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wilderness

A Framework to Assess the Effects of Commercial Air Tour Noise on Wilderness

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Human-made noise in wilderness degrades the quality of wilderness by interfering with natural sounds—a key attribute of wilderness. Commercial air tour overflights are a noise source of particular concern to the US National Park Service. To characterize noise from air tours in wilderness, we developed an assessment framework to guide the decisionmaking process for maintaining or improving the soundscape conditions in wilderness. Decision points in the framework were based on management policy and best available science. The result is a "tier" designation for a wilderness area that defines the current soundscape conditions based on known air tour activity. To demonstrate the utility of the framework, we applied the method to Haleakalā Wilderness in Haleakalā National Park, Hawai'i. Whereas the framework presented specifically addresses air tour noise in wilderness and the concerns associated with impacts on wilderness character, the framework may be applicable to managing other noise sources in and near wilderness or other human activities that degrade wilderness qualities.

Keywords: soundscape, wilderness character, air tour noise, National Park, acoustics, overflights, air tour

The 1964 Wilderness Act directs federal agencies to manage wilderness areas to preserve wilderness character. Federal agencies have defined "wilderness character" to mean "the combination of biophysical, experiential, and symbolic ideals that distinguishes wilderness from other lands," where the *qualities* of wilderness character include "natural," "untrammeled," "solitude or primitive and unconfined recreation," "undeveloped," and "other features of value" (Landres et al. 2008, p. 7–8, National Park Service [NPS] 2014, p. 8–9). To help manage wilderness and study impacts, specific *indicators* have been associated with each wilderness quality (Landres et al. 2008, NPS 2014). Natural sounds are one of the many components of wilderness, and remoteness from sights and sounds of people has been identified as an indicator for the wilderness quality "solitude or primitive and unconfined recreation" (Landres et al. 2008, p. 7–8). Further, natural sounds are a key attribute for how visitors define wilderness character (Watson et al. 2015), and wildlife depends on natural sounds for basic life functions (Barber et al. 2010).

The addition of human-made noise degrades wilderness character by interfering with natural sounds (NPS 2006, Marin et al. 2011). Noise from commercial air tours is one source of noise that is known to occur in wilderness (Miller 2008, Lynch et al. 2011), and the consequences to visitor experience have been quantified (Mace et al. 2013, Rapoza et al. 2014). The importance of natural sounds in federally protected areas has been recognized by the president in Executive Orders and by congress in several key pieces of legislation (Table 1). One of these acts, the National Parks Air Tour Management Act of 2000 (NPATMA) (Federal Aviation Administration [FAA] 2000), calls for

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Table 1. History of legislation and policy to address effects of aircraft overflights on protected areas.

Year	Legislation	Details
1949	Executive Order 10092 issued by President Truman	Banned flights below 4,000 ft mean sea level over specific areas of Superior National Forest. It established the first airspace reservation.
1978	Boundary Waters Canoe Area (BWCA) Wilderness Act (Public Law 95-495)	Included restrictions to motorized activities and into which Executive Order 10092 was incorporated by reference.
1987	National Parks Overflights Act of 1987 (Public Law 100-91)	Directed NPS to evaluate the effects of aircraft noise on park users' safety and experience. The act mandated the study include research on the impacts of aircraft flights over Haleakalā NP, other national parks that contained designated wilderness, BWCA wilderness, and National Forest Service System wilderness areas. The act also specified certain minimum altitudes for aircraft flying over Haleakalā NP. Before passage of the Overflights Act, commercial tour helicopters flew within the crater down to levels 300 ft above the crater floor. Noise generated by tour helicopter overflights greatly affected the wilderness users' enjoyment of Haleakalā Crater (NPS 1995).
2000	National Parks Air Tour Management Act [49 United States Code 4,0128(b)(1)(B)] on Apr. 5, 2000	Primarily passed because of concerns that noise from air tours over national parks could impair visitor experience and park resources. NPATMA requires the establishment of an ATMP for each park where the Federal Aviation Administration has granted authority to commercial air tour operators to conduct tours. The objective of air tour management plans is to "develop acceptable and effective measures to mitigate or prevent significant adverse impacts, if any, of commercial air tour operations upon the natural and cultural resources, visitor experiences, and tribal lands" (Federal Aviation Administration 2000).
2005	Federal Register notice (70 FR 58778)	Air tour operators initially applied for authority to conduct nearly 290,000 air tours at 100 national park units, not including flights over abutting tribal lands or the Grand Canyon. In response to the mandate to establish ATMPs at these parks, NPS began collecting baseline acoustic data at parks with existing air tours and conducted preliminary aircraft noise modeling.
2006	National Park Service Management Policies, Section 4.9	The Service will restore to the natural condition wherever possible those park soundscapes that have become degraded by unnatural sounds (noise), and will protect natural soundscapes from unacceptable impacts. Using appropriate management planning, superintendents will identify what levels and types of unnatural sound constitute acceptable impacts on park natural soundscapes. The frequencies, magnitudes, and durations of acceptable levels of unnatural sound will vary throughout a park, being generally greater in developed areas. In and adjacent to parks, the Service will monitor human activities that generate noise that adversely affects park soundscapes.
2012	NPATMA amended	Mandated the NPS and FAA to collect information from commercial air tour operators regarding their flight activity. Operators are now required to submit quarterly reports to the NPS and FAA that include data such as the date and time of each tour, aircraft make/model, departure location, and route information. The amendments also allow the NPS, FAA, and air tour operators to enter into voluntary agreements, as an alternative to an ATMP.

Before the Wilderness Act was passed in 1964 and since that time, the negative effects of aircraft noise on backcountry visitors' opportunities to experience solitude or natural quiet in the nation's protected areas has been recognized by Congress in several key pieces of legislation or Executive Orders by the President. NPS policies (NPS 2006) reflect these principles. ATMP, air tour management plan.

the management of noise from commercial air tours over national parks to mitigate or prevent significant adverse impacts to the natural and cultural resources and visitor experiences. Parks with wilderness needed a systematic way to assess current conditions in different wilderness areas—hence, the primary motivation for developing this framework.

Characterization of noise requires an understanding of the spatial extent, duration, and magnitude of the source in wilderness. The assessment framework we developed incorporates these characteristics of noise. The framework uses existing information on air tour overflight activity, sound propagation models, and best available scientific information on human responses to noise. The result is a "tier" designation for a wilderness area that defines the current conditions. To demonstrate the utility of this assessment process, we applied the framework to Haleakalā Wilderness in Hawai'i and defined an air tour noise tier based on air tour operations conducted in 2013. The focus of this case study was to demonstrate a tool for evaluating the impact of air tour noise on NPS wilderness; however, the framework we developed may be adapted to characterize other noise sources present in or near wilderness or to evaluate other indicators of wilderness qualities.

Framework Development

A decision-tree framework was developed to provide an approach for characterizing current conditions and then to guide the decisionmaking process for maintaining or improving the soundscape conditions in

Management and Policy Implications

Federal agencies are mandated to protect wilderness areas to preserve wilderness character. However, preservation of wilderness is challenged by vague definitions and the diversity of qualities that define wilderness. To help resource managers incorporate the preservation of natural acoustic conditions, one of the many attributes of wilderness, into wilderness management or planning documents, we developed and demonstrated an assessment framework. Our example is specific to the effects of noise from commercial air tour overflights on the visitor's ability to experience natural sounds and is intended for National Park Service air tour management and other planning processes. The framework presented takes advantage of reporting data from air tour operators, an existing noise model, and the best available science on the effects of noise on visitor experience to understand the soundscape conditions over an entire wilderness area. The framework provides a systematic method that can be applied to any park with air tours and wilderness; the results characterize current conditions and guide the decisionmaking process for maintaining or improving the soundscape conditions in wilderness. Ideas on how to adapt the framework to explore the effects of alternative scenarios in air tour overflights (e.g., number of flights or quieter aircraft), to address other noise sources in and near wilderness, or to evaluate other indicators of wilderness character conditions are offered.

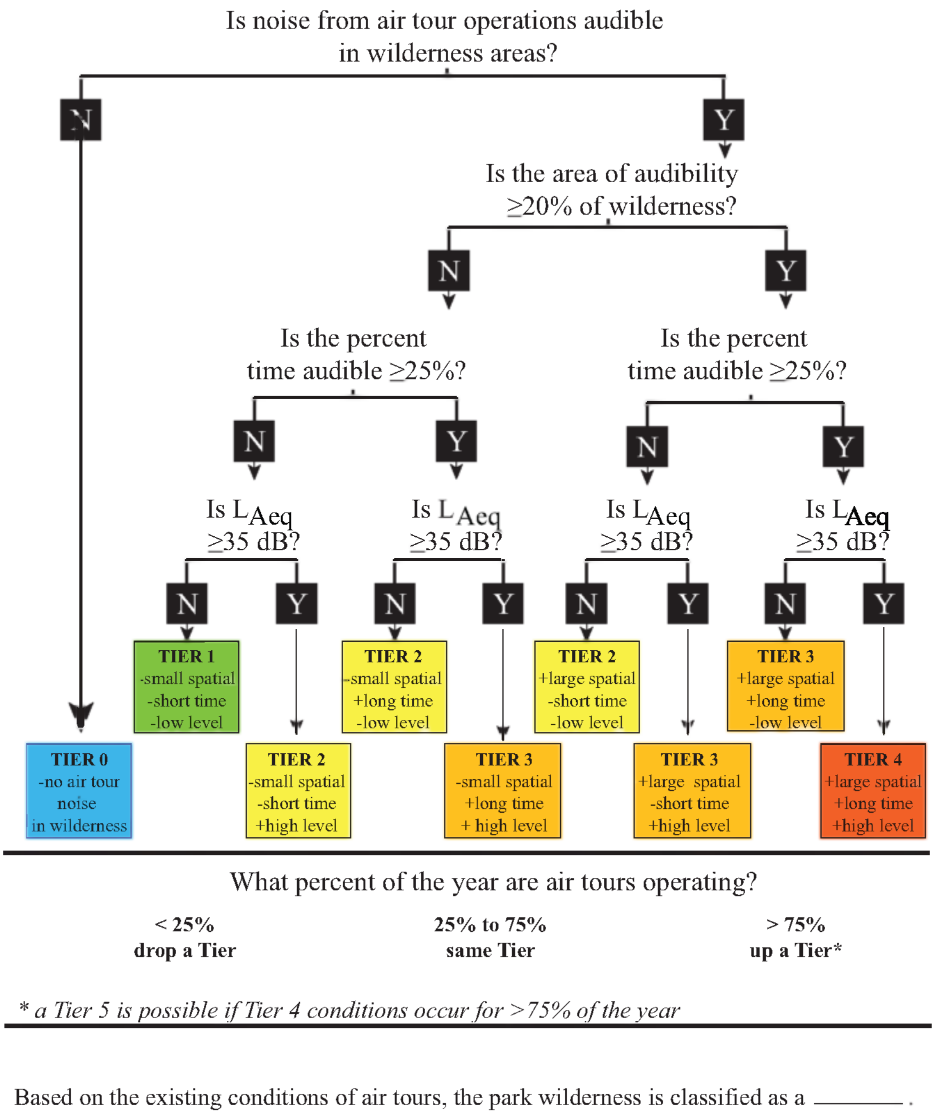

Figure 1. Assessment framework for defining the soundscape conditions in wilderness based on existing air tour activity. See Table 3 for definitions of acoustic metrics (area of audibility, time audible, and L_{Aeq}).

wilderness. Use of the framework requires knowledge of current air tour activity and the associated noise, estimated from sound propagation models, to characterize the acoustic conditions in a wilderness area. The decision-tree approach considers the spatial extent, duration, and level of noise from the modeled air tours and then categorizes wilderness based on the combination of existing acoustic conditions. Acoustic values used as decision points in the framework were based on management policy and the best available science on human response to noise. The result is an air tour noise "tier" designation for a wilderness area that defines the current acoustic conditions in wilderness based on known air tour activity. Tier definitions are based on the amount of existing air tour noise in a given wilderness area, ranging from tier 0 (no air tour noise) to tier 5 (air tour noise that covers a large area of wilderness, is of long duration, produces relatively high sound levels, and occurs during the majority of the year) (Figure 1). Preservation of and improvements in wilderness character will be achieved by either maintaining a tier 0 (no air tour noise) or reducing tiers 1–5.

Modeling the Acoustic Conditions in Wilderness

The acoustic conditions in a wilderness area were derived by modeling aircraft noise from air tour operations using the integrated noise model analysis tool (INMA), which is based on the integrated noise model (INM) (Table 2). Inputs to INMA include nominal tour routes, hours of operation, the average number of flights per day, and the type of aircraft flown. Air tour operator reporting data (required under amended NPATMA) (Table 1) were used to assign these model inputs. Hours of operation in a day represents the duration of hours during which air tour operations occurred, and the reported departure times are used to estimate hours of operations. The average number of daily flights is calculated by averaging reported total flights over the days flown. Using these details on the overflight activity combined with the spatial boundaries of the wilderness areas, INMA computes the acoustic metrics (area of audibility, time audible, and equivalent sound level) (Table 3) used in the framework (Figure 1) for the entire wilderness area.

Values Used at the Decision Points

Values for specific acoustic metrics, which describe the noise from air tours in wilderness, serve as the decision points within the framework that lead to a designated air tour noise tier (Figure 1). Multiple metrics are used to fully characterize the spatial extent, duration, and magnitude of the noise from air tours. At each decision point in the framework, the acoustic metric's modeled value is compared with the associated decision point threshold value. These decision point values were informed by management policy or best available science on human response to noise. Importantly, the values can be modified as new scientific information becomes available or new policies are established.

To evaluate the spatial extent of noise, an *area of audibility* metric was used (Table 3). Area of audibility was measured as the percentage of the wilderness acreage where air tour noise is audible, regardless of duration heard or level. If no air tour noise was audible in wilderness, tier 0 was assigned (Figure 1). A value of ≥20% of the wilderness having audible air tours was set as the second decision point and distinguished between small spatial and large spatial extent. The 20% decision threshold was set by park natural resource managers and meant to represent significant fragmentation of the natural soundscape and loss of opportunities for solitude.

The duration of air tour noise was measured as *percent time audible* (% T_{Aud}) (Table 3), indicating the percentage of time that noise from air tours was audible in wilderness on a given day, where the length of the day was defined by the hours of air tour operations in the NPATMA reports (Table 1). A value of ≥25% % T_{Aud} was set to differentiate between a short daily exposure

Table 2. Description of noise modeling process.

INM	
	Computes noise exposure due to aircraft operations. It is based on the algorithms and framework of SAE AIR 1845, using noise-power-distance data to estimate noise accounting for specific operation mode (speed and power settings), source-receiver geometry, acoustic directivity, and atmospheric absorption.
	Designed to estimate long-term average effects using average annual input conditions (Boeker et al. 2008).
	Outputs either noise contours for an area or noise level metrics at preselected locations. The noise outputs can be exposure-based (e.g., equivalent continuous sound level [L_{Aeq}]), maximum level-based (e.g., A-weighted maximum sound level), or time-based (e.g., percent time audible [% T_{Aud}]). Differences between predicted and measured values can and do sometimes occur due to real-world deviations in flight routes, aircraft configuration and operational parameters (engine, speed, and power), atmospheric effects (wind and temperature gradients), and localized shielding and reflections due to terrain or buildings.
	Has the following analytical uses: assessing changes in noise exposure resulting from new or extended airport runways or runway configurations, new traffic demand and fleet mix, revised routings and airspace structures, alternative flight profiles, and modifications to other operational procedures and evaluating noise impacts from aircraft operations in and around national parks. The model is widely used by the civilian aviation community for evaluating aircraft noise impacts in the vicinity of airports.
	Used since 1978 by the Federal Aviation Administration and made available to hundreds of US and international users.
INM 6.2	
	Is the INM model version that was recommended by the Federal Interagency Committee on Aviation Noise as the best modeling methodology currently available for evaluating aircraft noise in national parks, and agreed to by the NPS and FAA after extensive studies comparing the models currently available and upgrades to the previous version of INM.
	As with all models, is not 100% accurate, particularly with the calculation of audibility, which is dependent not only on the aircraft noise levels but also on the background sound levels and human detection of sound.
INMA	
	Is a Windows application developed by the US Department of Transportation, John A. Volpe National Transportation Systems Center.
	Allows users to easily assess noise exposure from various combinations and multiples of air tour activity from a suite of scenarios that have been premodeled in INM.

Our framework uses the Integrated Noise Model (INM) and INM Analysis (INMA) software to model noise from air tours in wilderness areas.

Table 3. Descriptions of acoustic metrics used in the air tour noise assessment framework.

Acoustic metric	Definition
Percent time audible (% T_{Aud})	Percentage of time* that air tours can be heard by the human ear. The metric depends on human hearing capabilities, natural ambient conditions, and flight operations (e.g., 25% T_{Aud} means air tour noise could be heard for 25% of the day, or 120 minutes during an 8-hour day, not necessarily consecutively).
Area of audibility	Percentage of the wilderness where air tour noise is audible (for a defined time period*) at and above a defined % T_{Aud}.
Equivalent continuous sound level (L_{Aeq}), dB	A-weighted total sound energy over a given period of time* and the preferred method to describe sound levels that vary over time.

* The length of day used for determining percentages is based on the first and last air tour of the day for each individual park (e.g., a 12-, 8-, or 4-hour day).

and long daily exposure in the decision-tree framework (Figure 1). In other words, does any part of wilderness experience noise from air tours ≥25% of the day? This decision point was informed by a recent study that examined and predicted the response of day-hike park visitors to different types of aircraft noise (Rapoza et al. 2014). In the study, typical aircraft audibility duration was 25% of a visit and produced by a mix of helicopter, fixed-wing propeller aircraft, and high-altitude jet overflights. For this audibility duration, 30% of visitors are predicted to report at least slight interference with natural quiet. Because the predicted percentage of visitors reporting interference with natural quiet will vary with the actual type of aircraft flown, the predicted percentage of visitors reporting slight interference with natural quiet will increase to 55% as the percentage of helicopters (a common air tour aircraft) increases to 100%.

The acoustic metric used to characterize the level or magnitude of noise was A-weighted equivalent sound level (L_{Aeq}) (Table 3), calculated over the total time air tours were operational in a given day. A value of ≥35 dB L_{Aeq} was set as the decision point between a low noise and high noise level (Figure 1). Sound levels in national parks can vary greatly, ranging from among the quietest ever monitored, to extremely loud (Lynch et al. 2011). For example, the din of a typical suburban area fluctuates between 50 and 60 dBA; the crater of Haleakalā National Park (NP) is intensely quiet, with levels hovering around 10 dBA. Justification for the 35 dB L_{Aeq} value is based on multiple studies on human response to noise. According to the American National Standards Institute's standard on community noise, in rural communities, where a greater value is placed on peace and quiet, a noise level of 35 dBA would result in 2% of a community being highly annoyed (American National Standards Institute 2005). According to the World Health Organization (1999), speech in a relaxed conversation is 100% intelligible in background noise levels of 35 dBA, and it is the recommended maximum level for school classrooms. For typical conditions where noise exposure from helicopters is 35 dB L_{Aeq}, 60% of visitors on backcountry day-hikes are predicted to report that aircraft noise has at least slightly interfered with the natural quiet (Rapoza et al. 2014). The 35 dB L_{Aeq} threshold is below the level that results in cardiovascular effects (65–70 dB L_{Aeq} over 24 hours), but above levels that interfere with sleep (30 dB L_{Aeq} over 8 hours), and the recommend maximum values for hospitals (30 dB L_{Aeq} over 8 hours).

The assessment framework makes a final adjustment based on the percentage of the year during which air tours operate (Figure 1). This adjustment accounts for the fact that parks can experience significant seasonal variation in air tour overflights, whereas the spatial extent, duration, and magnitude acoustic metrics are calculated based on an average number of flights per day. So, for example, an average of 10 flights per day could mean there were 1,000 flights over 100 days or 100 flights over 10 days, even though there is a 10-fold difference in the absolute level of activity. Therefore, the air tour noise tiers are adjusted up or down depending on the percentage of the year with overflights (Figure 1).

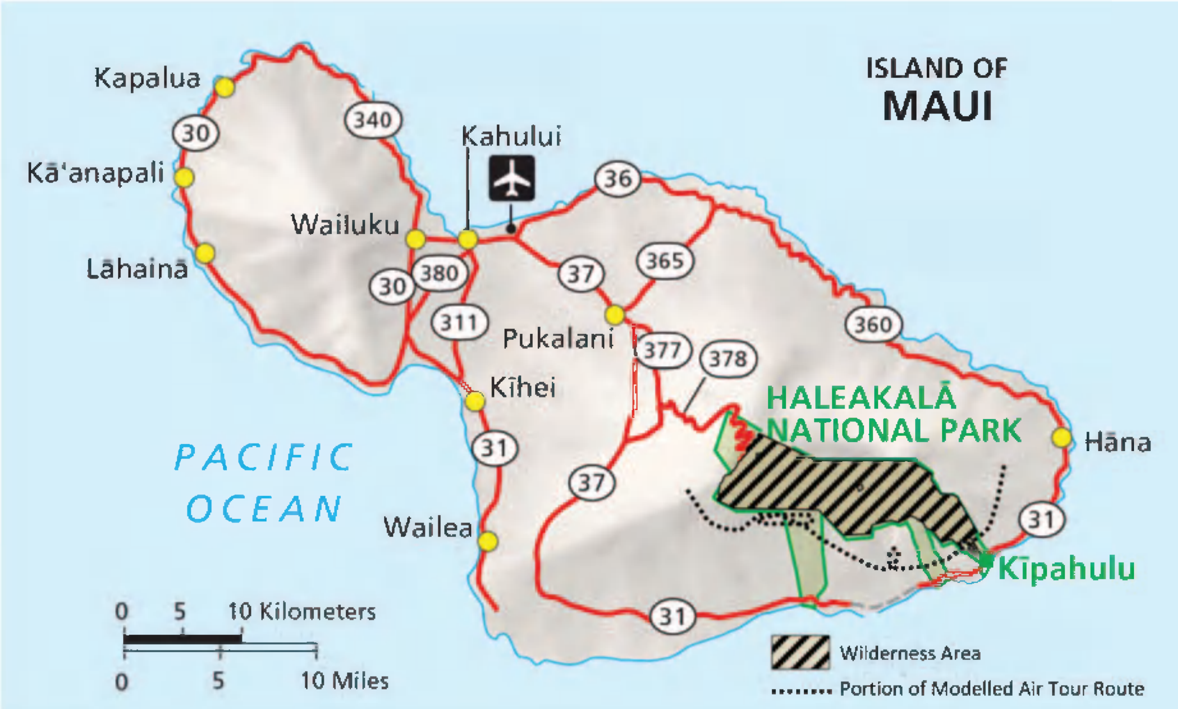

Figure 2. Haleakalā National Park, on the Island of Maui, Hawai'i. The map shows the park and wilderness boundaries and locations of cities, airport, and major roads. The modeled air tour route is designated by the black dotted line.

Figure 3. The crater area of Haleakalā National Park. Photo courtesy of National Park Service.

Application of Assessment Framework at Haleakalā NP

We applied our assessment framework to characterize the noise impacts related to air tours over the wilderness in Haleakalā NP in Hawai'i. Originally established as part of Hawai'i NP in 1916 to preserve the unique and exotic native flora and fauna and the outstanding geological resources, Haleakalā NP was created as a standalone park in 1961. The park hosts 1,450,000 ground-based visitors annually and encompasses 33,265 acres on the island of Maui (Figure 2). Within Haleakalā NP, 24,719 contiguous acres are federally designated wilderness. which are managed for their wilderness character under the Wilderness Act of 1964.

Sightseeing air tours over Haleakalā NP began in the early 1980s and grew throughout the 1990s. The crater area of Haleakalā (Figure 3) contains some of the quietest soundscapes in the National Park System; the background ambient levels are often below the threshold of human hearing (Lynch et al. 2011). Therefore, the impact of aircraft noise on Haleakalā NP has been a longstanding management concern and was called out for study in the Overflights Act of 1987 (Table 1). As a result, in 1998, the NPS and the Hawai'i Air Tour Association executed a Letter of Agreement regarding the conduct of air tour operations over and within the vicinity of Haleakalā NP. One of the goals of the agreement was to minimize noise impact inside Haleakalā Crater from commercial air tour operations by routing flights outside the crater and using the crater rim for terrain masking of noise. Air tour operators at Haleakalā NP are currently authorized by the FAA to conduct up to 25,957 commercial air tours per year, collectively, over the park.

Characterizing Air Tour Activity over Haleakalā NP

The 2013 NPATMA air tour reporting data for Haleakalā NP were used to determine the inputs for INMA and ultimately determine the air tour noise tier that describes the soundscape conditions in the park's wilderness. The NPATMA reporting data provided the necessary details to define daily hours of operation and average number of flights per day.

According to air tour reporting data from 2013, four operators conducted air tour flights over the park and reported a total of 4,631 air tours over Haleakalā NP. Air tours began at around 7:00 am and ran as late as 6:00 pm; most activity occurred in the morning according to the reported flight start times. We used "11" as the daily hours of operation input to INMA.

To determine the average number of daily operations needed as input to INMA, each operator was evaluated in terms of the types of aircraft, the total number of flights, and the days on which tours occurred. Operators flew two main models of helicopters. For the first helicopter model (Eurocopter EC130) a total of 1,862 flights were flown on 330 unique days, resulting in an average number of flights per day of 5.6. For the second helicopter model (Aérospatiale AS350), a total of 2,769 flights were flown on 351 unique days, resulting in an average number of flights per day of 7.9.

Defining a Wilderness Tier for Haleakalā NP

To answer the first decision point question (*Is noise from air tour operations audible in wilderness areas?*), the area of audibility metric was evaluated. As shown in Figure 4A, the presence of any nonzero value in the "Area of Audibility" column indicates that at least some level of noise from air tour operations was audible in the wilderness area. Percent time audible contours for the park as a whole are shown in Figure 4A.

To answer the second decision point question (*Is noise from air tours audible in ≥ 20% of wilderness?*), the area of audibility metric was again evaluated to describe the spatial extent of the noise. The air tour noise was audible in >20% of wilderness; in fact, Figure 4A shows that 100% of the wilderness area experienced at least up to 5% T_{Aud}. Therefore, the noise from air tours was considered to have a "large spatial extent."

For the third decision point question (*Is the percent time audible ≥ 25%?*), the % T_{Aud} metric was used to describe the duration of the noise. As shown in Figure 4A, column "Area of Audibility," 5% of the wilderness was within a % T_{Aud} interval of ≥25%. Therefore, noise from air tours was considered of "long duration."

The fourth decision point relates to the overall levels of the noise in wilderness and the L_{Aeq} metric was used. As shown in Figure 4B, column "Cumulative % of Wilderness," 12% of the wilderness had levels that were ≥35 dB L_{Aeq}. Therefore, noise from air tours was considered to have "high level." L_{Aeq} contours for the park as a whole are shown graphically in Figure 4B.

Following the framework, the wilderness tier for Haleakalā NP would be a tier 4 with respect to commercial air tour activity in 2013. The final adjustment is based on the percentage of the year during which air tours operate. Based on the 2013 reporting data for air tours over Haleakalā NP, operations occurred consistently throughout the year: 96.4% (352 days) of the year had reported air tours. This results in the highest tier designation, an air tour noise tier 5 for Haleakalā Wilderness, which characterizes the current soundscape conditions as air tour noise having a large spatial extent, long duration, and high levels and occurring for most of the year.

Improvement in Wilderness Character

We investigated two strategies that might reduce the noise impacts of commercial air tour overflights and therefore improve wilderness quality. The first strategy was to reduce the number of air tour operations per day. The second strategy was to maintain the current level of flights per day but to assign all activity to a quiet technology aircraft.

As shown in Table 4, both strategies reduced the tier. The tier designation decreased after a reduction of 2 flights per day, which was a 15% decrease in daily air tour activity. The tier designation also decreased when all activity was assigned to the EC-130, a quiet technology aircraft. Under both of these noise reduction strategies, the resulting tier 4 characterizes a large area of audibility and a high noise level but a shorter duration of audibility (<25% T_{Aud} in wilderness). The designation would further decrease to a tier 3 in each case if operations were to occur less than 75% of the year.

A reduction in the average number of flights per day and use of quiet technology aircraft are only two examples by which noise impacts and the associated air tour noise tier might be reduced. Other flight parameters such as route, speed, type of aircraft, and altitude may be modified to influence impacts on the soundscape. Adjusting scheduling to decrease the number of days with overflights might also improve conditions. Thus, there may be many options by which impacts can be reduced in wilderness. The options, however, must be weighed against potential consequences for the air tour operators and other park resources or neighboring communities.

Potential Modifications and Applications of the Framework

We focused on impacts of air tour noise on visitor experience in wilderness by incorporating the best available scientific knowledge of human responses to noise to inform the decision point values. Modifications to the decision point questions and/or values within the framework offer the ability to quantify the impacts of commercial air tour noise on natural or cultural resources in wilderness. For example, information on wildlife responses to noise (Shannon et al. 2015) could be developed and applied to assess the effects of air tour noise on natural resources present in wilderness.

The framework may also be adapted to evaluate other noise-producing activities that impact wilderness. Although our analysis addressed air tour noise in wilderness because there is a direct management need (Table 1), there are other noise sources that either occur in or propagate into wilderness (e.g., energy development or traffic noise from park road networks). The framework and decision points are transferable to address these noise sources, but acoustic values would need to be updated with visitor or wildlife responses to the specific noise source. One challenge with expanding the utility of the framework is characterizing the acoustic conditions. INM, the model on

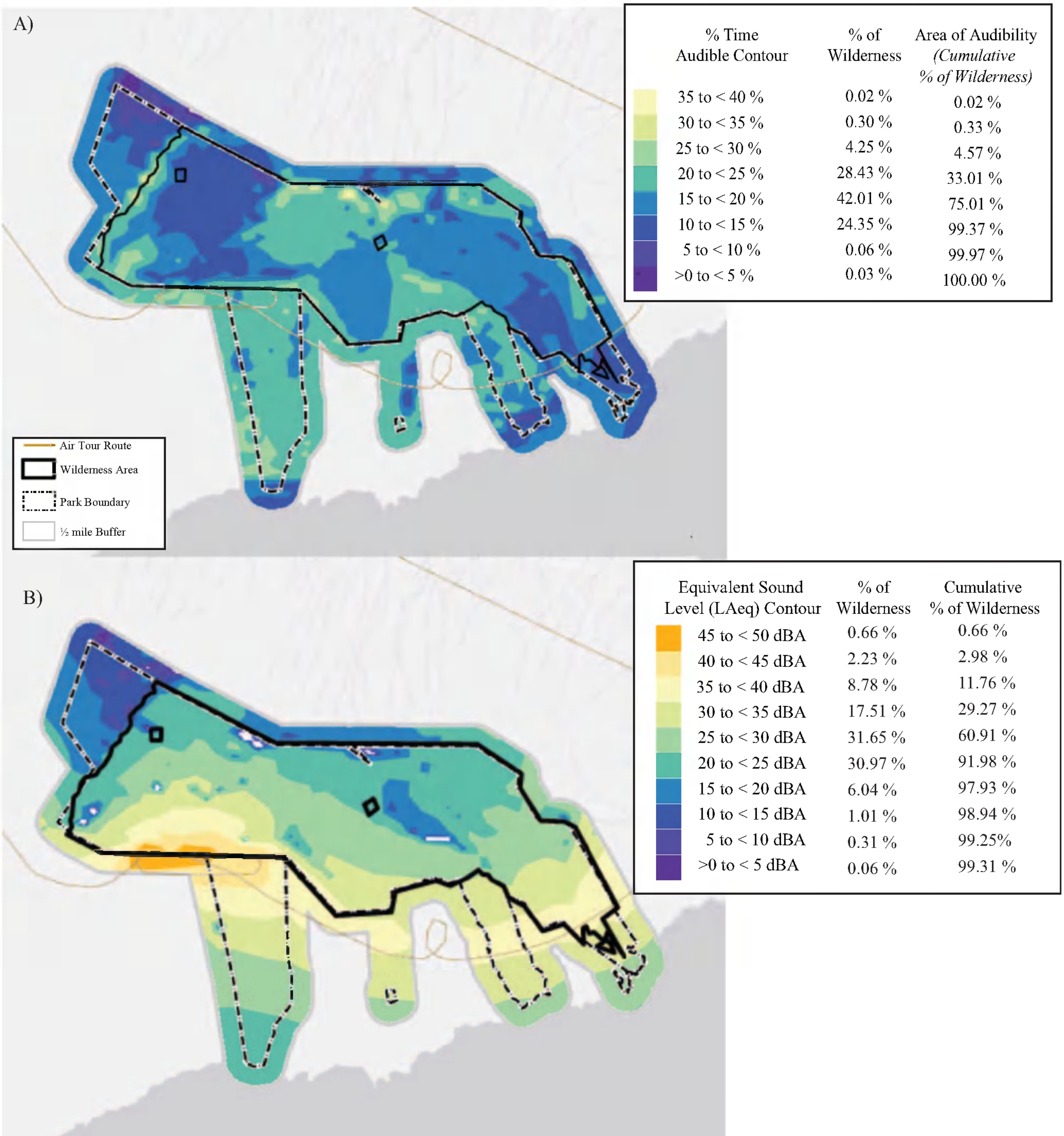

Figure 4. Haleakalā NP showing the spatial extent of acoustic metrics from the INMA model output. Legends provide the corresponding values for each contour color. A. % T_{Aud} contours for daily average air tour operations. B. L_{Aeq} contours from daily average air tour operations.

Table 4. Improvement in soundscape conditions for Haleakalā NP.

	Current condition: average flights per day	Reduction of 2 flights per day	Reduction of 4 flights per day	All aircraft-quiet technology
Eurocopter EC-130	5.6	4.6	3.6	13.5
Aérospatiale AS350	7.9	6.9	5.9	0
Total	13.5	11.5	9.5	13.5
Tier designation	5	4	4	4

which our study is based, was developed specifically for aircraft noise and another acoustic modeling program may be necessary. The key to modeling noise is knowledge of the human activity, similar to the data provided by the NPATMA air tour operator reports.

We designed the framework to characterize acoustic conditions as an indicator for the wilderness quality of "solitude or primitive and unconfined recreation" and the framework incorporates the spatial extent, duration, and level of noise in wilderness. Adopting this assessment framework to assist with the management of other indicators of wilderness qualities may be possible. For example, motorized vehicles and equipment are indicators of the undeveloped quality of wilderness character (Landres et al. 2008). The spatial extent, duration, and level of this activity in wilderness could be evaluated within the framework. The metrics and values would need to be changed to characterize this type of activity and mapping the metrics over the entire wilderness would require a modeling approach different from the one used in our study. The strength of the framework is that it addresses the complexity of impacts and illustrates that there may be multiple paths to the same tier designation due to the varying nature of activities or impacts within wilderness.

The scientific knowledge or policies used to set the decision points is key to evaluating conditions in wilderness. The framework can be updated as new information becomes available. As shown in this study, visitor survey techniques are a powerful method for understanding how certain activities in wilderness interfere with or have an impact on wilderness character from a visitor perspective (Rapoza et al. 2014). Ecological monitoring provides information on how the natural ecosystems respond to activities in wilderness and can inform measure of conditions in wilderness (NPS 2014).

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