these sites as inventory locations should be vetted against the park's acoustic goals.

Acoustic Modelling

Underwater Acoustic Modelling

Glacier Bay's staff have worked with many of the most active underwater acoustics laboratories in North America: the Cornell Bioacoustics Research Program, Scripps Institution of Oceanography, and Oregon State University. Currently the park is working with Dimitri Ponirakis and Christopher Clark of the Cornell Bioacoustics Research Program to develop a model of animal communication space for the bay. Such a model describes how vessel noise reduces the area over which marine mammals can communicate (for more on this topic, see Clark et al. 2009).

The park has used Acoustic Integration Model© (Marine Acoustics Inc., Figure 7) to predict the noise exposure of whales under a wide variety of vessel management scenarios (Frankel and Gabriele in review). Communication with Mike Porter, president and lead programmer for Heat, Light & Sound Research suggests that it would be possible to build a specific propagation tool for rapid use in developing scenarios for Glacier Bay (Porter, personal comm. 2017). Many of the required inputs for acoustic modelling are currently being collected by Glacier Bay's physical science program. Sedimentology data exist over the whole bay (Hodson et al 2013, Trusel et al 2010, Carlson et al. 2002). Oceanographic data such as salinity and temperature profiles are documented several times per year along a transect through the bay (Sharman 2011, Sharman 2013, Sharman 2013b).

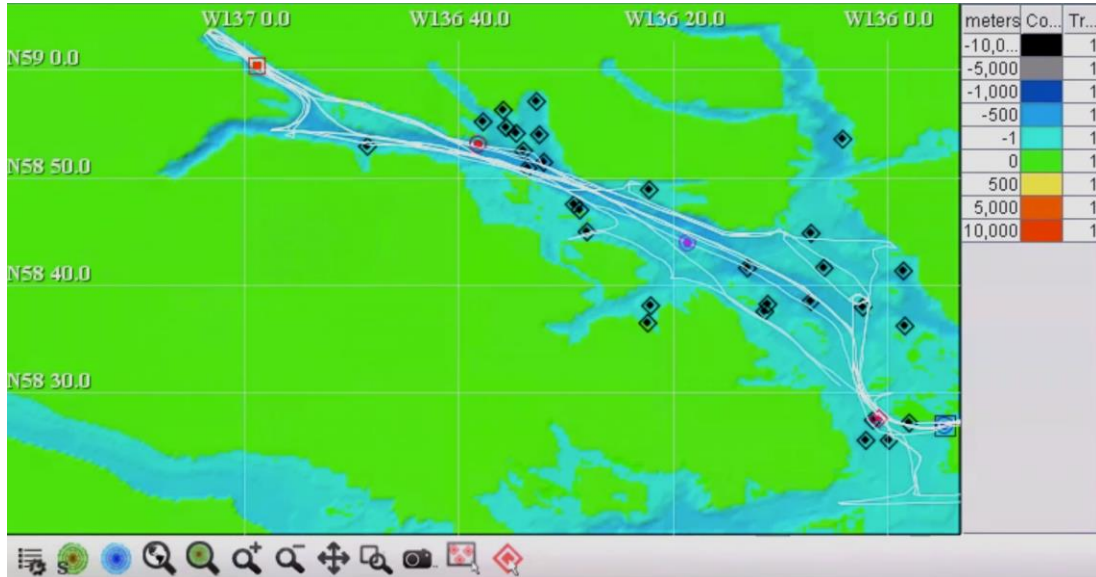


Figure 7. An example spatial output from underwater acoustics modelling software Acoustic Integration Model (AIM) showing the effects of vessel traffic on the listening area of humpback whales.

Considering the work that has already been done in this realm, the park might consider developing a GIS interface that would allow the park to quickly create *ad hoc* propagation scenarios using underwater modelling software.

Terrestrial Acoustic Modelling

Well-known tools exist to model the impact of noise sources on the terrestrial landscape. The National Park Service currently has protocols for CadnaA (useful for ground-based sources), SPreAD-GIS (ground-based sources), NMSIM (aircraft or ground-based sources), INM (aircraft or ground-based sources), and the NPS Attenuation Calculator (cursory estimation). NMSim is the NPS-preferred predictive noise modelling software, as it was found to be both the most likely to produce unbiased results, to have the lowest overall error for the calculation of audibility metrics (Miller et al. 2003) and has the ability to export ASCII raster data for the production of maps. Both INM and NMSIM have been used for predictive purposes in support of planning documents for Yellowstone National Park and Grand Canyon National Park using NMSIM and produce comparable results (Miller et al. 2003; Hastings et al. 2006; Fristrup et al. 2012; FICAN 2005). NMSIM was used in both cases to create maps of audibility for a number of highly-complex management alternatives. More recently the US Department of Transportation created an *INM Analysis Tool* for use by the NPS, which allows for rapid spatial assessment of alternatives using output data from INM models. Models are relevant to spatially and temporally managing complex vessel traffic throughout GBNPP. They provide a way to test causative predictions against observation - crucial for both minimizing impacts from decisions and for the development of mitigation strategies. NSNSD has the capacity to develop models or train others to use modelling software. Such work may be requested via the technical assistance request process.

Geospatial Acoustic Modelling

As described above, most acoustic models are based on the “source-path-receiver” concept: noise *sources* create acoustic waves, which take a *path* over the landscape based on physical properties of the matter that waves interact with, and arrive at a *receiver's* location. However, this is not the only useful concept for creating acoustic models. It is also possible to use geospatial regression to leverage the large volume of acoustic data collected thus far in Alaska. Acoustic data can be related to explanatory spatial datasets at a state-wide scale to predict levels at locations that haven’t been sampled yet (Mennitt et al. 2013, Figure 8). Because they regress towards a mean, such models are most useful for wide-area predictions, and represent a first attempt to understand the influence of broad-scale spatial processes on natural acoustics.. They are also useful in predicting chronic noise impacts from transportation networks that can be described at the state-wide scale (such as railroads, roads, or community noise. The collection of ambient acoustic data in Glacier Bay will do much to improve the quality of input data for southeastern Alaska and will probably change the output of the model considerably in future runs.

Alaska: modelled median Sound Pressure Level (L50)

Estimates for existing summer-season, daytime conditions.

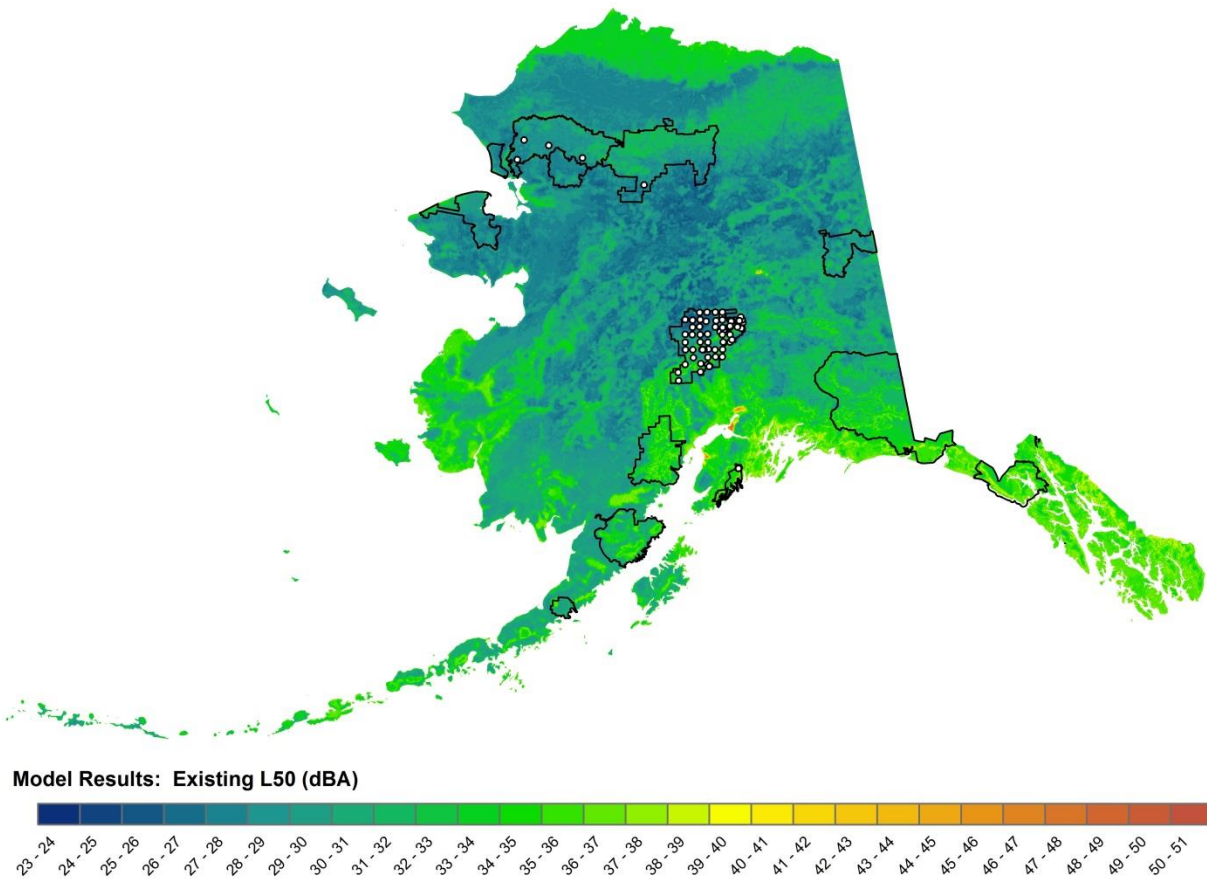


Figure 8. Median Sound Pressure Level (L50) estimated for existing summer-season, daytime conditions using geospatial regression (Mennitt et al. 2013). Inputs to the model are standard NPS acoustic monitoring data - site locations shown as white circles - and explanatory spatial layers at a state-wide scale. The resulting model has a spatial grain of 250m.

Geospatial modelling can also be used for the purposes of noise mitigation. GIS software such as Circuitscape (<http://www.circuitscape.org>) can be used to approach the protection of acoustic resources through cost-distance analysis. Cost-distance analysis balances the costs associated with travelling across a certain area (usually fuel costs or hazards) with costs related to noise impacts in the same area. (For example, non-motorized waters, wilderness boundaries, or critical wildlife habitat could all have a higher noise impact cost.) Results of such a geospatial model indicate ideal corridors for mechanical transportation. An example of this type of analysis was published in Denali's Long Range Transportation Plan (NPS 2017c.)

Supporting Data

Source Data / Visitor Use Data

The simplest form of information the park can collect regarding the *causes* of noise are data on the type and position of noise sources present. Such data are crucial to the mitigation of noise. They can visually suggest route modifications or imply when cumulative traffic rates are too high. Most importantly they allow for the creation of accurate acoustic models.

Data on administrative flights and vessel use can be collected with great ease via tracklog from a GPS unit. With slightly greater difficulty the park can log Automatic Identification System (AIS) signals from vessels or Automatic Dependent Surveillance-Broadcast (ADS-B) signals from aircraft. (The National Park Service has recently developed an inexpensive ADS-B logging system that will give 3D positioning and source type information for equipped aircraft within 60 nautical miles line-of-sight.) Simpler counts of transportation intrusions can be conducted with trained observers such as backcountry rangers or volunteers (*for example methodology, see* Georgette and Loon 1988, Morgan and Van Horn 2001, Abbe and Burrows 2014), or mechanically with timelapse/motion-sensitive/sound-sensitive field cameras, magnetic or pneumatic vehicle counting strips, or from information self-reported by CUA or Concessions Contract holders and maintained by NPS commercial services staff. (For example, tour and cruise vessels use AIS.)

Glacier Bay already has some documentation of source and visitor use data. Sample tracks from charter boats, airstrips, FAA Instrument Flight Rules (IFR) routes, and Off Highway Vehicle (OHV) trail locations are all available on the NPS Alaska Theme Manager in ArcGIS. If additional source data exists, it should be organized and ported to the GIS environment. Newly collected source data should be annotated for use in support of acoustic research.

Bioacoustic Data

Bioacoustics is a well-developed field that existed well before the shift toward the ecological paradigm of acoustics. Still, within the ecological paradigm, the NPS recognizes that the acoustic environment of Glacier Bay is an aspect of an organism's habitat. Thus, the documentation of natural ambient acoustic energy supports habitat protection.

More conventionally, bioacoustic records document the behavior of animals, which can be useful in the study of phenology (as in Glacier Bay, Buxton et al. 2016, NPS 2017b, Figure 9), biodiversity (Betchkal 2016), or even to describe evolutionary aspects of a population (Miller 2009). From 2012 to present data have been collected at Bartlett Cove during the avian breeding season from February through June. These data have allowed the park to temporally describe the dawn-chorus phenomenon and conduct a change-point analysis using the Acoustic Complexity Index (ACI) indicator (Buxton et al. 2016). This project has identified a precise date each year – so far, mid-April is typical – as marking the main influx of migratory birds. Such a repeatable, quantitative description which can be monitored through time (*see section 'Monitoring: Collecting Monitoring Data: Terrestrial Data'*).



Figure 9. Phenology monitoring station at Bartlett Cove, 2015.

Within Glacier Bay there has already been considerable biological mitigation related to vessels, creating areas where:

- 1) motorized vessel operators are required to modify their behavior to avoid striking or changing the behavior of humpback whales
- 2) motorized vessel operators are required to maintain a prescribed distance from the breeding colonies of nesting seabirds
- 3) motorized vessel operators are required to stay out of areas that are critical during harbor seal pupping and molting seasons
- 4) motorized vessel operators are required to maintain a prescribed distance from areas where Steller sea lions are hauled out
- 5) motorized vessel operators are required to respect quiet hours in common private vessel anchoring areas (not a specifically biological requirement, but has benefits to natural ecosystems)

These mitigations are based on a large volume of marine mammal research conducted in the park. Many reports on humpback whales are readily available on the park's website and within the peer-reviewed literature. Detailed information is crucial in managing to the provisions of the Marine Mammal Protection Act (Public Law 95-522).

As mentioned above (in the section entitled '*Acoustical Modelling: Underwater Acoustic Modelling*'), an animal's communication space is a physical measure capable of describing the effects of noise on an acoustic habitat. For now, the park has focused on marine mammals for this type of model, but such work is applicable to every organism with ears - which turns out to be the entirety of vertebrate animals, and most invertebrates as well (Horowitz 2012). This is the most compelling reason to conduct a listening area analysis similar to the underwater study which is underway: for terrestrial environments, at least, the

results represent impacts to wildlife and visitors in a unified way (Clark et al. 2009; Gabriele et al. *in review*). (For a definition of listening area, see ‘*Attachment 3: Glossary*’.)

Social Science Data

Because humans are at the same time enjoying and impacting the natural environments of national parks, data related to humans can supply crucial information regarding both the causes and effects of noise.

An early study by Robert Manning in 1989 provided insight into the social norms of cruise ship passengers when asked to evaluate various rates of vessel use in Glacier Bay. Manning found that cruise ship passengers imagined themselves having a less-pleasant experience when faced with a hypothetical increase in tour boats or ‘pleasure boats’. They did not expect a change in enjoyment if encounters with non-motorized watercraft or other cruise ships increased. When asked to recall *actual* encounters they had during their trip, visitors were largely ambivalent, with cruise ship and aircraft encounters providing the largest detractions from their enjoyment (Manning et al. 1996). Such conflicting reports suggest that visitors may have difficulty imagining the physical consequences of hypothetical scenarios.

A similar study was conducted in the park by Jane Swanson and Mark Vande Kamp in 2009, which broadened inquiry to multiple user groups. When surveying distinct user groups, these researchers from the University of Washington found that $45 \pm 8\%$ of non-cruise ship visitors stated that cruise ships detracted from their trip enjoyment. The authors then framed a course for management related to the qualities of wilderness character (defined by Landres et al 2012). They state, “*if providing opportunities for solitude to particular user groups is important to park managers, then the findings showing that cruise ships detracted from solitude for each group must be weighed to determine if sufficient opportunities for solitude are available.*”

The same study suggested impressive stability of visitor attitude: a 20% increase in cruise ship use-days would not substantially alter visitor enjoyment of the bay (Swanson and Vande Kamp 2010). Such a statistic should be analyzed more closely for the effects of bias. The question it is derived from requires the visitor to undertake two acts of cognition in sequence. First they must accurately visualize a 20% increase in use-days *and then* imagine the physical and acoustic consequences of the increase in terms of their experience. “*Without both a cognitive belief in alterability and a moral judgement of its character,*” states sociologist Joseph Gusfield, “*a phenomenon is not at issue*” (Gusfield 1981). Without a clear description of future conditions it is difficult to form a moral judgement. Therefore it is likely that the study overestimates the stability of visitor attitudes to change.

Author Eli Seigel wrote in 1970, “*all the opposites are two freedoms which question each other and complete each other.*” Transportation and solitude likely represent such a pair of mutually-exclusive freedoms. In Glacier Bay and other Alaskan parks we can immediately recognize a tradeoff between the ability to be easily and quickly transported to a location and the ability to participate in the tranquility of natural places beyond the reach of modern technology and crowds.

Following from this balance of freedoms, one conceivable future social science project for Glacier Bay would involve a '*stated choice*' analysis considering the spatiotemporal extent of existing vessel closures related to the protection of wildlife or quietude. Such a study would endeavor to describe the willingness of the public to give up some freedom of transportation to create quiet places for wildlife (which, when created, also have the potential to allow for visitor enjoyment as described in the NPS Organic Act).

Action Items

The following list summarizes tasks identified in this section that will improve the effectiveness and quality of acoustic research in Glacier Bay. These projects represent logical advances towards holistic management of the park's acoustic environment within the ecological paradigm:

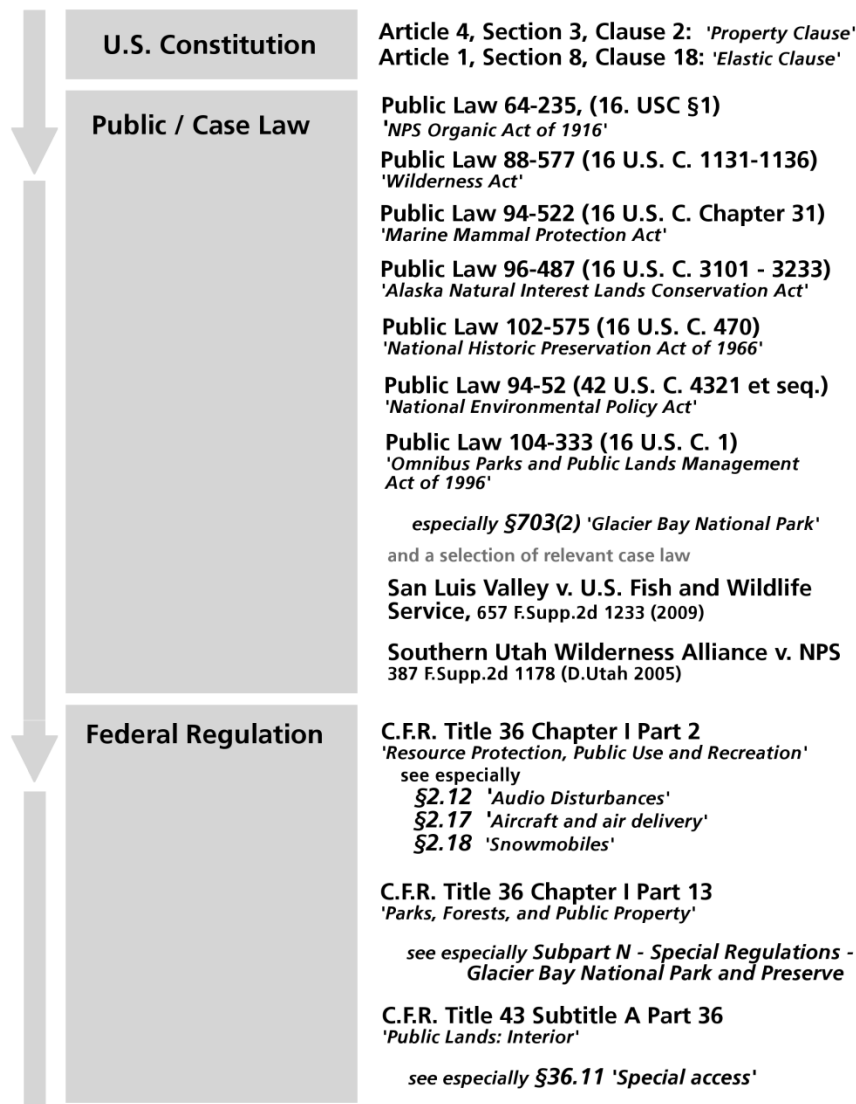
- 1) Scrutinize extant acoustic records for data quality. Organize all digital data collected to date in a location that can be accessed for computational analyses. Compile existing ambient spectra from these records, digitizing legacy documents when necessary.
- 2) Develop an inventory sampling plan that will: (1) achieve the park's management goals and prepare it for a successful monitoring program, (2) document additional ambient spectra, (3) be of the appropriate scale/density to monitor changes in noise impacts that the park finds important, (4) consider both the statistical efficiency and the practicalities of access, and (5) provide an adequate temporal sample while respecting the staff time required for iterative maintenance.
- 3) Discuss the potential for co-deployed underwater and terrestrial acoustic sensors as part of an inventory project.
- 4) Develop a 3D underwater acoustic propagation model of Glacier Bay with an intuitive user interface.
- 5) Review the source data (especially vessel tracks) that are already being collected and those that might be necessary for accurate modelling of the underwater and terrestrial environments.
- 6) Social science: conduct a discussion on the most promising research projects related to managing the acoustic environment. Consider whether traditional surveys can be supplemented or replaced with approaches that emphasize tradeoffs in freedom.

2. Management

Authorities

The following graphic identifies the primary laws, regulations and policies that authorize acoustic management in Glacier Bay:

Hierarchy of Authorities: Management of the Natural Acoustic Environment



Continued on next page...

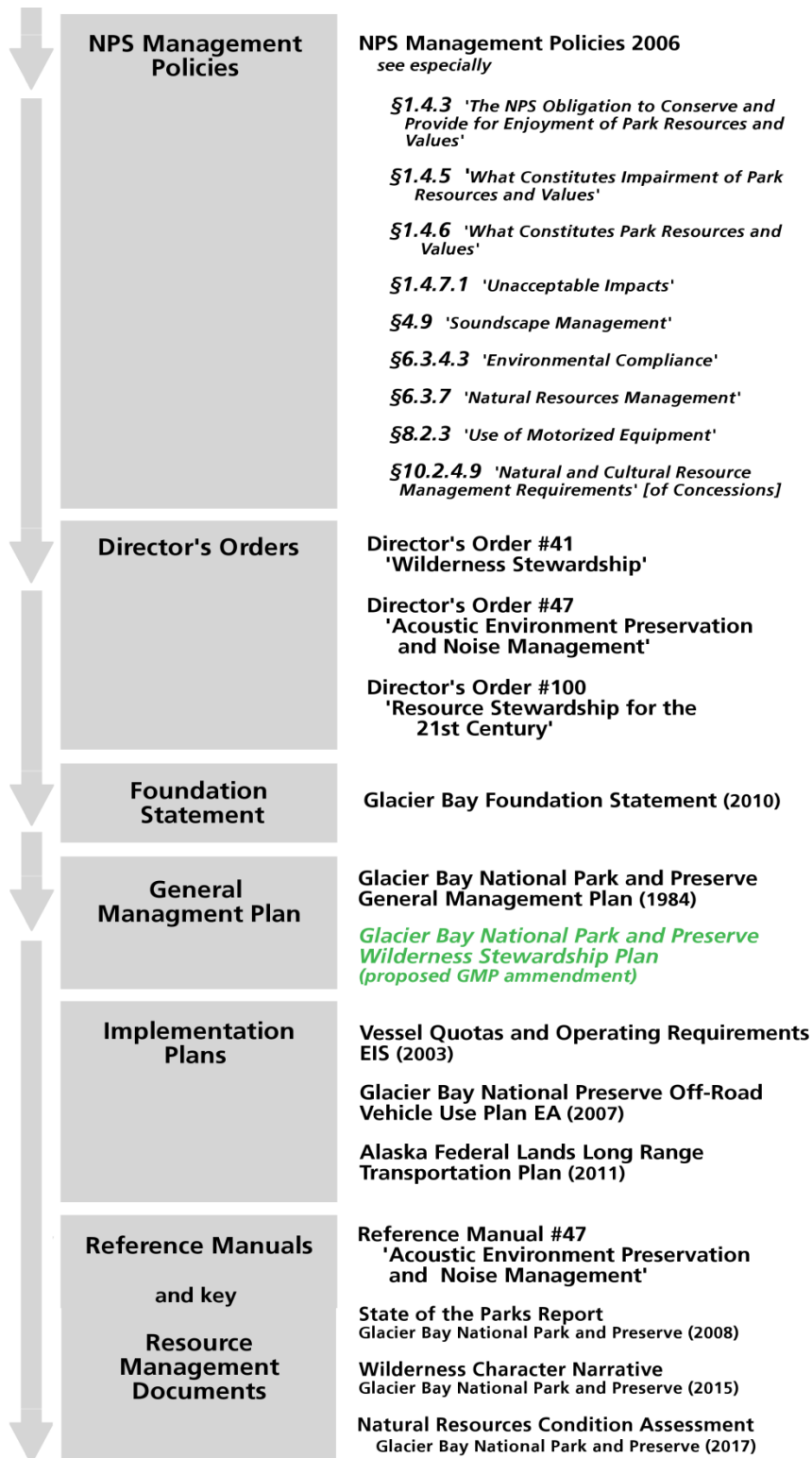


Figure 10. Hierarchy of Authorities for the Management of the Acoustic Environment in Glacier Bay. The proposed Wilderness Stewardship Plan and in progress Frontcountry Management Plan are highlighted in green.

The fundamental policy document at the park-level is the Glacier Bay Foundation Statement, published in 2010. Its purpose is to distill the core mission of Glacier Bay from the park's establishing legislation. The foundation statement thus provides an underpinning for all park-level plans. An in-depth review of the authorities with respect to acoustics are included in '*Attachment 1: Review of Glacier Bay Foundation Statement*'.

Science-based Management

Management Policies 2006 § 8.2.3, states, "*the environment of sound that exists in the absence of human-caused noise is the baseline condition, and the standard against which current conditions in a soundscape will be measured and evaluated.*" In other words, the management of noise is predicated on an understanding of the natural (noise-free) ecosystems of Glacier Bay.

NPS policy requires the use of best available science to support decision making. Director's Order #79: 'Integrity of Scientific and Scholarly Activities' is a useful resource in this area. It provides guidelines for improving the integrity of scientific research for all NPS employees, researchers themselves (internal or external), or for managers using scientific information.

Park-specific guidance and statutes also require Glacier Bay to use best available science. The 'Omnibus Parks and Public Lands Management Act of 1996' (Pub. Law 104-333 §703(2)) states:

"When competitively awarding permits to enter Glacier Bay, the Secretary may take into account the relative impact particular permittees will have on park values and resources, provided that no operating conditions or limitations relating to noise abatement shall be imposed unless the Secretary determines, based on the weight of the evidence from all available studies including verifiable scientific information from the investigations provided for in this subsection, that such limitations or conditions are necessary to protect park values and resources."

Thus Congress requires the park to base noise-related permitting decisions on scientific information. This statutory guidance further emphasizes the value of collecting defensible ambient and bioacoustic measurements for the purposes of management. (See *Research: Natural Ambience*, and *Research: Supporting Data: Bioacoustic Data* for more information on these research areas.)

The remainder of this section will follow the management-by-objectives framework (Manning et al. 2015). Several sections are devoted to the first step of the framework. This involves identifying park-specific acoustic management objectives that are authorized by law, regulation, or policy. Then the appropriate indicators and standards of quality can be selected. The second step of the management-by-objectives framework (Fig. 11) will be discussed in the '*Monitoring*' section of this document. Finally, implementation of management practices will be discussed.

The Management-By-Objectives Framework



Figure 11. Management-by-objective framework, adapted from *Manning et al. 2015*.

Management Objectives

Management objectives for the acoustic environment are best formulated by park staff intimately familiar with the issues of the landscape and seascape. The Glacier Bay Foundation Statement, as a summary of statutory authorization, is an excellent text from which to derive these objectives.

The Foundation Statement outlines Significance Statements that are related to the protection of acoustic resources:

1) Large, contiguous, intact ecosystems that are “dominated by natural processes.”

This implies Glacier Bay protects ecosystems where animal communication is largely natural and animals are not unduly displaced or restricted from their natural behaviors because of human noise. Furthermore, the words ‘large’, ‘contiguous’, and ‘intact’ suggest that protecting vast, connected ecological corridors should be seriously considered as a management objective of the park. Acoustics is a study unified across terrestrial and underwater environments, so the description above includes both terrestrial and marine ecosystems.

2) Wilderness.

As Glacier Bay was congressionally designated as “*one of the largest units of the national wilderness preservation system*” (NPS 2010), a reasonable management objective would be to protect proportionally large areas of solitude, one of the four qualities of wilderness character. Likewise, wilderness management further authorizes biological management objectives. The park should also follow the directives of Management Policies 2006 § 6.3.7 (NPS 2006) and manage acoustical resources of wilderness for non-degradation.

3) Tlingit cultural and spiritual significance.

When evaluating the integrity of a cultural landscape, NPS staff rate aspects such as ‘Setting’ or ‘Feeling’. Setting is defined as *“the physical environment of a historic property that illustrates the character of the place.”* Feeling is defined as an area’s *“expression of the aesthetic or historic sense of a particular period of time”* (NPS 1991). The acoustic environment of an area is a key component of the integrity of ‘Setting’ or ‘Feeling’ of a landscape.

Consultation with local Tlingit people will provide the park with greater understanding of the role the acoustic environment plays in managing for cultural and spiritual significance. Additionally, Tlingit people may provide the park with insight as to whether underwater acoustic environments - which humans don’t experience directly - may be significant for cultural reasons.

4) Visitor experience.

One of the reasons people love National Parks is the opportunity they present to enjoy tranquil natural beauty. Visitors have repeatedly asserted that they value hearing the sounds of nature as part of their park experience and that motorized noise detracts from that enjoyment (see *annotated bibliography on visitor experience and soundscapes* Pilcher and Turina 2010, also Roggenbuck et al. 1993, Miller 1995, Newman et al. 2014, Newman et al. 2015). Furthermore, federal case law has recently clarified language in the Organic Act, reminding us that, *“visitor enjoyment as used in the statute refers to visitor enjoyment of park scenery, wildlife, and natural and historic objects that are to be preserved. As used in this sense, visitor enjoyment does not refer to visitor enjoyment of outdoor recreational activities.”* (Southern Utah Wilderness Alliance v. Dabney 2000). In other words, the NPS protects parks for enjoyment of the resources parks were created for, not for enjoyment of recreational activities *per se*. Thus GBNPP managers should ensure that opportunities for the enjoyment of the natural acoustic environment are not superseded by motorized use for its own sake. ANILCA provides further reasons for access, but qualifies that such access should not be *“detrimental to the resource values of the unit or area”* (Public Law 96-487, § 1110).

See ‘Attachment I: Review of Glacier Bay Foundation Statement’ for additional discussion of each of these points.

The section ‘Research: Sampling: Spatial Sampling’ discusses how acoustic inventories are designed to suit monitoring objectives. If GBNPP intends to conduct status and trends monitoring, it should plan for an inventory project that can provide an administrative record of the current range of conditions within frontcountry and wilderness areas of GBNPP. Such data will provide a defensible rationale for desired future conditions, especially considering the NPS non-degradation policy as per Director’s Order #41 (NPS 2013b).

Indicators and Standards

In a complex world, we seek information. That is, data that have been contextualized (Wurman 2009). Selecting the numeric lens through which data are interpreted is critical when legal decision-making is based on scientific research. Park managers ultimately seek to understand the natural environment, and if necessary protect it by changing human behavior. To do so they rely on indicators of environmental quality: “*measurable, manageable variables that are proxies for management objectives*” (Manning 2015). A clear and well-documented process of indicator selection allows park managers to avoid the accusation of arbitrary or capricious decision-making under the Administrative Procedures Act (Pub.L. 79-404, 5 U.S. C. §703).

Like a series of high-grade optical lenses, an indicator of quality should minimize distortion in the decision-making process. The NPS Visitor Experience and Resource Protection (VERP) Handbook describes many general attributes of high-quality indicators (NPS 1997, pg. 61 - 62). These include measurement concerns, such as *objectivity*, *repeatability*, or *sensitivity*. They also include pragmatic concerns, such as *significance*, *specificity* (to the system being studied), or *resilience* (the responsiveness of the indicator to management action).

In the field of acoustics many indicators may be used. Truing these to the ecological paradigm is currently a major undertaking of the NPS and wider academic community. Though the ideal indicator will vary by application, key qualities are beginning to become clear. This document proposes a novel conceptual model by which high-quality indicators for the acoustic environment may be chosen (Figure 12):

Essential issues an acoustic indicator must address:

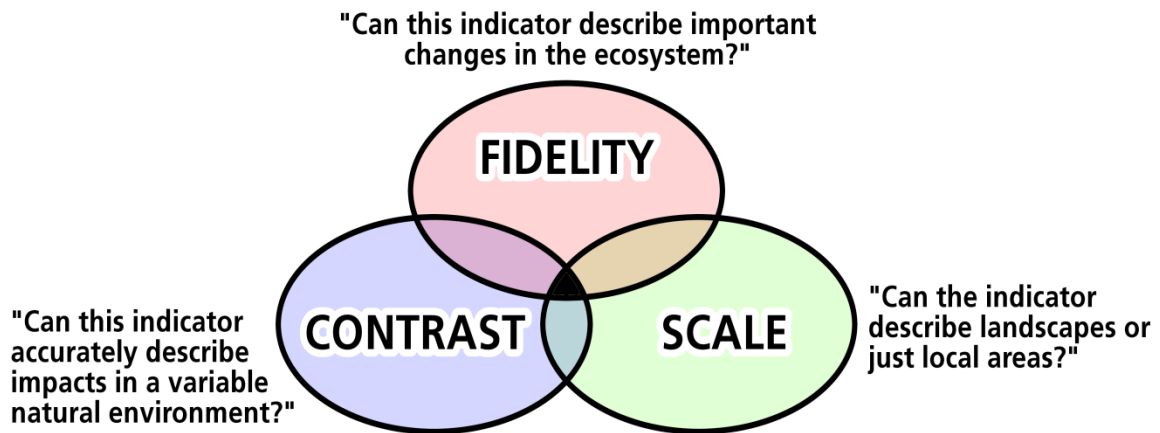


Figure 12. Essential issues an acoustic indicator must address: fidelity, contrast, and scale.

- 1) **Scale:** high-quality indicators are scaled to the acoustic energy of the source being managed. This issue maps to the VERP indicator qualities of *sensitivity*, *resilience*, and *reliability*.
- 2) **Contrast:** high-quality indicators are not unduly biased by changes in the natural acoustic environment. Indicators vary greatly in their sensitivity and thus identifying those that can be monitored most accurately is the preferred strategy for the park. This issue maps to the VERP indicator qualities of *repeatability*, *objectivity*, *sensitivity* and *resilience*.
- 3) **Fidelity:** high-quality indicators have supporting research such that standards (thresholds at which action should occur) are based on functional effects of noise to the natural environment or visitor experience. This issue maps to the VERP indicator qualities of *significance*, *specificity*, and *relation to the resource of concern*.

Scale

“Theoretical ecology, and theoretical science more generally, relates processes that occur on different scales of space, time, and organizational complexity. Understanding patterns in terms of the processes that produce them is the essence of science, and is the key to the development of principles for management” (Levin 1992).

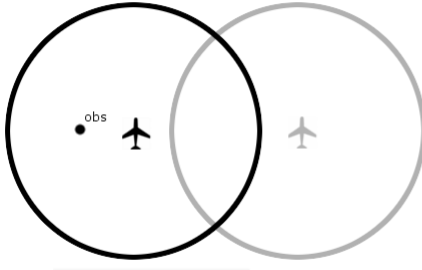
Given the same terrain and propagation media, the volume over which a sound can be detected scales with the power of the source (*for a detailed discussion of this topic see the section Research: Sampling: Spatial Sampling*). For this reason, highly-energetic human sources like aircraft or vessels are detectable over much larger areas than most natural sounds.

Issues of scale pose a tradeoff in the selection of acoustic indicators. This concept is illustrated in Figure 13, which shows the expected values of three indicator categories as a function of offset from an observer. Offset is expressed in terms of source radius, r . The indicator categories include those based on noise *detection*, those based on noise *duration*, and those based on the *energy* at a receiver location.

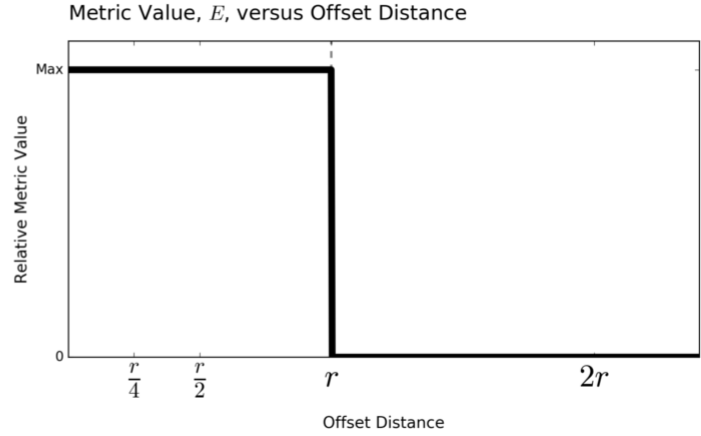
- **Detection-based metrics** are counts or rates, and binary in nature. If the source passes within the source radius, r , it is counted - else it is not.
- **Duration-based metrics** have to do with how long the source is detectable. Thus, they are proportional to a length of the chord traced by an observer through the source footprint.
- **Energy-based metrics** express how acoustic energy is spread out over space. They are usually expressed in logarithmic terms and so decrease by a power relationship to distance. Occasionally they are expressed as information metrics (Shannon 1948), which are dimensionless.

Note that in practice, indicators often span multiple categories. For example, Equivalent Sound Pressure Level (L_{eq}) - as the average energy level over the duration of an event - obviously depends on both energy *and* duration. Therefore, the scaling response for L_{eq} is more complicated than the pure categories shown in Figure 13.

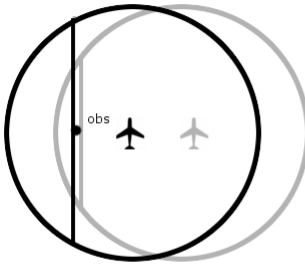
Detection-Based Metrics



$$E \propto r_{source}$$

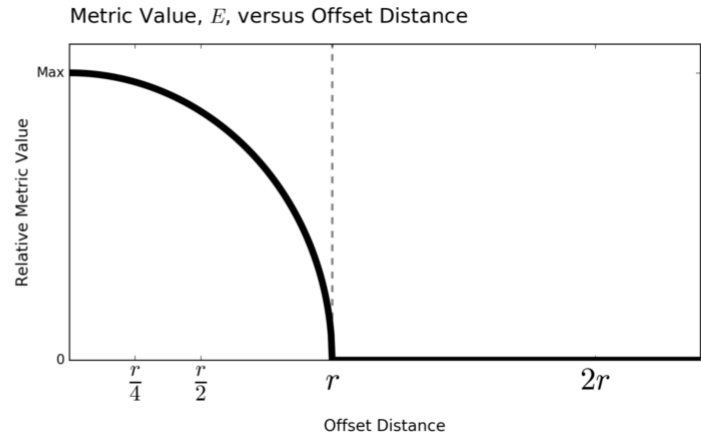


Duration-Based Metrics

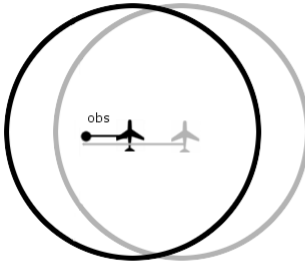


$$E \propto 2\sqrt{r_{source}^2 - x_{offset}^2}$$

"chord length"



Energy-Based Metrics



$$E \propto 10 \log_{10}\left(\frac{1}{2\pi x_{offset}^2}\right) + r_{source}$$

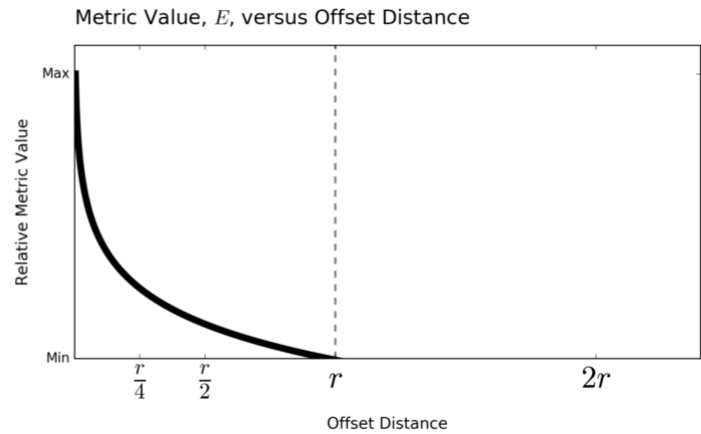


Figure 13. Expected values for basic categories of acoustic indicator as a function of offset distance, x_{offset} . The left-hand side shows a physical depiction of the measure (black) along with a symbolic representation of the scaling principle as the source moves away from the observer (gray). The plots show how the expected value of the metric, E , decreases with displacement from an observer in terms of the source radius, r . The radius corresponds to the limits of detectability for the acoustic environment of the observer, and is equivalent to $\frac{1}{2} \ell_{source}$ from the section *Spatial Sampling*, above, Figure 5.

Scale matters to management. The section ‘*Research: Spatial Sampling*’ has already discussed how issues of scale govern the ability to use inference across management areas. Detection-based metrics reflect the limits of a source’s acoustic footprint, and for GBNPP would represent the most inferential power for the least amount of sampling density. The tradeoff is that detection-based metrics are insensitive to small changes in source position, which makes them less useful for quantifying the effects of subtle actions. Energy-based metrics are the most sensitive way to measure change when a source is moved but doesn’t become inaudible. Generally speaking, indicators that summarize the loudest features of a sound will be more sensitive to small changes in space than indicators that try to summarize features over the entire duration of the event. If the park anticipates managing acoustic resources by moving sources in space, it should consider energy-based metrics like Maximum SPL ($L_{\max}$) or Sound Exposure Level (SEL) in planning documents. Principles of scale are equally useful for understanding metrics in both underwater and terrestrial environments (Southall et al. 2007, Frankel and Gabriele *In press*).

The scientific literature also warns managers to acknowledge the role that scale plays in describing sounds temporally, suggesting that long-term averages are mostly useful for describing chronic noise impacts, and that intermittent sources should be described on an event-by-event basis (Barber et al. 2011). The same authors further suggest that, “*any metric that averages over long periods does not represent how animals process sound.*”

Contrast

The measurement of noise impacts is dependent on the natural ambient energy of an environment (Moore 2012, Wickens 2002, Betchkal and Hoffman 2016, *for further discussion see also the section Research: An Ecological Paradigm of Acoustics*). This is the principle of contrast applied to acoustics. Consider the following example, where the same noise source is gradually masked by natural background energy:

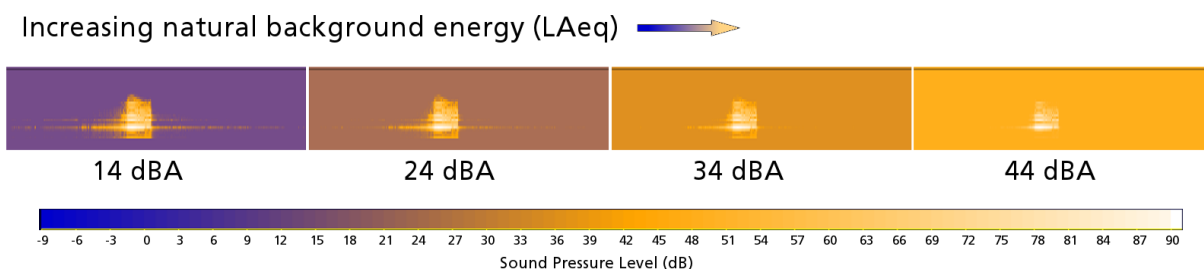


Figure 14. Noise gradually masked by natural ambience. The vertical axis of each spectrogram is frequency (from 12.5 to 20000 Hz), the horizontal axis is time (each spectrogram is 9 minutes long), and sound pressure level values are represented with a color scale (dark blue is quiet and yellow/white is loud.)

The graphic above shows an aircraft source gradually masked by natural ambience. In other words, a physical scenario where everything about the source and its trajectory remains the same but the ecosystem changes. Conceptually, the effect of changing background ambience is to reduce the size of the source footprint and its radius (*see Figure 13 for expected effects on metrics*). With increases in background level we expect to observe the following:

1. Decreases in noise event duration.
2. Decreases in the rate of event detection (as less-powerful events are no longer detected.)
3. Increases in the average energy of events (as less powerful events are no longer detected.)

For a specific noise event, duration-based metrics are the most sensitive to changes in contrast. Both the observed and maximum-attainable values of these metrics change steadily with the size of the source footprint. Energy-based metrics are less sensitive to changes in background because their maximum value is independent of contrast. The most robust energy-based metrics are those that emphasize the most energetic portions of the event (such as $L_{\max}$ or SEL). When background energy exceeds the maximum energy of the source, the event is no longer detected. Thus, detection-based metrics are equivalent to an energy metric that emphasizes the absolute maximum energy of the source. This makes detection-based metrics the most robust to changes in contrast.

When managing an entire category of sources (such as ‘vessels’ or ‘propeller aircraft’), parks usually write standards that encompass all noise events of that type. Issues of contrast apply to these categorical summaries as well. The simplest case occurs when managing roads, rivers, or other one-dimensional traffic flows. These cases represent a nearly constant source offset distance, and summaries may be reported the same as individual events. However, in cases where sources can move over the landscape in two or three dimensions, further attention to issues of contrast is necessary. When source offset distances are variable, changes in contrast may have pronounced effects on the categorical summary. These effects are dependent on the geometry of the traffic flow. (*The reader should convince themselves by considering the dependence of acoustic metrics on offset distance, x_{offset} as shown in Figure 13.*) Thus data describing the movement of noise sources through space may be helpful when implementing management action related to vessels, snowmachines, ORVs, or aircraft.

Acoustic information metrics - a category of energy-based metrics - behave similarly to categorical summaries in their response to changes in contrast. Most of these measures are based on Shannon Entropy, and thus, variability (Shannon 1948; Towsey 2013). Increasing background energy limits the variability of measured SPL values, and decreases the observed value of the information metric. Thus acoustic information metrics are relatively sensitive to changes in contrast and some measure of ambience should be reported along with them.

The issue of contrast is especially important when monitoring sites through time. For example, a rainy year may increase the acoustic power of flowing water near to the site, or lower wind speeds may reduce the energy dissipated by vegetation. Such variability suggests indicators that control for changes in the natural acoustic environment are preferred for monitoring purposes.

Finally, though this section has focused on changes in contrast due to natural background energy, changes can also be manifested by the measurement system, itself. In this way, the noise floor or digital sampling regime may also influence the observed value of acoustic metrics. Comparisons across measurement systems are possible (and at times necessary due to advances in technology or protocol), but should always be attempted with care to avoid bias.

Fidelity

Along with indicators of quality come *standards*, or thresholds at which management action should occur. Director’s Order #47 emphasizes the development of standards when it states that park superintendents must define the desired future conditions of the acoustic environment. To date, two parks have concrete examples of desired future conditions for the acoustic environment written into plans: Zion and Denali. For Zion, the desired future condition is expressed in the GMP generally, stating, “*Natural sounds predominate in [Zion National Park]. Visitors have opportunities throughout most of the park to experience natural sounds in an unimpaired condition. The sounds of civilization are generally confined to developed areas*” (NPS 2010c). All of Zion’s standards for the acoustic environment stem from this statement. For Denali, desired future conditions are expressed in the park’s GMP in terms of spatially specific acoustic standards (NPS 2006b). Thus each management zone has its own desired condition. Standards for both parks make use of VERP Handbook guidance, creating standards that are *quantitative, time and space bounded, expressed as a probability, impact-oriented, and realistic* (NPS 1997, pg. 68 - 69). Note that realistic standards may be achieved “*many years in the future*” and thus the standard “*would be used to measure long-term improvement in conditions.*”

Arbitrary standards detached from meaning are unlikely to change human behavior (Sunstein 2008). Instead, standards should rely on studies that link a measured value of an indicator to a meaningful functional effect on an ecosystem. In fact, a continuum of standards across these functional effects can be used very effectively to manage parks. An example of several well-documented functional effects are included in Table 1, below in terms of A-weighted equivalent sound pressure levels (*see ‘Attachment 3: Glossary* for more information on this metric). Many additional indicators could be developed from recommendations for the underwater environment (Southall et al. 2007, NMFS 2016).

Noise level (dBA)	Metric	Relevance
35	LA _{eq,1s}	Blood pressure and heart rate increase in sleeping humans (Haralabidis et al., 2008), maximum background noise level inside classrooms (ANSI Standard S12.60)
40	LA _{eq*}	Decline in species diversity (Proppe et al. 2013, Shannon et al. 2015)
45	LA _{eq,1s}	World Health Organization’s recommendation for maximum noise levels inside bedrooms (Berglund et al. 1999)
52	LA _{eq,1s}	Speech interference for interpretive programs (U.S. Environmental Protection Agency 1974)
60	LA _{eq,1s}	Speech interruption for normal conversation (U.S. Environmental Protection Agency 1974)

Table 1. Key sound level values and the effects of sound pressure levels on humans and wildlife.

Summary of Indicators

The following table summarizes a number of acoustic indicators. Note that indicators are related to one another in such a way that if multiple indicators are used careful attention to standards will be necessary to make sure that they are not incompatible.

Indicator	Units	Dimension	Definition	Benefits / Drawbacks
Percent Time Above (%TA)	% + dBA, % + dBT	Energy, Time	The percentage of a sample that exceeds a given Sound Pressure Level (SPL).	Is easily linked to functional effects when conducting modelling analyses; can be calculated without noise event annotation.
Event Rate	Events Per Unit Time	Time	The number of noise events normalized by the length of the sample.	Linear response to changes in traffic rate which tends to deemphasize impacts in areas with lower rate; sensitive to annotation error.
Noise Free Interval (NFI)	Hours, Minutes	Time	The time between when one noise event stops to when the next one starts. Usually expressed as an average or median.	Sensitive only to important changes in traffic rate / natural ambience; true to experience of animals; varies slowly over the landscape thus is an ideal indicator for spatial interpolation (generalization).
Percent Time Audible	%	Time	The percentage of the entire sampling period for which motorized sources were audible.	Moderately influenced by changes in natural ambience; may be well-suited to meso-scale changes in route position; sensitive to annotation error.
Maximum SPL (Lmax)	dBA, dBT	Energy	The maximum 1-second SPL sample during a noise event.	Volatile: highest levels change rapidly with small changes in position; aggregations are sensitive to contrast errors; useful for describing small changes in route position.
Equivalent Level (Leq)	Unweighted or A-weighted decibels (dB, dBA)	Energy, Time	The total amount of acoustic energy contained in an event normalized by the length of the event. Time-averaged acoustic level.	Frequently used for social science dose response work (Anderson et al. 2011, Rapoza et al. 2015). Sensitive to changes in background ambience.
Sound Exposure Level (SEL)	A or T-weighted decibels (dBA, dBT)	Energy	The total amount of acoustic energy contained in an event normalized by time. Usually normalized to 1 second. The ‘energy dose’ of the event.	Robust to changes in natural ambience; facilitates the comparison of events of differing in length; has been criticized as being difficult to explain.

Table 2. A description of acoustic indicators, including their name, measurement units, primary dimension(s), a written definition, and a few of the benefits or drawbacks in use.

Management Practices

The practice of addressing noise from park operations, commercial services, visitor activities, and research is a sensitive topic that requires consistent treatment at the local level. The laws, regulations, and policies that authorize the management of acoustic resources have been described earlier in this section. Acoustics-related management objectives are realized through the day-to-day activities and decisions of NPS staff at GBNPP.

NPS Internal Practices

An expedient means by which to achieve management objectives in GBNPP involves educating and changing the behavior of NPS staff and stewardship partners (researchers, educators, permit holders, and contractors). Paying attention to noise impacts within our own operations is a major step towards NPS staff internalizing the value of protecting the acoustic environment. Internal measures focus on incorporating Best Available Technologies and Best Management Practices into daily operations (NPS 2017). GBNPP staff will undoubtedly vary in how they internalize their obligation to protect acoustic resources, but awareness within the NPS workforce as a whole is increasing rapidly. Regular internal communication of the concepts within this document can do much to cultivate a competent, creative team of stewards. The following list provides ideas of where to begin:

- 1) **Compliance** with the Wilderness Act, National Historic Preservation Act (NHPA), and National Environmental Policy Act (NEPA) all involve analyses of effects on the acoustic environment to some extent. Minimum requirements analyses (MRAs) of proposed administrative and research activities in wilderness should address the potential for noise impacts on wilderness character. Along with determining whether an activity is necessary, MRAs identify the minimum activity necessary to achieve the project objectives in ways that optimally protect the natural acoustic environment. Cultural Landscape Reports developed under NHPA guidance should include a section on the acoustic environment's effect on 'Setting' or 'Feeling' of a landscape - only in this way can cultural soundscapes be protected through Section 106 compliance later on. NEPA documents should recognize that the acoustic environment has intrinsic value that is separate from its interactions with humans and wildlife (Fristrup et al. 2009). Impact analyses should define and address this value. Impacts to the intrinsic value of the acoustic environment should be assessed by examining the potential effects of a proposed action's noise on the natural ambient sound level. For example, if a proposed action will generate a noise level of 65 dBA, and the natural ambient sound level is 30 dBA, then the impact to the acoustic environment is based on a change of 35 dBA. The magnitude of the impact is based on this change in the context of other factors such as management goals and objectives, the presence of sensitive resources (e.g., threatened and endangered species), and visitor enjoyment of the acoustic environment. A rich description of the treatment of acoustic concepts within the context of NEPA can be found in Reference Manual #47 part 5 'Impact Assessment' (NPS 2017).
- 2) **Park Operations** should consider purchasing equipment that represents the best available technology for minimizing noise emissions. Technical specifications for items such as generators, chainsaws, or backup alarms can be found in the *NPS Acoustical Toolbox* (NPS 2010b).

Furthermore, GBNPP may wish to participate in the NPS Quiet Parks Program (<https://www.nps.gov/subjects/sound/quietparksprogram.htm>). The newly-launched Quiet Parks Program helps park units to identify sources of noise and their impacts, implement retrofits and noise-reducing behaviors, measure the effects of the mitigation activities, and develop a plan for long-term noise reduction. Such an approach might be especially fruitful for the facilities at Bartlett Cove. (In 2017, Denali National Park and Preserve requested funding to retrofit its fleet of vehicles with quieter, safer next-generation backup alarms and was granted 30% of the funding from the Quiet Parks Program.)

- 3) **Commercial Services.** Management Policies 2006 § 10.2.4.9 provides an excellent reminder that concessions contracts represent a *stewardship* relationship as well as a business relationship, stating, “*Concessioners are required to comply with applicable provisions of all laws, regulations, and policies that apply to natural and cultural resource protection.*” Concession contracts represent a formal and mutually-beneficial partnership between a business owner and the government. As such, it is a responsibility of the NPS to assure that acoustic resource protection is adequately treated in contractual language such that these businesses act in the best interest of the public and help steward GBNPP for future generations. The policy of the NPS is clear with respect to commercial use authorizations (CUAs) as well. The commercial service must: be an appropriate use of the park, have ‘minimal impact on park resources and values’, and be ‘consistent with the purpose(s) for which the unit was established, as well as all applicable management plans, park policies, and regulations’.

External Affairs

Park policies related to public or subsistence-related transportation are complex topics that must be carefully considered under provisions of the Organic Act and/or ANILCA. They will almost necessarily exceed the administrative thresholds for NEPA analysis. As mentioned earlier, one of the main purposes of this document is to support the development of GBNPP’s Wilderness Stewardship Plan, as well as the Frontcountry Management Plan. The park’s management objectives for the acoustic environment should also be incorporated into unit-level transportation plans, commercial service plans, and resource stewardship strategies.

Though also requiring care, the communication of soundscape topics can be deeply inspiring to the public and an excellent way to engage the media on park management topics. The ‘*Communication/Outreach*’ section of this document reiterates that much of management practice is, in fact, engaging other people in conversation and sharing new ideas about protecting natural ecosystems.

3. Monitoring

Prerequisites

In the words of the NPS Inventory and Monitoring program, “*to be truly institutionalized, a monitoring program needs to be sufficiently and formally integrated into the key operations (e.g., decision-making and planning), such that it helps the agency achieve its mission and goals*” (Fancy and Bennetts 2012). Thus, clear management objectives and indicators of quality are prerequisite to a successful monitoring program.

Furthermore, an appropriately extensive baseline inventory effort is required before acoustical monitoring can begin. The number of baseline soundscape studies has increased steadily over the last two decades (Betchkal 2016), but the number of parks prepared to monitor indicators of quality are few. In the Alaska region a number of parks are closing in on the monitoring phase for terrestrial acoustics, including Wrangell - St. Elias (repeat data and burgeoning Backcountry Management Plan), Kenai Fjords (repeat data and burgeoning Exit Glacier Management Plan), Katmai (inventory data and developing Backcountry Management Plan), and Gates of the Arctic (inventory data and proposed Ambler Road development with right-of-way provisions). Glacier Bay, too, has collected preliminary inventory data and has proposed a timeline for the publication of a Wilderness Stewardship Plan.

The collection of additional inventory data in GBNPP is the common thread connecting the research, management, and monitoring sections of this document. Such data are crucial to writing an articulate plan and managing with efficiency and grace. Inventory design should advance by the techniques described in ‘*Research: Sampling*’ in a form that suits the goals of the park’s Wilderness Stewardship Plan. Because this plan will be relevant to almost the entire surface area of the park, management should review the section ‘*Management: Management Objectives*’ and consider the value of an inventory that provides an spatially-widespread baseline of the current range of acoustic conditions. If other plans or actions are anticipated in the near future, their goals should also inform the design of the inventory sample. Articulating acoustic goals is the ideal ‘next step’ for the park’s management team (Reynolds et al. 2016).

With the converging trajectories of many Alaskan parks in mind, NSNSD has approached the development of a long-term monitoring strategy by focusing on Alaskan data collected to monitor the effects of management action (Betchkal 2013), also referred to as ‘*effectiveness monitoring*’ (Reynolds et al. 2016). In previous decades research on acoustic monitoring has focused on long-term energy-based metrics (Schomer 1979, Schomer 1981, Makarewicz 2012). Such approaches are sufficient for densely-populated areas where noise is ever-present. GBNPP recognizes a different reality: some acoustic energy experienced in the park is intrinsic and natural. Noise impacts are measured relative to this. Such a duality complicates monitoring in natural settings. Observed changes in resource condition can be caused by two different things: changes in human behavior, or changes in the natural acoustic environment (see ‘*Management: Indicators and Standards: Contrast*’, Figure 14). The methodologies to monitor noise in a changing natural acoustic environment are burgeoning, but until they are finalized NSNSD can only provide broad recommendations for a monitoring plan.

Glacier Bay's underwater acoustics program is unique in the NPS. The park has a large catalog of inventory data. The value of these data for ambient documentation has yet to be fully determined at some sites. Any monitoring program that Glacier Bay adopts undoubtedly has the potential to shape the wider NPS underwater monitoring schema. Thankfully the mathematics required to treat both terrestrial and underwater samples are similar, so many of the ideas being applied to terrestrial acoustics can be used for underwater data sets as well. To do this, data must be accessible for computation, another organizational step GBNPP can take to inform its monitoring plan.

Collecting Monitoring Data

Underwater

The clearest example of monitoring the underwater environment of Glacier Bay is the hydrophone deployed at Bartlett Cove. The instrument has been deployed since 2000, and is the premier underwater acoustics data set in the NPS. Its location in the bay guarantees that vessels entering or exiting the bay will be documented. Continued logging has provided opportunities to describe inter-annual variation (Kipple and Gabriele 2003, McKenna et al. 2017). Longer-term trend analysis could also be conducted.

Another possibility involves revisiting locations where ambient spectra were sampled by Charles Malme (Malme et al. 1982). This task will require a digitization effort, and some understanding of the instruments used to make the original measurements (i.e., their noise floor and dynamic range). A thoughtful comparison with measurements made with other systems could provide an unprecedented insight on the effects of glacial retreat on the acoustic environment of marine mammals.

As mentioned in '*Research: Supporting Data*', monitoring may also involve developing a robust way to collect source data. The park may wish to maintain a subscription to the Marine Exchange of Alaska's vessel tracking system or implement a land-based system for logging transmissions of the Automatic Identification System (AIS). This system allows for records on the identity, type, position, course, speed, navigational status of certain watercraft in Glacier Bay (33 C.F.R § 164.46) to be collected in support of monitoring projects.

Terrestrial

The clearest example of current monitoring in terrestrial environments involves the monitoring of avian phenology near Bartlett Cove (Buxton et al. 2016). These efforts over the long term offer the possibility of tracking climate effects on avian life - both at the local level and within the wider context of the Pacific Northwest region.

Revisiting sites sampled in 2011 (Lynch 2012, Figure 4) is another possibility for monitoring, but is only helpful if the original method can be shown to provide accurate measurements of natural ambient levels. For terrestrial work, the park is still in the inventory phase, as described in '*Research: Summary*'.

4. Communication/Outreach

“Educational efforts will generate in park visitors and the general public... ...a greater understanding of the National Park Service mission to preserve resources and values in national parks, including natural sounds, solitude, and tranquility.”

- The Nature of Sound, NPS Sound Education Plan, 1999

“In dismissing the effects of noise, we dismiss the importance of the small creature and the small human moment, an attitude with environmental and cultural costs that are anything but small. Not least of all we're dismissing intimacy: the firsthand knowledge and love of living things that can never come exclusively through the eye, the screen, the windshield—or on the run.”

- Garret Kiezer, Smithsonian Magazine, 2008

For nearly two decades the NPS has sought to communicate the importance of sounds. The fundamental mode is directly through the unimpaired landscape, itself. No human voice can articulate the timelessness of a natural landscape like silence can. Nor is it fruitful to rephrase the urgency of dawn chorus on an early summer's morning. Some experiences are best left unguided. Our role in communication, then, is twofold: first, protect natural acoustic environments for active listening. Second, raise awareness of the importance of intact acoustic environments to the GBNPP ecosystem and our human societies, beyond. Both communication tasks interlock with the other. An intimate park experience is an act of self-learning. A conversation with park staff can widen that experience to the context of the ecosystem, connecting that person's personal experiences to the natural world.

The scale over which the NPS communicates acoustical concepts is vast. At the most local it could involve GBNPP staff discussing details of a noise mitigation effort, scoping an implementation plan, or reviewing a project for wilderness compliance. Often these local-scale conversations are practical in nature and require some level of technical fluency. The same staff may then turn around and engage visitors from around the globe. Such conversations are often inspirational in nature and supported by an intimate appreciation of the natural landscape. A hybrid style is required when developing material for the public that addresses management action. NEPA documents, press releases, or public presentations facilitate public dialog when they can clearly connect the authority of the government to the relevance of the natural world.

Narrative

The following narrative provides storytelling ideas distilled from this document. It progresses from stillness, to sound, and finally, to noise:

Moments of stillness punctuate life in this kinetic and constantly changing world. The Tlingit noun *k'áatl'* is used to describe quiet things and quiet people. It is derived from a root-word meaning “to stop” (Twitchell 2016), equivalent to the etymology of the English word *quiet*, with

root “to be at rest.” In contemporary times the people of the United States continue to assert that places like parks exist in part to nurture such stillness within each of us as individuals (Pilcher 2010, NPS 2006).

Of course, nature isn’t always still. The experience of the Glacier Bay landscape is constantly sculpted by the energy of water, rain, wind, and rock. Powerful storms, lightning or avalanches can dazzle. Or destroy. Yet despite the intensity of the physical environment, an abundance of animal life fills the park with sound of motion and vocalization. All these varied sound sources – both abiotic and biotic – combine to form acoustic environments. Communicating sound as part of the grander ecosystem process of energy flow exercises the perspective of the landscape as *system* instead of just *aesthetic* (Meinig 1979). Sounds are capable of evoking an incredibly personal sense of *place* (Schafer 1977; Cresswell 2004). Whether negative or positive, such personal attachments to the landscape are not easily forgotten.

In 1981 Charles Malme and his crew of researchers recognized that Glacier Bay was different than surrounding waters in having less persistence of watercraft noise (Malme 1981). Continuing to actively manage for non-degradation is surprisingly similar to the artistry of a film soundtrack. *“You have to imagine the hundred musicians on stage in order for their silence to mean anything. You have to work with the psychic pressure exerted by the instruments or sounds that are not playing”* (Murch 2005). We live in a world full of motorized noise, but in parks our policy ultimately calls for sacrifice, humility, and restraint when it comes to protecting resources (Management Policies 2006 § 1.4.3).

Communicating the impact of noise on natural environments is further complicated by the symbolism of noise as a “sign of strength, power, and progress.” Such beliefs are contradicted by engineers who usually see noise as a symbol of inefficiency, instead - and work to remove it from their inventions (Bijsterveld 2008). Both concepts have a role in the narrative of Wilderness as *“an area where the earth and its community of life are untrammelled by man, where man himself is a visitor who does not remain,”* and which has *“outstanding opportunities for solitude”* (Pub. Law 88-577). In an age where earth’s ecosystems are dominated by human activities (Ellis 2011, Vitousek 1997) the state of quietude in remote areas of Alaska tells a story of the extent to which fossil fuels and motorized transportation have changed the planet. Such a realization also suggests the appreciating value of quietude to future generations (Iyer 2011) should quiet technologies and practices fail to be adopted.

Communication Objectives

The following ideas may help GBNPP develop communication objectives related to the importance of natural soundscapes:

1. Encouraging visitors to use their ears in directly witnessing the beauty of the park. An NPS “Ways to Enjoy Natural Sound” rack card speaks to these types of activities.
https://www.nps.gov/subjects/sound/upload/RackCard_WaystoEnjoyNaturalSound.pdf

2. Share narratives on the importance of quietude to the Tlingit people, and for the Preserve provide a depiction of ANILCA-provided “traditional activities” as part of an Alaskan subsistence lifestyle. When appropriate, traditional songs or music may also facilitate this dialog by evoking the spiritual significance of the land and the legends that manifest themselves there.
3. Elucidate ways that concessioners and NPS staff have mitigated noise. Make efforts to recognize the role of concessioners as joint stewards of Glacier Bay and part of the eventual solution to noise issues. Share these stories broadly with others, both internally and externally.
4. Engage local experts to speak on sounds and quietude. Hank Lentfer (Gustavus) and Richard Nelson (Sitka) are tremendous resources on this topic, and have provided a voluminous library of high-quality sound sources for any park purpose. They’ve entitled the work “Voices of Glacier Bay”, and much of the finest content is currently available on the park website: <https://www.nps.gov/glba/learn/nature/soundscape.htm>
5. Inspire cruise ship passengers during routine interpretive talks.
6. Help visitors absorb information at their own pace with signs, exhibits, or placards as part of a new visitor center at Bartlett Cove. This concept could be vetted through the current Frontcountry Management Plan process in 2018.
7. Hold specially-scheduled talks or ‘hands-on’ events (avian auditory ID workshop, sound recording workshop, listening sessions as part of ranger-led walks, hydrophones piped through speakers of a CUA vessel, artist-in-residence composers, etc.).
8. Develop a press kit including an ecologically-oriented program summary, noise issues brief, and compelling audio files.
9. Include text within all relevant NEPA documents, especially within ‘Affected Environment’ sections. Necessarily this will also involve the use of clear speech and graphics for public meetings or hearings.
10. Continue publishing scientific research in a variety of journals and engage a variety of fields in topics related to acoustics. Many scientific projects within Glacier Bay - or the wider world - have bearing on the emergent phenomena of sound. (For example, oceanography and/or climatology datasets are important inputs to sound models.)
11. Continue to engage educators in topics related to acoustics in Glacier Bay, an excellent example of which can be found here: <https://www.nps.gov/teachers/classrooms/glacier-bay-acoustics-lesson-three-on-the-trail-of-a-whale.htm>
12. Provide ‘inreach’ to park staff, either on an individual basis, or in a group setting. As mentioned in the Management section of this document, addressing noise from park operations, commercial services, and visiting researchers are sensitive topics that require consistent local advocacy within the NPS organization.

More ideas for communication and outreach are available on the Natural Sounds and Night Skies Division website (<https://www.nps.gov/subjects/sound/resources.htm> and <https://www.nps.gov/subjects/sound/teaching.htm>) including the ‘*Power of Sounds Interpretive Handbook*’.

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Attachment 1: Review of Glacier Bay Foundation Statement

The Glacier Bay National Park and Preserve Foundation Statement (NPS 2010) was reviewed for references that identify or affirm the significance of soundscapes as a fundamental purpose, resource, and value, and that high-quality soundscapes are important for meeting park purposes. References in Significance Statements to solitude, wilderness values, natural settings, remote settings, wildlife protection, etc., are related to soundscapes and are discussed below. These references demonstrate the role of the acoustic environment and soundscapes in terms of visitor experience, biotic communities, and related issues.

Park Purpose: The purpose of Glacier Bay National Park and Preserve is to protect a dynamic tidewater glacial landscape and associated natural successional processes for science and discovery in a wilderness setting.

Significance Statements

1. Glacier Bay National Park and Preserve fosters unique opportunities for scientific studies of tidewater glacial landscapes and associated natural successional processes.
2. Glacier Bay National Park and Preserve gathers and protects records of exploration, scientific endeavor and human use, and provides for understanding the landscape through the lens of human experience and study.
3. Glacier Bay National Park and Preserve protects ecological integrity by preserving a diversity of large, contiguous, intact ecosystems (from the highest peaks of the Fairweather Range to the open Pacific Ocean and sheltered inland fjords) that are strongly dominated by natural processes.
4. 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.
5. Glacier Bay National Park preserves one of the largest units of the national wilderness preservation system, encompassing more than 2.7 million acres of glacially influenced marine, terrestrial, and freshwater ecosystems.
6. Glacier Bay National Park preserves one of the largest (nearly 600,000 acres) areas of federally protected marine ecosystems in Alaska (including submerged lands) against which other less protected marine ecosystems can be compared.
7. Glacier Bay National Park and Preserve lies within two Tlingit ancestral homelands that are of cultural and spiritual significance to living communities today.
8. Glacier Bay National Park provides diverse opportunities for visitors to experience a dynamic tidewater glacial landscape.
9. Glacier Bay National Park and Preserve protects the remote and wild character of the Alsek River as a significant route of discovery and migration through the coastal mountain range to the Pacific Ocean.

10. Glacier Bay National Preserve protects a productive, evolving, glacial outwash ecosystem at the terminus of the Alsek River and provides a setting for subsistence uses, commercial fishing activities, and hunting as outlined by the Alaska National Interest Lands Conservation Act (ANILCA).

A. Preserve and protect: Significance Statements 3, 4, 5, 6

Protecting a tidewater glacial landscape includes preserving the ecological processes and interactions that depend upon or are affected by sound. (For more information on the effects of noise on wildlife please consult the NPS-compiled bibliography on the topic, Turina and Barber 2011.) The composition of biological and physical sounds is expected to change during the process of ecological succession following glacial retreat.

B. Scientific Studies: Significance Statements 1, 2, 6

Research on acoustics in natural settings is an emerging science. The National Park Service is on the leading edge of innovation in the field, and works intimately with academic researchers to develop engineering and analytical tools. Seventeen years of terrestrial research in Alaska has helped select equipment and sampling approaches appropriate to environments of the state (Ambrose and Burson 2004).

Glacier Bay, itself, has a strong history of conducting and facilitating research. It has distinguished itself among parks in conducting underwater acoustics studies over the course of 36 years (Malme et al. 1982, Kipple 2002, Kipple and Gabriele 2003, Kipple and Gabriele 2004, Gabriele et al. 2010). It has committed to a phenological monitoring program using acoustic recorders (Buxton et al. 2016) . It has conducted a preliminary baseline documentation of terrestrial sounds (Lynch 2011).

Research is a fundamental component of a successful soundscape program. However, because of the scale and history of previous efforts, defining a successful research program is a far more subtle challenge for Glacier Bay than for a park without any acoustical data.

C. Wilderness: Significance Statements 5, 9

The Wilderness Act mandates a feeling of solitude and a primitive setting (Public Law 88-577). In order to meet these two conditions it is important to consider both sight and sound. Locations across the Glacier Bay Wilderness may experience conditions where human noise predominates. In areas near water the experience of solitude is most diminished by noise from vessels (Lynch 2012). Farther inland, solitude is expected to be diminished most by noise from aircraft.

D. Preserving the cultural and spiritual significance of the Tlingit ancestral homelands: Significance Statement 7

Director's Order #47 requires Superintendents to assess whether sounds are appropriate to park purposes. Just as noise is detrimental to wilderness or wildlife purposes of Glacier Bay, acoustic resources are integral in ensuring an authentic experience of cultural and traditional landscapes, resources, and values. Culturally significant sites and resources can be diminished by unwanted or inappropriate noise.

When considering the integrity of a cultural landscape NPS staff rate such aspects as 'Setting' or 'Feeling'. Setting is defined as "the physical environment of a historic property that illustrates the character of the place." Feeling is defined as an area's "expression of the aesthetic or historic sense of a

particular period of time” (NPS 1991). This information helps the park appreciate and preserve the Tlingit experience of the landscape using all possible senses, including sound.

E. Discover/experience (experiencing sounds of nature is a very important reason for visiting national parks): Significance Statement 8

In numerous social science studies park visitors have repeatedly asserted the value of natural quietude (*see annotated bibliography on visitor experience and soundscapes* Pilcher and Turina in 2010, also Roggenbuck et al. 1993, Miller 1995, Newman et al. 2014, Newman et al. 2015).

F. Protect remote and wild character of Alsek River: Significance Statement 10

GBNPP protects the pristine nature of the river, preserves vast, intact ecosystems that retain their physical and biological components, and participates with Canadian partners in preserving the wild pristine character of the river (NPS 1989). The ecological paradigm of acoustics recognizes the sound as an integral part of an intact ecosystem. Thus the Alsek should also be inventoried and managed to maintain a pristine natural acoustic environment.

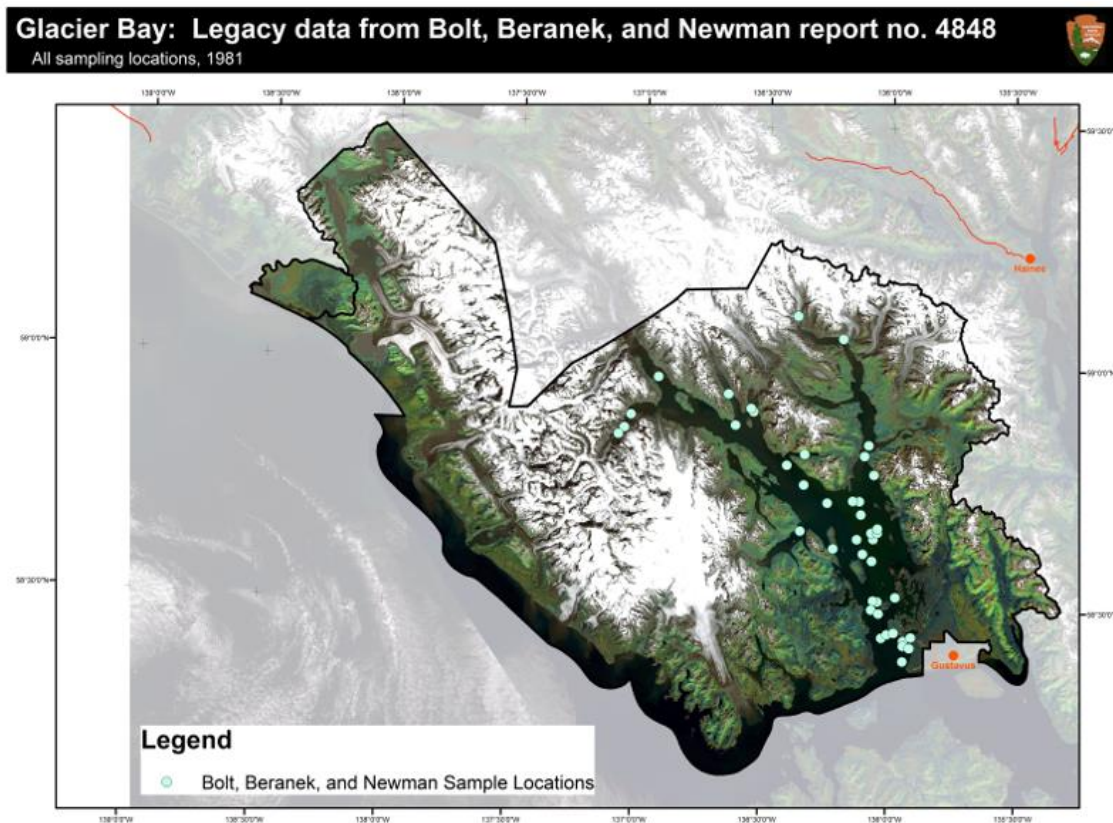
Attachment 2: Georeferencing Legacy Underwater Acoustics Metadata

The earliest underwater acoustics work in Glacier Bay was conducted in 1981 by the NPS in conjunction with NOAA's National Marine Fisheries Service. It was prompted by observations that there were fewer humpback whales in the bay. To research this possibility the NPS contracted three researchers from the acoustics firm Bolt Beranek and Newman (BBN) to define the acoustic environment of the bay, characterize noise sources, record noise sources, and identify acoustical characteristics that may have been causing whales to leave the bay.

To date, data and metadata related to the BBN project exist only in hard-copy form. Herein we explore the potential for exhuming a 36-year-old record of Glacier Bay's underwater acoustic environment.

The first step was to digitize site locations and accompanying metadata. To do so, NPS staff created an uncompressed 600 dpi scan of the sampling map from a hard copy of the BBN report. Then the ArcMap 10.4 Georeferencing toolbar was used to rectify the image to a NAD_1983_UTM_Zone_8N special reference system. A total of 75 control points allowed the scan to be transformed via a 3rd order polynomial fit to an estimated global accuracy of ± 106.8 meters.

The final digitized points from 38 site locations in Glacier Bay are shown in the map, below:



Metadata for each site has been added to the shapefile selection table, including (*if documented*): Point ID, Date, Marine Chart Reference, Water Depth (in fathoms), Bottom Type, Tide Direction, Wind Speed (mph), Measurement System Type, Hydrophone Depth (m), Transmission Loss Range (mi), Reverberation Measurement Type, Range to Recorded Whales, Hydrophone Utilized, and whether or not a plot of ambient is included for the site.

Attachment 3: Glossary

Acoustical Environment: The actual physical sound resources, regardless of audibility, at a particular location.

Acoustical Zones: Areas of similar vegetation, land cover, topography, elevation, distance to flowing water, and climate that are assumed to contain similar sources of natural sounds.

Amplitude: The instantaneous magnitude of an oscillating quantity such as sound pressure. The peak amplitude is the maximum value.

Audibility: The ability of animals with normal hearing, including humans, to hear a given sound. Audibility is affected by the hearing ability of the animal, the masking effects of other sound sources, and by the frequency content and amplitude of the sound.

Decibel (dB): A logarithmic measure of acoustic or electrical signals. The formula for computing decibels is: $10(\text{Log}10(\text{sound level/reference sound level}))$. 0 dB represents the lowest sound level that can be perceived by a human with healthy hearing. Conversational speech is about 65 dB.

dBA: A-weighted decibel. A-weighted sum of sound energy across the range of human hearing. Humans do not hear well at very low or very high frequencies. Weighting adjusts for this.

Extrinsic Sound: Any sound not forming an essential part of the park purpose, or a sound originating from outside the park boundary.

Frequency: The number of times per second that the sine wave of sound repeats itself. It can be expressed in cycles per second, or Hertz (Hz). Frequency equals Speed of Sound/ Wavelength.

Hearing Range (frequency): By convention, an average, healthy, young person is said to hear frequencies from approximately 20Hz to 20000 Hz.

Hertz (Hz): A measure of frequency, or the number of pressure variations per second. A person with normal hearing can hear between 20 Hz and 20,000 Hz.

Human-Caused Sound: Any sound that is attributable to a human source.

Intrinsic sound: A sound which belongs to a park by its very nature, based on the park unit purposes, values, and establishing legislation. The term “intrinsic sounds” has replaced “natural sounds” in order to incorporate both cultural and historic sounds as part of the acoustic environment of a park.

Listening Area (sometimes synonymous with **Active Space**): The range or limit of one’s hearing capabilities. Just as smog limits the visual horizon, so noise limits the acoustic horizon.

Leq: Energy Equivalent Sound Level. The level of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period.

Lx: A metric used to describe acoustic data. It represents the level of sound exceeded x percent of the time during the given measurement period. Thus, L50 is the level exceeded 50% of the time (it is also referred to as existing ambient).

Lnat: An estimate of what the acoustical environment might sound like without the contribution of extrinsic (anthropogenic) sounds.

Masking: The process by which the threshold of audibility for a sound is raised by the presence of another sound.

Natural Ambient (Acoustic) Energy: the acoustic pressure energy in an environment without human-caused sounds present; the ecological baseline.

Noise-Free Interval: The period of time between noise events (not silence).

Noise: Sound which is unwanted, either because of its effects on humans, its effect on fatigue or malfunction of physical equipment, or its interference with the perception or detection of other sounds (Source: McGraw Hill Dictionary of Scientific and Technical Terms).

Noise Floor: The measure of the signal created from the sum of all the electrical noise sources and unwanted signals within a measurement system.

Off-site Listening: The systematic identification of sound sources using digital recordings previously collected in the field.

Sound: Variations in local pressure that propagate through a medium (e.g. the atmosphere) in space and time.

Soundscape: Human perception of the acoustical environment.

Sound Pressure: The difference between instantaneous pressure and local barometric pressure. Measured in Pascals (Pa), Newtons per square meter, which is the metric equivalent of pounds per square inch.

Sound Pressure Level (SPL): A calibrated measure of sound level, expressed in decibels, and referred to an atmospheric standard of 20 micro Pascals.

Time Audible: The amount of time that a sound source is audible to a human with normal hearing.

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