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Exploring the Impacts of Protected Areas' Attributes on Pediatric Health: The Case for Additional Research beyond Greenspace

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Abstract: An increasingly vast segment of the literature examines the relationship between greenspace and pediatric health. However, the bulk of this research continues to use proximate relative greenness as a measure for exposure to the ecosystem services provisioned by natural areas, despite increasing recognition that relative greenness fails to capture the public accessibility, recreation potential, or desirability of natural areas. Thus, this present research demonstrates the use of emerging data sources that can be used in conjunction with traditional greenspace measures to improve modeling as it relates to nature's impacts on pediatric health. Using spatial park and protected area data in concert with mobile phone location data, we demonstrate exploratory analysis on how park and protected area attributes may influence pediatric health in northwest Montana, USA. Suggestive findings concerning how the attributes of park and protected areas (i.e., conservation status, access, recreation demand) influence pediatric health (i.e., attention-deficit/hyperactivity disorder, asthma, and anxiety/mood disorders) lead us to introduce directions for future research beyond greenspace. Importantly, this research does not intend to provide definitive or generalizable findings concerning how parks and protected areas influence pediatric health. Instead, we aim to provide an initial exploration toward a larger, future body of the literature, evaluating parks and protected areas' influence on pediatric health.

Keywords: pediatric health; parks and protected areas; beyond greenspace; outdoor recreation

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1. Introduction

In recent decades, interest in the health benefits of nature exposure and recognition of the importance of greenspace in public policy decisions have seen a considerable rise [1]. Research has demonstrated many positive health outcomes associated with natural environments, ranging from psychological and emotional well-being to lower body mass index (BMI) and type 2 diabetes, improved sleep, and better respiratory health [2–6]. There is substantial evidence that greenspace exposure and access are beneficial during the pivotal pediatric development period, not only as a factor of environmental quality but also as a mechanism for healthy lifestyle habit formation and social cohesion [2,7–10]. Furthermore, greenspace is recognized in the literature as a resilience factor for mental well-being and a tool for mediating health inequities across the socio-demographic spectrum [2,7,9,10]. Although the link between natural environments and general well-being is well documented, greenspace assessment metrics and associated outcomes vary widely in quantity and quality [11,12]. The definitions of greenspace used in different studies are often unique and context-dependent. In many cases, studies use cross-sectional mental health data, making causal inferences about greenspace impacts difficult (as reviewed by Collins et al. [11]). Additionally, previous research has primarily focused on the relationships between greenspace and human health in urban populations, leaving rural populations largely understudied [2,13].

Rural pediatric populations may face considerable health challenges due to economic deprivation, isolation, and sociocultural context in the rural environment [14,15]. Based on previous research, greenspace is a potential tool for mitigating health disparities and is recognized as a positive contributing factor to pediatric development [10,16]. However, the body of research on greenspace and health leaves gaps in understanding because of its urban focus [13,15]. The environmental landscape between rural and urban populations is vastly different: a built landscape versus agricultural land cover, utility and public works, community infrastructure, cultural heritage, geographic access to health and social services, and beyond. Therefore, consideration of the specific environmental context, greenspace measures, and demographics are essential to inform appropriate research methodology to address specific rural health questions and to better support the health of rural populations.

1.1. Impacts of Greenspace on Pediatric Health

Interaction with natural spaces such as parks, forests, backyard gardens, and other vegetation or natural areas is linked to numerous beneficial health outcomes for children and adolescents. Previous studies consistently show a positive relationship between greenspace and myriad pediatric health concerns, including anxiety and mood disorder diagnoses, obesity, attention-deficit/hyperactivity disorder (ADHD) diagnoses, and asthma [2–4,8,16,17]. Studies also show that parent-/guardian-reported health outcomes such as sedentary behavior, mental and emotional well-being, and better cognitive function are associated with proximity and access to greenspace [2,18]. Greenspace can promote these health indicators through multiple pathways: reducing stress; mitigating harmful exposures such as heat, pollution, and noise; restoring attention; and promoting physical activity, social interaction, and sleep [19–21]. Environmental conditions in the living environment are extremely influential during the pivotal developmental years, and children and adolescents benefit more from continuous greenspace exposure [18,22].

General exposure to nature and higher degrees of residential greenness may act as a buffer for pollution and noise and, thus, prevent illness from harmful environmental exposures. A higher prevalence of trees and green exposure has been linked to a lower incidence of asthma in urban-dwelling youth [17]. Greenspace exposure in the living environment or "surrounding greenness" is positively associated with prosocial behavior, improved attention, and academic performance in children [2,16]. The restorative qualities of natural environments alleviate psychological and emotional stress in adolescents and children [6], possibly lowering the risk of developing psychiatric disorders later in life [8].

Pediatric health benefits related to greenspace access and recreational opportunity are linked to positive habit formation and lower BMI, likelihood of being overweight, and behavioral concerns [2,18,19]. Adolescents who have access to parks and playing fields are more likely to engage in physical activity, such as walking, running, and playing sports. This can lead to improved cardiovascular health, weight management, and overall physical fitness [4]. These types of greenspaces provide opportunities to interact with other adolescents, improve social connections, and create a sense of community, which are important protective factors for mental health [23]. Additionally, Kuo [16] found that exposure to nature, such as walking in a park, improved attention, and cognitive functioning in children with ADHD. While environmental pathways related to greenspace exposure in the living environment are important for general well-being, the type of greenspace—such as playgrounds, parks, or wilderness—may be more significant during different developmental stages [9,22].

1.2. Greenspace and Rural Adolescents

Rural pediatric health has been a growing concern in recent years, as adolescents in rural areas often face unique challenges that can negatively impact overall health. Probst et al. [15] conducted a study that found rural adolescents had higher rates of obesity, tobacco and alcohol use, and physical inactivity compared to their urban counterparts. Additionally, Racevskis et al. [13] found that rural adolescents were less likely to have access to mental health services, which can exacerbate issues such as depression and anxiety. Exposure and access to greenspace are recognized tools for health intervention, yet, in the United States, children residing in non-urban areas are more likely to lack access to parks [10,14]. In rural areas, it is considerably more difficult for most children to access usable open spaces due to their distance from parks and protected areas (PPAs) and the lack of maintained recreational facilities. These factors curb regular visitation by rural adolescents, diminishing the potential health benefits associated with park use [4].

While there is a significant amount of research investigating the impact of greenspaces and outdoor recreation on urban adolescents, studies on the health of rural adolescents concerning outdoor recreation and natural amenities remain largely understudied [19]. It is evident that rural and urban populations exhibit distinct interactions with PPAs, varying recreational behaviors, diverse environmental views and values, and potentially different perspectives on the health benefits of outdoor recreation [13]. For example, densely populated, urban-dwelling is associated with higher rates of pollution, noise, and limited green infrastructure, but higher contact with other people. Alternately, individuals living in sparsely populated, rural communities may be more likely to experience isolation and loneliness, and may have fewer opportunities for communal engagement and social cohesion [24]. Interaction with different types of greenspaces shows different related health outcomes; thus, the mechanisms affecting health outcomes in urban-dwelling youth differ from rural-dwelling youth. As such, further investigation is necessary to quantify the health and well-being benefits of greenspace for adolescents in the rural context and provide frameworks to improve the facilitation of these benefits.

1.3. The Need to Move 'Beyond' Greenspace as a Monolith

The term "greenspace" is often used in public health research to refer to natural environments, ranging from PPAs to street trees and proximal neighborhood greenness, that show associations with health outcomes. While there is extensive evidence of greenspace's positive relationship with overall health outcomes, considerable variation exists across studies in how greenspace is defined and measured, which has led to conflicting findings for specific health outcomes and a lack of clarity regarding the mechanisms underlying the relationship between greenspace and health [11,12,17,23,25,26]. For instance, some studies on allergy and asthma in children have found asthma flare-ups in children and a higher prevalence of allergy disorders with increasing exposure to greenspace [2,27]. Others have shown no associations and even some evidence of protective effects of greenness [3,17]. A comprehensive look at greenspace quality and type reveals the complex and potentially competing mechanisms affecting overall health outcomes.

Greenspace exposure in the living environment or "surrounding greenness" is thought to facilitate health benefits through multiple pathways, including the mitigation of environmental pollutants, psychological restoration, and promotion of healthy lifestyle behaviors [3,10,23,28]. Access to greenspace and spending time in nature-rich environments has been linked to improved physical and psychological health, lower morbidity, and prosocial behavior in adolescents [3,9,21]. However, researchers have found the quality and characteristics of greenspace in the living environment, such as their size and ecological complexity, to be crucial factors in determining the mechanisms that promote health benefits [16]. For instance, a nature preserve may provide opportunities for physical exercise and social cohesion, but "ecosystem disservices", such as exposure to certain pollutants commonly found in greenspaces, such as nitrogen dioxide, may increase the risk of respiratory and allergic symptoms [2,29,30].

Observed discrepancies in the relationships between greenness exposure and health outcomes may stem from methodological variations such as the types of greenspaces (e.g., parks, woods, residential greenness), the extent of engagement with nature, and the timing or frequency of exposure [31]. Moreover, the strength and direction of associations between nature exposure metrics depend on the geographic scale (e.g., counties vs. tracts) and the region of the country or the nationwide context [7].

The homogenization of "greenspace", as reported in the literature on nature and health, has been suggested as a significant weakness in the field, with a lack of attention to the mechanisms by which greenspace promotes health and the strength of association depending on type and quality of greenspace [9,11,23,28,32]. Many foundational studies on nature and health broadly evaluate greenspace by exposure in the living environment and by access to greenspaces, although, more recently, the literature on nature and health has extended consideration to ecological quality and the social and cultural factors that shape people's experiences and perceptions of nature [25,33].

The value of greenspace as a resource for physical activity and social connection has been evaluated by an individual's access to usable greenspaces, and the strength of association related to greenspace access and visitation frequency. Beyond proximity to greenspace in the living environment, an array of characteristics such as biodiversity, amenities, size, and land cover type can significantly impact the greenspace's accessibility for certain populations. Several studies have demonstrated that public perception of greenspaces, including factors, such as safety, usability, and communal engagement, can have a significant impact on their likelihood of being exposed to the greenspace and their ongoing use of the greenspace (i.e., parents allowing their children to spend time in a certain park) (e.g., [28,34]). Consequently, these factors can have implications for individuals' health benefits from surrounding greenspaces. Moreover, the positive effects of greenspace are stronger for lower-income populations and those living in more deprived areas [28]. This finding is based on the theory that children, the elderly, and people with lower socioeconomic status spend more time in the area around their homes (thus demonstrating less mobility), resulting in greater exposure to the greenspace in their living environment [3].

When considering greenspace as a health indicator, the consideration of greenspace as a monolith inhibits policy-makers' and researchers' ability to quantify a perceived effect for a targeted population or outcome. Such studies are required to give a more comprehensive picture of the potential risks and advantages of being exposed to nature, as well as to aid health professionals and decision-makers in better incorporating the research evidence into recommendations, focused interventions, policy, and urban planning. Ultimately, it is essential to consider more comprehensive measures of greenspace and the mechanisms that promote beneficial health outcomes to define the qualities and measures of greenspace most applicable to specific populations.

1.4. Protected Area Impacts on Health

Proximity to PPAs, such as national parks, wilderness areas, and conservation lands, is associated with an array of physiological, psychological, sociocultural, environmental, and economic benefits [35]. Individuals living closer to protected public areas tend to have lower rates of obesity and diabetes, better cardiovascular health, increased physical activity and social cohesion, and improved mental and emotional wellness [2,5,35]. The most notable community-wide benefits of parks and protected areas include increased community well-being and pride, protection of biological diversity, protection of drinking water, clean air, noise abatement, and greenspaces for leisure, tourism, or recreation, all of which are identified pathways for positive individual health outcomes [20,21]. More importantly, the opportunity for outdoor recreation and exposure to nature in PPAs and the associated favorable health outcomes among adolescents highlight the critical role that proximity and accessibility to PPA can play in supporting pediatric development [4,22].

Protected areas such as parks, playgrounds, or ballfields facilitate and promote regular physical exercise, social cohesion, and a sense of community, which can positively impact mental and physical health [22]. The majority of physical health benefits result from multiple and frequent visitation, and proximity to parks is shown to increase visitation [7,18]. Amenities such as public restrooms, designated sports fields, or walking paths can improve the visitor experience and encourage long-term participation; alternately, PPAs such as forests or wilderness areas provide exposure to nature and act as barriers to noise and other environmental pollution, which can have a calming and restorative effect on the mind [6,20,21]. Quantifying health benefits enables park managers and public health officials to develop evidence-based policies that promote access to PPAs and prioritize the most beneficial qualities of greenspace to meet desired health objectives.

1.5. Study Purpose

Considering this body of existing literature, the purpose of this present research is to examine PPAs' attributes on pediatric health through documentation of an exploratory study in a rural context and, thus, to provide a conduit toward future research. It is *not* our goal to provide definitive or generalizable findings about how PPAs influence pediatric health. Instead, given the lack of exploration which has been conducted in this area of study, we aim to provide initial exploration toward a larger, future body of literature evaluating PPAs' influence on pediatric health. In service of this aim, we demonstrate the use of emerging data sources for measuring protected area conservation status, visitation patterns, and access across space. We conclude with implications for future research in this area of study—stemming from this early exploration.

2. Methods

2.1. Study Site

Montana is classified as a frontier (very rural) and remote state, and as one of the most rural states in the United States by the percentage of residents residing in rural areas. Our area of focus in northwestern Montana is known colloquially as the Mission and Jocko Valleys, bounded by Flathead Lake to the north, the Mission Mountains to the east, and the Salish and Cabinet Mountains to the west. U.S. Highway 93 transects the region, connecting the two nearest cities, Missoula to the south, and Kalispell to the north. The area covers Lake County and parts of Missoula and Flathead County and is significantly overlapped by the Flathead Indian Reservation of the Confederated Salish and Kootenai Tribes (CSKT). A map of the study area is detailed in Figure 1.

The population of the Mission and Jocko Valleys is primarily white (67.5%), with a significant percentage of Indigenous people (24.2%). Nearly 22% of the population in the region lives below the poverty level, and the poverty rate is significantly higher in Lake County compared to other non-metropolitan areas across Montana and the overall state and U.S. poverty rates. The CSKT Reservation largely encompasses our study area and is home to the Salish, Pend d'Oreille, Confederated Salish, and Kootenai tribes. Of the approximately 7914 enrolled tribal members, about 5267 live on or near the reservation.

Residents of the Mission and Jocko Valleys live in more densely populated areas of townships or smaller and more rural communities, interspersed by farms, ranches, and PPAs. Agriculture dominates the rural landscape, with over 67% of Lake County classified as farmland supporting the base economy (U.S. Department of Agriculture, 2019). The remarkable natural landscape and recreational opportunities attract a large number of temporary residents to the area, particularly during the summer months. The significant PPAs in this region include the Flathead National Forest, Lolo National Forest, CSKT fee-access and tribal-owned land, state trust lands, roadless areas, conservation easements, wilderness areas (including the Bob Marshall, Rattlesnake, and Mission Mountain Wilderness), and wildlife refuges. These PPAs allow varying degrees of natural, cultural, and recreational resource use throughout the year in accordance with federal or state agency and tribal regulations.

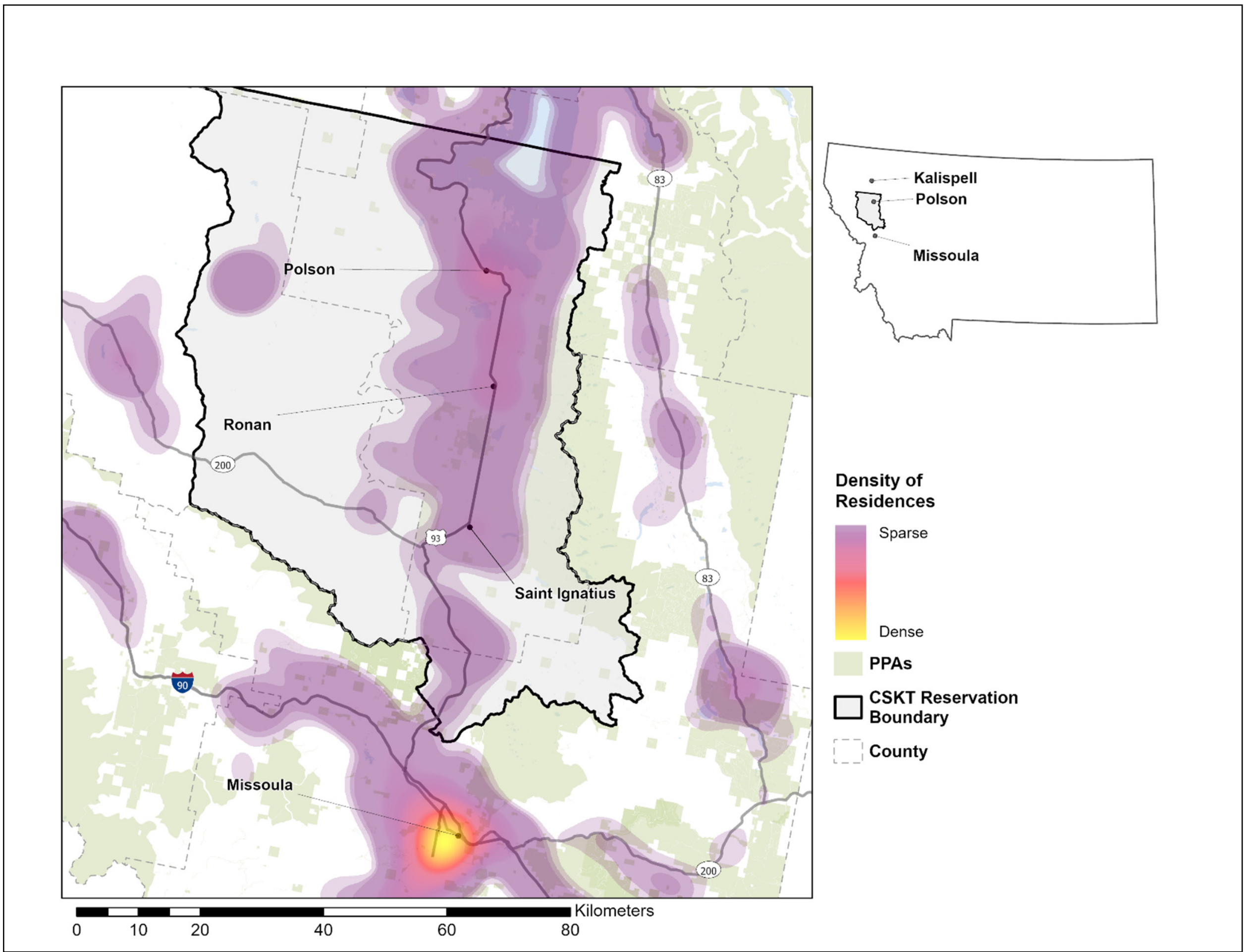

Figure 1. Study area, including density of all residences (not participants) across the study area.

2.2. Data Sources

2.2.1. Pediatric Health Records

Health records analyzed in this study were obtained from St. Luke's Community Healthcare (SLCH), a rural critical access hospital in Ronan, MT. St. Luke's serves the residents of the Mission and Jocko Valleys with clinics in Ronan, St. Ignatius, and Polson. Data were acquired from SLCH through a 2021 Business Associate Agreement (BAA) with the University of Montana. Electronic health data were acquired for all children aged 0–17 years who had at least one visit to SLCH between 1 January 2017 and 31 December 2020. Specifically, the residential address, age, sex, and BMI were collected for each child, as well as whether the child had been diagnosed with ADHD, anxiety or mood disorder, or asthma. In total, there were 5863 health visits corresponding to 3193 unique addresses. After removal of missing addresses, out-of-state addresses, and those with only a P.O. Box, a total of 3195 health visits—corresponding to 2065 unique addresses—were retained for analysis. The individual data in this study were clustered within or immediately surrounding these towns, with some extension into parts of Missoula and Flathead Counties along U.S. Highway 93.

2.2.2. Protected Area Data

PPAs across the United States are inventoried by the Protected Areas Database of the United States (PAD-US). PAD-US is an important reference for conservation planning, resource management, and research as a publicly available, accurate, and standardized spatial dataset. PAD-US is maintained and regularly updated by the United States Geological Survey (USGS). PAD-US provides information about an area's geographic boundaries, land ownership or responsible agency, management designation, visitor information, ecological attribute data, and fee-protected public parks and lands [36]. The PAD-US conservation status (GAP 1-4) indicates the level of biodiversity and public, cultural, and recreational uses [37].

The four GAP categories are assigned according to the area's level of protection and mandated management plan, with GAP-1 having the highest protections and GAP-4 having the fewest protections. PPAs with GAP-1 status include wilderness areas, national parks, private nature preserves, and other relatively strict conservation areas. GAP Status classification within PAD-US has been used previously for wildlife habitat mapping, noise research, and studies on the distribution and attributes of PPAs (e.g., [38,39]). This study relied upon 12 months of PPA use-level data and PPA attribute data provided through PAD-US for each of Montana's 1801 PPAs to examine how PPA attributes and use attributes influenced proximate pediatric health indicators.

2.2.3. Protected Area Visitation Data

Data concerning relative visitation to the PPAs within the study area were sourced from mobile phone location data purchased from the vendor Near. Location data provided by Near are captured by mobile device (i.e., phone) applications that have been approved to collect location information when location services are enabled [40]. Software Development Kits (SDKs) embedded into device applications report coordinates from individual GPS-enabled mobile devices [40]. Raw location data are then aggregated by Near and screened for accuracy and quality—including removing outlier data (i.e., movement patterns that signal residency or employment in the area of interest). Given the volume, velocity, and variability inherent to mobile device location data collected across diverse landscapes, Near uses multiple layers of data screening. Initial screening removes erroneous data reporting from individual devices followed by "power law" screening, which removes implausibly high levels of device requests or device density. Further levels of screening consist of audit-based data testing and other report-based screening methods [40]. Near's mobile phone location data had been previously ground-truthed using population-level data from campground reservations within PPAs in the western United States [41].

In accordance with the goals of this study, we exported both the number of devices observed in each protected area within the study area in 2019 and the median distance travelled to each protected area by device users in 2019. Median distance travelled to each protected area was calculated using the Euclidean distance from each device's common evening location to the closest boundary of the protected area in which it was observed. Common evening location is "estimated [by Near] by determining where a device most frequently appears during the 'non-work' hours [defined as between 18:00 and 08:00 during weekdays and all day on weekends]" [42] (p. 2). This location is then "jittered [by] 50 m [meters] a random direction" to "help maintain the de-identification of device-level data" [42] (p. 4). Importantly, these mobile device location data are derived from a panel of mobile devices—not from every mobile device that enters a protected area. Data obtained from any vendor (e.g., Streetlight, AirSage, Near, and SafeGraph) are the result of "a sample of about 30% of U.S. cell phone users" [43] (p. 30) designed to be representative of their service area's population. Thus, these data have proven useful in estimating relative (or comparative) visitor use levels in PPAs, rather than gross visitation estimates (e.g., [44,45]). The spatial distribution of primary PPA attributes are mapped in Figure 2.

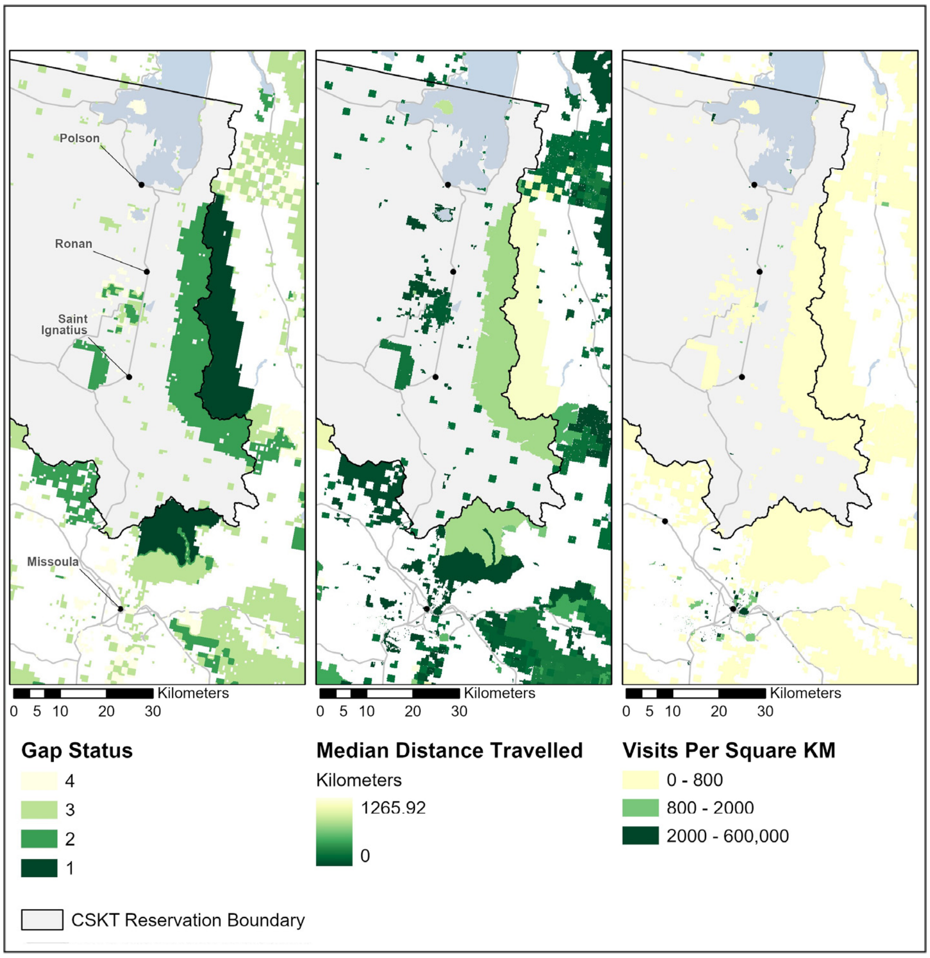

Figure 2. Distribution of PPA attributes across the study area, including GAP status, median distance travelled, and visitation density.

Other Data Sources

In addition to the health records and protected area data sources described above, we used three additional datasets to assist with variable generation: Montana Natural Heritage Program's official state landcover raster layer (Level 3; 30 m resolution), healthcare facility spatial information data supplied by ESRI via the USGS Geographic Names Information System, and the American Community Survey Median Household Income Variables dataset supplied through a U.S. Census Bureau API. The Montana landcover raster layer was used to generate a binary variable for green/blue space—wherein any hardened surfaces, buildings, mines, or similar non-vegetated or water-covered pixels were coded as 0 and all vegetated surfaces and open water (including rivers) were coded as 1 [22]. Green- and bluespace were combined due to the seasonal dynamics of the study area which affect the accuracy of binary measures of greenness or blueness [33,46]. Thus, following Knight et al. [32] greenspace and bluespace were not measured separately, but were combined for the purposes of our analyses. Healthcare facility data included primary, emergency, urgent care, and tribal health facilities within the study area—as coded in the USGS Geographic Names Information System. Median household income was measured at the census tract level.

2.3. Data Cleaning and Generation of Variables

2.3.1. Cleaning and Preparation of Protected Area Data

Protected area data were cleaned using the methods described by Rice et al. [39] for cleaning PAD-US data. In this method, overlapping PPAs were erased by yielding to the protected area with the higher conservation status. In the PAD-US dataset, many PPAs layer on top of one another. For example, a broader national forest (GAP Status 3) may contain (and, thus, overlap with) a designated Research Natural Area (GAP Status 2) which may be contained by an overlapping wilderness area (GAP Status 1). Thus, not erasing the overlying, overlapping portions of lower conservation status PPAs leads to an issue of double (or triple) counting.

Additional cleaning of the PAD-US data included erasing all roadways from the associated polygons using a 100 ft buffer and removing areas from the vast national forest lands of western Montana which offer non-dispersed recreation opportunities, using layers provided by the U.S. Forest Service through the FSGeodata Clearinghouse—thus limiting U. S. Forest Service-administered polygons from the PAD-US dataset to those polygons (or portions of polygons) included in official layers of Special Interest Areas (e.g., Rattlesnake Wilderness, Pattee Canyon Recreation Area, Lookout Pass Ski Area, etc.), Developed Sites (e.g., Holland Lake Recreation Site, Flathead Picnic Grounds, Lake Inez Campground, etc.), and 100 ft buffers around all designated trails. Following data cleaning, 1400 protected area polygon features (some being multi-part polygons) remained in the study area. These protected area polygons were then used to export both the number of devices observed in each protected area within the study area in 2019 and the median distance travelled to each protected area by device users in 2019 from the Near Vista online platform. Exported tabular data on protected area visitation were then merged with protected area attribute data using ArcGIS Pro.

2.3.2. Preparation of Health Records Data

Prior to acquisition of pediatric health data from SLCH, a separate dataset of residential addresses was created and submitted to the Data and Modeling (DM) Core within the [center and institution blinded for peer review]. The DM Core geocoded all addresses using ArcGIS and then geomasked these locations using the random perturbation method where addresses were blurred to a distance within 100 individuals, according to 2010 Census Bureau population density estimates within a block. The geomasked locations were returned to SLCH and appended to the health data using a unique ID, and the actual addresses were removed before securely transferring the finished data set to the DM Core for analysis. In this way, our research team was never in possession of both residential addresses and health information, limiting our handling of Protected Health Information (PHI).

2.3.3. Variable Generation

Two buffer distances were used to generate variables related to greenspace and PPAs surrounding individuals' homes: 500 m and 2 km. Two distinct buffer distances were selected given the exploratory nature of this research and the limited research conducted on PPAs' impacts on pediatric health across an urban–rural continuum (such as our study area). Notably, 500 m is an established buffer distance in the research literature lying at the nexus of greenspace, health, and leisure (see review by Browning & Lee [47]). It is often cited as a walking distance metric [7]. A 2 km buffer is cited as a measure of multi-modal accessible greenspace [48] as a plateau for greenspaces' significant impacts on health (see review by Browning & Lee [47]).

Using buffer variable generation methodologies, protected area shapefiles containing information about the attributes of each protected area in the study area—including visitation—were converted into four unique raster datasets to create and summarize variables for access, conservation status, median distance travelled to a protected area, and visits per km^2. These four raster datasets contained pixels 0.001 degree $\times$ 0.001 degree (approximately 0.0123 km^2) in size with units listed in Table 1, along with their calculations. For both the 500 m and 2 km buffers, the four raster datasets were used to calculate four variables for every buffer calculated as the mean raster value—within a given buffer—for each respective protected area attribute (access, conservation status, median distance travelled to a protected area, or visits per km^2). In this way, each adolescent in the sample is represented by two different buffers (500 m and 2 km) and each of their buffers contains four protected area attribute mean values (mean access, conservation status, median distance travelled to a protected area, and visits per km^2). Additionally, the percentage of landcover delineated as green/bluespace (defined above) was calculated within each buffer. Finally, access to healthcare was calculated as the distance to the nearest healthcare facility (defined above) from an individual's centroid and median household income of the individual's home locale was calculated based on the census tract in which the individual's centroid fell.

2.4. Analysis

Univariate statistics and bivariate associations between sociodemographic factors and three pediatric health outcomes—ADHD, asthma, and anxiety/mood disorder—were calculated. At each buffer size (500 m and 2 km), three independent logistic regression models were developed to identify the sociodemographic and PPA measures associated with each health outcome. A priori, we determined sex, body mass index (BMI), age, and median household income needed to be controlled in each multivariable logistic regression model. Additionally, an interaction between age and BMI was tested in all models. All PPA measures were considered for inclusion in these models, and each model was tested for multicollinearity. Because this analysis was restricted to one geographic region with relatively homogeneous access to PPAs, there was limited variation in PPA measures. Weak associations that were not statistically significant at the alpha = 0.05 level, but showed a moderate to strong effect size with potential clinical and public health implications, were reported. All analyses were conducted using R version 4.2.1.

Table 1. Buffer-derived variables.

Variable	Code	Calculated As:	Unit	Discrete Values Defined in PAD-US (If Applicable)	Data Source(s)
Conservation Status	avg_gap	Mean (via spatial extent) of GAP status(es) of PPAs in buffer	PAD-US GAP Status Unit (continuous weighted mean of discrete values)	See https://gapanalysis.usgs.gov/padus/data/metadata/ (accessed 5 March 2022).	USGS PAD-US
Access	access	Mean (via spatial extent) of degree of access for PPAs in buffer	PAD-US access code (continuous weighted mean of discrete values)	Open access = 3 Restricted access = 2 Closed to access = 1	USGS PAD-US
Visitation Density	avg_VD	Mean (via spatial extent) of visits per km^2 for PPAs in buffer.	Visits per km^2 (continuous weighted mean of continuous values)	N/A	USGS PAD-US; Near
Median Distance Traveled to protected area	avg_DT	Mean (via spatial extent) of median distance travelled to PPAs in buffer.	Miles	N/A	USGS PAD-US; Near
Landcover	GS	Percentage of buffer occupied by green or blue space	%	N/A	Montana Natural Heritage Program
Access to Healthcare	km_to_health	Distance to nearest healthcare facility	Kilometers	N/A	Esri; USGS Geographic Names Information System
Median Household Income of Home Locale	med_hh_income	Median household income in past 12 months (inflation-adjusted dollars to last year of 5-year range) of resident's home census tract	USD	N/A	U.S. Census Bureau API for American Community Survey

3. Results

3.1. Asthma

Among n = 3195 pediatric acute care encounters, asthma was the most prevalent health outcome. Approximately 8.6% of medical visits documented a new or existing asthma diagnosis. Asthma was more common among older children and children with a higher BMI (*p*-values < 0.001; Table 2). After adjustment for sociodemographic factors, there was some evidence of a weak association between average visitation and the likelihood of having asthma (adjusted odds ratio (aOR): 0.94, 95% CI: 0.87–1.01; Figure 3). For every tenfold increase in average visitation, the odds of having asthma decreased by 6% in the 2 km buffer.

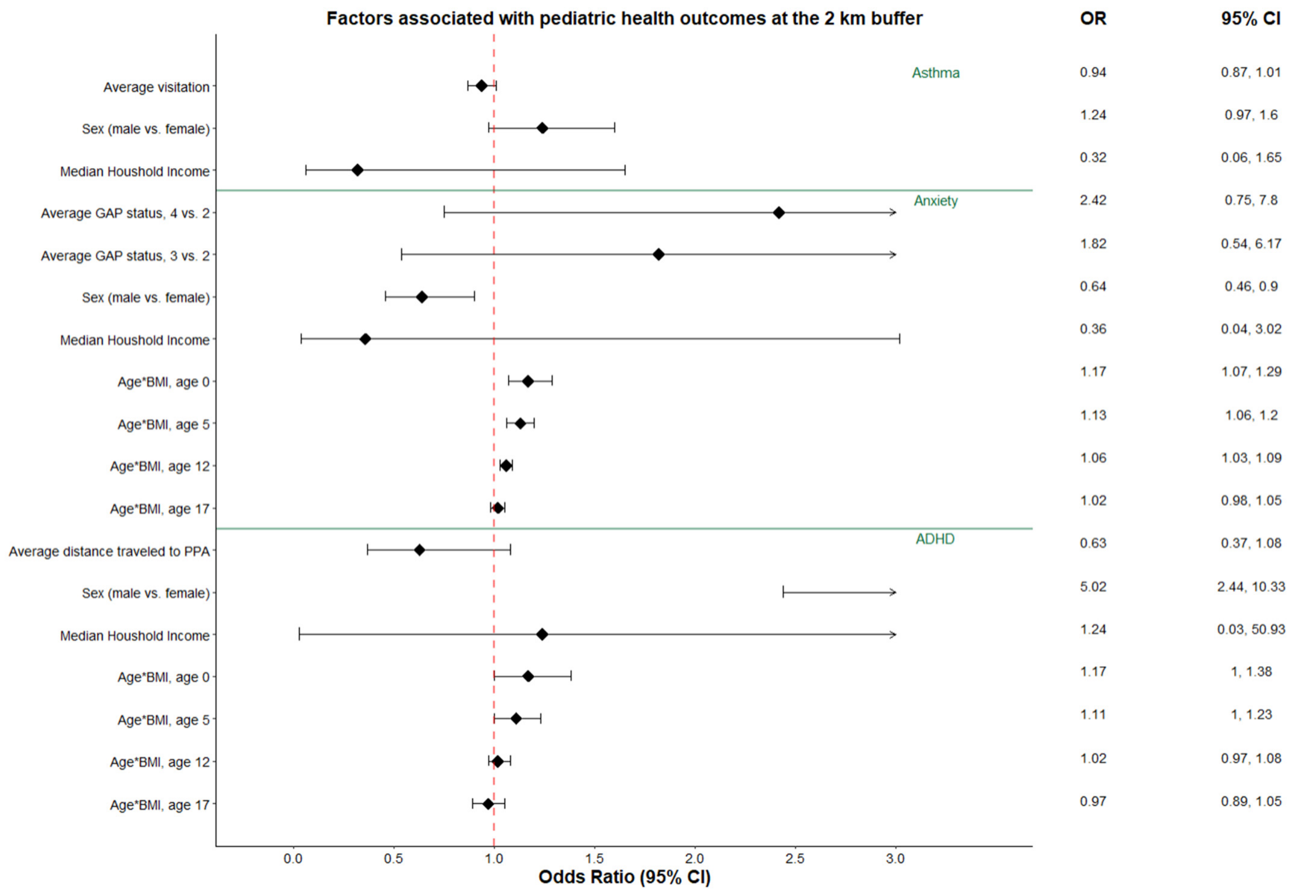

Figure 3. Factors associated with pediatric health outcomes at the 2 km buffer.

Table 2. Characteristics of study population and bivariate associations between sociodemographic and geographic factors and pediatric health outcomes, Montana children ages 0–17 years, St. Luke's Healthcare.

			Health Outcomes					
		Total Study Sample	Asthma		Anxiety		ADHD	
Characteristics	**Statistic**	**N = 3195**	**n = 274 (8.6%)**		**n = 153 (4.8%)**		**n = 99 (3.1%)**	
Child's sex								
Female	n (%)	1571 (49.2%)	122 (44.4%)	$p = 0.11$	92 (60.1%)	$p = 0.006$	19 (19.2%)	$p < 0.001$
Male		1624 (50.8%)	152 (55.5%)		61 (39.9%)		80 (80.8%)	

Table 2. *Cont.*

		Total Study Sample	Health Outcomes					
			Asthma		Anxiety		ADHD	
Characteristics	**Statistic**	**N = 3195**	**n = 274 (8.6%)**		**n = 153 (4.8%)**		**n = 99 (3.1%)**	
BMI	mean (SD)	20.9 (5.7)	22.3 (6.5)	$p < 0.001$	24.5 (6.4)	$p < 0.001$	21.3 (5.1)	$p = 0.46$
Age (years)	mean (SD)	9.94 (5.4)	11.3 (4.7)	$p < 0.001$	13.5 (3.6)	$p < 0.001$	11.1 (4.0)	$p = 0.03$
Median household income	mean (SD)	46,920 (8687)	45,982 (8327)	$p = 0.07$	45,919 (7850)	$p = 0.19$	47,116 (8976)	$p = 0.83$

In contrast to findings at the 2 km buffer, the effect of average visitation was not significant at the 500 m buffer ($p = 0.64$). At the 500 m buffer, access to a PPA within a 500 m buffer was associated with 1.58 times greater odds of asthma as compared to children who lived in a buffer without access to a PPA (aOR: 1.58, 95% CI: 0.92–2.73; Figure 4).

3.2. Anxiety and Mood Disorders

In the source data, n = 153 cases of anxiety were documented, representing 4.8% of acute pediatric care encounters at SLCH during the study period. Children assigned female at birth were more likely to have a documented anxiety diagnosis as compared to children assigned male at birth. Additionally, older children and children with a higher BMI were more likely to have a documented anxiety diagnosis (Table 2). At the 2 km buffer, average GAP status had a suggestive effect on anxiety. In a multivariable logistic regression model, sex, BMI, and age were associated with anxiety in this sample population ($p = 0.01$ and BMI*age interaction $p < 0.001$, respectively). Living in a less, or not at all, conserved region with an average GAP status of 4 was associated with 2.42 times greater odds of anxiety as compared to children living in more PPAs with a GAP status of 2 (aOR: 2.42, 95% CI: 0.75–7.80; Figure 3). At the 500 m buffer, an association between GAP status and anxiety was not identified. However, higher levels of visitation to PPAs within a 500 m buffer of a child's residence were shown to have a weakly protective effect against anxiety. After controlling for sociodemographic factors, tenfold increases in visitation of PPAs were weakly associated with 13% lower odds of anxiety (aOR: 0.87, 95% CI: 0.72–1.04; Figure 4).

3.3. ADHD

ADHD was the least prevalent pediatric health outcome in this sample population. Among n = 3195 acute care encounters at this rural critical access hospital, 3.1% had a documented ADHD diagnosis. Children assigned male sex at birth and older children were more likely to have an ADHD diagnosis (Table 2). In a multivariable logistic regression model at the 2 km buffer, there was suggestive evidence that average distance traveled to PPAs may be protective against ADHD (aOR: 0.63, 95% CI: 0.37–1.08); for every tenfold increase in distance traveled to PPAs within a child's 2 km buffer, the odds of having ADHD were on average 37% lower as compared to children who lived near PPAs with hyperlocal visitation (Figure 3). At the 500 m buffer, no association between average distance traveled to PPAs within the buffer and ADHD was observed. No other PPA measures demonstrated any suggestive effects on ADHD within the 500 m buffer.

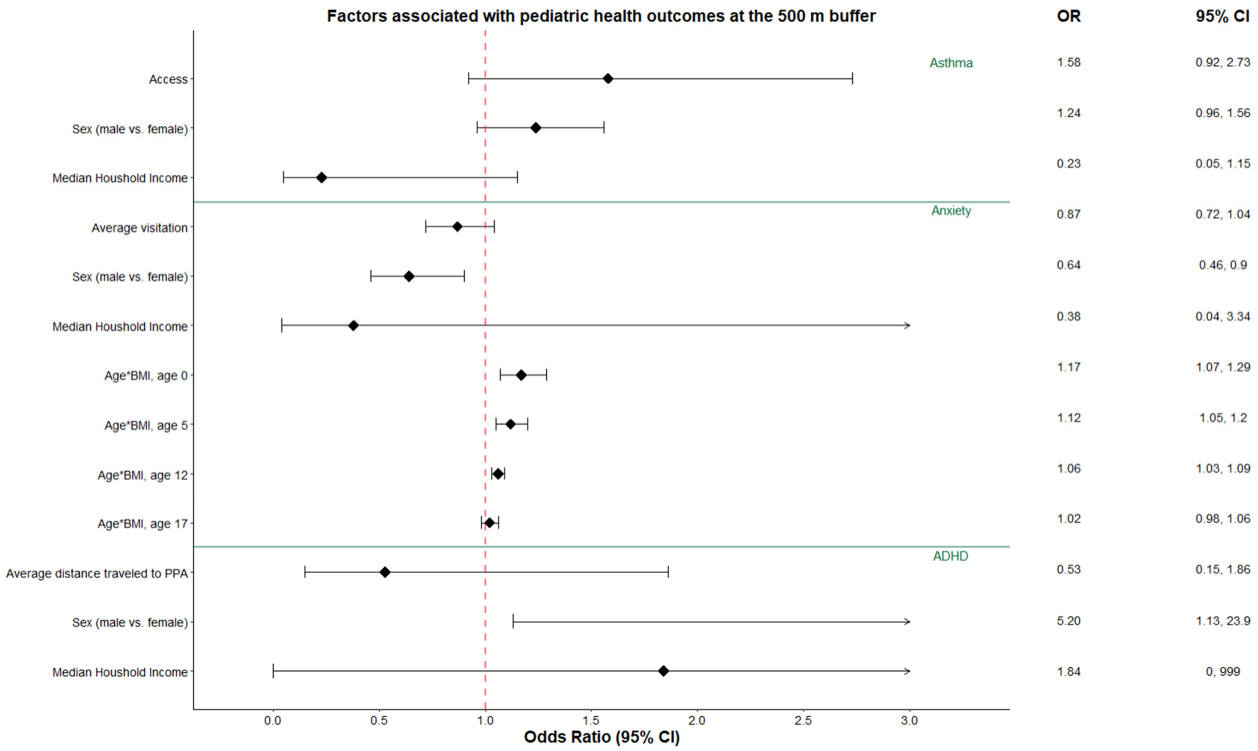

Figure 4. Factors associated with pediatric health outcomes at the 500 m buffer.

4. Discussion

4.1. How Does Conservation Status of PPAs Impact Health Outcomes?

In the U.S., measuring conservation status of proximate PPAs (e.g., mean GAP status of PPAs within a 500 m or 2 km buffer around an adolescents' residence—the measure utilized in this study) is relatively easy via the USGS PAD-US database. Thus—depending on the nature of the health data available—large-scale, rather time-efficient analysis can be undertaken to understand how the conservation status of PPAs influences health outcomes (see Knight et al. [32]). The suggestive finding concerning how conservation status of proximate PPAs may influence the likelihood of anxiety diagnosis suggests the need for additional research to this end. As noted in the results presented above, living in a less, or not at all, conserved region with an average GAP status close to 4 was associated with 2.42 times greater odds of anxiety as compared to children living in more PPAs with an average GAP status close to 2.

Based on the variations in conservation status between PPAs with GAP statuses of 2 and 4, we can posit theory-driven reasonings for these disparate odds. For instance, GAP status 2 PPAs in the study area include large PPAs such as the Mission Mountains Tribal Wilderness and Pablo National Wildlife Refuge, which are relatively undeveloped wildlands with trails that enable visitors to immerse themselves in primitive recreation settings. In contrast, GAP status 4 PPAs in the study area include city parks largely composed of non-native lawns and private PPAs with limited, or no, public access. Thus, while both classifications of PPAs definitively offer "greenspace" within this study area, the ecosystem services produced by these PPAs which support public health likely vary based on the underlying conservation mandate which drives the management of these areas [49]. The suggestive finding presented here concerning anxiety and conservation status of PPAs further underscores the limitation of nature and health research centering on less nuanced greenspace measures such as the Normalized Difference Vegetation Index [12]. Measures of greenness and/or blueness fail to capture the more nuanced qualities of PPAs that conservation status can signal (i.e., naturalness, development, trammeling, etc.) [5,12,25,32]. Future research should consider the use of proximate PPAs' conservation statuses to perhaps improve our understanding of not only how natural areas relate to health outcomes, but also how we can manage natural areas to improve health outcomes of nearby residents or visitors.

4.2. What Does the Recreation Demand for PPAs Signal about the Potential to Support Health Outcomes?

A key exploration of the present study included exploring how visitation to PPAs, across a geographically diverse region, may relate to proximal pediatric health. As noted in the results, weak associations between visitation density and decreased risk for asthma and anxiety were revealed through our analysis. Additionally, median distance travelled to PPAs proximate to a child's home was positively related to lower ADHD risk. We posit, based on these weak, suggestive findings, that future research is merited toward exploring how recreation demand and popularity (or desirability) of PPAs can be used as a signal for green- or bluespace "richness" or the ability for PPAs to provision recreational ecosystem services [50]. With the advent of readily accessible mobile device location data, it is becoming increasingly possible to measure relative visitation density for PPAs across large regions [51].

We further recommend that future research to this end incorporate spatial data related to the *types* of outdoor recreation available within proximate PPAs. As reported by Pasanen et al. (2019), activity type can mediate the role of home-proximate PPAs in supporting physical and mental health. While neither of the two datasets related to PPA characteristics and visitation employed in the present study (PAD-US and Near Vista) provide information about specific park recreational amenities (e.g., playgrounds, trails, beaches, etc.), such data are increasingly found in large spatial datasets. OpenStreetMap has an increasingly comprehensive layer of trails across the world [52]. The Trust for Public Land offers a growing dataset of playgrounds across the U.S. (Cheng et al., 2021). And websites such as eBird and iNaturalist offer spatial data related to wildlife and plant viewing opportunities [53]. These, and similar spatial datasets, could be used in future research as potential signals of PPAs' potential to support health outcomes.

4.3. How Does Recreational Access to PPAs Impact Health Outcomes?

Finally, we posit the need for future research concerning recreational access to PPAs as it relates to pediatric health outcomes. In the present study, we found that a child's access to a PPA (or PPAs) within a 500 m buffer corresponded to 1.58 times greater odds of asthma as compared to children who lived in a buffer without access to a PPA. Here, access was measured on a three-point scale (ranging from closed to open access) derived from the PAD-US dataset (see Table 1). Previous research has found mixed results as they relate to the relationship between greenspace exposure and asthma. Some studies have found a positive relationship, while others report a negative relationship [17,27,54]. These disparate relationships signal two primary implications for future research concerning PPAs and health: (1) we should consider both the ecosystem services *and* disservices provisioned through PPAs and (2) we should recognize that access to PPAs is a nuanced phenomenon.

As noted by Li et al. [33], natural landscapes preserved via PPAs may also provision negative health outcomes to humans (e.g., risk of injury, dehydration, risk of bacterial infection, exposure to zoonotic diseases), known as ecosystem disservices: "functions of ecosystems that are perceived as negative for human well-being" [30] (p. 311). In the case of asthma, exposure to increased levels of outdoor allergens and antigens such as pollen represent ecosystem disservices [29]. Building on these previous findings related to PPA exposure and ecosystem disservices, we recommend that future research attempt to more holistically consider the possible negative health impacts provisioned by PPAs, along with those positive impacts more frequently studied. Relatedly, we recommend that researchers think more holistically about what contributes to exposure and access to PPAs—beyond travel distance or level of administratively allowed access. Here, we point to the rather large body of leisure-constraint literature as it relates to outdoor recreation (see review by Zanon et al. [34]). As posited by Stodolska et al. [55], constraints to leisure (including recreation in PPAs) occur at multiple levels, including the individual (e.g., lack of knowledge), interpersonal (e.g., lack of availability of co-participants), context (e.g., neighborhood environment), and system (societal beliefs and attitudes). By reducing measures to exposure or access to PPAs to Euclidian or walking distance, we use a measure of just one component of access to serve as a proxy for a highly complex social construct.

4.4. Limitations and Future Research

This study had several limitations. First, because the source data were limited to emergency department visits extracted from an electronic health database at a rural critical access hospital, the prevalence of asthma, anxiety, and ADHD were lower than national estimates [56,57]. It is possible that the protective effects of PPA access were underestimated because well-managed cases of asthma, anxiety, and ADHD may be less likely to utilize emergency medical services [58]. While these findings are not generalizable to all rural pediatric populations, these exploratory analyses work toward describing the associations between these seven PPA measures and three pediatric health outcomes in northwestern Montana. Second, due to somewhat limited data availability for some PPA visitation measures derived from the mobile device location data, the distance traveled measure contained a large proportion of missing data. Third, this data source did not include race and ethnicity data. Future studies should strive to measure and disaggregate effects by race and ethnicity to describe possible health inequities and differential access to outdoor spaces that impact health. Additionally, as noted in the discussion above, we recommend that future research examine (1) how we can manage natural areas (e.g., conservation status) to improve health outcomes of nearby residents or visitors, (2) how recreation demand and popularity (or desirability) of PPAs can be used as a signal for green- or bluespace "richness" or the ability for PPAs to provision recreational ecosystem services, and (3) how leisure constraints theory can inform operationalization of park access in environmental epidemiology.

5. Conclusions

As stated in our study purpose, providing definitive or generalizable findings about how PPAs influence pediatric health was not the goal of this research. Instead, we aimed to provide initial exploration toward a larger, future body of literature evaluating PPAs' influence on pediatric health. To this end, none of the empirical findings presented here offer clear relationships. However, they *do* signal that more research is needed at the nexus of PPAs and pediatric health. Here we detail the use of emerging data sources that can aid in the development of this future research, and help researchers measure nature's conferrence of health benefits beyond greenspace or bluespace. In service of future research, based on our suggestive findings, we recommend the use of PPA characteristics (e.g., conservation status), visitation data, and recreation amenity data (e.g., spatial information related to trails or playgrounds) in future modeling of these relationships. Further, we recommend the consideration of ecosystem disservices provisioned by PPAs, as they relate to pediatric health, and the use of a more holistic understanding of PPA access which is mindful of leisure constraint theory.

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