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US lakes are monitored disproportionately less in communities of color

Jessica Díaz Vázquez[1*†], Ian M McCullough[1], Maggie Haite[1,2], Patricia A Soranno[1,3], and Kendra Spence Cheruvelil[1,2]

Local-scale environmental justice studies of freshwaters have found that marginalized populations are more likely than others to be burdened with poor-quality waters. However, studies have yet to examine whether monitoring data are sufficient to determine the generality of such results at the national scale. We analyzed racial and ethnic community composition surrounding lakes and the presence of one-time and long-term (≥15 years) water-quality data across the conterminous US. Relative to lakes in White and non-Hispanic communities, lakes in communities of color and Hispanic communities were three times less likely to be monitored at least once. Moreover, as compared to lakes in White communities, lakes in communities of color were seven times less likely to have long-term monitoring data; similarly, as compared to lakes in non-Hispanic communities, lakes in Hispanic communities were nineteen times less likely to have long-term monitoring data. Given this evidence, assessing the current water quality of and temporal changes in lakes in communities of color and Hispanic communities is extremely difficult. To achieve equitable management outcomes for people of all racial and ethnic backgrounds, freshwater monitoring programs must expand their sampling and revise their designs.

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The scientific discipline of environmental justice (EJ) investigates the impacts of environmental burdens borne by marginalized groups (Bowen and Wells 2002). EJ links ecology and sociology to analyze the equitability of environmental protections, access, conditions, and enforcement (Brulle and Pellow 2006; Mohai *et al.* 2009). While initial EJ studies examined the proximity of certain groups of people to environmental hazards, the field has since expanded to investigate broader socioenvironmental conditions (Schlosberg and Collins 2014).

Decades of EJ research in the US have demonstrated that marginalized groups, including people of color (POC), are disproportionately affected by environmental burdens (Bowen and Wells 2002; Mohai *et al.* 2009). For example, POC are more likely than White people to be exposed to air pollution (ALA 2021), and POC are twice as likely as White people to live in areas with fewer natural areas (Landau *et al.* 2020). Although much of the EJ literature has concentrated on air quality and land degradation, water-related studies—most of which focus on drinking water—have come to similar conclusions. For instance, drinking water-quality violations occur more frequently in marginalized communities than in non-marginalized ones (Fedinick *et al.* 2019). Other studies have examined access to or quality of waterbodies at local or regional scales. For example, Sanchez *et al.* (2014) found that POC in Michigan's Saginaw River watershed were more likely to live near streams with poor water quality, while Hill *et al.* (2018) reported that Erie–Niagara watersheds in New York State with "impaired" water quality consistently had disproportionally more POC as residents than did "unimpaired" watersheds. Whether similar patterns occur broadly across the US remains unclear, however.

An important precursor to broad-scale research on EJ and freshwaters is to determine whether sufficient and equitably distributed monitoring data exist across US communities of different races and ethnicities. However, studies quantifying the distribution of environmental monitoring stations are rare. McLaughlin *et al.* (2020) found that the US Environmental Protection Agency (EPA) air-quality monitoring network missed many pollution hotspots, including ten of the biggest refinery explosions. Although this study excluded community demographics, it underscores the importance of well-designed monitoring programs for detecting environmental hazards. Freshwater monitoring is mostly conducted at the local and state levels using different sampling designs and frequencies, whereas quinquennial EPA national-scale assessments (National Aquatic Resource Surveys) use stratified random site selection based on location and waterbody physical characteristics (Pollard *et al.* 2018). Given the disparate nature of most US water-quality monitoring programs, the degree to which water-quality sampling as a whole is equitably distributed across all US communities is unknown.

To examine lake water-quality monitoring and demographics, we used two data sources: the LAGOS-US research platform (Cheruvelil *et al.* 2021) for data on lakes and reservoirs (hereafter, lakes) in the conterminous US, and the 2010

[1]*Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI* [*]*(jessica.dv405@gmail.com);* [2]*Lyman Briggs College, Michigan State University, East Lansing, MI;* [3]*Department of Integrative Biology, Michigan State University, East Lansing, MI;* [†]*current address: Maryland Sea Grant College Program Fellow to the Office of the Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator*

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US Census for data on community racial and ethnic composition surrounding lakes. Our primary objective was to address the question: how does the percentage and frequency of lakes sampled differ by community race and ethnicity?

Methods

We consolidated the nine US Census divisions in the US into six regions—namely, (1) Northeast, (2) Midwest East, (3) Midwest West, (4) Southeast, (5) South Central, and (6) West (Figure 1a; Table 1)—to account for low abundance of lakes in some regions. Across all regions, the number of lakes ranged from a low of ~14,000 (in the Northeast) to a high of ~32,000 (in the Midwest West).

Water-quality data availability

We obtained water-quality data from two sources. (1) For 17 states in the northeastern and midwestern US, we used the LAGOS-NE LIMNO data package (v1.087.3), which contains data from 87 state, federal, citizen-science, nonprofit, tribal, and university monitoring programs, including the primary water-quality monitoring agency for each state (Soranno *et al.* 2019). (2) For the remaining 31 states and the District of Columbia, we used data from the Water Quality Portal (WQP; www.waterqualitydata.us), which integrates publicly available data from more than 400 state, federal, tribal, and local agencies. The EPA strongly encourages government agencies to upload their water-quality data to the WQP. Therefore, these two sources provide the best available data for studying national water quality in an EJ context. We included lakes ≥4 ha because lakes <4 ha are rarely sampled (Soranno *et al.* 2017). We analyzed three common lake water-quality metrics: (1) water clarity (Secchi disk depth), an overall ecosystem indicator and the most commonly measured variable; (2) chlorophyll-*a* concentration; and (3) total phosphorus concentration. We tallied sample presence or absence and calculated the percentage of lakes sampled at least once for each variable per region between June 15 and September 15 (period of lake stratification and peak data collection) from 1970 to 2016. We counted the number of years each lake was sampled; ≥15 years (consecutive or non-consecutive) of data were defined as "long-term" records. Results for water clarity are reported below, whereas results for chlorophyll *a* and total phosphorus are provided in Appendix S1: Table S1 and Figures S1–S4.

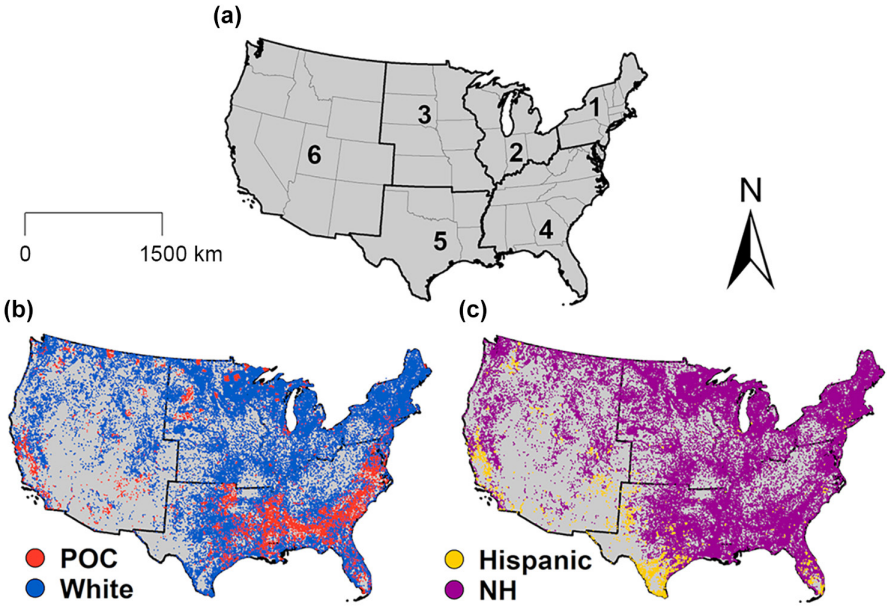

Figure 1. Maps of the US showing (a) the six regions used in our study: (1) Northeast (CT, ME, MA, NH, NJ, NY, PA, RI, VT), (2) Midwest East (IL, IN, MI, OH, WI), (3) Midwest West (IA, KS, MN, MO, NE, ND, SD), (4) Southeast (AL, DE, FL, GA, KY, MD, MS, NC, SC, TN, VA, WV, DC), (5) South Central (AR, LA, OK, TX), and (6) West (AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY); (b and c) all lakes in our database in (b) people of color (POC) or White communities and (c) Hispanic or non-Hispanic (NH) communities.

Demographic data

We obtained 2010 US Census data on race and ethnicity for block groups through the National Historical Geographic Information System (Manson *et al.* 2022). Block groups contain 600–3000 people and are an aggregation of census blocks and a subdivision of census tracts. We chose block groups to balance the computational demands of a national-scale analysis with the need to represent racial and ethnic diversity surrounding the 137,072 lakes included in our analysis. A threshold of ≥25% was set to designate block groups as POC or Hispanic, with all other block groups being White or non-Hispanic, respectively. We chose 25% because the total 2010 US population was 72% White and 64% non-Hispanic (Humes *et al.* 2011). The 2010 Census was used due to concerns about data quality in the 2020 Census, including possible severe undercounting of Hispanic populations (Winkler *et al.* 2022). We used POC to represent all non-White racial groups (Black/African American, American Indian/Alaskan Native, Asian, Native Hawaiian/Pacific Islander, some other race alone, and two or more races; Humes *et al.* 2011). Hispanic represents groups of South or Central American or other Latino or Spanish culture or origin, regardless of race. Although we recognize that each racial and ethnic group experiences different inequities, POC and Hispanic are unifying terms to indicate the racial and ethnic inequities these groups face and we therefore chose to focus our analyses on these broad groups and make respective comparisons to White and non-Hispanic groups. We capitalize the first letter of all racial and ethnic categories, including

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Table 1. Numbers and percentages of human population, lakes, lakes sampled for water clarity, and lakes with long-term water clarity data (≥15 years) sorted by US region

		1. Northeast	2. Midwest East	3. Midwest West	4. Southeast	5. South Central	6. West	US Total
(a) Population by race and ethnicity (*n*, %)	POC	14,148,902 16.9%	9,531,157 11.4%	2,972,321 3.5%	23,526,215 28%	10,856,384 12.9%	22,896,937 27.3%	**83,931,916** **27.4%**
	White	41,168,338 18.5%	36,890,407 16.6%	17,533,116 7.9%	54,683,327 24.5%	25,489,818 11.4%	46,978,084 21.1%	**222,743,090** **72.6%**
	H	6,991,969 13.9%	3,544,373 7.0%	1,117,305 2.2%	8,055,970 16.0%	10,171,538 20.2%	20,436,348 40.6%	**50,317,503** **16.4%**
	NH	48,325,271 18.9%	42,877,191 16.7%	19,388,132 7.6%	70,153,572 27.4%	26,174,664 10.2%	49,438,673 19.3%	**256,357,503** **83.6%**
	Total	**55,317,240**	**46,421,564**	**20,505,437**	**78,209,542**	**36,346,202**	**69,875,021**	306,675,006
(b) Lakes by race and ethnicity (*n*, %)	POC	418 1.7%	1096 4.4%	2539 10.2%	12,534 50.2%	5964 23.9%	2415 9.7%	**24,966** **18.2%**
	White	14,017 12.5%	19,561 17.4%	29,697 26.5%	16,933 15.1%	17,187 15.3%	14,711 13.1%	**112,106** **81.8%**
	H	100 1.4%	127 1.7%	133 1.8%	1934 26.3%	3080 41.9%	1979 26.9%	**7353** **5.4%**
	NH	14,335 11.1%	20,530 15.8%	32,103 24.7%	27,533 21.2%	20,071 15.5%	15,147 11.7%	**129,719** **94.6%**
	Total	**14,435**	**20,657**	**32,236**	**29,467**	**23,151**	**17,126**	137,072
(c) Lakes sampled for water clarity by race and ethnicity (*n*, %)	POC	49 4.6%	181 17.0%	318 29.9%	399 37.5%	48 4.5%	69 6.5%	**1064** **7.5%**
	White	2951 22.4%	3529 26.8%	4462 33.9%	1242 9.4%	221 1.7%	771 5.9%	**13,176** **92.5%**
	H	13 5.3%	15 6.2%	9 3.7%	127 52.3%	16 6.6%	63 25.9%	**243** **1.7%**
	NH	2987 21.3%	3695 26.4%	4771 34.1%	1514 10.8%	253 1.8%	777 5.6%	**13,997** **98.3%**
	Total	**3000**	**3710**	**4780**	**1641**	**269**	**840**	14,240
(d) Lakes with long-term water clarity data by race and ethnicity (*n*, %)	POC	0 0.0%	20 31.7%	32 50.8%	10 15.9%	1 1.6%	0 0.0%	**63** **3.1%**
	White	454 23.0%	572 29.0%	851 43.2%	66 3.3%	18 0.9%	11 0.6%	**1972** **96.9%**
	H	0 0.0%	1 16.7%	2 33.3%	1 16.7%	1 16.7%	1 16.7%	**6** **0.3%**
	NH	454 22.4%	591 29.1%	881 43.4%	75 3.7%	18 0.9%	10 0.5%	**2029** **99.7%**
	Total	**454**	**592**	**883**	**76**	**19**	**11**	2035

Notes: The percentages for each region (1–6) are calculated "by row" using the corresponding US Total value for that row (that is, the percentage for the number of lakes in communities of people of color [POC] sampled in each region is out of the total number of lakes sampled in POC communities). For the US Total column, the percentage for all lakes in POC communities is out of the total number of lakes (POC + White). To reduce the width of this table, H is short for Hispanic and NH is short for non-Hispanic.

"White", to emphasize that race is a social construct and refute the notion of White as normal and other races as different (NABJ 2020).

Using ArcMap (v10.6), we rasterized the block group race and ethnicity data, with 60 m set as the minimum cell size to ensure that the smallest block group filled at least one pixel. We then used a 500-m buffer around each lake to designate its nearby racial (POC or White) and ethnic (Hispanic or non-Hispanic) composition. The R code and data used in our analysis are available on Zenodo (see Data Availability Statement below). All analyses were performed in R (v4.1.1; R Core Team 2022).

Results

Percentage and distribution of people and lakes by region

In 2010, the demographic composition of the population in the conterminous US was 27% POC versus 73% White and 16% Hispanic versus 84% non-Hispanic (Table 1a). We found

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that 18% and 5% of lakes had POC populations and Hispanic populations as ≥25% of the surrounding population (Table 1b; Figure 1, b and c), respectively. Regional variation in lake community demographics somewhat corresponded to national variation in overall demographics. For example, POC populations overall and lakes in POC communities were concentrated in the Southeast (28% and 50%) and South Central (13% and 24%) regions (Table 1; Figure 1b). Hispanic populations overall and lakes in Hispanic communities were concentrated in the South Central (20% and 42%) and West (40% and 27%) regions (Table 1; Figure 1c). However, the spatial distribution of lakes in White and non-Hispanic communities was similar to that of lakes overall rather than demographic distribution. For example, the highest concentration of lakes occurred in the lake-rich Midwest West region, with 27% and 25% of lakes in White and non-Hispanic communities, respectively (Table 1; Figure 1).

Percentage of lakes sampled by race and ethnicity

Of the 137,072 lakes in the US that were included in our analysis, 10% (14,240) were sampled at least once for water clarity. Of all lakes sampled, lakes in POC and Hispanic communities comprised 7.5% (1064 of 14,240) and 1.7% (243 of 14,240), respectively (Table 1c). Across most regions, the percentage of lakes sampled at least once in the region was lower in POC (0.8–17%) and Hispanic (0.5–13%) communities than in White and non-Hispanic communities (both 1.3–21%; Figure 2). However, the percentage of lakes sampled also varied regionally. For example, in the Northeast region, 12% (49 of 418) and 13% (13 of 100) of lakes in POC and Hispanic communities, respectively, were sampled as compared to 21% of lakes in both White (2951 of 14,017) and non-Hispanic (2987 of 14,335) communities (Figure 2). In contrast, the South Central region, which contained 42% of all lakes in Hispanic communities, had the lowest sampling of lakes overall (269 of 23,151, or 1.2%; Table 1) and similar sampling percentages across all community types (Figure 2). Similarly, although 50% of lakes in POC communities were in the Southeast region (Table 1), only 3% (399 of 12,534) were sampled (Figure 2). The Southeast is also the only region in which lakes in Hispanic communities were sampled more than in non-Hispanic communities (7% Hispanic, 6% non-Hispanic; Figure 2).

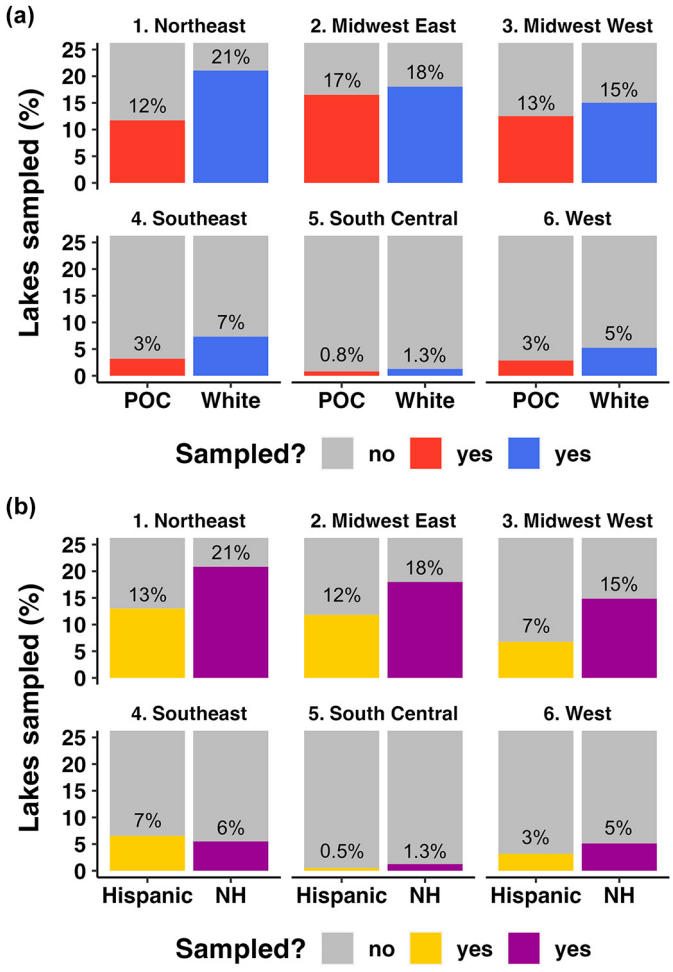

Figure 2. Percentage of lakes sampled for water clarity within a region according to nearby community (a) race (people of color = "POC") or (b) ethnicity (non-Hispanic = "NH") designation. The *y* axis is zoomed in to 25% instead of 100% for visual clarity.

Frequency of lake sampling by race and ethnicity

Of all lakes that were sampled, lakes in POC and Hispanic communities were sampled less frequently and for fewer years than lakes in White and non-Hispanic communities (Figure 3). The maximum number of years any lake in POC or Hispanic communities was sampled was 37 years (Midwest West) and 34 years (Midwest East), respectively, whereas lakes in White and non-Hispanic communities were sampled a maximum of 41 years (Figure 3). In all regions, lakes in POC communities were sampled less frequently than lakes in White communities (median = 1–2 versus 1–4 years across individual regions, respectively; Figure 3, a and b). In five of the six regions, lakes in Hispanic communities were sampled less frequently than lakes in non-Hispanic communities (median = 1–3 versus 1–4 years across individual regions, respectively; Figure 3, c and d). In the Midwest West region, lakes in Hispanic communities were sampled more frequently than lakes in non-Hispanic communities (median = 5 versus 3 years, respectively; Figure 3d).

Lakes in POC and Hispanic communities comprised 3% (63 lakes) and 0.3% (6 lakes), respectively, of all 2035 lakes for which long-term data were available (Table 1d). Across all lakes for each community type, the percentage of lakes with long-term data was lower for lakes in POC (0.3%, 63 of 24,966) and Hispanic (0.08%, 6 of 7353) communities than for lakes in White (1.8%, 1972 of 112,106) and non-Hispanic (1.6%, 2029 of 129,719) communities (Table 1d). Finally, for lakes in POC and Hispanic communities, there were several regions for which long-term data were unavailable

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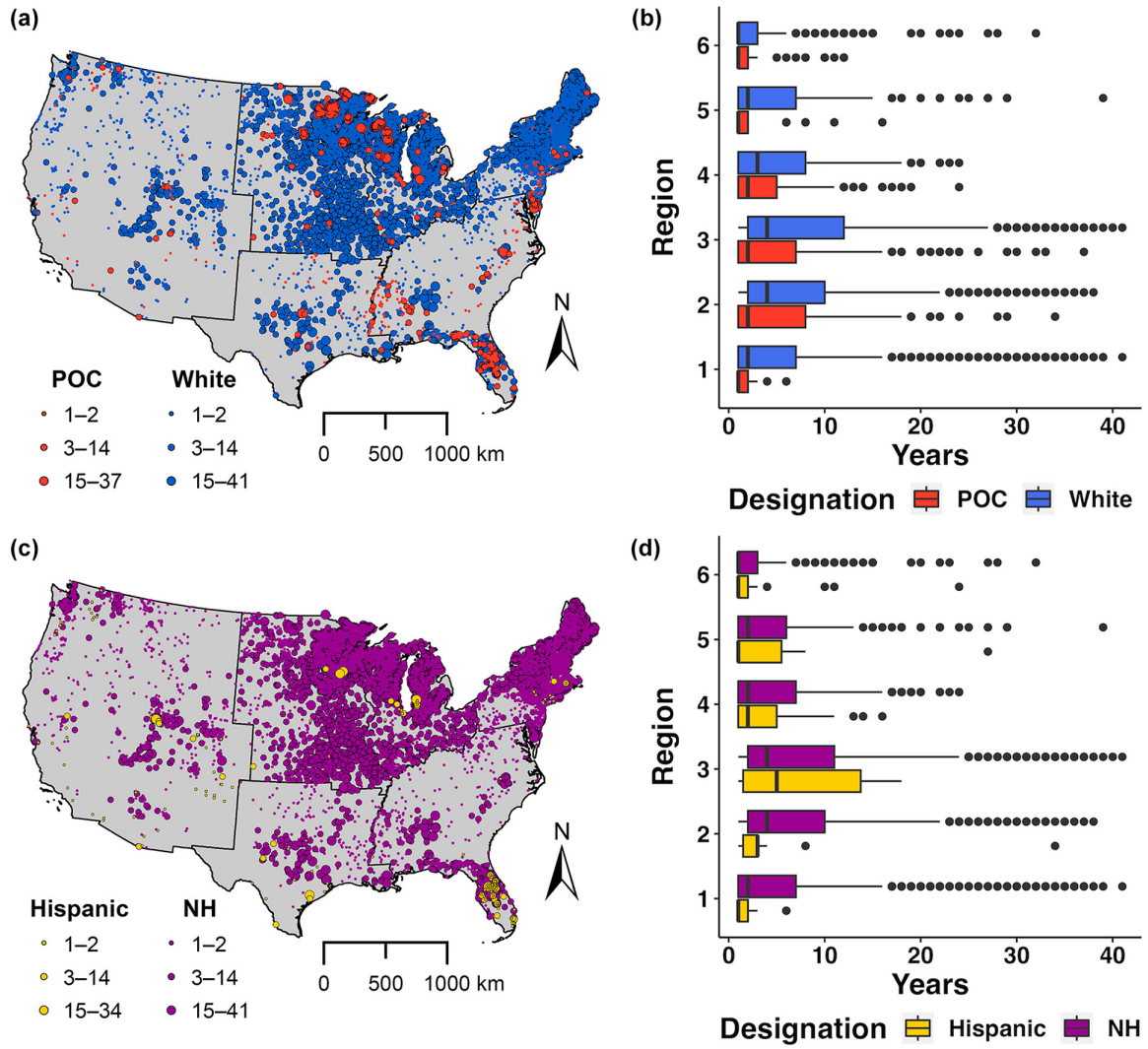

Figure 3. Record length of (non-consecutive) years that lakes were sampled for water clarity by region for (a and b) race (people of color = "POC") and (c and d) ethnicity (non-Hispanic = "NH"). Region numbers for (b) and (d) correspond to the regions shown in Figure 1a. In (b) and (d), vertical lines within boxes depict median values, boxes represent the interquartile range (25th–75th percentiles), whiskers (horizontal lines) represent 1.5×interquartile range, and solid circles depict outliers.

(Northeast and West for POC; Northeast for Hispanic; Table 1d; Figure 3).

Discussion

To the best of our knowledge, our study is the first to examine the availability of lake water-quality monitoring data at the national scale from an EJ perspective. We quantified the racial and ethnic composition of people living near lakes in the US and found that POC and Hispanic people are less likely to live near lakes. Moreover, lakes in POC and Hispanic communities are three times less likely to be monitored (and when monitored are done so less frequently) than lakes in White and non-Hispanic communities. Specifically, lakes in POC and Hispanic communities are seven and nineteen times less likely to have long-term data than lakes in White and non-Hispanic communities, respectively. Our findings suggest that structural inequities might have excluded POC from living near lakes and participating in water-quality monitoring programs. Future research should examine whether water quality differs in lakes that are in POC and Hispanic communities as compared to lakes in White and non-Hispanic communities. However, the gaps in current water-quality datasets that we have documented here limit our ability to perform such examinations, such as in POC communities in the South Central region that have too few lakes sampled (48 of 5964 lakes) to permit robust analysis of water quality. There were also only six lakes with long-term monitoring data in Hispanic communities, preventing quantification of trends over time in these communities at the national scale.

We also found regional differences in sampling patterns by race and ethnicity. Although it is difficult to explain the mechanisms that drive large-scale, empirical patterns, there are known influences for the variety of approaches that local, regional, and

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state monitoring programs use to select sample locations. Monitoring programs tend to favor large, connected lakes and those surrounded by urban areas, agriculture, and forests (Wagner *et al.* 2008). Moreover, long-term lake water-quality data not only are very rare but also mostly come from citizen-science programs (Poisson *et al.* 2020). Across citizen-science programs and disciplines, the majority of volunteers are White, and for volunteer-driven programs, chosen sites may be of low EJ concern (Blake *et al.* 2020). Therefore, by primarily engaging populations living near lakes (which we demonstrate are predominantly White), citizen-science programs likely preclude long-term monitoring in POC and Hispanic communities. We add to the growing literature that documents the many ways in which environmental sampling programs can be biased by adding an important social dimension. Current sampling biases may continue if the organizations and agencies responsible for water-quality monitoring do not intentionally engage with and sample lakes in POC and Hispanic communities.

Lakes are a type of "blue space" (areas with visible waterbodies like lakes or rivers) that provide unique ecological and social benefits (Völker and Kistemann 2011). However, as compared to their blue counterparts, land-based green spaces, which often refer to natural terrestrial spaces, are more commonly studied through an EJ lens. The few studies of blue spaces that consider demographics have found that people of marginalized ethnicities are less likely to use blue spaces, even when living near them (White *et al.* 2020). Blue space use is influenced by numerous factors including access (eg transportation availability, proximity, cost) and awareness (Landau *et al.* 2020). Our findings that POC and Hispanic people are less likely to live near lakes suggest an inequity in access (represented by proximity) to lake-based blue spaces across the US. Both inequitable access to and knowledge of blue spaces represent an important, overlooked aspect of EJ that should be addressed in communities with blue spaces.

We encourage local, state, or regional environmental monitoring programs to explicitly incorporate equity in their sampling designs by selecting sampling locations by stratifying not only on natural features (such as lake size or land cover) but also on the social environment. This would ensure that POC and Hispanic communities are not under-sampled and left unknowing about environmental hazards, demonstrating how an EJ perspective can guide a program's goals and outcomes. National-scale monitoring programs can also help to address these sampling equity issues by intentionally over-sampling lakes in POC and Hispanic communities that have been historically under-sampled. Without these changes, marginalized communities will continue to lack information about potentially negative impacts of local environmental hazards on their health and quality of life.

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Data Availability Statement

Data and code generated for this study are available from Zenodo, at www.doi.org/10.5281/zenodo.7314494. US Census datasets used for this research were retrieved from the National Historical Geographic Information System (www.nhgis.org). The US Census data can be queried using the following filters: geographic levels of block groups, dataset of 2010_SF1a under "decennial", table topics of Race "OR" Hispanic Origin. Select tables named "Race" and "Hispanic or Latino Origin".

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