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Protected areas and noise abatement: A spatial approach

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ABSTRACT

Protected areas have the capacity to provide an array of benefits to humans—ecosystem services. Concerning the acoustic environment, these ecosystem services are provisioned as natural soundscapes and quietness. A substantial body of literature has examined protected areas' performance in preserving soundscapes and management strategies to ensure the continued preservation of natural sounds in park settings. However, protected areas' abilities to abate noise are not understood to such a robust degree, especially concerning how noise abatement occurs at a landscape scale. Few studies have considered green space noise abatement beyond a city-scale. This study utilizes two national datasets previously employed in a study of soundscape preservation to examine what characteristics of protected areas aid in the abatement of noise at the county level. Using spatial regression models, this study represents the first assessment of conservation status, ownership, and level of access as potential determinates of abatement performance. Findings indicate that conservation status has a significant impact on noise abatement. Potential explanations for this finding are discussed, including wilderness amenity migration, habitat fragmentation, and the geographic distribution of protected areas.

1. Protected areas and noise abatement: a spatial approach

Nature provides a variety of ecosystem services that support human wellbeing. Protected natural areas, specifically, provide two fundamental functions with concern to acoustics—noise exclusion and noise abatement—which lead to the ecosystem service of quietness (Wang, Bakker, de Groot, & Wörtche, 2014). These two functions are positively related but provide intrinsically distinct benefits. Noise exclusion provides a mostly internal benefit, whereas natural sounds are preserved within the bounds of protected areas by prohibiting development and other forms of noise emission (Votsi, Kallimanis, & Pantis, 2017). Noise abatement, conversely, provides a mostly external benefit, whereas ambient noise is reduced in the surroundings of protected areas (Chen & Jim, 2008). The notable publication of the Buxton et al. (2017) contribution in *Science* concerning noise pollution in protected areas brought considerable new attention to soundscape conservation within protected areas (see Francis et al., 2017). Using two national datasets of noise propagation and protected area networks, the authors found significant levels of noise pollution permeating protected areas. This permeation, however, suggests that these same protected areas are effectively provisioning their service of noise abatement. By absorbing noise pollution at the levels reported by Buxton et al. (2017), it could be hypothesized that the services provided through noise abatement might also be significant at a national scale.

Given what is known about noise pollutions' broader impacts on human health and wellbeing (see Baliatsas, van Kamp, van Poll, & Yzermans, 2016; Passchier-Vermeer & Passchier, 2000; Votsi, Mazaris, Kallimanis, Drakou, & Pantis, 2014) there is surprisingly sparse research examining how protected areas' noise exclusion and abatement impact the developed—or developable—areas that surround them. In other words, while Buxton et al. (2017) revealed how noise permeates protected areas at a national scale, it is largely unknown how protected areas' presence and absorption of noise impacts the sound levels in their surroundings. Moreover, how the characteristics of protected areas—such as conservation status, ownership, and level of accessibility—impact noise exclusion and abatement has not yet been studied. Without an understanding of how conservation lands affect ambient sound levels, planning efforts to reduce the adverse effects of noise pollution are at a considerable disadvantage. The purpose of this research is therefore to explore how protected areas influence and abate the ambient noise of their surrounding regions, using the same two datasets employed by Buxton et al. (2017). Applying a spatial regression approach, we examine the following research question: do conservation status, ownership, and accessibility of protected areas impact sound levels at a county scale?

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1.1. Soundscape preservation and protected areas

Noise—though often used synonymously with sound—is distinguishable as undesirable, annoying, or extraneous human-caused sound (Marin, Newman, Manning, Vaske, & Stack, 2011; Newport, Shorthouse, & Manning, 2014). Some protected area management agencies, such as the U.S. National Park Service, preserve natural sounds as they would any other natural resource—such as wildlife, water quality, and unique geologic features (Dumyahn & Pijanowski, 2011). The management of these resources, including sounds, is designed to fulfill a dual mandate of providing human and ecological benefits (Newman, Manning, & Treviño, 2010; Sax, 1980). However, most land management agencies do not have formal policy associated with soundscape conservation and anthropogenic noise. The International Union for Conservation of Nature and Natural Resources (IUCN), a global body dedicated to protected area management, does not place soundscapes among the specific determinates of the conservation status of protected areas (Dudley, 2013). Despite the lack of broad formal recognition of soundscape conservation within a protected area, the science supporting protected areas' ability to preserve natural quiet is robust and growing. The majority of this research examines strategies of preserving quiet within protected area boundaries (see Miller, 2008).

1.2. Noise exclusion and protected areas

Because protected areas generally have a goal of reducing human development within their bounds, they tend to harbor and preserve natural quiet by excluding noise (Pavan, 2017). The exclusion of noise is primarily the result of limited development and limitations on human habitation. However, exclusion is also carried out through a variety of management strategies meant to limit development or its impacts, such as limiting overflights, implementing shuttle bus systems, designating "quiet zones", and limiting mineral exploration (Lynch, Joyce, & Fristrup, 2011). Hence, the general lack of noise produced by relatively undeveloped protected areas—enhanced by efforts to further reduce the amount of noise produced therein—not only leads to lower amounts of noise in protected areas, but also likely leads to lower levels of noise in the areas that encompass them—all else being equal (Manning et al., 2018). Some have questioned, however, the capacity of small parks and urban "pocket parks" to significantly provide this exclusion of noise given their size (e.g. Wilson, McGinnis, Latkova, Tierney, & Yoshino, 2016).

1.3. Noise abatement and protected areas

In addition to preserving natural quiet through noise exclusion, protected areas can also abate anthropogenic noise. Much of the research in this area has been driven by interest in how noise impacts human health, as reviewed by Passchier-Vermeer and Passchier (2000) and, more recently, by Baliatsas et al. (2016). Newport et al. (2014) also review the negative effects anthropogenic noise has on ecological health and provide a series of implications for protected area managers in reducing noise impacts. In response to these human health and conservation concerns, numerous studies examined the capacity of protected areas to absorb and abate anthropogenic noise—that is, how protected areas reduce the amount of noise pollution in a given area. Derkzen, van Teeffelen, and Verburg (2015) frame this abatement as an ecosystem service provided by green space, especially in urban areas. Derkzen et al. (2015) conceptualize these ecosystem services as either direct—green spaces absorbing noise and destructing sound waves—or indirect—vegetation reducing wind speeds and soils absorbing noise. The masking of anthropogenic noise with natural sounds in urban areas is another important service of green space—with evidence showing that even narrow vegetation belts can abate noise (Chen & Jim, 2008).

1.4. Emerging issues

In addition to soundscape conservation and noise abatement, new trends are emerging concerning land development, anthropogenic noise, and protected areas. It is unsurprising that development impacts ambient noise, however scientists recently began assessing both the sources and ecological consequences of an increasing human footprint proximate to protected areas. Concerning the sources of development, recent literature in the social sciences analyzed the various "pull factors" of development near wild areas, such as migration to areas near national parks and designated Wilderness areas (e.g. Breen, Hurley, & Taylor, 2016; Culbertson, Case, Fowler, Morgan, & Schwellenbach, 2008; Gimmi et al., 2011; Glass, 2006; Locke, 2006). This increased development on park and protected area borders raises additional concerns about soundscape conservation (e.g. Hanes, 2018; Laitos & Ruckriegle, 2013; Lynch, 2006). As development increases, habitat fragmentation is apt to follow (Pijanowski, Farina, Gage, Dumyahn, & Krause, 2011). This too can have adverse effects on soundscape conservation and green spaces' ability to abate noise (Tucker, Gage, Williamson, & Fuller, 2014). In sum, the negative noise impacts of development around protected areas are likely to interplay with the known positive effects of green space. This research seeks to shed light on these emerging issues of noise propagation by applying a large scale, spatial approach to the examination of how conservation status, ownership, and access impact sound pressure level.

2. Methods

2.1. Study area

The geographic scope of this study was limited to the eastern United States, as defined by counties lying east of the 100th meridian (Stegner, 1992). The American West, including Alaska and Hawaii, were not included in the analysis for the following reasons. First, counties tend to be much larger in the West, therefore causing inconsistencies in the data and making a distance-based spatial weight matrix infeasible due to size constraints. Second, the Eastern United States is more homogenous than the West in terms of climate and ecology, making it more suitable for this analysis (Omernik & Griffith, 2014; Ward, 1925). Counties were selected as the unit of analysis due to the availability of land development data and their manageability from a computational perspective as opposed to zip code or minor civil division.

2.2. Data

2.2.1. Sound level data

The dependent variable in our analysis is operationalized as average sound pressure level at a county level. These data were derived from a national noise dataset published by the US National Park Service Natural Sounds and Night Skies Division (2017) developed by Mennitt and Fristrup (2016). Using a random forest model (Breiman, 2001), the developers considered 115 explanatory variables from 7 categories—topography, climate, landcover, hydrology, anthropogenic, time, and control—before selecting 45 variables based on their predictive performance of sound pressure level to create a continuous raster of A-weighted sound pressure levels on a typical summer day across the United States. Data for the Eastern United States is provided at a resolution of 270 m and sound pressure level is measured in A-weighted decibels (dBA). These data were averaged across U.S. counties using ArcMap, creating the dependent variable of average dBA. Fig. 1 shows the results of this aggregation.

2.2.2. Protected area data

Given our research question of understanding how conservation status, ownership, and accessibility of protected areas influences ambient noise levels, we gathered spatial protected area data from the U.S.

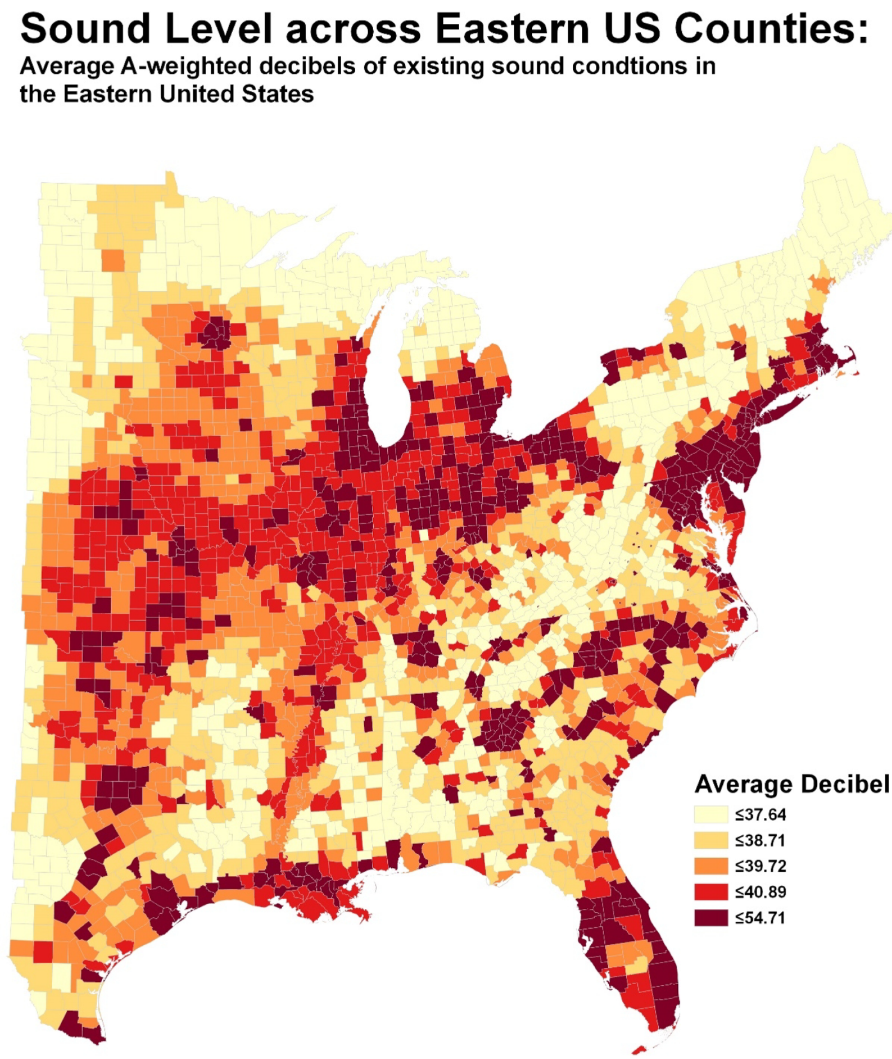

Fig. 1. *The distribution of average sound pressure level across counties in the eastern United States.* Data provided by the National Park Service, Natural Sounds and Night Skies division.

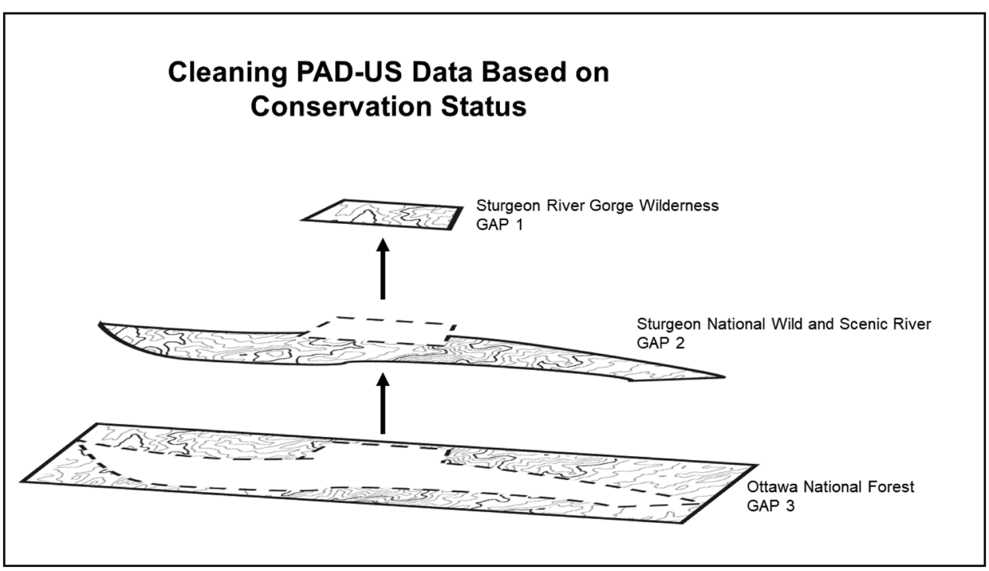

Fig. 2. *In order to avoid double-counting protected area land areas, protected areas were erased from those with lower conservation status, or GAP status. In this example, a protected area with GAP 2 status is first erased from a protected area with GAP 3 status and then an area with GAP 1 status is removed from both the protected area with GAP 2 status and that with GAP 3 status designation.*

Geological Survey (USGS) Protected Area Database of the United States (PAD-US) (USGS PAD-US, 2016). This dataset is the official inventory of public and private protected areas for the United States, holding spatial information and metadata for more than 150,000 protected areas in the United States (Gergely & McKerrow, 2016). For each inventoried protected area, information is available concerning its geometry,

Table 1
Descriptive statistics for GAP status lands considered in the study.

GAP Status	Count	Total Area (km^2)	Average Area (km^2)	Median Area (km^2)
GAP 1	4448	43,543,276	9792	276
GAP 2	34,307	319,699,000	9319	301
GAP 3	21,275	260,853,000	12,262	137
GAP 4	57,654	167,359,000	2903	84

ownership, manager, designation, conservation status, and accessibility. For the purposes of this analysis, metadata concerning protected area geometry, ownership, conservation status, and accessibility was aggregated at a county level.

2.2.2.1. Data cleaning. Prior to analysis, however, the shapefiles downloaded from the PAD-US website required substantial cleaning. In the dataset, many protected areas layer on top of one another. This presents a problem of double-counting their geographic extent within a county. For instance, many national forests contain designated Wilderness areas within their boundaries. In all cases, these are presented as two separate layers. Therefore, when tabulating the portion of a county falling under a given conservation status related to generic national forest lands, the resulting percentage is inaccurate because a substantial portion of the national forest may actually contain a higher level of conservation status prescribed by its Wilderness designation. To avoid this issue, the Erase tool was used in ArcGIS Pro to remove areas with higher conservation status from their enveloping, or partially enveloping, protected areas (Fig. 2). The final descriptive statistics for each GAP status are listed in Table 1.

2.2.2.2. Data operationalization. After cleaning the protected area data, six explanatory variables were derived. We used the USGS measure of "GAP Status" (Gap Analysis Project Status) to operationalize conservation status. This categorization system is based on the protected area categories prescribed by the IUCN and has four levels, with GAP 4 holding the least amount of conservation protections and GAP 1 holding the most (see Table 2). Since each of these protected area classifications hold very different portfolios of lands and because we were interested in how each of these performed individually, we created explanatory variables for each GAP status. Each variable was then calculated as the portion of land within a county falling under a given GAP status. In addition to conservation status, ownership and recreation access were included in the analysis due to previous findings of their impact on conservation performance (Brockington, Duffy, & Igoe, 2008; Reed & Merenlender, 2008). Public versus private ownership of protected areas was operationalized as an explanatory variable by calculating the total area of a county's protected areas falling under private ownership divided by the total area of a county's protected areas. The average degree to which protected areas allowed for public access was conceptualized as a continuous explanatory variable by coding open access (e.g. a national park or national forest) as "3", restricted access (e.g. designated Wilderness or national wildlife refuge) as "2", and closed to access (e.g. ranching easement or private cultural site) as "1" and then calculating the average access across counties.

2.3. Land developability data

Development data, derived from the Land Developability Index (Chi & Ho, 2013), were also employed. This dataset presents an index value for every U.S. county based on the potential for future land development. The index is based on variables pertaining to surface water, wetlands, built-up lands, slope, and tax-exempt lands (Chi, 2010). In this way, the index was used as a continuous, composite variable to control for a number of known factors that influence noise propagation including: the amount of urbanization in each county, the terrain of each county, and the amount of surface water in each county (Aneshensel, 2015; Waldorf & Chen, 2010). Urbanization has been directly linked to noise levels (Çoban, Dalkılıç, Kaya, Türkmenoğlu, & Çoban, 2018; Lobo Soares & Bento Coelho, 2016), steeper slopped terrain inhibits noise propagation (Dailey & Redman, 1975), and surface water has been shown to be slightly better at propagating sound as opposed to natural lands (Dailey & Redman, 1975). Higher numbers in the index indicate that land has more potential for development. For the purposes of this analysis, high numbers would be expected to correlate with both green space and low ambient sound levels, thus making the index a confounding control variable.

2.4. Spatial model

Noise propagation and soundscapes are often studied within the context of space (Farina, 2014). On a regional scale sound level exhibits a clustered pattern (Votsi, Drakou, Mazaris, Kallimanis, & Pantis, 2012). Given this study's goal of understanding how protected areas influence ambient sound levels, we relied on these previous findings to develop

Table 2
Conservation Status of GAP coded Protected Areas.

GAP Status	Conservation Status	Examples
GAP 1	"An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management."	Wilderness Area, National Park, State Wild Area
GAP 2	"An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance."	National Conservation Area, State Park, National Wild and Scenic River, National Wildlife Refuge, Nature Conservancy lands
GAP 3	"An area having permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low-intensity type (e.g., logging, OHV recreation) or localized intense type (e.g., mining). It also confers protection to federally listed endangered and threatened species throughout the area."	State Game Lands, National Forest, State Forest, historic site
GAP 4	"There are no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitat types to anthropogenic habitat types. The area generally allows conversion to unnatural land cover throughout or management intent is unknown."	Municipal recreation area, city parks, urban pocket park, sections of American Indian reservations, state trust land, Department of Defense land, uncategorized conservation easements

Note: Definitions for GAP Status were retrieved from https://gapanalysis.usgs.gov/padus/data/metadata/.

an approach to model this relationship using spatial regression. In this way, we emulated a previous spatial study by Chi and Marcouiller (2013) of natural amenities and protected areas. This approach included first establishing a neighborhood structure through a spatial weight matrix, testing for autocorrelation, assessing spatial dependence, and finally running a spatial regression based to the results of the previous steps.

2.5. Spatial weight matrix

Before assessing autocorrelation and spatial dependence, a spatial weight matrix needed to be generated to establish how counties relate to their neighbors (Chi & Zhu, 2019). Previous studies of soundscapes and space have opted for a distance-based matrix, where neighbors are determined by the distance from the center of each unit of analysis (Hong & Jeon, 2017; Salvi, 2008; Thanos, Bristow, & Wardman, 2012). Since no spatial regression on soundscapes has, to the researchers' knowledge, been published on a scale as vast as the eastern United States, we derived weight matrix based on a data-driven approach. In this way, six different distances were selected and tested: 55, 65, 75, 100, 125, and 150 miles.

Sixty-five miles was used as a reference distance, as it presents the lowest distance with which every eastern U.S. county has at least one neighbor. Following the findings of Bivand and Portnov (2004), distances allowing isolated counties were considered as long as 1) they created only a few isolates and 2) their placement did not display an apparent pattern. Therefore, distances of 55, 45, and 35 miles were also considered. Fifty-five miles was included in the analysis, as Aroostook County, Maine—the largest, northernmost county in the Eastern U.S.—represents an outlier in the data and is the only isolated county at this distance. Distances of 45 and 35 miles isolated 7 and 28 counties, respectively, with clusters in northern Minnesota and northern Maine and therefore were determined to be unfit for further analysis. Following Chi and Zhu (2019), inverse distance-based spatial weight matrices of powers 1 and 2 were assessed based on their Moran's I statistics, a measure of spatial autocorrelation (Table 3). A distance of 55 miles exhibited the greatest Moran's I and was therefore selected as the matrix to be used in the subsequent analyses. There were no differences among powers and therefore a power of 1 was selected.

Table 3
Univariate Moran's I for Dependent Variable (Noise) using eight different Inverse Distance Spatial Weight Matrices.

Miles	Power	Moran's I
55	1	0.467185***
	2	0.467185***
65	1	0.416188***
	2	0.416188***
75	1	0.380738***
	2	0.380738***
100	1	0.31513***
	2	0.31513***
125	1	0.263166***
	2	0.263166***
150	1	0.223966***
	2	0.223966***

* p < .1, ** p < .01, *** p < .001.
Calculated using inverse distance-based spatial weight matrices, 999 permutations.

Table 4
Comparison of Model Fit.

Variable	R^2	AIC	BIC
OLS	0.00932	11982.1	12028.7
SEM	0.51559	10446.2	10492.8

AIC = Akaike info criterion.
BIC = Schwarz criterion.

2.6. Model specification

Given that an inverse distance-based spatial weight matrix of 55 miles boasted a Moran's I of the dependent variable equal to 0.467185, the data were determined to be positively autocorrelated, or clustered. It was therefore necessary to conduct an Ordinary Least Squares (OLS) regression to determine the nature of the spatial dependence in our model. Robust Lagrange Multiplier (LM) tests of spatial lag and spatial error based on the OLS results revealed a non-significant spatial lag effect and a significant spatial error effect. It was therefore determined that a spatial error model (SEM) should be used in our final regression.

In the final step of the analysis, a SEM was derived to assess our research question such that:

$$Y = C + (\mathrm{GAP1})\beta_1 + (\mathrm{GAP2})\beta_2 + (\mathrm{GAP3})\beta_3 + (\mathrm{GAP4})\beta_4 + (\mathrm{PRIVATE})\beta_5 + (\mathrm{ACCESS})\beta_6 + (\mathrm{DEVELOP})\beta_7 + u,\ u = \rho W u + \varepsilon$$

Herein, Y is equal to the response variable—sound pressure level. β_x represents regression coefficients. u is the vector for the error term. ρ is the scalar spatial error parameter. W is the spatial weight matrix. C is the constant. And ε is a vector for the error terms that are not identically distributed (Chi & Zhu, 2019).

3. Results

The SEM resulted in a better model fit than the OLS as seen in Table 4. Both AIC and BIC statistics are smaller in the SEM model. Results of the SEM are listed in Table 5. Empirical results suggest that the portion of lands protected under GAP 4 status are negatively related with sound level at 95% confidence; as GAP 4 lands increase, sound levels decrease. Results also suggest that the portion of lands protected under GAP 1 status is positively related with sound level at 95% confidence; as GAP 1 lands increase, sound levels increase. Lands protected under GAP 2 and GAP 3 status were not significantly related to sound level. However, both GAP 2 and GAP 3 status lands show a negative relation to sound level. Land developability has a negative relationship

Table 5
Results from SEM regression.

Variable	Variable Code	Coefficient	Standard Error
GAP 1	GAP1	0.982*	0.456171
GAP 2	GAP2	−0.302	0.373242
GAP 3	GAP3	−0.315	0.220671
GAP 4	GAP4	−0.765*	0.366593
Private/Public Ownership	PRIVATE	0.030	0.126808
Access	ACCESS	−0.063	0.0629167
Land Developability	DEVELOP	−0.032***	0.00253787
Lambda	LAMBDA	0.882***	0.0141127
Constant	CONSTANT	41.895***	0.389399

*p < .05, **p < .01, ***p < .001 R^2 = 0.5156, AIC = 10446.2, BIC = 10492.8 Multicollinearity Condition Number = 13.273818 Standard error = estimate of standard deviation for the sampling distribution specific to the coefficient in question.

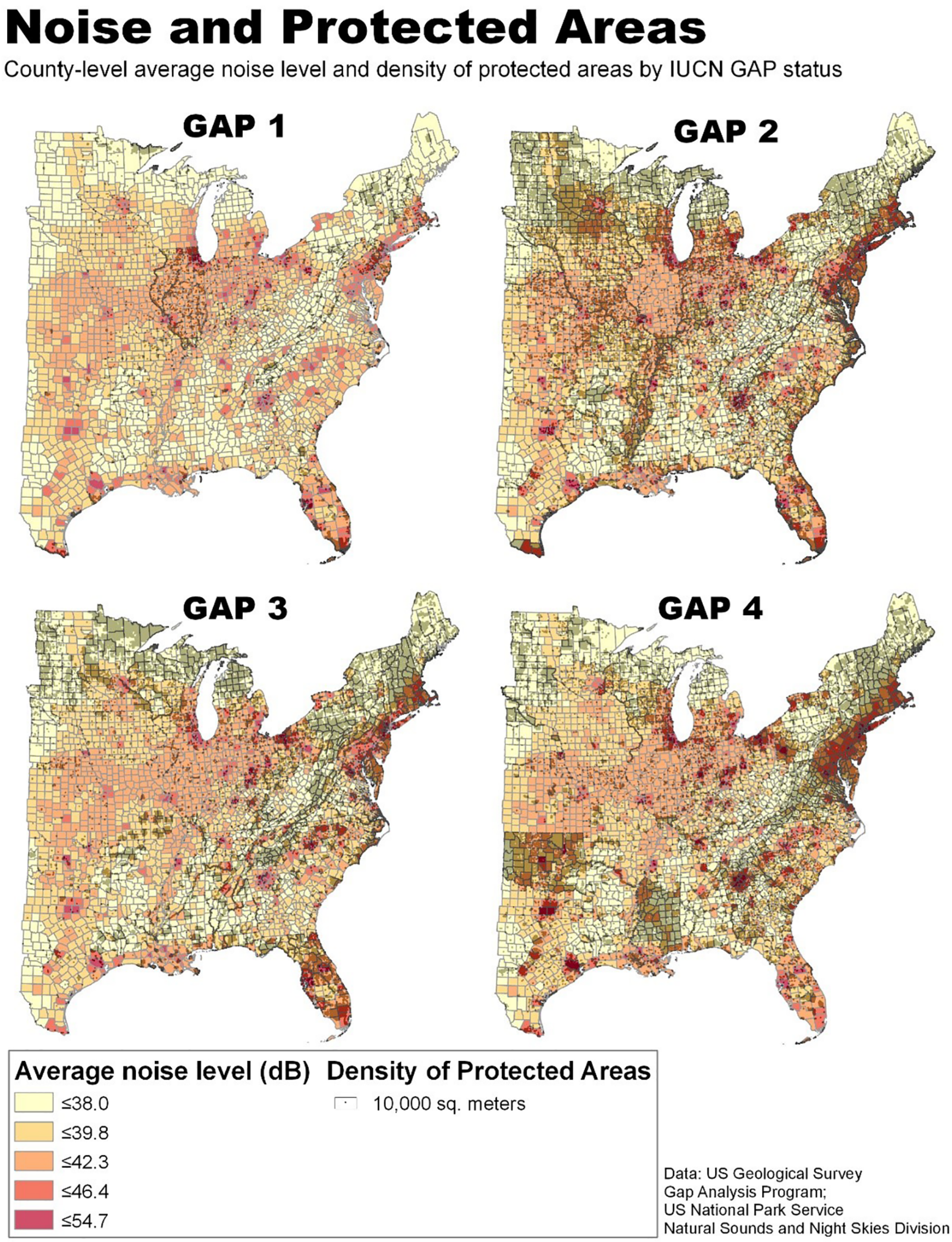

Fig. 3. *Average sound level and dot-density of protected areas in the Eastern United States. Note the density of GAP 4 lands in the urban areas of greater New York, Boston, Atlanta, Chicago, Dallas, and Houston (not labeled on the map).*

with sound level at 99.9% confidence. All other explanatory variables did not have significant relationships with sound level. Examining the effects of GAP status on sound level, results suggest that a 10% increase in GAP 1 lands result in a 9.8% increase in sound level. To the contrary, a 10% increase in GAP 4 lands would result in a 7.7% decrease in sound level. Lamda, the spatial error lag term, was significant at 99.9% confidence. Based on the Lamda coefficient, results indicate that if the sound levels in surrounding counties increase an average of 10%, the surrounded county's sound level will increase 8.8%, all else being equal.

4. Discussion

4.1. Sound impacts of wilderness protected areas

The contrast between the effects of wilderness (GAP 1) and non-conservation (GAP 4) protected areas is not immediately intuitive. GAP 1 lands are, after all, the most pristine of all protected areas, encompassing designated Wilderness areas, national parks, and other similar lands—and hence presumably offer the greatest amount of noise exclusion. Their positive relationship with sound level is therefore of particular interest. It would appear that this might be the result of an emerging phenomenon concerning designated Wilderness and national parks: wilderness amenity migration (Holmes et al., 2015). This form of amenity migration, broadly defined as the "the movement of people based on the draw of natural and/or cultural amenities" (Gosnell & Abrams, 2011, p. 303), is specific to public lands and protected areas (Locke, 2006; Rasker, Alexander, van den Noort, & Carter, 2004). Within the eastern U.S., this phenomenon has been studied with respect to national parks (e.g. Breen et al., 2016; Culbertson et al., 2008) and designated Wilderness areas (e.g. Glass, 2006). This migration leads to increased visitation and development in and around these protected areas. Gimmi et al. (2011) provide a case study of Indiana Dunes National Park, Indiana finding that migration directly linked to the park's creation—alone—in 1966 led to the construction of 6800 to 9500 new buildings within a 3.2-kilometer-wide zone around the park's boundary. It follows that as interest increases around these GAP 1 lands, noise follows suit—ushered in by increased road traffic, aircraft traffic, and other anthropogenic sources. In this way, GAP 1 designation acts as a pull-factor for noise—suggesting a positive relationship.

Unsurprisingly, noise associated with wilderness amenity migration and the growth it brings has also been noted in a number of studies. Lynch (2006) provides a case study from Grand Teton National Park, Wyoming, where migration prompted the expansion of a community airport within the park—bringing larger and more frequent flights into the area. Concerns of increased noise levels followed. Hanes (2018) finds similar results in a study of amenity migration and aquaculture development near Acadia National Park, Maine, where concerns of increased noise levels were a primary theme of hearings associated with the increased development. Laitos and Ruckriegle (2013) cite similar issues in the ski towns of the Friuli Alps, Italy.

While it is not possible to definitively link the finding of a significant positive relationship between GAP 1 lands and sound level directly to wilderness amenity migration, the literature available makes a rather compelling case for their association. If this is the case, then the noise exclusion and abatement ecosystem services provided by GAP 1 protected areas are being outweighed by the noise of development on their periphery. Regardless, given how amenity migration can affect protected areas' ecosystem services—acoustic and otherwise, Kruger, Mazza, and Stiefel (2008) underscore the need for park managers to work with communities to ensure that resources are not impacted. For example, Miller (2017) highlights this necessity for community engagement in the designations of new national parks, using the case study of Katahdin Woods and Water National Monument, Maine.

4.2. Sound impacts of non-conservation protected areas

Concerning the results of the other GAP status lands, it is not surprising that the coefficients for GAP 2, 3, and 4 designations are negative. Overall, these lands do not harbor the same amount of attraction of GAP 1 lands, and therefore the noise exclusion and abatement they provide emerge in the results as expected. It is interesting, however, that non-conservation (GAP 4) lands provide the only significant relationship of the three categories. Understanding why this might be the case requires an examination of the nature and distribution of these lands. Returning to Table 1, GAP 4 lands are the most frequently occurring in the eastern U.S. and are also the smallest protected areas, on average. This is consistent with the types of lands that fall under this designation, including, among others: city parks, county parks, "pocket parks", and greenways.

As seen in Fig. 3, the densities of these GAP 4 lands in urban counties with relatively high sound levels exceeds that of GAPs 1, 2, or 3. Therefore, GAP 4 lands are spatially positioned to make a measurable difference in noise abatement. And while literature has well-established the link between housing preference and urban green space (see Crompton, 2001, 2005), the difference between this phenomenon and amenity migration lies in the difference between moving within an urban area that has already been developed versus moving to a rural area that has yet to have been developed (Waltert & Schläpfer, 2010).

Additionally, this finding presents implications for human health and well-being. The abatement of noise is a crucial component of green spaces' ability to benefit human well-being (Gidlöf-Gunnarsson & Öhrström, 2007). Protected areas' significant ability to abate noise in more developed areas, as implied by our findings, provides incentive for urban land managers to consider the impact they can make on the human well-being of their surrounding communities through noise abatement strategies.

Perhaps the most intriguing implication of the GAP 4 result is that based on this data protected areas with no formal conservation standards are still significantly effective in excluding and abating noise. As previously stated, the IUCN protected area categories do not formally consider soundscape conservation (Dudley, 2013). Indeed, however, GAP 4 lands do provide noise exclusion and abatement ecosystem services, as confirmed by these results.

4.3. Broad impacts of conservation status

It should also be noted that whereas soundscape preservation and noise abatement seem to have little to do with protected areas' conservation status, the amenity migration to wilderness (GAP 1) lands may have little to do with their environmental quality, but rather their conservation status or designation. Research suggests that both the labels of national park (Fredman, Friberg, & Emmelin, 2007; Weiler & Seidl, 2004; Weiler, 2006) and Wilderness area (Loomis, 1999) are draws all to themselves and are not necessarily indicative of their conservation potential (Boitani et al., 2008; Leroux et al., 2010; Muñoz & Hausner, 2013). In this way, GAP 1 lands may not be all that different from GAP 2 and 3 lands in terms of their conservation performance, but labels like "national park" draw public interest and sound to, and within, their borders. Our research takes the first step in providing a glimpse into how soundscapes may be impacted by amenity migration.

4.4. Limitations and future research

The PAD-US dataset is limited by its inconsistent data quality. The feature layers that make up the dataset are provided by mostly external agencies and organizations and are unaltered by USGS data compilers. It is also not absolutely exhaustive of all protected areas in the United States (USGS, 2017). Additionally, like all spatial regression models, this study is reliant on its selected spatial weight matrix (Chi & Marcouiller, 2013). While using an inverse-distance spatial weight matrix was driven both by theory and data, it is possible that a different matrix could lead to a different result. The county-level unit of analysis is also recognized as a potential limitation, as a finer geographic unit would provide a greater resolution to these findings. However, as previously mentioned, this was necessitated due to data resolution.

This study has brought to light the general lack of research examining how landscape conservation impacts soundscape conservation and noise abatement. This is especially the case with concern to landscape scale research. Though a few studies have examined how green space can abate noise (e.g. Jang, Lee, Jeon, & Kang, 2015), virtually nothing has previously analyzed noise abatement within regional networks of protected areas or the like. Additionally, more research is needed to examine how amenity migration has influenced the noise pollution in and around GAP 1 status lands described by Buxton et al. (2017) and this study. Finally, future research might ask how conservation statuses of protected areas could integrate noise exclusion and abatement potential.

5. Conclusion

The purpose of this study was to analyze how the characteristics of protected areas influence sound levels of surrounding areas, as a complement to Buxton et al. (2017). The findings indicate that conservation status of protected areas are significantly linked to their effectiveness at abating noise. However, we theorize that this effect is largely the result of external influences such as wilderness amenity migration and the geographic distribution of protected areas. Additionally, ownership and permitted access do not seem to influence abatement performance. The two primary upshots of this research are 1) the need for additional study of how external phenomena impact the acoustic ecosystem services of protected areas—noise exclusion and abatement—and 2) the need for further consideration of soundscapes in protected area designation. Thus, further quantification of noise abatement as an ecosystem service is urgently needed to aid planners and park managers in understanding just how designation, increased development, fragmentation, and distribution of protected areas are impacting their ability to provision quiet and absorb noise.

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