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Widespread practices and sustainability benefits of foraging in urban blue spaces of India

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Urban blue spaces, such as lakes and rivers, are increasingly recognized for their ecological and social roles, yet their contributions to sustainable food systems remain understudied. Here we examine the extent and benefits of foraging in urban blue spaces across four major Indian cities through a survey of 1,200 users. We identify three forager groups, that is, 'rare', 'occasional' and 'frequent' foragers, whose behaviors differ in frequency and practice. Women, the elderly and marginalized communities most frequently collect, share, cook and sell edibles. Access to home or community gardens strongly motivates occasional foragers. Frequent foragers emphasize benefits relating to nutrition and income, as well as culture and social capital, whereas occasional foragers appreciate nature- and culture-related benefits. Our findings challenge conventional perspectives on urban food provisioning, highlighting urban blue spaces as vital yet overlooked spaces for food access and resilience. Integrating foraging into urban planning can enhance equitable food systems, fostering transformative change toward sustainable urban landscapes.

Urban blue spaces (UBS) such as lakes, rivers and channels are increasingly recognized as vital assets in urban landscapes, contributing to climate adaptation, biodiversity conservation and human well-being[1,2]. They regulate local climate, support water purification, enhance air quality and provide spaces for social cohesion and recreation[3,4]. A growing body of evidence links the quality of blue spaces in terms of biodiversity, esthetics, safety and infrastructure with positive health outcomes[1,5]. In urban planning, UBS are now framed as nature-based solutions for climate resilience and social inclusion[6].

However, historically, blue spaces have also played an essential role in sustaining urban food systems[7]. They were once hotspots of complex socioecological systems, supplying fish, edible greens, mushrooms and other food sources[8]. These spaces were embedded in the daily lives and traditional practices of communities. Such practices started to decline since the 1950s, when rapid urban development, pollution and privatization have led to the degradation and loss of many urban waterscapes[9]. The remaining UBS are often repurposed for recreation or commercial interests, neglecting their multifunctional uses, particularly for marginalized populations[10] (though with a few exceptions, in cities like Bengaluru, where citizen-led movements have led to UBS restoration[11]).

Today, especially in the Global South, UBS are ecologically and politically contested spaces. Rapid urbanization is projected to expand urban areas by 1.2 to 1.8 million km^2 between 2000 and 2030 (ref. 12), and will intensify pressure on natural resources and increase the vulnerability of urban poor populations[13]. As cities expand and densify, UBS face competing demands—the recreational desires of the middle class, the real estate ambitions of political and commercial actors,

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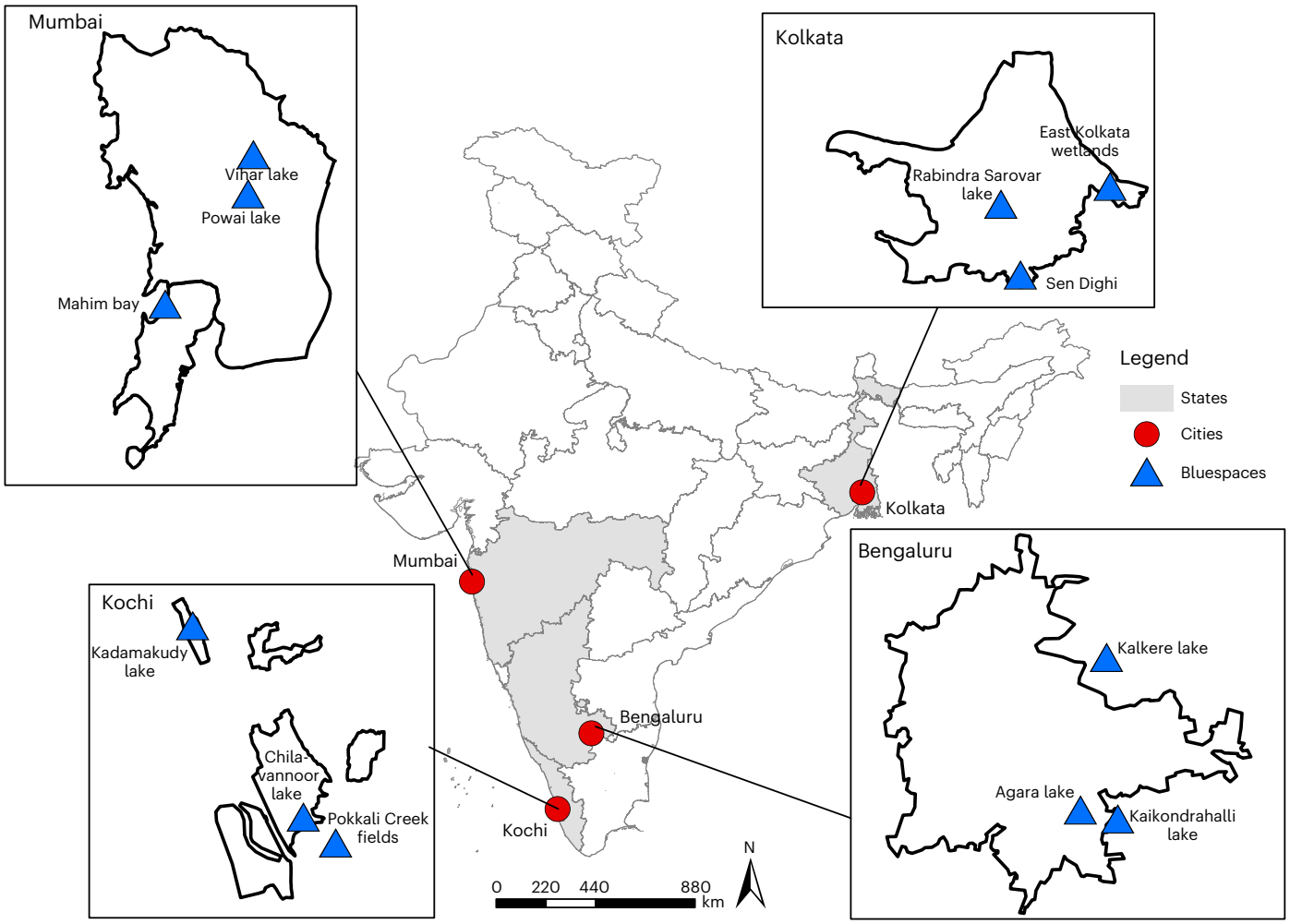

Fig. 1 | Map of the four cities and the blue spaces selected as the study sites within each city. The map shows the geographic location of the four Indian cities included in the study: Bengaluru, Kochi, Kolkata and Mumbai. Red circles indicate the four study cities. Inset maps provide enlarged views of the blue-space sites surveyed within each city. Blue triangles denote the three waterscapes in each city where respondents were recruited. State boundaries are shown for spatial reference.

and the subsistence needs of the urban poor[8]. So far, much research on the degradation of urban waterscapes has focused on their importance for ensuring water security[14,15], but their equally critical role in food security remains underexplored. Many studies indicate that urban foraging is a prevalent practice that goes beyond recreation[16–19], serving as a vital source of nutrition, livelihood support and food security, particularly for low-income communities in urban areas of the Global South[20–23]. In this context, blue spaces hold potential to support food security through overlooked practices such as foraging[20–24].

In this study, we define urban foraging practices more narrowly than the broader term that includes non-food resources[25]. We refer to urban foraging as the practice of accumulating edibles like plants, fruits, fish or mushrooms from public water landscapes that provide multiple benefits: cultural and social identity, livelihood support, recreational activity and local food provisioning. Although the Global North has seen a growing interest in edible cities, promoting foraging and hobby gardening (for example, Berlin, New York, Vancouver and Bristol)[26–30], cities in the Global South often overlook or stigmatize foraging practices. In African and South Asian urban contexts[21,23,24,31], foraging offers provisioning services essential to urban resilience, especially for marginalized groups. However, due to regulatory and planning frameworks, foraging is often seen as illegitimate or undesirable[23]. Despite the evident multifunctionality of blue spaces, their contributions to food systems, especially through informal and culturally embedded practices like foraging, often remain under-researched. Most urban food system studies focus on agriculture, gardening or technological innovations (for example, vertical farming or aquaponics)[31–34], whereas the role of blue spaces in sustaining urban food provisioning is limited[7].

This study situates urban foraging as a practice that can foster transformative relationships with nature. The 2024 Transformative Change Assessment by the Intergovernmental Platform on Biodiversity and Ecosystem Services[35] emphasizes that addressing biodiversity loss and building sustainable futures requires fundamental changes in the ways people interact with and value the natural world[35]. It highlights that transformative change toward a just and sustainable world emerges when efforts are informed by diverse knowledge systems and support inclusive, well-resourced stewardship focused on areas of high ecological and cultural value. In this context, understanding the extent of urban foraging from UBS is crucial because it reveals how widespread these nature-based practices already are, especially among communities that rely on them for nutrition, livelihood or cultural identity. Simultaneously, assessing the values associated with foraging helps uncover the deeper dimensions of people's engagements with urban nature. Recognizing and quantifying the extent and values are essential for supporting inclusive, equitable and nature-positive urban sustainable transformations. In cities where blue spaces are rapidly shrinking or privatized, foraging becomes a form of everyday

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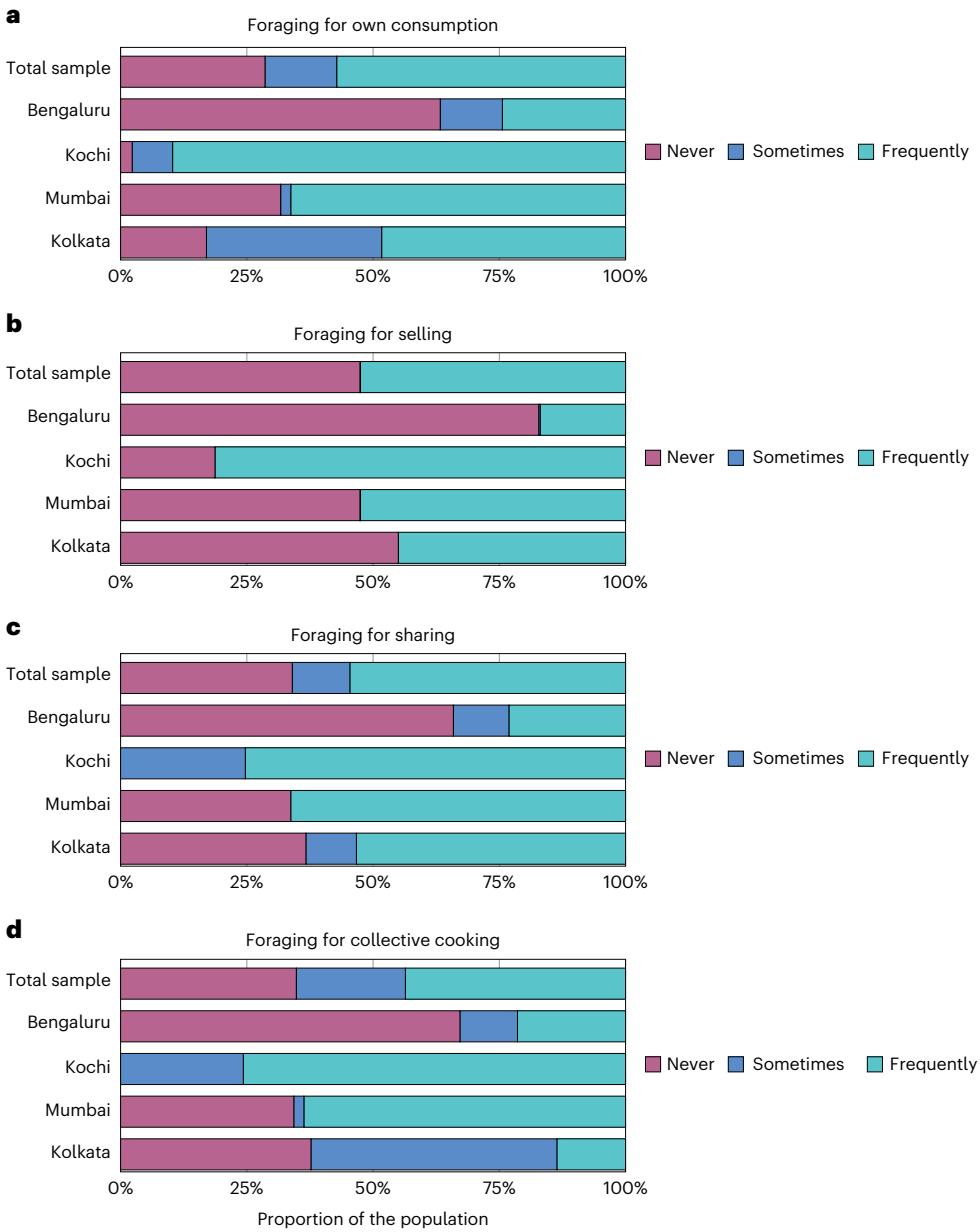

Fig. 2 | Frequency of engaging in foraging practices around urban blues spaces in the four cities (n = 1,190). a, Foraging for own consumption. **b**, Foraging for selling. **c**, Foraging for sharing. **d**, Foraging for collective cooking. Bars represent the proportion of respondents who forage never, sometimes or frequently.

ecological stewardship, a livelihood strategy for the marginalized and a pathway for rebuilding reciprocal human–nature connections. By uncovering these often-overlooked practices, this study contributes to reimagining UBS not just as ecological or recreational assets but as edible, multifunctional landscapes central to resilient urban food systems and community well-being.

The overall aim of this study is to analyze the extent of foraging practices in UBS and the perceived values of foraging among blue space users in Indian cities. We undertook a questionnaire-based survey (face to face) with 1,200 blue space users across four Indian cities (Bengaluru, Mumbai, Kochi and Kolkata) that inquired into their foraging practices for collecting, selling, sharing and cooking with edibles from UBS. Our four specific objectives are to (1) reveal the extent of foraging practices from blue spaces in rapidly growing cities, (2) understand the differences in foraging practices between actors from different sociodemographic backgrounds, (3) identify the influence of behavioral characteristics of blue space users on foraging practices and (4) analyze the values associated with foraging benefits and their determinants across different blue space users. Overall, the findings here will address the limited recognition of UBS within food system research and planning, highlighting their overlooked role in supporting everyday food practices like foraging and contributing to urban sustainability benefits.

A focus on Indian metropolises

We selected four rapidly urbanizing cities in India with diverse geographical locations to capture a broad spectrum of UBS (Fig. 1). Bengaluru, located on the Deccan plateau, has a population of 13.6 million and spans 741 km^2. Kochi, a smaller coastal city on the southwestern seaboard, has 2.2 million residents within 98 km^2 under the Kochi Municipal Corporation. Mumbai, a highly urbanized metropolis on the western coast, covers 467 km^2 and houses 22.8 million people. Kolkata, situated on the eastern bank of the Hooghly River delta, has a population of 4.5 million and spans 207 km^2 under the Kolkata

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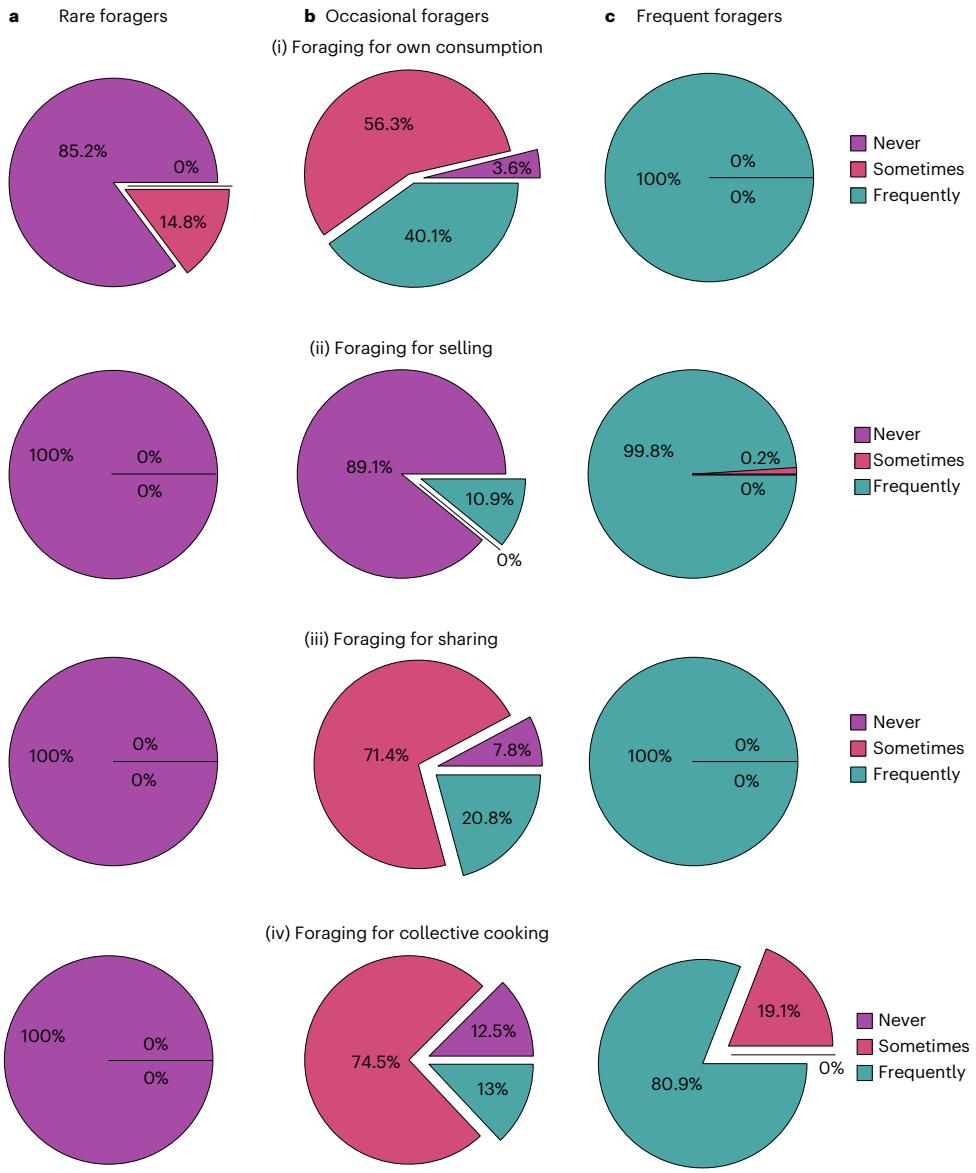

Fig. 3 | Three forager groups and their foraging practices across the four Indian cities (n = 1,190). a, Rare foragers. **b**, Occasional foragers. **c**, Frequent foragers. Each pie chart shows the proportion of respondents who forage for own consumption, selling or sharing, and collective cooking categorized as never, sometimes or frequently.

Municipal Corporation. These cities offer contrasting urban ecologies and demographic profiles. For instance, Bengaluru is characterized by a high density of artificial lakes, whereas Kochi's varied coastal water bodies shape distinct foraging patterns. Mumbai's intense urbanization places heavy pressure on its coastal and inland blue spaces, whereas Kolkata faces unique socioecological challenges related to river-based foraging along the Hooghly River delta. In each city, we selected three water bodies like lakes, ponds, canals and wetlands, across different neighborhoods to understand foraging practices among diverse socio-demographic groups (Fig. 1).

Results

Extent of foraging practices

The majority of the surveyed blue space users engaged in diverse foraging practices across the four Indian cities, with more than half of them frequently collecting edibles from blue spaces for personal consumption, selling, sharing and collective cooking (Fig. 2). They foraged various types of greens, fruits and berries, flowers, mushrooms, fish, crabs and clams. Foraging practices were the most prevalent in Kochi and Mumbai, where more than half of the respondents frequently collect (Kochi, 89.7%; Mumbai, 66.3%), sell (Kochi, 81.3%; Mumbai, 66%), share (Kochi, 75.3%; Mumbai, 66.3%) and collectively cook (Kochi, 75.7%; Mumbai, 63.7%) edibles. In Bengaluru, the majority of respondents were not involved in any of the targeted practices. The analysis identified three distinct groups of respondents across the four cities, differing in their patterns and frequencies of foraging practices (Fig. 3): frequent foragers (50.9%), occasional foragers (16.1%) and rare foragers (32.9%). The terms frequent, occasional and rare foragers are used to define their frequency in pursuing certain activities. Frequent foragers were found to regularly collect edibles from urban water bodies for personal consumption, sale in local markets and sharing with neighbors and others. In some cases, these foraged items were also used for preparing meals together with the people they shared the food with. By contrast, occasional foragers sometimes collect, share and cook these items but rarely engage in selling them to the local markets. Rare foragers did not engage in sharing, selling or cooking with foraged edibles, though some of them sometimes collect them for personal consumption around the surveyed water bodies. Although frequent foragers

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Table 1 | Percentage of sociodemographic groups belonging to one of the three forager groups identified and the corresponding chi² tests

	N	Rare foragers (%)	Occasional foragers (%)	Frequent foragers (%)	Chi² test	*P* value (two sided)
Gender						
Female	799	20.9	16.1	63.0		
Male	391	57.5	16.1	26.3	176.112	$P<0.001$
Total (*n*)						
Age (years)						
Below 31	106	50.9	14.2	34.9		
31 to 50	476	34.7	14.7	50.6		
51 to 70	432	33.1	16.2	50.7		
Above 70	176	17.0	21.0	61.9	37.370	$P<0.001$
Caste						
General	673	56.3	23	20.7		
Scheduled Caste	289	4.2	7.3	88.6		
Scheduled Tribe	228	0.4	7.0	92.5	582.248	$P<0.001$
Education						
No school	258	0.0	8.5	91.5		
Primary and secondary schools	348	2.0	1.1	96.8		
High school	52	32.7	38.5	28.8		
University	532	69.2	27.4	3.4	982.439	$P<0.001$
Occupation						
Daily wage labor	611	0.8	3.4	95.7		
Private employee	358	68.4	30.4	1.1		
Homemaker[a]	34	38.2	20.6	41.2		
Public sector	104	66.3	31.7	1.9		
Unemployed[b]	82	73.2	26.8	0.0	1,039.355	$P<0.001$
Annual family income (US$)						
Below 3,500	216	0.9	4.6	94.4		
3,500 to 6,999	378	2.4	5.3	92.3		
7,000 to 10,599	313	53.0	30.7	16.3		
10,600 to 17,500	249	83.1	16.9	0		
Above 17,500	34	23.5	70.6	5.9	974.547	$P<0.001$

n=total per demographic factor [a]Homemaker is defined as an individual who provides labor within the household that contributes to the well-being and productivity of its members, without direct monetary compensation [b]Unemployed includes retired people and students.

prevailed across all four cities, and especially in cities like Kochi (75.3%) and Mumbai (65.3%), rare foragers were the dominant blue space user group in Bengaluru (66.9%).

Sociodemographic variation in foraging behavior

Foraging behavior varied substantially between sociodemographic groups (Table 1 and Fig. 4). Women were notably more engaged in different practices related to foraging than men, with the majority of women classified as frequent foragers (63% compared with 26.3%). Age also played a crucial role, as individuals older than 70 years were more commonly frequent foragers (61.9%), whereas nearly 50.9% younger users under 30 years were rare foragers. Caste-based disparities were pronounced, with 92.5% of individuals belonging to Scheduled Tribes and 88.6% belonging to Scheduled Castes—recognized as among the most disadvantaged in India—classified as frequent foragers. By contrast, more than half of all respondents (56.3%) from the General Caste were rare foragers, reflecting stark socioeconomic divides in access to and reliance on foraged resources. Educational attainment further shaped foraging behavior. The vast majority of respondents without a formal education were frequent foragers, whereas rare foragers were particularly prevalent among users with a university degree (69.2%). Occupational status also influenced foraging engagement, with 95.7% of daily wage laborers and 41.2% of homemakers being frequent foragers. By contrast, respondents working in the private and public sectors as well as the unemployed (including retirees and students) were mainly rare foragers (between 66.3% and 73.2%) and, to a lesser extent, occasional foragers (between 26.8% and 31.7%). Income level exhibited a slightly different pattern, with the vast majority of respondents having a family income below US$7,000 being classified as frequent foragers, those with a family income above US$7,000 and less than US$17,500 as rare foragers, and those with a family income of more than US$17,500 predominantly as occasional foragers. Overall, the non-metric multidimensional scaling (NMDS) plot (Fig. 4) confirms that respondents with lower levels of education and income, who work as daily wage laborers and belong to lower castes, are frequent foragers involved in multiple foraging practices. By contrast, those with a medium income and a high school education, who are either unemployed (including retired people and students) or employed in the private or public sectors, were more likely to be rare foragers, either not foraging at all or only for their own consumption.

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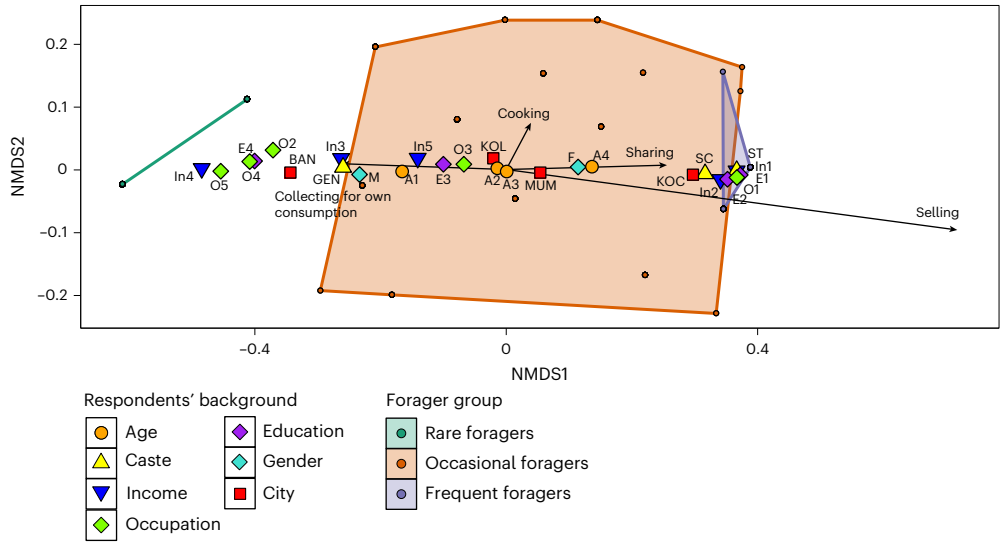

Fig. 4 | NMDS plot displaying Bray–Curtis dissimilarity in foraging behavior between surveyed respondents (n = 1,189; dimensions k = 5 and stress = 0.012). Hulls represent the three forager groups identified, whereas symbols represent the centroid values for each sociodemographic factor and the four cities. The following abbreviations are used: age (years): <31 (A1), 31–50 (A2), 51–70 (A3), >70 (A4); gender: male (M), female (F); education: no school (E1), primary and secondary schools (E2), high school (E3), university (E4); caste: general (GEN), Scheduled Caste (SC), Scheduled Tribe (ST); income (US$): <3,500 (In1), 3,500–6,999 (In2), 7,000–10,599 (In3), 10,600–17,500 (In4), >17,500 (In5); occupation: daily wage labor (O1), private employee (O2), homemaker (O3), public sector (O4), unemployed (O5); and city: Bangalore (BAN), Mumbai (MUM), Kochi (KOC), Kolkata (KOL).

Influence of behavioral characteristics on foraging

In addition to a great influence of sociodemographic factors, individuals' behavioral characteristics also influenced the foraging behavior of UBS users (Fig. 5; odds ratio (OR) and 95% confidence interval). Key influential factors included the frequency of accessing the surveyed blue space, the frequency of noticing edible items in and around these water bodies, and having access to a personal backyard or community garden. Although some of these factors played an important role in predicting the respondents' membership of the frequent and occasional forager groups, other factors were only prominently associated to one particular group. For instance, the ability to identify edibles was associated with a 35 times greater likelihood of being an occasional forager (P < 0.001) and a 19 times greater likelihood of being a frequent forager. By contrast, access to a private or community garden significantly increased the likelihood of being an occasional forager (OR = 5.67, P < 0.001) compared with being a rare forager, whereas the same pattern could not be found for frequent foragers (OR = 0.88, P = 0.814). Similarly, frequent access to the respective blue space was exclusively linked to the group of frequent foragers (OR = 28.00, P < 0.001), indicating a positive notable association between frequently accessing these spaces and frequently engaging in diverse foraging practices.

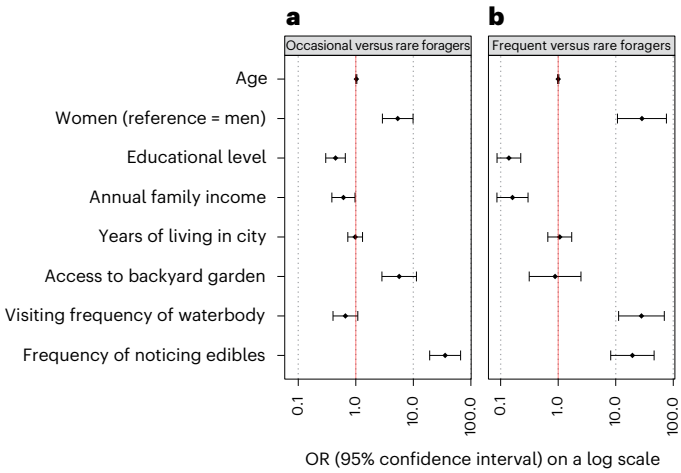

Fig. 5 | Results of the multinomial logistic regression model (P < 0.001, two sided), showing the influence of behavioral and sociodemographic characteristics on foraging behavior (n = 1,184). Rare foragers represent the reference category in the model. **a**, Occasional vs. rare foragers. **b**, Frequent vs. rare foragers.Variables with OR values (closed dots) and error bars lying entirely above or below 1 are considered significant at a level of P < 0.05.

Foraging benefits perceived by different blue space users

Respondents identified a broad range of values, associating foraging with benefits related to nature, nutrition and income, social capital, and culture and identity. The three forager groups associated different benefits with their foraging from UBS (Fig. 6). Frequent foragers most strongly emphasized nutrition and income-related benefits, such as dietary security and subsistence income, as well as valued foraging for cultural aspects, tradition and social capital. However, they placed less emphasis on nature-related benefits, with the exception of spiritual connection (Nat6). Occasional foragers, on the other hand, expressed nature- and culture-related benefits highly, and, to a lower degree, values related to social capital like community gardening (SC1) and local festival participation (SC6). Both frequent and occasional foragers similarly appreciated cultural benefits related to culinary heritage (Cult3), connections to roots (Cult6) and the preservation of traditional foraging memories (Cult7). Rare foragers instead moderately valued nature-related benefits, but rarely acknowledged other types of benefit.

We conducted a redundancy analysis (RDA) to examine statistical associations between UBS users' valuation of foraging benefits and the three key factors, that is, forager groups, sociodemographic characteristics and the four Indian cities studied. The RDA explained 70.8% of the total variance in respondents' valuations, with the first axis (RDA1) explaining 55.5% of the variance and the second axis (RDA2) explaining 10.5% (adjusted R^2 = 0.70, F = 126.66, df = 22, P < 0.001, 999 permutations; Fig. 7). Frequent foragers and UBS users in Mumbai primarily associated foraging as a source of nutrition and income. This view was also shared by people with minimal education, daily wage laborers and members of Scheduled Tribes and Scheduled Castes. By contrast, occasional foragers and UBS users of Kolkata associated foraging more

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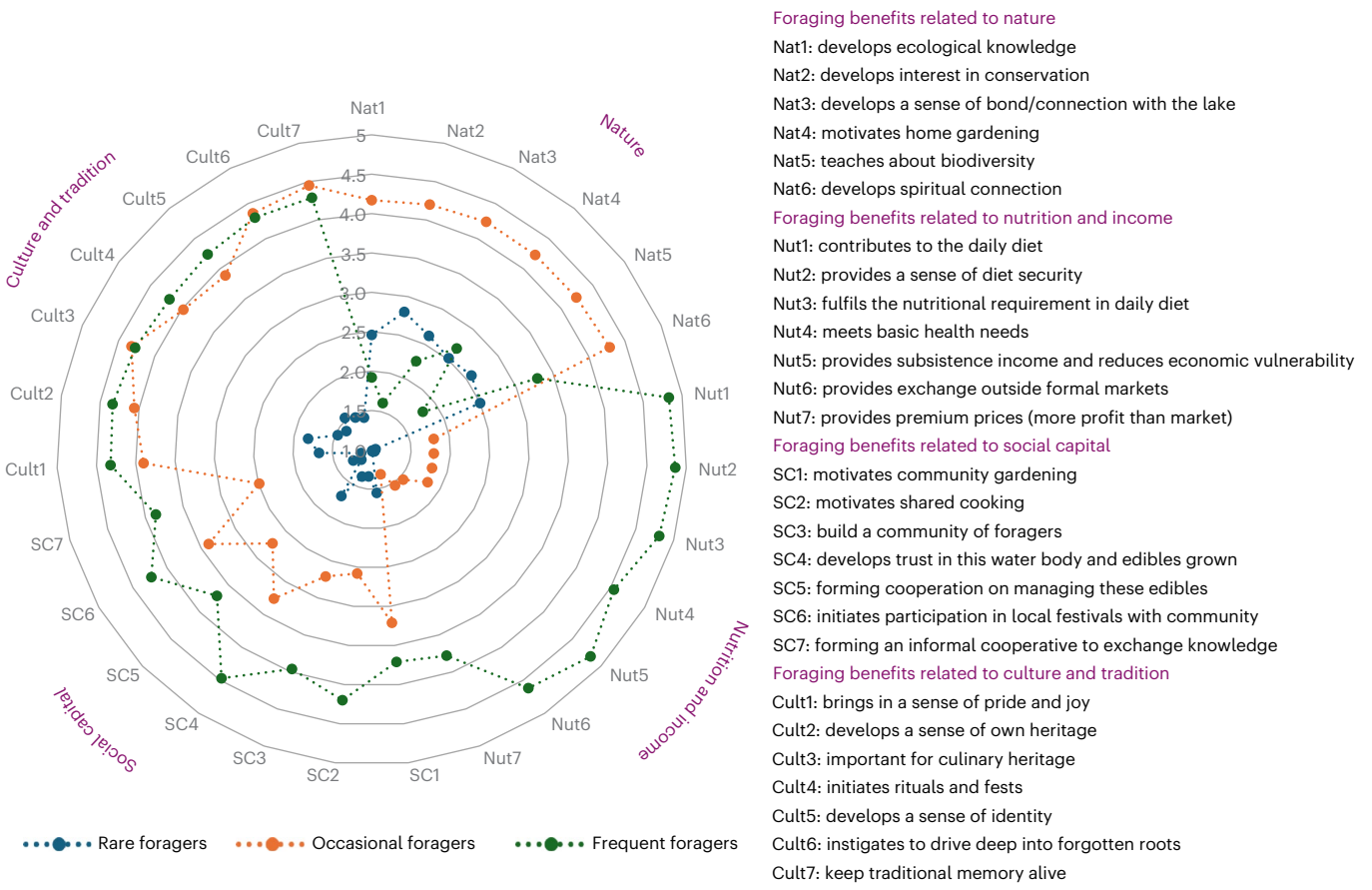

Fig. 6 | Mean values attributed to foraging benefits by different groups of foragers. Values range from 1 (least important) to 5 (most important).

with nature-related benefits. This was also true for individuals with higher incomes (above US$17,500) and university degrees. Meanwhile, female, older adults over 70 years and Kochi UBS users valued it for its cultural meaning, identity and social capital benefits.

Discussion

Urban foraging for food in blue spaces remains a substantially underexplored domain, particularly in the context of the Global South. Our study addresses this gap by empirically examining the extent and values of foraging in UBS across four major Indian cities. We conceptualize foraging not just as an act of food collection but as a socioecological practice that is embedded in diverse cultural, economic and environmental realities. Our findings provide one of the first, qualitative estimates of the scale of foraging in blue spaces. We identified a considerably higher proportion of foragers among urban populations than other studies[18,20]. More than half of the respondents engaged in foraging frequently, and many others were classified as occasional foragers. Prior research on urban foraging has often focused on green spaces like parks, forests, unused lands or streets[10], whereas only a few studies have underscored the significance of blue spaces[36]. The differences in the way frequent and occasional foragers used collected edibles reflect not only varying motivations but also the interplay between ecological availability and social accessibility. For example, frequent foragers used UBS for multiple benefits like consumption, sharing and other communal use. This suggests stronger social and resource dependencies, which are often shaped by proximity, familiarity and necessity. Occasional foragers, on the other hand, may have physical access to blue spaces but used them more for cultural or recreational purposes. As other studies highlighted, such patterns are shaped by how people perceive, access and derive value from urban nature, underlining the importance of inclusive and equitable design in the provision of ecosystem services[23,37]. The local patterns, in which frequent foragers engaged in the sharing, selling and communal use of foraged foods, highlight how everyday practices rooted in local knowledge and community networks can contribute to sustainability-oriented urban transformations by fostering place-based food systems, social cohesion and inclusive stewardship. Previous research indicates that traditional ecological knowledge can persist across generations, enriching urban ethnobotanical practices[37]. However, urbanization may gradually erode these culturally rooted foraging traditions, which are especially valuable during times of distress[38]. Our study finds that frequent foragers in Indian cities not only draw on such knowledge but also actively engage in sharing, selling and communal use of foraged foods. These localized patterns illustrate how everyday, community-based interactions with urban nature can foster place-based food systems, strengthen social ties and promote stewardship, contributing meaningfully to sustainability-oriented urban transformations. To strengthen this potential, urban planners and policymakers should acknowledge foraging as a valid urban practice and promote it through inclusive food policies, community-led education initiatives, and the conservation of biodiverse public and semipublic spaces that enable such practices to flourish.

Sociodemographic background plays a crucial role in shaping local residents' specific reliance on foraged edibles[39]. However, in contrast to other studies[25,40], our field-based intercept sampling was designed to capture a broader sociodemographic cross-section of UBS users and usage patterns across diverse Indian cities. Although socioeconomically disadvantaged people more often valued blue spaces for food[41,42], some other correlations were less clear. For instance, blue space users with access to a backyard or community garden were more often occasional foragers, indicating that this group may not depend on foraging for a living but rather use edibles from water bodies as a complementary food source. A previous study suggested that habitual

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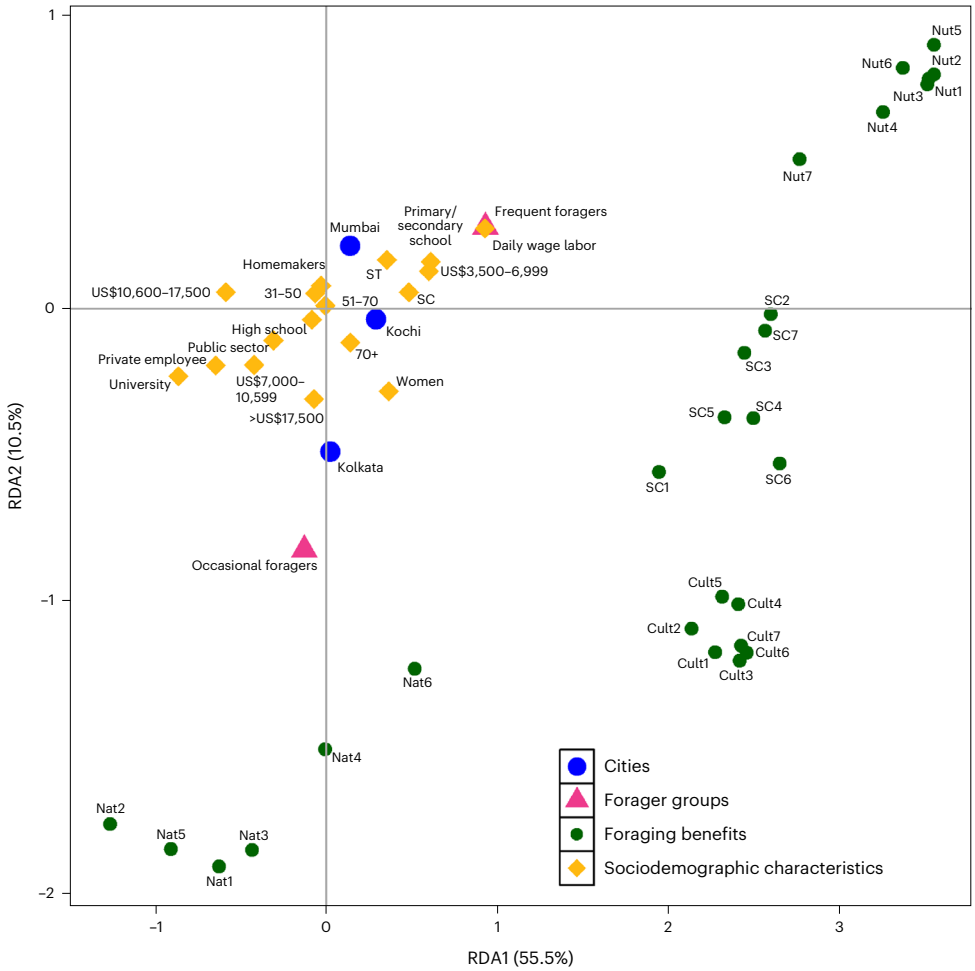

Fig. 7 | Biplot of the first two axes of the RDA illustrating the relationship between valued foraging benefits and various influential factors (F = 126.66, df = 22, P < 0.001, two sided). The diverse foraging benefits serve as the dependent variables, whereas city, forager groups and sociodemographic backgrounds act as explanatory variables. Foraging values cover four categories: (i) nature-related benefits (includes Nat1–6), (ii) nutrition and income (includes Nut1–7), (iii) social capital (includes SC1–7) and (iv) culture and identity (includes Cult1–7). Figure 6 provides a full list of abbreviations.

gardeners reflected ethnobotanical knowledge and often foraged occasionally for wild edibles[43]. This suggests that individuals with access to private gardens may already possess knowledge of edible plants, which could inform and motivate occasional foraging. Similarly, increased interaction with water bodies emerged as a potential influencing factor for engaging more frequently in foraging activities. Similar to our findings, people who engaged more intensively with the landscape in other geographic contexts assigned higher values to it[44]. The UBS function underlines the multifaceted influence not only as complementary food sources but also as culturally and ecologically substantial urban landscapes, where accessibility influences both dependence and stewardship in unique ways.

Our results highlight the complexities of values that people attach to foraging. Frequent foragers valued foraging for nutrition, income and social capital. By contrast, occasional foragers valued foraging mainly for interactions with nature or for cultural values. UBS, therefore, have the promising potential to provide not only regulating and supporting ecosystem services (similar to many green spaces[45]) but also food provisioning services[46], which, in turn, may increase the sustainability benefits in cities[47]. Thus, our findings indicate that UBS users link foraging with multiple aspects of human–nature interactions. Although food provisioning remains notably high, its importance lies not in the volume or nutritional yield compared with farmed food[18], but in its role as a subsistence strategy, especially for marginalized communities. Frequent foragers in our study appeared to be motivated more by necessity, using foraged resources to supplement unstable food access, reduce household expenses or bridge seasonal gaps. Therefore, foraging offers microscale food security and a degree of autonomy in precarious urban environments. Occasional foragers, by contrast, tended to engage more for cultural, recreational or nature-based experiences, indicating a spectrum of dependency and value systems tied to foraging. Thus, although the nutritional yield may be low, the social, cultural and economic importance of foraging for certain user groups remains deeply relevant.

Our results emphasize the transformative potential of blue spaces in the sustainability of urban food systems. The high reliance on foraged edibles among socioeconomically marginalized groups in our study points to the underlying issues of access and equity, highlighting how blue spaces serve as critical livelihood support systems. The diversity of participants, including women, older adults, and those from different caste and income backgrounds illustrates the pluralism of knowledge systems that inform foraging practices. These behaviors, especially communal cooking, gifting and local sale of foraged goods, function as everyday practices through which local ecological knowledge is circulated and reinforced. They also foster social cohesion by enabling trust, reciprocity and shared cultural rituals among neighbors and community members. In this way, UBS serve not only as food provisioning sites but also as relational spaces in which knowledge and social ties are maintained and renewed. Acts of sharing, gifting and communal cooking reflect reciprocal relationships with nature and community,

whereas intercity differences in motivations (for example, nutrition, culture or natural connection) suggest the need for adaptive, context-sensitive governance. Ultimately, our study frames foraging in UBS as a lens through which to understand broader socioecological dynamics in Indian cities. The presence of diverse values, motivations and patterns of use speaks to the potential of blue spaces to support transformative urban change.

During the current critical juncture marked by rapid urbanization, environmental volatility and food insecurity, comprehending the overall scope of foraging and the sociodemographic characteristics of those who forage is important for raising awareness and mitigating any associated stigma or legitimacy issues. Through an examination of influential factors for foraging and the plurality of different foraging benefits assigned by different waterbody users, we highlight that the functions of UBS go far beyond the recreation and regulating ecosystem services that largely benefit a narrow range of (often privileged) beneficiaries only. Our analysis can help build a framework for identifying populations who may be dependent on foraging in different cities of the Global South. Such insights will enable urban planners and policymakers to develop strategies that generate benefits for a wider population.

The presented values attributed to foraging, as perceived especially by occasional and frequent foragers, offer a deeper understanding of UBS users' attitudes toward foraging for edibles. However, it is crucial to assess the sustainability of foraging to prevent unintended consequences such as rebound effects[18,48]. For example, increased foraging activities inspired by positive perceptions could lead to overharvesting, ultimately depleting local plant populations and negatively impacting ecosystem health. Other relevant factors in urban foraging practices include concerns about soil contamination and the absorption of heavy metals and pollutants[49].

One limitation of this study is that none of the respondents in our sample self-identified as belonging to the Other Backward Classes category and this gap reduces the representativeness of our sample and limits the applicability of caste-related insights. Another limitation of this study is that it does not delve into intercity differences. We instead aimed to build a broader argument that is applicable across diverse urban contexts, which future research could explore in greater depth. Assessing the multifunctional capacity of UBS, we argue that meaningful interventions must begin by addressing the vulnerabilities of user groups to ensure equitable access, as well as tackling issues of resource contamination and overexploitation. Such a strategy can be operationalized through the lens of the Intergovernmental Platform on Biodiversity and Ecosystem Services framework: (1) recognizing UBS as vital biocultural sites, as demonstrated by the deep cultural significance of edible species identified in our study; (2) strengthening legal protections for biodiversity in UBS, and enabling sustainable foraging; (3) designing conservation strategies that reflect the multiple values embedded in foraging practices, including cultural, traditional and social dimensions; and (4) promoting integrated spatial planning that ensures landscape-scale conservation of UBS within urban systems.

Methods

Pilot survey and questionnaire design

To gain an insight into the practice and benefits of foraging edibles from UBS, we first performed an exploratory qualitative investigation. We conducted a pilot study across all the selected water bodies in May 2023. From the survey, we identified the edibles that were available and foraged by locals across different cities. They included various types of greens, fruits and berries, flowers, mushrooms, fish, crabs and clams. This pilot phase enabled us to determine the appropriate sample size, categorize the users of the blue spaces and identify potential factors influencing foraging behaviors. During the pilot study, we conducted semistructured interviews and ethnographic observations with local users, as well as semistructured interviews with waterbody managers, local NGOs and institutions, including municipal corporation servants, community-based organizations and trusts, which are responsible for maintaining, managing and daily operations of the water bodies. These interactions provided us with insights into user behaviors, visitation patterns and foraging practices, aiding us in refining our questionnaire survey design.

We utilized a paper-based questionnaire for data collection purposes. We categorized our questionnaire in three broad categories. Under the first category, inquiries pertained to factors influencing the foraging of edibles. From our pilot study, we identified six sociodemographic and behavioral characteristics that influence foraging edibles from UBS. The first category covered six distinct aspects: (1) years residing in the city, (2) frequency of visiting blue spaces, (3) frequency of noticing edibles in/around blue spaces, (4) access to own or community garden, (5) awareness/knowledge of foraging learned from previous generations and (6) sociodemographic characteristics of the respondents. Years residing in the city often indicated a respondent's familiarity with local landscapes, seasonal availability of edibles and gradual accumulation of informal knowledge about nearby foraging opportunities. Longer residence often implied deeper local ecological knowledge and stronger social ties that supported foraging behaviors. Frequency of visiting blue spaces was related to the physical opportunity to engage with foraging sites. Frequency of noticing edibles in or around blue spaces reflected the space design along with the availability of edibles as well as the level of ecological awareness and attention to edible species in the surroundings. Access to own or community garden nurtured plant identification skills, food knowledge and interest in alternative food sourcing. Such access also fostered a closer relationship with nature and increased confidence in identifying and collecting wild edibles. Awareness or knowledge of foraging passed down from previous generations underscored the cultural continuity and informal learning often central to foraging. Sociodemographic characteristics of respondents, including age, gender, education, income level and caste aided to understand broader patterns in who forages and why. In the second category, questions focused on the respondents' personal foraging preferences, the ancestral knowledge or involvement of their parents or grandparents in foraging, and whether they had observed foraging practices in the waterbody. In the third category, we queried users about their frequency with which they engaged in four different practices related to foraging, that is, "foraging for personal consumption", "selling in local markets", "sharing among neighbors and others" and "cooking collectively with neighbors and others". Collective cooking is a common practice, particularly in rural settings, where neighbors come together to prepare special meals out of the edibles collected. This often involves blending different traditional recipes or simply cooking and eating together as a way of celebrating shared time. Sharing edibles refers to the gifting of the collected edibles, often as a token of love and generosity. Although collective cooking emphasizes communal bonding and collaboration, edible sharing functions more as an expression of care and goodwill. For each practice, survey respondents were asked to indicate their frequency in engaging in the practice, choosing from the following five response items: 'very frequently' (daily or several times a week), 'frequently' (once a week or several times a month), 'sometimes' (once or twice in six months), 'rarely' (once or twice a year) and 'never at all'. The subsequent analysis of the data was facilitated by merging these answers into three response categories: 'never', 'sometimes' (includes rarely and sometimes) and 'frequently' (includes frequently and very frequently). From our pilot study, we found some broad aspects that aligned with the multiple functions of landscape products defined in an existing study on landscape products and sustainable agricultural practices[50]. Therefore, we integrated this framework adopted from that study and incorporated four overarching sections on the values of foraging: (1) connection to nature, (2) connection to nutrition and income, (3) connection to social capital and (4) connection to cultural identity. Each of these was then further subdivided to cover six to seven benefits,

following the framework, resulting in a total of 27 foraging values considered (Fig. 5). To assess the importance or values of these benefits for survey respondents, we applied a five-item Likert-scale assessment ranging from 1 (least important) to 5 (most important) (Supplementary Information provides the full questionnaire). Although foraging is distinct from agriculture in that it involves harvesting rather than cultivation, both practices contribute to food provisioning, livelihood support, cultural continuity and ecological engagement. Therefore, we found this agricultural framework to be well suited to systematically capture the multifunctional values of foraging, especially in relation to how people interact with and derive benefits from landscapes as well as enabled a structured categorization of values that emerged during our qualitative pilot study.

Sampling and data collection

We used an opportunistic intercept sampling technique to survey UBS users and capture the sociodemographic characteristics and values of local residents. Only individuals residing within a 5-km radius of the selected water bodies were eligible to participate. At each site, people were approached in public areas and asked how far they lived from the UBS; if they resided beyond the 5-km radius, the interview did not proceed. Although participants were approached at random times and locations within the site, this approach is classified as opportunistic due to its reliance on intercepting individuals present at the site rather than drawing from a complete sampling frame.

We surveyed 1,200 respondents across four Indian cities—Bengaluru, Mumbai, Kochi and Kolkata—covering 12 UBS sites (three per city). At each site, we aimed to interview 100 participants. Data collection took place between May and September 2023, spanning both summer and monsoon seasons. Surveys were conducted between 5:30 a.m. and 5:30 p.m., corresponding to the hours of public access to these spaces. Sampling hours were distributed across different days of the week and times of day to capture variation in UBS usage and user profiles. Interviews were conducted in the local language or English, based on participant preference. Each interview lasted between 15 and 20 min. Participants ranged in age from 18 to 100 years. Although we aimed for gender balance, a higher proportion of women ultimately participated, possibly reflecting greater availability or willingness to engage during the survey hours[51]. This study was approved by the Ethics Committee of the University of Göttingen and adhered to all ethical guidelines for research involving human participants. Informed consent was obtained from all respondents before participation.

Data analysis

We conducted a two-step cluster analysis to categorize the surveyed blue space users based on similar patterns of foraging practices. To this end, the frequencies with which respondents engaged in the following four practices were considered: collecting edibles from the vicinity of waterbodies ('collecting'), selling these items at local markets ('selling'), sharing them with neighbors or others ('sharing') and cooking them collectively with neighbors or others ('cooking'). The clusters were determined using Schwarz's Bayesian information criterion and the log-likelihood distance measure, resulting in the identification of three distinct forager groups (Fig. 3): rare foragers, occasional foragers and frequent foragers. The rare foragers category includes people who do not sell, share and cook with edibles but may still collect them for own consumption, although rarely and much less so than the other two categories. Cluster quality was measured by silhouette values[52], achieving a good classification performance of 0.7. The variables of cooking and sharing were the most influential in the clustering process, with a high predictor importance (1.00). Own consumption and selling were also influential, with predictor importance of 0.99 and 0.78, respectively. The relationships between the three clusters and respondents' sociodemographic backgrounds were analyzed using chi^2 tests and the NMDS plot. We used NMDS as an unconstrained ordination technique with the Bray–Curtis dissimilarity measure to plot dissimilarities in the foraging behavior between the surveyed respondents. NMDS was created by retaining two dimensions ($k = 2$) and reaching a stress level of 0.012, which indicates an excellent fit[53]. To explore patterns between individuals with a distinct foraging behavior (as indicated by the three forager groups) and respondents' sociodemographic background and city environment, we added the centroid values of the sociodemographic factors and city to the plot. If centroids cluster in certain areas of the plot, it suggests that they have a similar foraging behavior. Although both two-step cluster analysis and chi^2 tests were conducted in SPSS (v. 28), the NMDS plot was created with the function meta MDS of the package 'vegan' in R (v. 4.1.3).

Following these analyses, multinomial logistic regression was used to test the influence of the respondents' behavioral characteristics on their cluster membership. The three forager groups (clusters 1, 2 and 3) were used as the dependent variable, whereas the effect of years lived in the city, access to one's own or a community backyard garden, frequency of visiting the blue space and the frequency of noticing edibles in and around the waterbody were used as explanatory variables. To test the relative effect of these variables on the likelihood of belonging to one of the three forager groups, we additionally added the respondents' sociodemographic characteristics (that is, age, gender, formal education level and income) as the control variables. Due to high correlations with the dependent variable, respondents' occupation, caste and whether previous generations were involved in the foraging practices were not considered as explanatory variables in the model, as this would cause a Hauck–Donn effect and quasicomplete separation. Before running the regression analysis, the model was checked for multicollinearity using variance inflation factor(VIF) and tolerance values. All variables had VIF values of <5 and were retained. The regression was run with 1,184 valid responses after omitting cases with missing values. Multinomial logistic regression was conducted using the package VGAM in R (v. 4.1.3).

To explain variations in the respondents' valuations of various benefits of foraging, an RDA was conducted. Redundancy analysis is commonly applied to explore the causal relationship between a multivariate response variable and a set of explanatory variables. We used RDA (with Monte Carlo permutations of 999) with 27 potential foraging values as response and the three identified forager groups, respondents' sociodemographic variables and the four cities as explanatory variables. The RDA was conducted using the vegan package.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

All the data used in this paper are publicly available via Zenodo at https://doi.org/10.5281/zenodo.14887076 (ref. 51).

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Author contributions

S.B. conceived and designed the research, collected the data and wrote the original draft. B.M.Z. co-wrote the methods and results part, analyzed the data, performed the formal statistical analysis, created some of the figures, and edited and reviewed the paper. H.N., P.H.V. and T.P. edited, reviewed and supervised the research. T.P. was awarded the grant.

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Competing interests

The authors declare no competing interests.

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Population characteristics	All participants recruited for the study were over the age of 18 and met the eligibility criteria for survey participation.
Recruitment	Surveys were conducted from early morning until late evening to minimize population biases, with participants randomly selected from individuals present in the field area. They were provided with information about the study and asked to give their consent before participating. Participants were free to withdraw from the survey at any time if they chose to do so.
Ethics oversight	The study was subjected to University review and was approved by the Research Ethics Committee of the University of Goettingen, Germany. The study complies with the Research Ethics Code and the Code of Research Conduct of University of Goettingen. Informed consent was sought before participation.

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Research sample	The survey was designed to collect data at individual level. The data was collected from a total of 1200 responses from four cities in India. All the participants were interviewed within the boundaries of the study areas. During the survey, a longer duration of data collection was maintained in order to have well representation of the overall sample.
Sampling strategy	Random sampling techniques has been used to correct potential biases in sample of users and to ensure population representation.
Data collection	Local enumerators were recruited and underwent two weeks of training prior to starting the survey. They were hired from various cities, ensuring they could speak the local language, Hindi, and English, as most urban areas in India are multilingual. We used paper based methods for data collection purpose to keep it accessible for population of all gender, age, educational or social backgrounds.
Timing	The average completion time for the survey was 23 minutes. The data collection was conducted from May 2023 to September 2023 ranging from 5:30 am to 5.30pm ion both weekdays and weekends to avoid biases. The study period also covered seasonal variety.
Data exclusions	We excluded 59 interviews due to taking too less time to finish the survey.
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