Available online at www.sciencedirect.com

ScienceDirect

Applied Acoustics 69 (2008) 77–92

applied acoustics

www.elsevier.com/locate/apacoust

US National Parks and management of park soundscapes: A review

Nicholas P. Miller *

Harris Miller Miller & Hanson Inc., 77 South Bedford Street, Burlington, MA 01803, USA

Received 8 August 2005; received in revised form 27 March 2007; accepted 27 April 2007
Available online 28 June 2007

Abstract

For more than 17 years the US National Park Service has been developing the methods, processes and skills required to effectively manage the soundscapes of the National Parks. The author and his company have had the honor of providing technical acoustics related assistance throughout much of this period. This article presents his reflections on the process, its technical and political complexities, and provides what are hoped to be useful syntheses derived both from his experiences and from past and recent discussions with many of the participants. Specifically, the article describes the fundamental questions that need to be answered for management of natural soundscapes, the types of noise issues that arise in parks, the need for quantitative data, approaches to identifying, measuring and collecting those data, and a suggested approach for developing criteria designed to effectively manage sounds in natural areas.

Keywords: Parks; Soundscape; Natural sounds; Audibility; Dose–response

Contents

* Tel.: +1 781 229 0707; fax: +1 781 229 7939.
E-mail address: nmiller@hmmh.com.

0003-682X/$ - see front matter
doi:10.1016/j.apacoust.2007.04.008

1. Origins of interest in natural soundscapes

In the US, the National Parks have been the primary focus of efforts to understand, manage and preserve or restore natural sound environments.[1] Since at least the end of World War II, there has been explicit expression of public interest in preserving the opportunity for experiencing "natural quiet" or the sounds of nature, unencumbered by the sounds of human activities [1]. Since humans visit parks and can make noise, however, providing both opportunities to visit the Parks and to experience an abundance of natural sounds leads directly to conflicting interests. In fact, the 1916 law that created the National Park Service (NPS) implicitly establishes this type of conflict as part of the NPS mission:

> "The service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." [2]

In other words, the traditional NPS mission was twofold: conservation of resources and providing for their enjoyment by visitors. (More recent legislation has emphasized the role of preservation of resources [3].) Ironically, the more NPS provides for access by visitors, the greater the risk that resources will be impaired – that is: degraded, disturbed, damaged or even stolen. The resources that NPS works to preserve vary from park unit to park unit since each unit is established by the US Congress to preserve some specific collection of unique characteristics or qualities. Resources can be scenic natural areas, historic or cultural structures or sites, unique natural formations, bodies of water or wildlife and wildlife habitats. "Natural quiet" or natural sounds have been recognized in law and policy as a park resource and thus natural sounds are as clear a subject for management and preservation or restoration as is any other park resource.

This article presents the author's perspective on the issues associated with preservation of natural sounds in parks and wildernesses based on his 15 years of providing acoustics consulting assistance, primarily to the NPS, but also to the US Air Force and the US Federal Aviation Administration. It seems every person has an opinion about the value of preserving "natural quiet" and the author does as well. But the attempt has been made here to provide an objective review of the issues, not only because the usefulness of any information or concepts offered here is greater if they are presented objectively, but also because all opinions contain in their essence legitimacy.

2. The fundamental questions

To set the stage for the following discussions, we need to acknowledge three fundamental questions that must ultimately be answered if management of natural sounds is to be seriously addressed. The most difficult question that must be answered is: *How much human produced sound is appropriate in a National Park setting?*[2] The simple answer of "none" is generally not feasible. But whether the answer is "none" or "a little" or "some" or "quite a bit" the end result will be the placing of limitations on the activities of some individuals or groups. Though it may not be true in all cultures, in the US most limitations on individual actions need to be legally defensible. A viable defense means that,

[1] In this discussion, and in most discussions, the expressions "natural sound environment", "natural quiet", "natural sounds", "natural soundscape", and "natural ambient", and possibly some similar expressions are used to mean the same acoustic environment: what you might expect to hear if you are hiking in a remote wilderness and stop to listen, i.e. only sounds produced by the natural outdoor environment. A survey conducted for the US Air Force revealed that park visitors seem to have no trouble understanding what terms like these, and specifically "natural quiet" mean. For specifics on this survey, see [13].

[2] For this discussion, "human-produced sounds" or "human sounds" means any non-natural sounds – any sounds produced by humans or human developed equipment or devices. Whether specific human-produced sounds are appropriate or inappropriate depends on the type of sound and the context. For example, the sound of a marching band or cannon fire may be completely appropriate at certain times at a Civil War battlefield.

among other things such as procedural requirements, limitations must be reasonable, and generally supported by a policy, a documented body of evidence and logic train, or historical precedent. Since little history of preservation of natural sounds exists (we are making history and all involved parties are well-aware of this), an articulated policy and a logical chain of evidence are necessary. For NPS, a policy of preservation is well-established, but the documented evidence and associated logic train for preservation of natural sounds have only recently begun to accumulate.

From this fundamental question, the second question becomes: *What logical chain of evidence is needed to support decisions about appropriate levels of human-produced sound?* Ultimately, the approach to answering this question requires identifying the true objectives of natural sounds preservation. For NPS, one of the initial main objectives identified has been limiting the "audibility" of inappropriate sounds. It is logical, and certainly easily understandable that the less human sounds are heard, the greater the time when only natural sounds are heard. This concept may have first originated in Hawaii Volcanoes National Park where the local resource manager began keeping track of how much of the time he could hear helicopter tours while sitting in a remote location near the Pu'u O'o cone on the east rift zone of Kilauea Volcano.

The defining application of audibility arose, however, from the problem posed by the US Congress to the Department of the Interior (DOI) and hence to NPS in The National Parks Overflights Act of 1987. This act required that the Secretary of the Interior identify actions related to aircraft overflights of the Grand Canyon that would "...provide for substantial restoration of the natural quiet and experience of the park..." [4]. NPS interpreted "substantial restoration of the natural quiet" to be hearing no aircraft for 75–100% of the day in at least 50% of the Grand Canyon [5].

As work on this goal proceeded, and the use of the concept of audibility became common in discussing management of natural sounds, other questions arose. What about the effects of human sounds on wildlife? Animals can have hearing thresholds different from those of humans [6]. Hence, should "audibility" be based only on human hearing? How is audibility of human sounds to be determined for current conditions and predicted for hypothetical future conditions? What is the current distribution in the Canyon of aircraft audibility? How can achievement of the "substantial restoration" goal be determined? Should all aircraft sound be counted in determining aircraft audibility in the Canyon, or only that produced by air tour aircraft?[3] As of this writing (June 2005) the primary focus has remained on considering human audibility, at least for aircraft overflights of the Grand Canyon, but other metrics as well as audibility are still being considered for assessing the soundscapes of the National Parks.

These questions have ultimately led to the third crucial question: *How are National Park soundscapes to be quantified?* It should be recognized from the outset that some people will view quantifying a natural soundscape as equivalent to trying to describe a Beethoven symphony with acoustic metrics. This view should not be dismissed, but acknowledged as identifying a fundamental validity. What really matters to those who are charged with managing park soundscapes and to those who find value in having opportunities to experience a predominantly natural soundscape, is what the soundscape should sound like – not the numbers that describe it.

In fact, a non-quantitative approach may have best suited the traditional NPS approach to management of the parks. Most important management decisions are initiated by the park superintendent. These are individuals with many years of experience working in and managing the National Parks. Historically, a superintendent will draw upon his or her experience, knowledge of the laws that define the National Park Service and its mission, knowledge of the laws establishing the specific park, quantitative and qualitative information developed by staff and others as part of the decision-making process. The process often requires considerable judgment by the Superintendent to fashion solutions that, in his or her judgment, will meet management goals and NPS policies. Usually this process is informed by public involvement. However, because of the restrictions on activities that management of human-produced sounds generally requires, an organized resistance to the restrictions developed, found this approach difficult to understand and expressed concern that it was too subjective, if not arbitrary. NPS found that developing quantitative measures of park soundscape would better define its positions and be more resistant to challenges, as well as provide metrics or indicators that could be measured to determine progress toward goals.

Hence, the NPS approach to managing sounds in the parks has evolved to finding a method for quantifying park soundscapes and identifying values of the metrics that will achieve management goals of preserving natural sounds and limiting inappropriate sounds. Whether audibility or some other metric is used, quantification can provide a seemingly more objective basis for defining current baseline conditions, setting goals and monitoring future changes in park soundscapes. It should be acknowledged, however, that quantification, even based on any amount of rigorously collected and analyzed data (called science), cannot provide answers to the fundamental question. Eventually, a policy decision needs to be made about how much human-produced sound is appropriate, whatever the metrics used. Quantification does, however, aid in building a series of logical steps that can be documented and

[3] Though the initial assumption was that the restoration effort would focus on tour aircraft, Public Law 100-91 [4] did not specifically identify tour aircraft. Also, a law suit filed in 2002 by the US Air Tour Association and others challenging the Federal Aviation Administration's limiting the number of air tours permitted to fly over the Canyon resulted in a ruling that, among other decisions, the exclusion of non-tour aircraft from consideration was arbitrary and capricious and required reconsideration. 298 F.3d 997.

defended. Quantification can permit using objective procedures to monitor progress – eliminating human judgment once the quantitative goals are established.

One very important consideration should be addressed in concert with selection of metrics and goals. A process should be established for regular review of the goals, whether progress is being made, and whether the quantitative goals are providing the expected results in terms of how the soundscape sounds. Noise metrics do not always relate well to human experience. Too many assumptions are contained in any metric and in any associated quantitative goal to expect that the desired future condition will always be exactly defined by a few admittedly simple numbers.

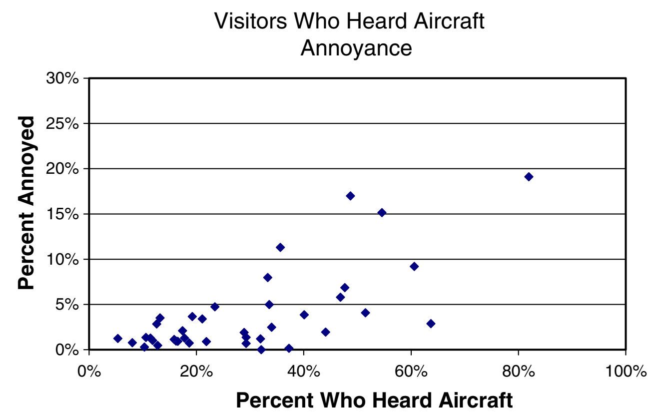

Fig. 1. Percent of visitors at each of 39 parks who heard aircraft and who reported aircraft noise moderately to extremely annoying.

3. Sources and scenarios

Many sources of human-produced sound can affect the soundscapes of the parks. Some that are used within the park may be subject to NPS control; those that are outside the parks generally are not within NPS jurisdiction. A few sources have been studied fairly extensively, while others have been reported almost anecdotally.

3.1. Aircraft

Aircraft operations, especially air tours, have been studied extensively. Aircraft flight operations in US airspace traditionally are subject only to the authority exercised by the US Federal Aviation Administration. Of the various types of aircraft operations, air tours over or near the parks have received the most attention and effort to understand how they affect parks and if and how their use can or should be managed [5]. A 1986 mid-air collision of tour aircraft over the Grand Canyon caused 25 fatalities and the US Congress passed Public Law 100-91 in 1987, The National Parks Overflights Act [4]. This act led to a detailed design of the airspace over Grand Canyon National Park and a continuing effort by NPS and FAA to develop an approach to manage tour aircraft over parks. That effort led to passage in 2000 of The National Parks Air Tour Management Act [7] that sets out a joint FAA/NPS process for developing "Air Tour Management Plans" (ATMPs) for any park where air tours operate. Currently there are reported to be approximately 107 National Parks that have air tours and that are subject to development of ATMPs [8].

In the author's experience, except for the Grand Canyon, air tours tend to fly nominal routes around or over a park, taking passengers to see specific areas of interest. In the Canyon, very specific routes and altitudes are specified by FAA regulation [9]. Tours may provide passengers with a recorded running commentary describing the park and the sites. From information gathered in Grand Canyon, Hawaii Volcanoes and Haleakala National Parks, between 88% and 97% of passengers report enjoying the experience very much or extremely. Ninety-six percent to Ninety-nine percent would recommend the air tour to others. Ninety-one percent to Ninety-six percent said that seeing the park from a unique perspective was a very or extremely important reason for taking the tour, while 49–58% said that limited time in the park was a very or extremely important reason for the taking the tour. Small percentages (3–6%) reported taking a tour because of health or physical limitations. In both Hawaii and the Grand Canyon, several hundred thousand visitors are reported to take air tours annually [5].

The reactions of visitors on the ground who might hear aircraft vary widely. A 1992 National Park System-wide park exit survey explored visitor awareness of and reactions to the sound of aircraft [10]. Visitors were first asked whether they had heard aircraft. Across 39 parks surveyed, between 8% and 82% reported hearing aircraft. Those who heard aircraft were asked whether they were bothered or annoyed and whether the sound of aircraft interfered with their "appreciation of the natural quiet and sounds of nature at the park". The answers to these questions, averaged for each of the 39 parks, are plotted in Figs. 1 and 2. These figures depict for each park the percent of visitors who heard aircraft and the percent of those who said they were affected. Each person who heard aircraft said how annoyed they were with the sound and how much the sound interfered with their appreciation of natural quiet.[4] In this context, annoyance was judged by visitors to be an emotion that may last for a while, while interference is an occurrence that ceases after the sound has passed. Interference does not always result in annoyance.

The 39 park survey had no independent measure of aircraft sound level which the visitors might have experienced. However, NPS, the FAA and the US Air Force all sponsored several "dose–response" surveys [11–13] for which simultaneous sound level measurements and visitor surveys

[4] Both annoyance and interference responses used five point scales: not at all, slightly, moderately, very and extremely. Visitors were considered annoyed or to have experienced interference if they answered moderately, very or extremely.

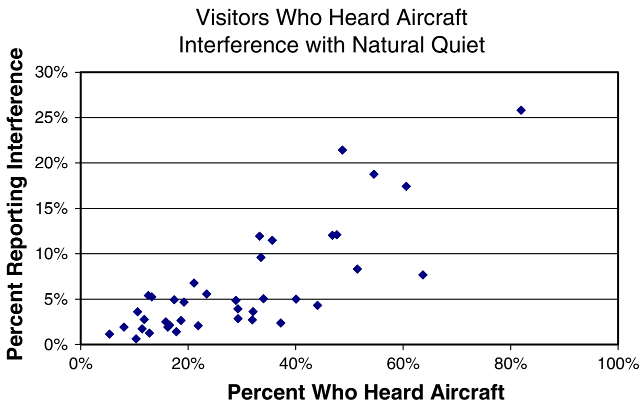

Fig. 2. Percent of visitors at each of 39 parks for whom aircraft sound interfered with appreciation of natural quiet moderately to extremely.

were conducted. (For a summary discussion of the method used, see [14].) These studies were at first regarded, and still are by some, as a means for setting policy relating to the fundamental question of how much human-produced (aircraft produced) sound is appropriate. We discuss the strengths and weakness of dose–response data in Section 5.2.

Air carrier jet aircraft, though receiving little attention compared with air tour operations, can be a significant contributor to the human produced sounds present in parks. Their presence over or near any park depends on the park's location relative to major air carrier airports and routes. Table 1 presents some results produced by observers logging which aircraft were audible as part of a dose–response study conducted in Bryce Canyon National Park [12] while Fig. 3 depicts jet flight tracks over the US produced by one hour of departures.

General aviation aircraft also fly near or over units of the National Park System. Their numbers vary considerably depending on the park unit's location relative to airports, flying conditions and areas of visual interest. Almost no data have been collected on general aviation operations relative to parks, but a series of brief measurements in 1993 across eight parks showed that numbers vary from one or two every few hours, to more than a dozen an hour. Numbers vary considerably also by time of day and season.

Table 1
Percent of hour different aircraft audible, Bryce Canyon NP

Date	Hour interval start time	Percent of hour aircraft audible			
		Helo	Jet	Prop	All aircraft
7/12/97	7:00	19	7	6	32
7/12/97	8:00	0	28	6	34
7/14/97	7:00	0	18	13	31
7/14/97	8:00	20	33	32	85
7/14/97	9:00	22	29	5	56
7/14/97	10:00	31	20	13	64
7/15/97	11:00	31	2	30	63
7/15/97	12:00	42	14	5	61
7/15/97	13:00	34	26	28	88
7/16/97	7:00	11	39	0	50
7/16/97	8:00	1	76	6	83
7/18/97	9:00	9	30	7	46
7/18/97	10:00	16	27	4	47

3.2. Snow machines

Because of their extensive use in Yellowstone and Grand Teton National Parks, snowmobile use was measured, modeled and analyzed for its effects on park resources, including the opportunity to experience the natural sounds of the park with the sound of snowmobiles limited in time and location. Litigation by various groups, first by environmental organizations, then by snowmobile manufacturers and users led finally to a temporary plan to limit the number of snowmobiles entering per day into the various portions of the parks, and to require that these snowmobiles would be commercially guided and comply with NPS identified Best Available Technology requirements that focus on exhaust emissions and noise levels [15]. Use of "snowcoaches" is also permitted. These are various types of multi-passenger vehicles equipped to travel over snow (see for example, Fig. 4). The effects of this limited use are being monitored to develop a long-term plan, scheduled to go into effect in the winter of 2007–2008.

It appears that the use of snowmobiles has dropped considerably. In Yellowstone NP, 720 snowmobiles are permitted per day, but an average of 258 entered per day during January and February 2004. During the winter of 2004–2005, the number of visitors on snowmobiles decreased 25% from 2003 to 2004 while the number of visitors using snowcoaches increased 14% for the same period [16].

3.3. Water craft

Though NPS sets limits on the sound levels produced by vessels operated on inland waters [17], the introduction and use of "personal water craft", PWC, (also called "jet skis") brought a new source of sound to many parks. The overall A-weighted sound levels, both in terms of maximum level and Sound Exposure Level, SEL, of a PWC can be quite similar to those of boats with standard outboard motors, however, the operating characteristics and spectra are quite different [18]. PWC are often used on limited areas of a waterway providing the rider with the opportunity to execute high speed turns and accelerations. Sound levels fluctuate rapidly, and the tonal components make its sound easily distinguishable from that of other types of watercraft. Users often rotate, one operating the PWC for a period, then a second using it – usually in a manner similar to that of the first rider. The result can be that visitors elsewhere or on the shore experience a continuous, repetitive pattern of recognizable sound events.

3.4. Road vehicles

Most parks provide easy access to road vehicles. Normally, the sound produced by such traffic is an expected

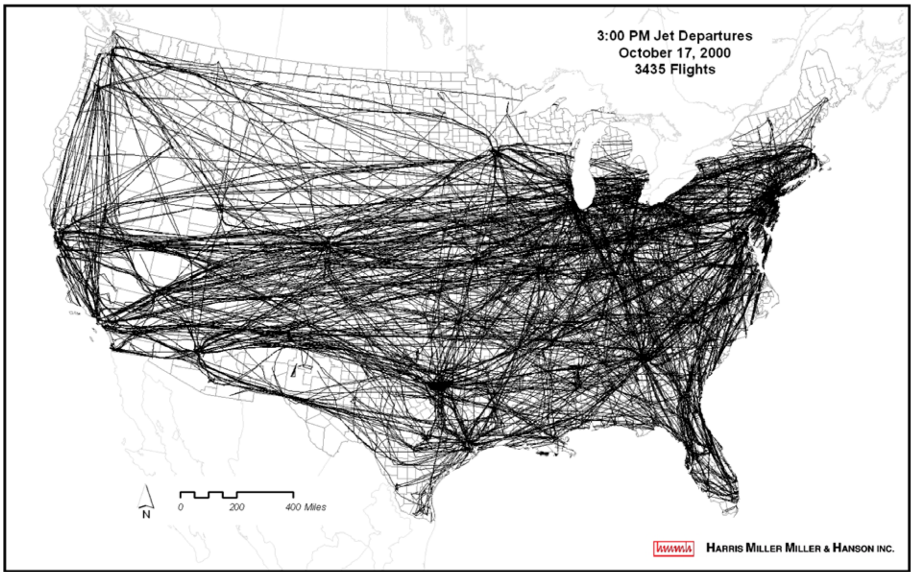

Fig. 3. One hour of commercial jet departures tracked to first stop.

Fig. 4. Example of snowcoach type vehicle.

part of the "front-country" areas where visitor activity is high. Management efforts, if required, are usually directed at relieving congestion. For example, the Zion Canyon Scenic Drive of Zion National Park is now accessible by shuttle bus only. Visitors must park at the Visitor's Center or leave their car in the near-by town. Significant portions of roadway in Grand Canyon and Denali National Parks are also off limits to private vehicles and Yosemite National Park may restrict access at peak visitation periods. Such limits serve to reduce congestion and improve the visitor experience in scenic areas, but also help to preserve a park's resources, including the natural soundscape.

Tour buses are common in the National Parks and their size, exhaust emissions and sound levels have made them subject of limitations in some of the parks. Idling of tour bus engines can be a disruption, both in terms of sound generated and exhaust fumes. Some parks regulate tour bus operations, as in Acadia National Park where idling of bus engines is restricted at the Jordan Pond House.

Various locations in the US annually host motorcycle rallies or meets. Major events, such as those in Sturgis, South Dakota, Motorcycle Week in Laconia, New Hampshire or Bike Week in Daytona Beach, Florida attract thousands of riders from across the country. National

Parks, either near-by or enroute provide attractive rides, and many attendees make a ride through the park part of their itinerary and the familiar exhaust sound of large displacement, low rpm bikes can become a part of the soundscape.

3.5. Resource extraction

Many of the National Parks are in wilderness areas and surrounded by unpopulated, often federally controlled lands. These surrounding areas may be available for extraction of resources such as coal, oil, gas, minerals and timber. All of these activities can produce sounds that may intrude into a park. Associated trucking, drilling, blasting, transportation vehicles including helicopters, and construction and process equipment are possible sources of sound. Two cycle engines used on chain saws and blasting can be heard miles from the activity and helicopter routes may pass near or over National Park lands [19].

4. Soundscape quantification

Faced with the necessity of quantifying park soundscapes, NPS has explored many approaches and faced difficult decisions that can affect policy implementation. This section describes some of the decisions that need to be addressed in quantifying park soundscapes, and the following section, Section 5, explores the question of determining criteria.

4.1. What to and how to measure

Measurements are required to: (1) determine existing conditions, (2) to provide information necessary for examining possible future scenarios, and (3) to monitor changes in the soundscape over time. Though there have been a number of efforts made to measure sound levels in National Parks ([20–29] to list a few, see [30] for a more complete listing), as of this writing there is no convincing argument to be made that measurements are not necessary or important if the soundscape is to be quantified. Certainly, findings indicate that there may be a consistency of natural sounds based on topography, vegetative cover, wind conditions and presence and type of water action, but it seems there is so much variation in even these characteristics, that it is easier to measure than to attempt to infer the natural sound levels of a given park location. Additionally, the number and sound levels of human-produced sounds are unique to each location and need to be measured in some way if a full characterization is the goal.

All discussions of what should be measured to quantify park soundscapes ultimately must address audibility: When can a person of normal hearing acuity detect the presence of human-produced sounds in a natural environment? Reliance on some measure of audibility presents significant issues, some are technical while some are policy related, but all will have to be addressed.

Probably the greatest motivation for using an audibility metric is its relevance to the primary issue as most people would define it. Managing park soundscapes means limiting the audibility of inappropriate human produced sounds. This type of definition is easy to explain and easy to understand.

4.1.1. Measurement of source audibility and level

Measurement of the audibility of sounds can be quite simple and require little more than a trained observer with a notepad and a watch. This method of using observers, sometimes referred to as Observer Based Source Identification Logging or OBSIL, has been used successfully in several studies [11–13,31]. Table 2 presents an example of the type of information that was acquired with OBSIL using a programmed Palm Top computer (Hewlett Packard 200LX) for the study of Ref. [31].

To summarize or characterize the results of any measurement of audibility, however, a metric is needed. The audibility metric most investigated has been "percent of time audible". It is a useful metric for describing how long sources are heard, particularly at the extremes of duration. For example, if human-produced sounds are audible for less than 5% of the time, it is likely that most people will judge such a soundscape as relatively pristine or natural. Conversely, if human produced sounds are audible 50–90% of the time at some location, then we would probably decide that it is not a place to expect solitude or escape from the sounds of civilization.

Percent of time audible has at least two short-comings, however. First, for intermediate values of audibility it may be misleading. To learn that snowmobiles are audible at Colter Bay in Grand Teton National Park for 20% of the time may lead us to expect that we will hear natural sounds for a reasonable amount of time. If the 20% results from hearing snowmobiles approximately one minute for every five minutes we are there, our experience will be quite different from our expectation. One proposed metric that might provide clearer information is the "noise-free interval" or NFI. The NFI is the duration of a continuous period when no human-produced sounds are audible. This metric has not been much tested, and it is unclear what statistic of this metric would be most informative. The author believes that, for a given period, the median NFI would likely communicate best what type of soundscape was experienced: half the time longer periods of only natural sounds would be audible, and half the time shorter periods.

The second short-coming of audibility is that it says nothing about the sound levels of any source. Fig. 5 provides an example. For this period of time, aircraft overflights were audible 21% of the time. There are four such overflights and their maximum A-weighted levels are 45–50 dB above the background levels. Hence, though 21% of the time overflights are audible suggests perhaps a moderate amount of aircraft noise, when they are audible they are loud enough to interfere with speech. To include

Table 2
Example of OBSIL log created using programmed palm top computer

National Park Service – Grand Canyon Model Validation – 295860.29					
Site:	4A – Horseshoe Mesa				12 September 1999
Time	Acoustic state	A/C type	A/C oper	Backgnd description	Comments
7:41:43	Beg log	***	***	***	NPM
7:42:50	Time chk	...	...	...	07 42 50
7:59:59	Aircraft	Prop	Other	***	Far to west
8:02:06					
8:02:51	Aircraft	Jet	Other	***	SW to NE
8:04:55	Natural	***	***	Wind/fol	Occ lite gusts
8:08:35	Aircraft	Helo	Tour	***	
8:10:14	Aircraft	Helo	Tour	***	Second heard before first ended
8:11:38	Aircraft	Prop	Other	***	Heard before second tour ended
8:14:50	Natural	***	***	Wind/fol	
8:15:14	Aircraft	Helo	Tour	***	
8:16:10	Aircraft	Helo	Tour	***	2 Helo bef first ended
8:18:25	Aircraft	Jet	Other	***	
8:18:54	Natural	***	***	Wind/ear	
8:23:57					Seems to be barely audible stuff, some tonal
8:25:38	Natural	***	***	Wind/fol	Lite gusts from S
8:27:47	Natural	***	***	Wind/ear	
8:29:59	Aircraft	Jet	Other	***	W to E
8:32:00	Aircraft	Jet	Other	***	Second jet, far to S
8:33:12	Natural	***	***	Wind/ear	
8:33:32	Aircraft	Jet	Other	***	Same jet to S
8:33:54	Natural	***	***	Wind/ear	
8:34:01	Aircraft	Prop	Other	***	To SE
8:34:47	Natural	***	***	Wind/fol	
8:35:25	Aircraft	Prop	Tour	***	
8:37:13	Aircraft	Prop	Tour	***	Heard bef pref gone
8:40:00	Aircraft	Prop	Other	***	
8:42:25	Aircraft	Jet	Other	***	E to W, S of site
8:43:53	Natural	***	***	Wind/fol	
8:45:16	Natural	***	***	Insects	When still, hear insect flight
8:46:42	Natural	***	***	Wind/fol	
8:47:08	Natural	***	***	Birds	Can hear aerodynamic sound of swifts
8:47:50	Aircraft	Helo	Tour	***	
8:50:10	Aircraft	Jet	Other	***	
8:50:57	Aircraft	Jet	Other	***	Overhead, E to W
8:53:24	Natural	***	***	Wind/fol	
8:53:39	Aircraft	Prp/Hel	Other	***	To SW

this additional information, typical maximums can be measured and provided.

Alternatively, an additional metric could be a decibel difference between the human-produced sounds and the background or natural ambient sound levels. For aircraft overflights of Fig. 5, the difference in equivalent levels between aircraft and background (in this case the levels when no human sounds were heard) is 29 dB. Hence, for the informed reader or observer, learning that aircraft are audible 29% of the time (21% plus 8%) and that the aircraft equivalent level is 29 dB greater than the natural background should begin to convey what type of soundscape might be experienced in this location. In truth, all the information in Fig. 5 helps to understand the soundscape at the particular site.

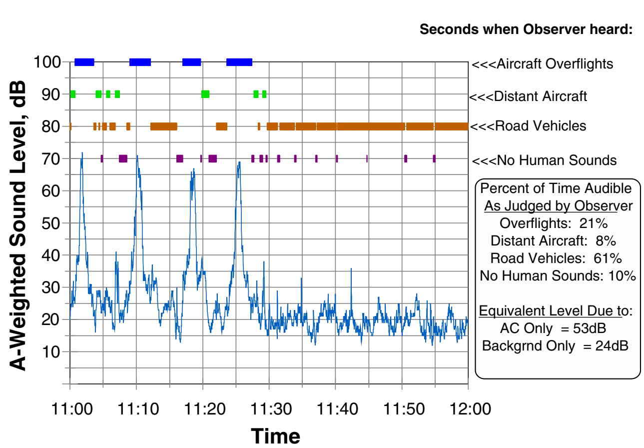

Fig. 5. Example A-weighted time history with observer log information.

Though information like that of Fig. 5 is very informative, it requires both sound monitoring instrumentation and an attentive observer and hence is demanding of both capital resources and labor and usually can be acquired for only relatively short and few periods of time.

For quantification of the complete soundscape – types of sources, their sound levels and their periods of audibility – new processes are required. Ideally, we would like unattended monitors that are capable of acting like a human by identifying each source and its audible duration. An initial attempt has been made to automate such source identification [32], but the task is a complex and challenging one, not likely to be satisfactorily accomplished soon.

As a suitable intermediate approach, a combination of sound level monitoring, OBSIL and sampling of digital audio (WAV) files has been used. Monitors are set up to collect continuous one-second 1/3 octave band levels and to periodically save a brief WAV file. The WAV files are later played back and sources identified. These files provide estimates of types of sources audible and amount of time they were present. OBSIL data can be used to supplement these measurement results.

4.1.2. Prediction of audibility

Audibility, or more formally "detection" is well understood for human hearing of a signal in a background of "noise" [33]. Equations are available that reasonably predict when a given signal will be detected by a human in the presence of noise [34]. Prediction, however, requires detailed knowledge of both the background or ambient

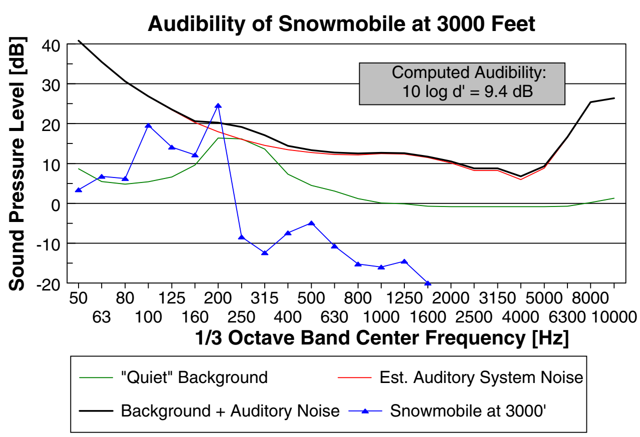

Fig. 6. Simplified depiction of audibility determination using a snowmobile spectrum and a "Quiet" background measured in yellowstone NP.

spectra and the source spectra. Fig. 6 suggests how this computation is done. It is essentially a computation of the signal to noise ratio (d' or "d prime") done in narrow bands usually comparable to 1/3 octave bands. When a signal has sufficient energy in one or more bands compared to the background, the signal becomes audible. In Fig. 6, the background levels are very quiet and below the estimated level of human auditory noise. Hence, both the background and the human auditory noise are combined to yield the masking spectrum. The audibility computation using this masking spectrum and that of the snowmobile results in a detectability level of 9.4 dB. The threshold of audibility derived from field observations occurs at about $10\log d' = 7$ dB [25].

To predict audibility of any source, a decision needs to be made about what "background" or "ambient" is appropriate. In locations where human sounds are heard only occasionally, the decision is an easy one, provided measurement procedures can identify when the "natural only" periods occur. For more complex soundscapes, such as those front-country locations where there may be almost constant traffic noise, or talking, identifying the proper ambient can be difficult and, in fact, involves policy decisions about what sounds are appropriate for the location.

Assuming that a proper ambient is identified, the appropriate metric of the ambient sound levels needs to be chosen. At a minimum, the ambient needs to be quantified in terms of 1/3 octave band levels. Ambient levels vary with time. Figs. 7 and 8 show two examples derived from approximately four months of monitoring in Hawaii Volcanoes National Park [29]. Each spectrum, depicted as a single line in these two figures, presents the median level in each of $33\frac{1}{3}$ octave bands from 12.5 Hz to 20 kHz for the hour between 2:00 p.m. and 3:00 p.m. In other words, each spectrum represents the median spectrum for that hour on one day.

These figures suggest the complexities of choosing an appropriate ambient level for prediction of audibility.

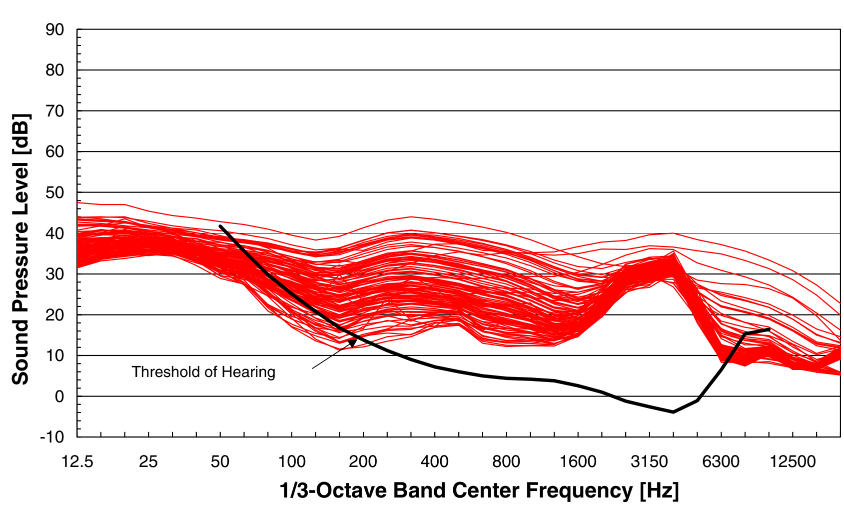

Fig. 7. Example background spectra, Hawaiian Rain Forest.

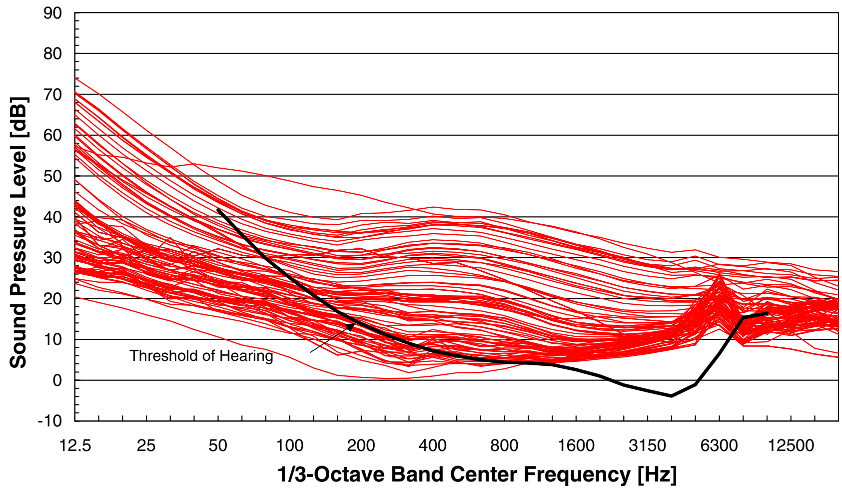

Fig. 8. Example background spectra, Hawaiian Open Woodland.

For these data the L_{50} or median value in each 1/3 octave band was used.

A time or times of day needs also to be chosen. Generally, the time can be based on the period(s) when the audibility of the source in question is either expected or of most concern. Since most human produced sources operate in diurnal patterns, selecting the time of day should not be too difficult. Having chosen, in this case a mid-afternoon hour, it is apparent that the levels vary considerably day-to-day. A median of all spectra might be selected, or a detailed analysis can show the spectra for just specific days of the week or for a specific week and an appropriate representation chosen. It may be helpful to include consideration of the source frequencies that are the main determinants of the audibility of the source. For example, most human-produced sounds, which are usually from engine powered equipment, have dominant tonal components between about 80 Hz and 300 Hz. Hence, this would be the range of frequencies where the ambient should be best known.

Spectra, like those of Figs. 7 and 8 when combined with OBSIL information can be quite revealing about the soundscape of a location. The location for the levels of Fig. 7 was in a rain forest, well protected from direct wind, but wind produced an audible and measurable rustle of foliage. The increase in levels between approximately 200 Hz and 1600 Hz is due largely to this sound. The rise in levels below 100 Hz is likely due to distant automotive traffic or possibly helicopters, though an observer would not have heard these sounds. Finally, the almost constant levels between 1600 Hz and 6300 Hz are due to bird song. The location for Fig. 8 was an open area and the microphone/windscreen was unshielded from direct wind. The levels below about 100 Hz are produced by wind induced pressure fluctuations at the microphone and do not represent acoustic sound. (This effect suggests strongly the value of collecting wind speed data along with sound level information, see Section 4.3.) Traffic produced sound levels are also apparent, but the high frequency levels in the 6300 Hz 1/3 octave band are produced by insects.

To predict audibility, the spectrum of the source also needs to be known. If the source is moving, which many are, audibility will be a function of time, and changing source levels due to changing distance should be modeled. One approach is to conduct controlled pass-by/fly-over measurements of the source and either use spectra as a function of direction or use the spectrum at the maximum level, and adjust it for distance in the modeling. The process is rather complex, but can be accomplished with spreadsheets. The US Federal Aviation Administration has included audibility calculations in its aircraft noise computer model, the Integrated Noise Model, INM, version 6.2.

4.1.3. Other issues associated with audibility

Audibility, as suggested, is a difficult metric to measure and to predict, but there are other issues raised by use of the use of audibility. The audibility metric, as discussed above, is based on human hearing and as mentioned earlier, wildlife are known to have hearing thresholds different from that of humans. Should additional measured levels, applicable to wildlife also be collected?

Use of audibility means that one source can affect large areas of a park. In park or wilderness areas, natural background levels can be very low – below the human threshold of hearing – so that sources may be audible at distances of 5–10 miles or even further. This phenomenon means that a single source may be audible over large areas of a park making control or management difficult by limiting the effectiveness of options other than total prohibition of operation. This widespread audibility means that compromise or acceptance of some degree of audibility is almost inevitable.

Use of audibility in such naturally quiet areas as parks also means that high altitude jet aircraft are likely to be a contributor to human produced sounds in many of the parks, see Fig. 3. In most cases, it is unlikely that these aircraft routes can be altered so that this source becomes an irreducible baseline condition for areas of some parks. If for some locations, all human-produced sounds are treated as equally inappropriate, how should other sources be treated when jet aircraft will also be audible – possibly for more of the time and at levels louder than those produced by the other sources?

4.2. Where to measure

Parks can be very large, containing thousands to millions of acres (Grand Canyon is about 1.2 million acres or about 4500 km^2), and there are over 300 units of the National Park system. Both within parks and from park to park, there are tremendous variations in geology, topography, vegetation, sensitive wildlife species, visitor activities, infrastructure or the lack of it, etc. Because there are so many factors, measurement sites must be purposefully selected based on park management experience and judgment.

The most efficient approach that has been tried is to divide the measurement site selection task into at least four essential decisions. First, define the various natural areas. Using primarily vegetation type, but also terrain, wind conditions and proximity and type of water, map out homogeneous areas of the park. Second, create an overlay of the locations or potential locations of sources of human-produced sounds. Some acoustics expertise will be required to estimate the likely geographical reach of the audibility of these sources.

Third, identify the areas of the park judged to be most sensitive to human-produced sounds. Of the four site location decisions, this is the only one that requires referral to policy and emphasizes why policy, at least in terms of desired soundscape conditions, should be articulated early in the soundscape management process. A full discussion of policy formation is provided below in Section 5, Determining Criteria.

Finally, fourth, consider ease of access. Sites that will be visited only once or twice can be less accessible than those that require regular visits over an extended period of time. The amount and weight of the instrumentation also needs to be considered. Is hiking necessary, and if so, what means are needed to transport the instrumentation?

4.3. How long to measure

Park soundscapes vary hour to hour, day-to-day and season to season. Fig. 9 shows two weeks of A-weighted sound level metrics and wind speed measured at the Hawaii Volcanoes Open Woodland site of Fig. 8. (In Fig. 9, NFC means ‘‘noise floor corrected’’ indicating that a process was used to correct low sound levels for the instrumentation noise floor. See Appendix A of Ref. [29].) The data for the first half of the period clearly demonstrate the high correlation of wind speed and measured levels. It is most likely that these data, because of the spurious sound levels caused by wind on the microphone windscreen, should be excluded from any determination of the site's ambient levels. In the latter days of the sample, the effects of insects are apparent. Throughout the time period, a diurnal pattern is evident. Best practice for determining required sampling times is to measure for an extended period, then compute confidence limits for the metrics of interest, using different numbers of contiguous days to determine how confidence is affected by the number of days measured. It is likely that such analysis would be necessary for each season of interest.

4.4. Instrumentation issues

Collection of soundscape data in parks raises several instrumentation issues not usually encountered in most measurements of environmental noise. First, park areas can be

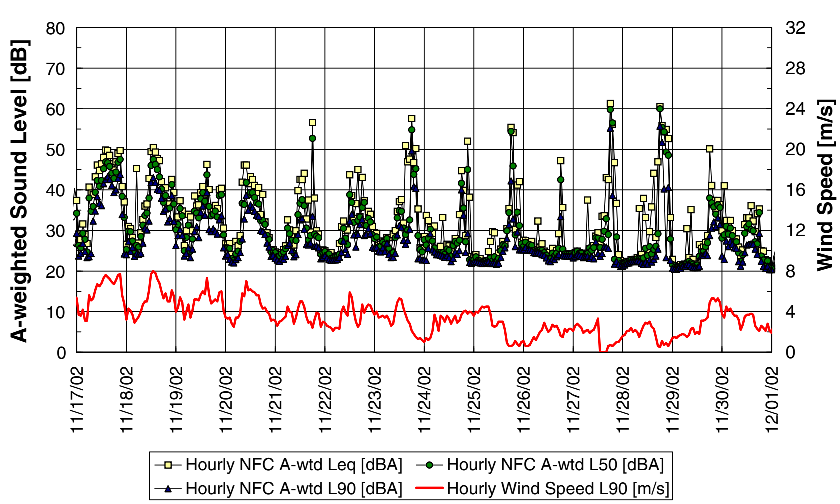

Fig. 9. Example sound level and wind speed time histories, Hawaiian Open Woodland.

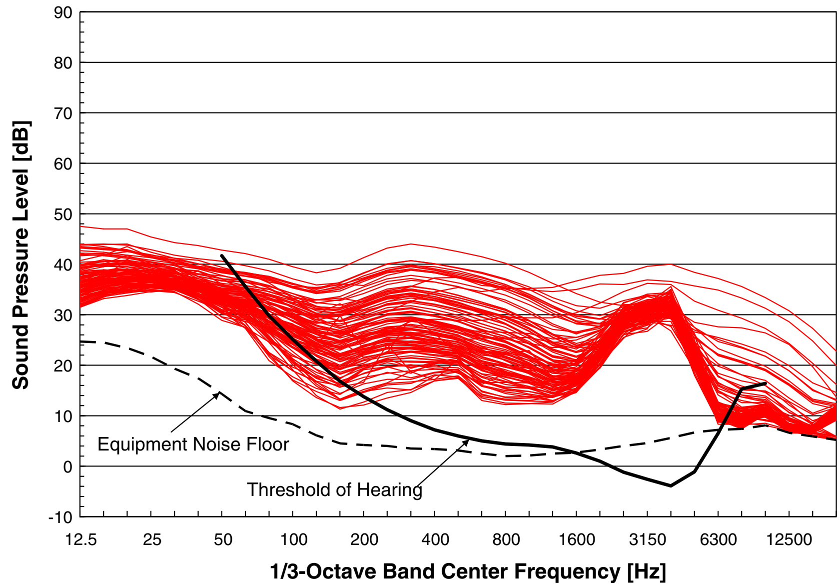

Fig. 10. Typical equipment noise floor compared with Hawaiian Rain Forest spectra.

exceedingly quiet. Most microphone systems have noise floors, which, in terms of A-weighted levels, will be higher than the A-weighted levels of the quietest periods and locations. These noise floor issues arise mainly at frequencies below about 100 Hz, see "Quiet" background in Fig. 6, and above 1000 Hz. Fig. 10 shows a typical instrument noise floor in relation to the data of Fig. 7. For these data, the noise floor is below the measured sound levels (recall that these are median levels for each hour plotted). The noise floor, however, is below the human threshold of hearing for all frequencies except between approximately 1600 Hz and 7000 Hz and hence will not always provide data in this range useful for audibility analyses. For very quiet background levels, such as those of Fig. 6, this instrumentation will not be capable of accurately measuring the levels, and a more sensitive (and more expensive) instrument will be needed.

Because park areas are quiet, even low wind speeds can cause sufficient turbulence around the microphone that spurious levels will be generated. Seven to ten mile per hour winds can produce apparent A-weighted sound levels in a standard $3\frac{1}{2}$ in diameter foam windscreen of about 35–40 dB (see Appendix A of Ref. [11]). Larger windscreens of 12–20 in. in diameter serve to lower the wind generated noise, with the larger one lowering the levels by 10–15 dB for winds under 10 miles per hour.

Power consumption, resistance to the weather, portability and length of time between site visits are all concerns not always encountered with measurements in populated areas. Complete solutions are gradually being developed with power supplied by solar cells, and weather-proof containers and connectors resisting rain, snow and humidity. Progress in miniaturization of recording and data storage devices will ultimately permit lighter, less bulky equipment and greater data storage capability so that neither downloads nor battery replacements will be necessary for periods of several weeks to a month or more.

4.5. Observations about quantification

Regardless of what decisions are made about how, where and when to measure, it is the author's observation that at least two types of metrics are required for proper quantification of any park soundscape: one that quantifies the duration of either the audibility or the in-audibility (e.g. percent of time audible, or length of noise-free interval) of human-produced sounds, and one that quantifies how loud human-produced sounds are relative to the natural sounds. These two metrics of duration and relative level are uncorrelated in natural areas, and one alone is inadequate to fully describe the soundscape. The next section examines how making the decisions about appropriateness, i.e. determining criteria, can be used to select the best combination of metrics.

5. Determining criteria

Though determining what, how, where and how long to measure requires a plethora of sometimes difficult decisions, identifying criteria – the point at which human-produced sounds become inappropriate – is far more challenging. On the one hand, though experienced park managers may be capable of knowing what sounds are inappropriate when they hear them, turning this experience into a logical series of documented steps that arrive at quantifiable criteria has for parks, other than the Grand Canyon for air tours, been an elusive goal.

Perhaps the primary reason for the difficulty in developing criteria lies with the conflicts that arise in reaction to anticipated implementation of any non-trivial criteria. Such criteria may, as mentioned, limit the actions of individuals or groups, some of whom have an economic interest in the *status quo*, while others see their freedoms abridged. The conflicts are, in fact, so basic as to be grounded in a difference in values. In this section, we first describe some of the fundamentals of the conflicts since these are largely what retard development of criteria. The fundamentals described here are based primarily on personal conversations with as well as public discussions by the various "stake-holders". Second, we present a process that could build a logical train of decision-making to yield criteria.

5.1. Fundamentals of the conflict

There are many dimensions to the conflict between those who wish to preserve or experience the natural environment uninterrupted by inappropriate sounds of human activities and those who pursue the associated sound-making activities. Fundamentally, the former are likely to believe the purpose of the parks is that expressed by Sax [35]. In this view, parks provide the opportunity for visitors to experience nature on its own terms. To-do lists, and the pursuit of objectives, even recreational ones are set aside so that the visitors can discover what they, themselves are like when totally surrounded by the natural environment. The alternative view is that parks present opportunities for active recreation and sight-seeing, for seeing and experiencing as much of what the park has to offer as possible, for excitement and new experiences. Both of these views are legitimate; the problem is that they can be mutually exclusive.

These two views can affect how sounds, both human produced and natural are perceived. For some, human-produced sounds may carry the desirable connotations of action, tension, excitement – while for others these sounds detract from the desired sense of serenity, solitude and tranquility. For these latter individuals, the absence of human sounds is relaxing and provides an ideal setting for day-dreaming, reflecting, introspection. To others, the absence of human sounds connotes isolation, aloneness, wildness, lack of civilization, and creates uneasiness and an absence of feeling secure.

Another important element of the conflict is economic. Many individuals and companies derive income from providing the active experiences – air tours, snowmobile touring, rental of PWCs – or from arranging such activities as do tour organizations for whom providing these recreational opportunities helps sell their tour services. Expectation of loss of jobs or loss of income is a frightening prospect. When viewed from this perspective, such losses may seem to be a cost that is out of balance with the benefit of restoring or preserving the natural soundscape or limiting inappropriate sounds.

5.2. Steps in a criteria development process

This section presents the author's version of a process for developing criteria. It is untried but based on experience gained not only from observing the evolution of soundscape management issues in National Parks but also from working with environmental noise issues related to highways, airports, racetracks, parking garages, building code provisions, noise control regulations and associated litigation.

The process is presented here as applicable to development of criteria for any park-type environment, and therefore does not directly reference the experiences or policies of the US National Park Service. Rather it assumes managers of parks everywhere have many similar experiences, responsibilities and authorities. The process is based on four assumptions:

1. The decision makers who are involved in developing soundscape criteria are sufficiently experienced with the park lands in question, their purposes and management objectives to make informed judgments about what, when and where human-produced sounds are appropriate or inappropriate. As mentioned, no amount of data, quantitative or not, will determine when human-produced sound is inappropriate for a park setting. This is the fundamental question that must be answered as policy by decision makers. In the best of all worlds, such decisions depend upon knowing the purposes of the park, the resources protected, the management policies, the different uses and opportunities offered by the park, and the long-term plans for the park.
2. Knowledge of visitor reactions to park soundscapes can provide useful insight into setting criteria.
3. Historic and cultural structures or monuments that may be sensitive to noise induced vibrations need to be treated separately. NPS conducted a review of the literature on the effects of aircraft noise on cultural resources, and general guidance was developed [36]. This guidance is also available in the Report to Congress [5].
4. Effects on wildlife need also to be considered separately. Some research has been conducted on the effects of aircraft overflights on wildlife, was reviewed for NPS [37], and guidelines for identifying impacts provided in the Report to Congress [5].

5.2.1. Decide how the park should sound

This effort encompasses the fundamental policy decisions about how a park soundscape should be managed. Park managers understand the purposes of the park, the resources the park was established to preserve and the recreational opportunities that the different areas of the park provide for visitors. Using this knowledge, qualitative descriptions of the desired conditions can be developed to guide decisions.

Different managers will likely approach this task in different ways, but all approaches should include spending time at important park locations listening and possibly noting the different sources heard. The goal is to identify areas of the park that are as they should be and areas where the amount or type of human-produced sound is inappropriate.

It is probably best at this stage to avoid thinking about specific metrics. This process would probably be facilitated by combining it with developing descriptions of park, resource and visitor sensitivities to human-produced sounds. The following descriptions are offered as examples:

High sensitivity to human-produced sound. These are locations intended to preserve as completely a natural state as possible. They may be habitat for rare or sensitive species, contain ancient cultural, historic or religious resources, or be set aside to offer outstanding opportunities to experience solitude, tranquility and quiet. These areas are managed so that there is low probability that visitors will encounter other visitors. Visitor expectations for experiencing this type of soundscape are likely to be highest in locations that are moderate (perhaps a half mile) to long distances (several miles) from road traffic or intense visitor use, and that require a significant portion of an hour on foot (or horse back) for access.

Moderate sensitivity to human-produced sound. Surroundings offer a sense of remoteness and peace, but may be developed with clearly delineated and maintained trails and markers. Landscapes may be predominantly natural, or may have historic or cultural structures or meaning. As far as visitor expectations are concerned, such locations are probably close to road access. Some human sounds are unavoidable, but not loud, and do not diminish the visitor experience. There is management expectation that visitors will occasionally encounter other visitors and small groups.

Low sensitivity to human-produced sound. These are moderately developed areas but somewhat removed from roadway traffic and parking lots. Visitors pass through enroute to other areas. Nearby activities are likely to include regular interpretive and educational opportunities. Visitors are likely to expect moderate levels of human-produced sounds and frequent encounters with other visitors.

5.2.2. Compare with metrics

Once the sensitivities of different park areas are defined and judgments have been made about whether the various areas have appropriate or inappropriate soundscapes with respect to the sensitivities, collection of acoustic data can begin. By having judged the acceptability of the various soundscapes before measurements, management will have a context for understanding the relationship of the soundscape to the resulting metrics of audibility and sound levels. Virtually all metrics, being simplifications of the soundscape, cannot fully convey what a soundscape sounds like. It is better to first know how the soundscape sounds and whether it is appropriate before attempting to choose a metric or metrics to describe it.

Table 3 provides a conceptual example of how the judgments of appropriateness could be associated with sound metrics for each area or location measured. By gathering this type of information, it should be possible to establish criteria that not only meet management objectives, but that have been developed through a documented series of logical steps.

5.2.3. Consider feasibility and workability

The criteria developed through the above steps need to be refined in light of feasibility and workability considerations. Do they require sources to be quieter than current technology permits? Do they mean that current types of visitor uses would no longer be possible? Will it be possible to monitor any conformance required of visitors or concessionaires? Will it be possible to monitor progress toward the goals represented by the criteria? What is the public reaction to the proposed criteria and the proposed method of implementation?

5.2.4. Consider dose–response results

Several studies have developed dose–response relationships for specific sites within National Parks [11–13], but the specific relationships may be too site specific, based on too few visitors, reflect only visitor expectations rather than management objectives, and address only visitor reactions to aircraft noise. All these concerns have merit, but there is useful information to be extracted from these studies:

- Visitor sensitivity to aircraft noise varies considerably site to site.
- Visitors who take a short hike to access a more remote park location appear to be more sensitive to aircraft noise than visitors at overlooks that are only a short walk from the parking lot.
- Visitors distinguish between annoyance and interference; the former being an emotional feeling that lasts, the latter an objective term describing something that temporarily prevents them from doing what they were doing.
- Aircraft noise that interferes with appreciation of the natural quiet and the sounds of nature does not always result in annoyance.

Table 3
Example sound measurement results table

Location	Sensitivity	Conforms with sensitivity?	Sound metrics				
			Percent time only natural audible	Median level of natural ambient	Median NFI	Typical maximum levels of human sounds	Human produced Leq minus natural Leq
Trail A	High	Yes	95%	25 dBA	20 min	35 dBA	−5 dB

- Visitors understand the concept of "natural quiet and the sounds of nature".
- The louder the aircraft noise with respect to the background sound levels, the greater the percentage of visitors annoyed and who feel the noise interfered with their appreciation of the sounds of nature.
- The longer aircraft noise is audible, the greater the percentage of visitors annoyed and who feel the noise interfered with their appreciation of the sounds of nature.
- Visitors who are aware of the possibility of hearing human produced sounds (of aircraft overflights) are less annoyed by those sounds than are visitors who have no knowledge before hand.

These conclusions tend to support many "common sense" notions about natural sounds, human sounds and park environments. Visitor sensitivity in a park setting to human-produced sound varies from location to location, and greater sensitivity seems to be associated with degree of remoteness from the means of transportation and possibly from other visitors. Different measures of visitor reaction – interference and annoyance – even though they represent truly different reactions, both affect increasing percentages of visitors as human sounds increase in level and time present. Finally, expectation management may help reduce visitor annoyance or the sense of interference caused by human-produced sounds.

Consequently, though the reservations listed above about the dose–response studies and results are valid, the general observations derived from the studies should provide additional support for soundscape management decisions. Identifying different sensitivities for different areas and developing approaches to reduce both the level and duration of human-produced sounds are appropriate actions for improving the visitor experience. Managing visitor expectations, for example by identifying areas of a park where "natural quiet" dominates may also be an appropriate means for providing a desired visitor experience.

5.2.5. Develop monitoring and review process

Once criteria are established, some type of monitoring to judge progress should be designed. With criteria developed in the manner described here, monitoring and data reduction techniques will be known, and primarily the monitoring process needs to be developed. Which locations to monitor and how often to monitor are likely to be the primary questions that need to be answered.

It is also important to expect to review not only the progress toward the criteria, but also to determine whether or not meeting the criteria will achieve the desired objective. Experience and monitoring may show that what was once thought to be appropriate criteria no longer meet the management objectives of the park. On the other hand, if the criteria have been met, does the resulting soundscape sound right? In other areas of environmental noise, criteria or goals were established long ago and changing technology has affected feasibility. Quieter vehicles or engines may mean that criteria based on earlier technology should be revised to take advantage of the new technology.

6. Conclusions

Legitimately different personal values mean conflicts about the importance of restoring and preserving natural soundscapes and managing park soundscapes are inevitable. Therefore, progress is likely only through compromise. But to compromise effectively without either side "giving away the farm", both sides need to have a clear understanding of park goals. Park managers therefore need to clearly articulate their goals, have trusted methods for estimating what actions are necessary to achieve the goals, and be able to confidently estimate how various compromises will affect these goals. Knowing what actions the goals require and how compromise affects these goals means having reliable measurement and modeling methods. In the US, despite facing considerable challenges, reasonable measurement and modeling methods have been developed and are in use. As future park managers tackle soundscape management, these methods can be adopted for their use. However, before spending effort on measurement or modeling, prudence suggests that decision makers should first decide how they want the parks to sound.

Acknowledgements

Over the years, far too many people have contributed directly or indirectly to the author's understanding of the issues to fairly acknowledge them all. Staff personnel from the National Park Service, the Federal Aviation Administration, the Department of Interior, the Forest Service, the Departments of the Army, Navy and Air Force, the National Aeronautics and Space Administration, the US Congress, non-governmental organizations, trade groups and consultancies have all played a role in developing the issues since 1987 when natural soundscapes in the National Parks became a high priority. Rather, this article is dedicated to the memory of Dr. Wes Henry who, for more than a decade, was the driving force at NPS who oversaw production of a land-mark Report to Congress and with whom the author spent many hours debating the issues and developing ideas to help manage the soundscapes of the National Parks.

References

[1] As early as the 1930s floatplanes provided fishing access to the Superior National Forest (now the Boundary Waters Canoe Area Wilderness) in northern Minnesota. By 1948, Ely, Minnesota was said to have about 70 planes making multiple round trips per day into the remote lakes. Publicity brought national attention, and on December 17, 1949 President Truman issued Executive Order 10092 prohibiting flight below 4000 ft Mean Sea Level over specific areas. (See Federal Aviation Administration, Report to Congress, "Results of Surveillance of Aircraft Flights Over the Boundary Waters Canoe Area Wilderness," 1988.)

[2] NPS organic act, 16 USC 1.
[3] "The Redwood Act" of March 27, 1978, P.L. 95-250, 92 Stat. 166, codified at 16 USC 1, emphasizes the importance of preserving the "...public value and integrity of the National Park System..." and that these shall be managed in such a way as to prevent "...the derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress".
[4] Public Law No. 100-91, 16 U.S.C. 1a-1 note, 1992.
[5] NPS, Report on effects of aircraft overflights on the National Park System, Report to Congress, US Department of the Interior/National Park Service, July 1995.
[6] Fay RR. Hearing in vertebrates: a psychophysics databook. Winnetka, Illinois: Hill-Fay Associates; 1998.
[7] Public Law 106-181, 49 USC 40128.
[8] See FAA website <http://www.atmp.faa.gov/>.
[9] Federal Aviation Administration, Special Federal Aviation Regulation 50-2.
[10] McDonald CD, Baumgartner RM, Iachan R. National Park Service visitors survey, HMMH Report No. 290940.12, NPOA Report No. 94-2, January 1995.
[11] Anderson GS, et al. Dose–response relationships derived from data collected at Grand Canyon, Haleakala and Hawaii Volcanoes National Park, HMMH Report No. 290940.14, NPOA Report 93-6, October 1993.
[12] Fleming GG, et al. Development of noise dose/visitor response relationships for the National Parks Overflight Rule: Bryce Canyon National Park Study, FAA-AEE-98-01, July 1998.
[13] Miller NP, et al. Mitigating the effects of military aircraft overflights on recreational users of parks, USAF Report AFRL-HE-WP-TR-2000-0034 (or DTIC ADA379467 at http://www.ntis.gov/), July 1999.
[14] Miller NP. Aircraft overflights in parks. Noise Control Eng J 1999;47(3):112–7.
[15] 36 CFR Part 7.
[16] McMillon S. Snowmobiles guaranteed one more year in park. Bozeman daily chronicle, May 21 2005.
[17] 36 CFR Section 3.7.
[18] Menge CW, Ross JC, Volk JDS. Technical report on noise: personal watercraft and boating activities at Glen Canyon National Recreation Area, HMMH Report 295860.370, October 2002.
[19] Foch Jr JD, Burke RE. Sound levels from oil and gas exploration activities, Flathead National Forest, Glacier National Park, Helena National Forest, EPA 908/1-85-001. February 1985.
[20] Black CH. Report of preliminary survey of noise levels in Grand Canyon National Park, Northern Arizona University, 1971 [submitted to NPS, no report number or other identification].
[21] Bowman EG. Aircraft noise evaluation, Grand Canyon, May–August 1975, Northern Arizona University, 1975 [submitted to NPS, no report number or other identification].
[22] NPS. Aircraft noise evaluation. Resource Management Division. Grand Canyon NP, 1978 [no report number or other identification].
[23] Dura PS. Aircraft noise evaluation – Grand Canyon NP, MSEE Student, U. of Wyoming, 1983.
[24] Dunholter PH, et al. Methodology for the measurement and analysis of aircraft sound levels within National Parks, Mestre Greve Associates, MGA Technical Report Number 89-P07, March 1989.
[25] Fidel S, et al. Evaluation of the effectiveness of SFAR 50-2 in restoring natural quiet to Grand Canyon National Park, BBN Report Number 7197, NPOA Report Number 93-1, February 1992.
[26] Horonjeff RD, et al. Acoustic data collected at Grand Canyon, Haleakala and Hawaii Volcanoes National Parks, HMMH Report Number 290940.18, NPOA Report Number 93-4, August 1993.
[27] Bennet R, Fox C. Grand Canyon comparative sound study, Bennett/Cox, Consultants, 148 Gazania Court, Thousand Oaks, CA 91362, Prepared for Air Access Coalition, 1101 King Street #350, Alexandria, VA 22314, January 1994.
[28] Hobbs C, Downing M. The soundscape in Zion National Park. Wyle Laboratories, WR 02-07, 2003.
[29] Miller NP, et al. Acoustic data collected at Hawaii Volcanoes National Park, HMMH Report Number 295860.341, September 2003.
[30] Anderson GS, et al. NPS acoustic metadata and its corresponding acoustic data:current status, HMMH Report Number 295860.330, November 2003.
[31] Miller NP, et al. Aircraft noise model validation study, HMMH Report 295860.29, January 2003. Available from: http://www.nps.gov/grca/overflights/documents/anmvs/index.htm.
[32] Ross JC, et al. Development of an automated noise source identification system for Grand Canyon National Park, HMMH Report Number 295860.044, July 2005.
[33] Green DM, Swets JA. Signal detection theory and psychophysics. Peninsula Publishing; 1988.
[34] For a basic discussion of audibility and its calculation, see Appendix C of Ref. [31].
[35] Sax JL. Mountains without handrails. The University of Michigan Press; 1980.
[36] Hanson CE, et al. Aircraft noise effects on cultural resources: review of technical literature, HMMH Report No. 290940.04-1, NPOA Report Number 91-3, September 1991.
[37] McKechnie AM, Gladwin DN. Aircraft overflight effects on wildlife resources, HMMH Report 290940.22, NPOA Report Number 93-8, November 1993.