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Examining Capacity-Outcome Relationships to Develop an Environmental Stewardship Capacity Index in New York City

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Abstract
Civic capacity to care for the urban environment is a key factor in urban sustainability efforts. Civic environmental stewardship groups play critical roles in solving governance challenges associated with sustainability, serving as brokers, acting as stewards, advocating for policies, and being repositories of social-ecological memory. Understanding the existing capacity of such groups to create social-ecological outcomes across the urban landscape enables better planning and implementation of equitable nature-based solutions. In this paper, we draw upon existing frameworks of community capacity and environmental stewardship to operationalize an empirical, organizational stewardship capacity index at a neighborhood scale. We applied survey-based civic environmental stewardship mapping data from the New York City 2017 Stewardship Mapping and Assessment Project (STEW-MAP) to create this index. We evaluated stewardship capacity variables against perceived social and environmental outcome measures collected by groups in the STEW-MAP survey to develop the stewardship capacity index. We find that neighborhoods where more groups exist, where more time is spent on stewardship, and where more types of stewardship actions are supported have better perceived *Cumulative outcomes*. Our results highlight the known role of networks in community capacity and reveal the roles of diversity of stewardship actions (*Stewardship types)* and level of effort (*Time spent on stewardship)* in achieving outcomes. The result of our analyses is a mapped index of stewardship capacity, which visualizes the in current capacities at a neighborhood level and identifies future opportunities for capacity building. With a focus on transparency, this index can be applied by managers, public and civic alike, as they seek to support and increase civic capacity to care for the environment.

Keywords Environmental stewardship · Capacity · Community · Care

Introduction

Civic capacity to care for the urban environment is a key factor in urban sustainability efforts (Frantzeskaki et al. 2016, Hölscher et al. 2019). Civic environmental groups play critical roles in solving associated governance challenges, often serving as brokers between government and communities (Connolly et al. 2014), acting as land stewards (Svendsen and Campbell 2008, Andersson et al. 2014), advocating for environmental policies and land conservation (Portney and Berry 2016), and providing repositories of social-ecological memory about specific neighborhoods and sites (Barthel et al. 2010). Civic groups function differently and serve different roles than government sectors. This is in part because their structure differs. Depending on the specifics of a group's structure, civic groups can have flexible boundaries, fluid membership, or an ephemeral presence over time (Oliver 1989, Minkoff 1999, Fisher et al. 2012, Landau et al. 2021). The distribution of these groups is also uneven across space (Johnson et al. 2019), raising questions of capacity in the civic sector. A recent systematic review of nonprofit capacity identified inconsistent findings between capacity and social performance, as well as limited research on factors influencing these relationships (Nordin et al., (2024)), indicating more research is needed to unpack these relationships. Understanding the existing capacity of these groups enables governance actors of all scales and sectors to better plan and activate efforts towards just nature-based solutions (Toxopeus et al. 2020, Pineda-Pinto et al. 2021).

Many civic groups are overlooked as components of social infrastructure (Campbell et al. 2022), since they are too small, localized, or grassroots to be part of standardized databases for registered non-profit organizations (Boris and Steuerle 2006).

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In the United States, non-profit organizations are registered with the Internal Revenue Service (IRS), and their names and office locations are included in many charity mapping tools derived from the IRS database (Boris and Steuerle 2006). Community groups working on stewardship actions and critical actors in urban environmental governance are not included in the IRS registry and, therefore, not as easily discoverable. Additionally, individuals can be connected to multiple organizations or groups, through both strong and weak ties, resulting in a fluid and decentralized structure (Fisher et al. 2017, 2018). As a result, existing measures of community capacity may underestimate actual capacity.

Studies have looked to identify larger sets of civic actors beyond registered nonprofits, including grassroots groups, in a particular location (Svendsen and Campbell 2008, Andersson et al. 2014, Andrews and Edwards 2005). One such approach, the Stewardship Mapping and Assessment Project (STEW-MAP) develops survey-based datasets that map civic organizations' geographic areas of influence, collaborative networks, and additional organizational characteristics (Svendsen et al. 2016). While there are different scales of community capacity, this organizational scale has been shown to better predict instrumental, or material, civic actions, as compared to individual social capital (Son and Lin 2008). Civic environmental stewardship groups act as and support social infrastructure (Campbell et al. 2022) and their reach extends beyond environmental outcomes to include social outcomes (Rigolon and Gibson 2021).

Here, we draw upon Bennett et al. 2018 existing framework of environmental stewardship to operationalize an organizational-level stewardship capacity index. With a focus on civic environmental stewardship groups, we consider this index to represent a stewardship-focused subset of community capacity. We apply organizational-level civic environmental stewardship mapping data from the New York City (NYC) STEW-MAP project from 2017 to create this index. We evaluate stewardship capacity against perceived outcomes, thereby advancing empirical measures of stewardship capacity and our understanding of capacity-outcomes relationships for stewardship organizations. We then combine capacity measures associated with outcomes into a single measure. The result is a mapped index of stewardship capacity, which visualizes the differences in current capacities at a neighborhood level and identifies future opportunities for capacity building for nature-based solutions.

Background

Capacity and Social Capital

Community capacity has been conceptualized as the interaction of human, organizational, and social capital within a community, which can be applied to address collective issues and improve community wellbeing (Chaskin 2001, Beckley et al. 2008). Models of community capacity are broadly used and have been found in applied social science fields like public health, social work, community psychology, and conservation. Capacity also has been described by researchers from these fields as forms of capital: natural, social, human, institutional, and economic. A prominent example is the Community Capitals Framework (Emery and Flora 2020). Other researchers also define capacity as a focus not only on the capital but also on the *processes* enabled by capital (Hölscher et al. 2019). Such capacity is theorized to manifest through informal social processes and more organized efforts by individuals and organizations within broader systems to which the community belongs. Beckley et al. 2008 multifaceted model of community capacity points to capacity as not only a protective or reactive phenomenon but also part of proactive initiatives resulting from changes in conditions.

A similar concept to community capacity is that of social capital. Defined as the "norms and networks that facilitate collective action" (Woolcock 2001), social capital is often measured as a series of stocks (groups, people, institutions) and, less frequently, flows (networks). Multiple definitions exist for this concept, which makes comparative work for social capital challenging (Glanville, Bienenstock (2009)). It is also important to understand the diverse types and scales of social capital. There is a critical distinction between types of social capital that broadly measure everyday interactions versus when those interactions scale up and involve deliberate organizing and working towards a goal, or collective action (Stone 2001, Wollcock 2001). At present, multiple indices and approaches to measuring social capital exist (Rupasingha, Goetz, and Freshwater 2006, Kim et al. 2006, Kyne and Aldrich 2020, Chetty et al. 2022), which examine a mixture of everyday interactions (e.g., friendship networks or informal social interactions in a given area) and collective action (e.g., number of civic groups, volunteering rate in a given area).

Stewardship Capacity

Stewardship capacity is the capacity of individuals or communities to steward their resources (Bennett et al. 2018). Stewardship also has been theorized as interactions between knowledge, care, and agency (Enqvist et al. 2018). In a recent framework of environmental stewardship, Bennett et al. (2018) identify two factors affecting this capacity: local community assets and broader governance. Local community assets include social, cultural, financial, physical, human, and institutional capital. Drawing on a capital assets framework, the social capital Bennett et al. (2018) refer to includes relationships, trust, and networks.

Mumaw et al. (2019) developed a model of community capacity building for assessing urban biodiversity conservation with similar components to Bennett et al. (2018) stewardship framework, with human capital, social capital, natural capital, economic capital, and increased conservation actions.

Stewardship capacity affects stewardship outcomes. Community-based natural resource management effectiveness has been predicted by group capacity (Mountjoy et al. 2013). When validating a conceptual model of community capacity as it relates to biodiversity conservation outcomes, interviews with environmental non-profit practitioners included mentions of social and human capital by almost all respondents, as compared to other forms of capital (natural, institutional, and produced economic) (Moore et al., (2006)). This theme of human and social capital serving as key components of stewardship capacity is identified repeatedly in other studies. For example, key factors in group-level capacity for community-based natural resource management include motivation, leadership, respect, mutual interest or shared values, outreach and education, marketing, communication, planning, all human and social capitals, along with funding, equipment, and supplies (Mountjoy et al. 2014). Organizational actors in stewardship groups in Ontario identified a set of factors contributing to success, including financial capacity, motivation, actors, organizational reputation, actions, priorities, routine, communication, and having longer timeframes (Kapeller et al. 2022). They note that their methodology did not specifically elicit social and human capital, but that these themes emerged from the data. Networks and partnership arrangements, both measures of social capital, can extend capacity from within groups to between groups, helping "friends of" groups with human and financial capital (Dhakal 2011). Examining stewardship networks and the cumulative associated actions of multiple, intersecting actors on the landscape can reveal the patterns and processes that contribute to social-ecological resilience.

Social Networks

Social network research does not always overlap conceptually with social capital, but the need to combine these research threads is well recognized (Moody and Paxton 2009). Networks can affect individual, group, and system-wide outcomes of organizations' efforts (see Floress et al. 2011). Of key importance to this paper, community capacity is strongly influenced by pre-existing socio-spatial networks of community-based organizations at the neighborhood level (Graham et al. 2016). This neighborhood-level measure of connectedness contributes to differences in outcomes, as communities can influence decision-making through these socio-spatial networks. Outcomes of social networks can lead to higher collective efficacy (Sampson 2012). Social network analysis can be applied to advance our understanding of urban environmental governance structure and function in many ways. It has often been incorporated into stakeholder analysis, to understand the power dynamics and influence of network connections (Prell (2006), Levesque et al. 2017) and applied to examine institutional fit (Epstein et al. 2015, Ulibarri et al., (2021)). Additionally, social network analysis can be used to analyze the contributions of different actors with differing and intersectional goals (Jasny and Fisher 2022, Fisher et al. 2019). In a qualitative examination of network position, Campbell et al. (2022) found the number of group connections affected actions: groups with fewer network connections focus on building friendships and social ties, while moderately connected groups develop programs and brokers advance planning and visioning.

Perceived Outcomes

Efforts to measure capacity raise the critical question of *capacity for what?* With environmental stewards, empirical measures of the effectiveness and effects of actions are not always available. Often stewardship groups collect data themselves, but not all groups do. Also, these data may not be sufficient to understand complex system effects. To overcome this problem, the use of perceived outcomes has been proposed in the conservation field as a way of examining ecological outcomes, social impacts, legitimacy of conservation, and acceptability of conservation management (Bennett 2016). Perceptions by experts or those with traditional ecological knowledge or local knowledge are likely able to more accurately assess changes in the system (Berkes et al. 2000). When evaluating perceptions against other methods of measuring ecological outcomes like remote sensing and field data collection, Baird et al. (2021) found at an overall site assessment level, community scientists and stakeholder perceptions provided a relatively accurate assessment. At finer scales, they suggested a field expert and multiple methods of data collection are needed.

Index Evaluation

Indices are composite measures of multiple indicators for a particular phenomenon. Indicators can be combined via simple additive or summative means, or individual variables can be weighted based upon existing knowledge about influence or stakeholder preferences (Sheppard and Meitner 2005, Strager and Rosenberger 2006). For reliable interpretation, index creation needs index validation. Bakkensen et al. (2017) highlight that indices should clarify what the index explains and should use explicit testing to identify index performance. Such tools give decision-makers

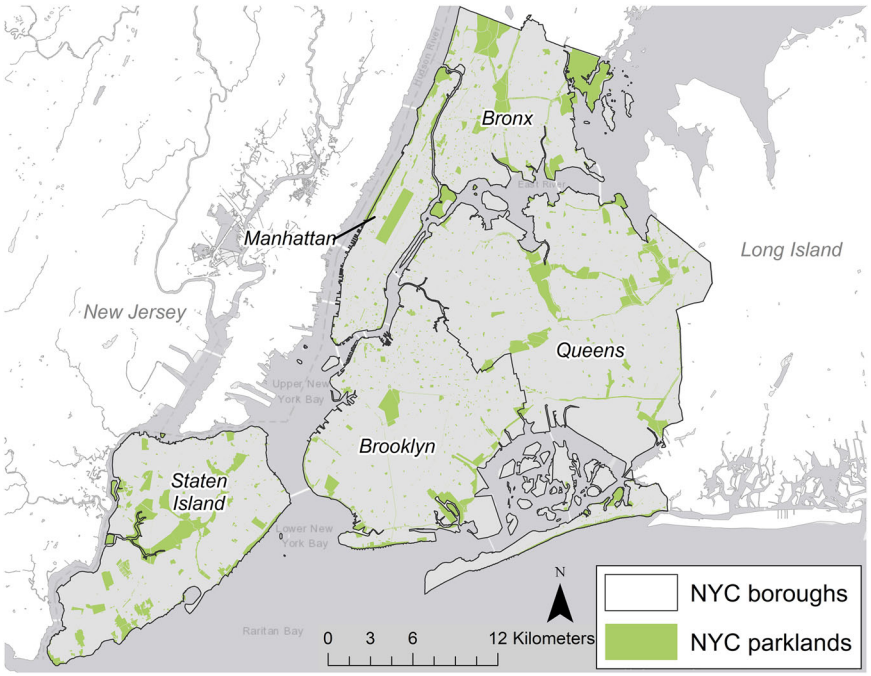

Fig. 1 New York City study area, showing boroughs and parklands

information about which index to choose for which decision. The Organisation for Economic Co-operation and Development (OECD) offers guidance when developing composite indices for decision-making that suggest a need for a theoretical framework; care with data selection; imputation of missing data, if necessary; multivariate analysis; normalization; weighting and aggregation; robustness and sensitivity; transparency; comparison to other variables; and evaluation of presentation and visualization (Organisation for Economic Co-operation and Development OECD (2008)).

Methods

Study Area

We focused this stewardship capacity analysis on New York City, New York, USA (Fig. 1). New York City (NYC) is a large city of 8.3 million people comprising five boroughs, 59 community districts, and 195 neighborhoods (U.S. Census Bureau 2022, New York City Open Data (2023a); New York City Open Data (2023b)). Civic environmental stewards have contributed to the care of the city over time, such as during the 1970s and 1980s, when the city had reduced municipal resources and lost population, during disturbance events, and onto the present day (Connolly et al. 2014, Landau et al. 2021). Because the environmental stewards are known to play a critical role in the care of NYC at multiple scales from a single parcel to the entire city (see Landau et al. 2021), NYC is an important study area for developing a geographic stewardship capacity index.

STEW-MAP Data

We launched the NYC STEW-MAP questionnaire in May 2017 and it remained open for 8 months (see Landau et al. 2019 for detailed methods). The questionnaire was sent to 3254 civic groups within NYC, identified from multiple mailing lists until saturation (Landau et al. 2019) using the survey software Maptionnaire. We made the questionnaire available in multiple languages: English, Spanish, Haitian Creole, Korean, Russian, and Mandarin Chinese. We sent three reminder emails at 4- to 8-week intervals to groups that had not previously responded. Our second reminder email introduced an incentive of a $500 gift card through a drawing of all respondent groups. Items on the STEW-MAP questionnaire include organizational characteristics, a description or map of where a group works, and a list of other groups with which a group collaborates, goes to for information, or receives funding. Organizational characteristics include personnel, budget, mission, stewardship site types, time spent on stewardship, and types of stewardship (see questionnaire in SI1). All responses were associated with a mapped area of where a particular group works, referred to herein as a turf.

The response rate was 11% for groups within New York City. We assessed survey responses for spatial representativeness by comparing the spatial distribution of office locations or contact addresses for respondents and non-respondents using the cross L function (a variation of

Table 1 Mean, standard deviation (s.d.), and range of variables included in stewardship capacity index and perceived outcomes, collected in the STEW-MAP dataset and presented at the neighborhood level

Variable	Description	mean	s.d.	range
STEW-MAP dataset—capacity measures				
Number of groups	# of groups with activity areas (i.e., working) within the area	72.48	11.03	58 - 131
Number of staff	Average number of staff of STEW-MAP groups working within the area	14.73	5.39	6.72–28.4
Number of volunteers	Average number of volunteers of STEW-MAP groups working within the area	452.57	66.89	300.36–1031.76
Number of members	Average number of members of STEW-MAP groups working within the area	3008.01	460.37	429.08–4474.83
Number of connections	Average number of collaborative ties between groups working within the area	12.72	0.97	8.5–15.58
Betweenness	An average across groups in a neighborhood of the number of shortest distance paths each group is central to in the larger stewardship network. Higher numbers indicate more collective betweenness centrality of the set of groups in a neighborhood.	2627	359.21	1531–3525
Stewardship types	Average number of stewardship types for groups working within the area	3.64	0.10	3.38–4
Time spent on stewardship	1 = 0–19%, 2 = 20–39%, 3 = 40–59%, 4 = 60–79%, 5 = 80–100% of time spent on stewardship (average value for neighborhood)	3.06	0.13	2.77–3.36
STEW-MAP dataset—perceived outcomes measures				
Community participation	1-7 Likert scale (1 = strongly disagree, 7 = strongly agree) (average value for neighborhood)	4.47	0.15	4.09–4.85
Trust between neighbors	1-7 Likert scale (average value for neighborhood)	3.11	0.12	2.85–3.49
Influence on public policy	1-7 Likert scale (average value for neighborhood)	3.81	0.15	3.45–4.14
Plant and habitat quality	1-7 Likert scale (average value for neighborhood)	3.56	0.16	2.84–3.96
Air and water quality	1-7 Likert scale (average value for neighborhood)	3.31	0.15	2.94–3.66
Land protection	1-7 Likert scale (average value for neighborhood)	2.90	0.17	2.42–3.31
Urban sustainability	1-7 Likert scale (average value for neighborhood)	3.43	0.18	2.95–3.77
Other datasets				
Population	Number of people in neighborhood (New York City Open Data (2023b), summarizing 2020 U.S. Census data)	43,301	22,817	0–132,455
Neighborhood area	Neighborhood area in square kilometers	4.02	4.15	0.52–30.45

bivariate Ripley's K). We selected office locations as the variable for analyzing spatial representativeness because a group's area of activity was only available for groups that responded to the STEW-MAP survey. We applied the cross L function using the spatstat package in R 4.4.1 (Baddeley and Turner 2005, R Core Team 2024). This method identifies whether the two-point patterns are spatially clustered together, are dispersed with respect to each other, or have no statistically significant spatial relationship.

Capacity Index Creation and Evaluation

To apply stewardship capacity as a construct, we developed an organizational stewardship capacity index. We selected a set of variables from the STEW-MAP survey dataset. We included variables that measure human and social capital resources (Table 1, see Landau et al. 2019 for group-level summaries). The survey question about budget was not answered by a large number of groups (22%), so we excluded budget from the list of capacity variables considered. Our set of variables maps onto Bennett et al. (2018) conceptualization of stewardship capacity, through social capital (network measures, including number of connections, betweenness centrality) and human capital (staff, members, organizations). Betweenness is a network measure of the centrality of a group to the whole network, calculated by measuring how often a node occurs on all shortest paths between two nodes within a larger network (Freeman 1977).

At the neighborhood level, we aggregated results from survey responses, for each of these variables, along with measures of perceived outcomes (Table 1). Measures of perceived outcomes were derived from Likert scale measures from the STEW-MAP survey, in response to questions

that described "Our group has improved the following outcomes in the community(ies) in which we work:", with 1 being strongly agree and 7 being strongly disagree. Respondents to the STEW-MAP survey engaged in a variety of stewardship activities, as such, survey respondents were provided with a breadth of social and ecological categories of outcomes to assess (Table 1).

To aggregate stewardship groups' responses within each NYC neighborhood, we first summarized each survey variable associated with individual stewardship group turf polygons to all neighborhood tabulation areas (New York City Open Data (2023b)) in NYC, using spatial joins in ArcGIS Pro (ESRI 2020). Neighborhood tabulation areas are NYC government's approximation of neighborhoods and align with Census boundaries; hereafter, we refer to these areas as neighborhoods. We elected to sum *Number of groups* values and average values for all other capacity and outcome variables from all stewardship groups' turfs overlapping with each neighborhood polygon (ESRI 2020). To identify which variables to retain in the index, we developed a series of ordinary least square regressions, to examine each capacity variable against the perceived outcomes variables, as well as a cumulative outcome variable. Aside from the count of *Number of groups* per neighborhood, we selected average values of each capacity variable per neighborhood rather than summed values, to reduce multicollinearity with count of groups. Capacity variables significantly related to the cumulative outcome measure were retained and combined into a single stewardship capacity index score for each neighborhood. To create the capacity index, we first standardized each retained variable as a z-score and then created an average of all the z-scores for retained variables, to create the index.

Results

Spatial Distribution of Respondents

We examined the representativeness of the spatial distribution of respondent office locations as compared to nonrespondent office locations for NYC by running 10,000 simulations of the L cross-function. We observed no statistical difference in the spatial distribution of respondent addresses as compared to nonrespondent addresses (SI2).

Capacity and Perceived Outcomes

Each capacity variable was associated with social and environmental outcomes in different ways (Table 2a, b). *Number of groups* was positively associated with all outcomes. Network measures (*Number of connections, Betweenness*) were significant for social outcomes but not environmental outcomes. *Stewardship types* and *Time spent on stewardship* were significant for environmental outcomes, but not social outcomes.

For environmental outcomes, more groups (*Number of groups*), higher values of *Stewardship types* (e.g., conservation, management, monitoring, advocacy, education, and transformation), and higher values of *Time spent on stewardship* were associated with higher perceived outcomes. Some capacity variables were only associated with certain environmental outcomes. -> For example, higher *Number of volunteers* was associated with lower *Land protection* and *Urban sustainability* outcomes and higher *Air and water quality outcomes*, while higher *Number of members* was associated with all environmental outcomes except *Plant and habitat quality. Number of staff, Number of connections, and Betweenness* had no observed association with any environmental outcome.

For social outcomes, neighborhoods with more groups (higher *Number of groups*), and more connections (higher *Number of connections*) self-assessed their group as contributing to all social outcomes: *Community participation*, *Trust between neighbors,* and *Influence on public policy* (Table 2b). *Number of staff* was negatively associated with *Community participation* and *Influence on public policy*; *Betweenness* was negatively associated with *Trust between neighbors* and *Influence on public policy* outcomes. *Stewardship types* were positively associated with *Influence on public policy*. The capacity variables not affecting any social outcomes were *Number of volunteers* and *Time spent on stewardship*.

When examining a combined variable of all social and ecological outcomes (*Cumulative outcomes*), *Number of staff* was the only capacity variable not associated with the *Cumulative outcomes* variable. *Population* was also not associated with *Cumulative outcomes*.

Stewardship Capacity Index for New York City

The constructed capacity index included the following variables for stewardship groups at the neighborhood scale: *Number of groups*, *Number of members*, *Number of volunteers (*negative*)*, *Number of connections*, *Betweenness (*negative*)*, *Stewardship types*, and *Time spent on stewardship*, as these stewardship groups variables were significantly related to the cumulative outcomes variable in regressions (Table 2b, Fig. 2). *Neighborhood area*, while significant, was not included as it was a control variable. We elected to create an unweighted capacity index by averaging z-scores calculated for all retained variables, although some variables (*Number of groups*, *Stewardship types*, *Time spent on stewardship*) were more strongly related to outcomes than others. Spatial variation exists among the input layers, affecting the patterns of the overall

Table 2 a. Multiple linear regressions of individual capacity variables as associated with perceived environmental outcomes (summed across groups in neighborhood), with beta coefficients (β), confidence intervals (CI), and p-values (p); b. Multiple linear regressions of individual capacity variables as associated with perceived social and combined outcomes (summed across groups in neighborhood), with beta coefficients (β), confidence intervals (CI), and p-values (p)

a

	Plant and habitat quality			Air and water quality			Land protection			Urban sustainability		
Predictors	*β*	*CI*	*p**	*β*	*CI*	*p**	*β*	*CI*	*p**	*β*	*CI*	*p**
(Intercept)	−172.64	−233.19–−112.09	**<0.001**	−218.18	−263.73–−172.64	**<0.001**	−211.18	−271.35–−151.01	**<0.001**	−107.73	−171.61 to −43.84	**0.001**
Number of groups	3.02	2.78–3.26	**<0.001**	2.98	2.80–3.16	**<0.001**	2.47	2.23–2.71	**<0.001**	2.29	2.03–2.54	**<0.001**
Number of volunteers	−0.00	−0.03 to 0.02	0.840	0.03	0.01–0.05	**0.012**	−0.04	−0.07 to −0.01	**0.003**	−0.05	−0.08 to −0.02	**0.001**
Number of members	0.00	−0.00–0.01	0.302	0.00	0.00–0.01	**0.025**	0.01	0.00–0.01	**0.001**	0.01	0.00–0.01	**0.021**
Number of staff	−0.36	−0.75–0.02	0.065	0.27	−0.02–0.57	0.066	0.27	−0.12 to 0.65	0.171	0.27	−0.14 to 0.68	0.190
Number of connections	0.10	−3.00–3.19	0.951	2.04	−0.29–4.37	0.086	0.79	−2.29–3.87	0.613	0.46	−2.81 to 3.72	0.783
Betweenness	−0.00	−0.01–0.01	0.779	−0.00	−0.01–0.01	0.751	−0.00	−0.01 to 0.01	0.381	−0.01	−0.02 to 0.00	0.094
Time spent on stewardship	35.15	18.35–51.95	**<0.001**	19.62	6.99–32.26	**0.003**	38.24	21.54–54.93	**<0.001**	25.01	7.29–42.74	**0.006**
Stewardship types	27.46	9.00–45.92	**0.004**	36.66	22.78–50.55	**<0.001**	32.13	13.78–50.47	**0.001**	35.16	15.68–54.64	**<0.001**
Population	0.00	0.00–0.00	**0.046**	−0.00	−0.00 to 0.00	0.081	−0.00	−0.00 to −0.00	**0.009**	0.00	−0.00 to 0.00	0.170
Neighborhood area	0.36	−0.08–0.80	0.104	−0.36	−0.69 to −0.04	**0.030**	0.87	0.43–1.30	**<0.001**	−0.09	−0.55 to 0.37	0.706
Observations	195			195			195			195		
R^2/R^2 adjusted	0.932/0.928			0.954/0.952			0.915/0.910			0.893/0.887		

b

	Community participation			Trust between neighbors			Influence on public policy			Cumulative outcomes		
Predictors	*β*	*CI*	*p**	*β*	*CI*	*p**	*β*	*CI*	*p**	*β*	*CI*	*p**
(Intercept)	−107.95	−167.01 to −48.90	<0.001	−79.92	−133.75 to −26.09	0.004	−60.55	−114.35 to −6.76	0.028	−958.16	−1216.57 to −699.75	<0.001
Number of groups	4.46	4.22–4.70	<0.001	3.28	3.07–3.50	<0.001	3.19	2.97–3.41	<0.001	21.70	20.66–22.73	<0.001
Number of volunteers	−0.02	−0.05–0.01	0.146	−0.02	−0.04–0.01	0.136	−0.02	−0.05–0.00	0.077	−0.13	−0.24 to −0.01	0.032
Number of members	0.01	0.01–0.01	<0.001	0.00	−0.00–0.01	0.078	0.01	0.00–0.01	0.011	0.04	0.02–0.06	<0.001
Number of staff	−0.48	−0.86 to −0.10	0.014	−0.05	−0.39 to 0.30	0.790	−0.51	−0.86 to −0.17	0.004	−0.59	−2.24 to 1.07	0.484
Number of connections	4.50	1.48–7.52	0.004	4.06	1.30–6.81	0.004	4.10	1.34–6.85	0.004	16.04	2.81–29.26	0.018
Betweenness	−0.01	−0.02–0.00	0.167	−0.01	−0.02–−0.00	0.022	−0.01	−0.02 to −0.00	0.004	−0.04	−0.08 to −0.00	0.032
Time spent on stewardship	2.54	−13.85–18.92	0.760	6.71	−8.22–21.65	0.376	−8.82	−23.75 to 6.10	0.245	118.45	46.76–190.15	0.001
Stewardship types	12.17	−5.84–30.18	0.184	4.99	−11.42–21.40	0.549	31.05	14.65–47.45	<0.001	179.62	100.83–258.41	<0.001
Population	−0.00	−0.00 to −0.00	0.022	−0.00	−0.00–0.00	0.520	−0.00	−0.00 to −0.00	0.004	−0.00	−0.00–0.00	0.169
Neighborhood area	0.96	0.53–1.38	<0.001	0.24	−0.15–0.63	0.222	0.72	0.33–1.10	<0.001	2.69	0.83–4.55	0.005
Observations	195			195			195			195		
R^2/R^2 adjusted	0.964/0.962			0.949/0.947			0.948/0.946			0.974/0.972		

*$p < 0.05$, $p < 0.01$, $p < 0.001$

*$p < 0.05$, $p < 0.01$, $p < 0.001$

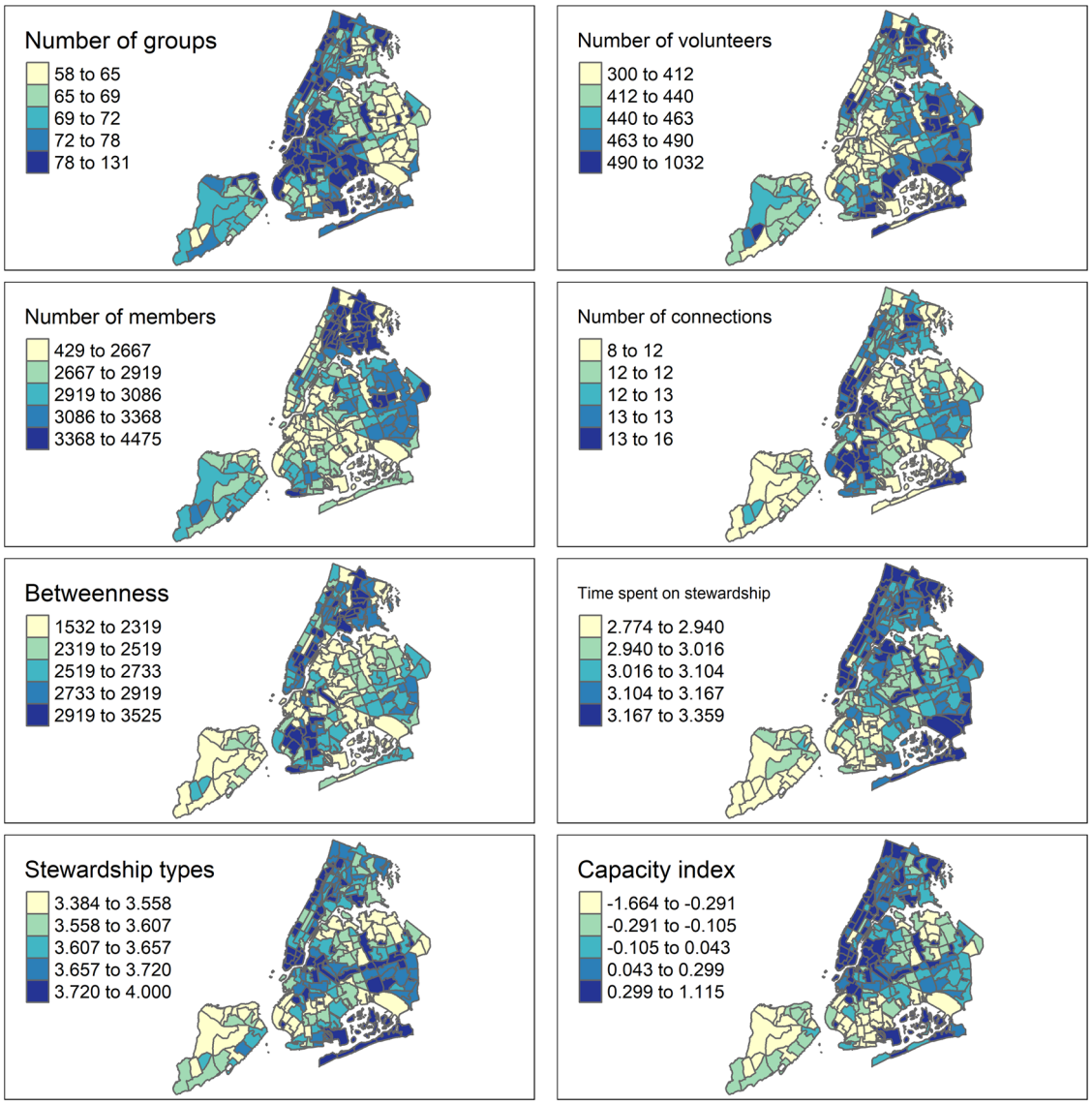

Fig. 2 Stewardship capacity variables and final capacity index mapped at neighborhood scale

capacity index. Overall, neighborhoods with the highest stewardship capacity are in the Bronx, Manhattan, western Queens, northern Brooklyn, and parts of the

Rockaways (barrier islands that are the southernmost part of Queens). Southern Brooklyn, parts of Eastern Queens, and western Staten Island neighborhoods, with less amount of *Time spent on stewardship* and fewer *Stewardship types* are the areas with lowest stewardship capacity.

Discussion

Here, we present an empirically derived index of stewardship capacity at the neighborhood scale that can be applied to practitioner decision-making for natural resources and environmental management in cities. Our work builds on existing community capacity and stewardship frameworks by advancing measures of environmental stewardship capacity. With this stewardship capacity index, we operationalize and spatialize human and social capital as conceptualized for environmental stewardship in Bennett et al. (2018), and in alignment with Chaskin's (2001) conceptual model of community capacity. With *Number of groups* and *Number of members* variables, we consider local community assets. The *Number of connections* and *Betweenness* variables examine local community assets within the broader environmental governance network, including local and state government agencies.

By first examining relationships between potential stewardship capacity variables and perceived outcomes, we were able to measure individual relationships. Our analyses showed *Number of groups*, stewardship network measures

(*Number of connections, Betweenness*), *Stewardship types*, and *Time spent on stewardship* were related to higher outcomes, but *Number of staff* had no relationship, and *Number of volunteers* had a negative relationship. These last two results were surprising, as *Number of staff* is a common measure of capacity (Bennett et al. 2018, Fisher et al. 2012), and we would expect a higher *Number of volunteers* to create higher capacity for outcomes. Notably, it was only with the environmental outcomes where a *Number of volunteers* relationship was identified. There may be a perceived sense held by group leaders that trained staff are better able to support management and policy actions, or it may be that fewer, trained volunteers rather than large numbers of volunteers are perceived as better able to create desired changes. This dynamic has been demonstrated for civic science projects, where scientists do not view volunteers' data as having the same quality as data collected by scientists (Kosmala et al. 2016). This does not negate the role of volunteers in science but rather identifies that their outputs and contributions may be different – for example, large amounts of volunteers may be most valuable for events like plantings, while smaller, focused groups of volunteers may be better able to do policy and advocacy work or skilled restoration activities. Additionally, we had expected that groups that are more central to the larger stewardship network (*Betweenness*) would report higher outcomes, but instead, the more local organizations lacking broader network ties reported higher outcomes. We speculate this may be because of how the scale of the connections (e.g., local versus citywide) affects outcomes, not just how connected groups are within the broader stewardship network.

The role of networks (*Number of connections*) was positively associated with perceived outcomes for all social variables, reinforcing the known importance of networks to achieve policy outcomes (Howlett 2002), build trust (Brass et al. 2004), and increase participation (Fisher et al. 2016). We were surprised to not see network measures be associated with environmental outcomes, as they have been elsewhere (Ruseva et al. 2016). Examining these relationships at finer scales instead of in aggregate may tease apart whether and where networks may matter for achieving environmental outcomes.

Through this process, we also identify new stewardship capacity variables central to *Cumulative outcomes*. By examining perceived outcomes against capacity variables specific to stewardship, we also identify group measures of *Time spent on stewardship* and *Stewardship types* as other key measures of stewardship capacity, with strong effect sizes relative to other variables. The influence of the measure *Time spent on stewardship* is intuitively understandable, as more time spent on stewardship would be expected to yield more results. However, interpreting the influence of the measure *Stewardship types* requires more unpacking. Our results identify that neighborhoods with higher *Stewardship types* values are more likely to have higher *Cumulative outcomes* than neighborhoods with groups with lower *Stewardship types* values. In these later cases, neighborhood stewardship groups are more specialized on particular stewardship actions like only advocacy or only management and conservation. The positive association between *Cumulative outcomes* and *Stewardship types* shows that more types of stewardship actions are important for groups' perceptions of outcome achievement. These two associations highlight that when considering stewardship capacity, it is not only important to look at organizational structure, but also at practices held by groups and the ways in which groups are enacting these practices. Inclusion of these measures, *Stewardship types*, and *Time spent on stewardship* enables a further refinement of measuring the variation and extent of capacity among neighborhoods in a city. Many of these variables, including network variables, are not included in existing indices on social capital or civic capacity (e.g., Rupasingha, Goetz, and Freshwater 2006, Kim et al. 2006, Kyne and Aldrich 2020, Chetty et al. 2022), likely due to a lack of consistent data availability. From our analysis, we are able to move beyond number of groups as a metric of stewardship capacity, enable neighborhood-level comparison of variation, and present the index in a transparent fashion. This also fills an identified need for additional empirical research on capacity and social outcomes (Nordin et al., (2024)). Below, we highlight four important considerations from these results.

Capacity Measures Vary by Outcome

We find that beyond number of groups, capacity-outcome relationships can be specific to a given outcome, similar to previous studies on collaboration's effects on outcomes (Ulibarri et al., (2021)) and Beckley's model of community capacity (Beckley et al. 2008). Capacity variables associated with higher perceived social outcomes are not always synonymous with those that lead to higher environmental outcomes. Perceived social outcomes emphasize network connections (*Number of connections, Betweenness*), but *Number of staff*, *Number of members*, and *Stewardship types* are only related to one or two of the individual social outcomes (e.g., *Stewardship types* and *Influence on public policy*). Perceived ecological outcomes are all associated with *Time spent on stewardship* and *Stewardship types*. We found less consistent relationships between individual ecological outcomes and measures of human capital (*Number of staff, Number of volunteers, Number of members*) and social capital (*Number of connections, Betweenness*).

Funding organizations and public agencies can consider these capacity dimensions in their stewardship capacity-building efforts and also as a complement to existing metrics for measuring performance (Lee and Nowell 2015, Stefanovic 2018).

Capacity Varies among Neighborhoods

Our stewardship capacity index provides information beyond a simple count of groups, continuing to highlight that capacity for caring for the urban environment is uneven across neighborhoods and community districts in NYC (Johnson et al. 2019). In addition, our index reveals that distinct aspects of capacity can be strengths in some neighborhoods and limiting factors in others. Our index allows for comparison of stewardship capacity in neighborhoods with different combinations of capacity variables, such as higher *Number of groups* with a lower *Stewardship types* value or lower *Number of groups* with a higher *Stewardship types* value. For organizations that guide and support civic groups in their stewardship work, this unevenness in capacity is an important equity consideration when working with existing groups and volunteers and when considering where to invest in capacity building. Government agencies, foundations, and non-profit organizations that provide critical funding to the civic sector can apply such data in decision-making to both fund groups with capacity to implement complex projects and engage in capacity building where needed to co-create just nature-based solutions in cities.

Synthesis and Transparency Support Decision-making

Our limited variable indices of capacity provide clear and transparent decision-making tools, critical components of applied indices (Organisation for Economic Co-operation and Development OECD (2008)). Rather than providing complex survey results, which were mentioned by practitioners as a barrier to applying the survey results to their work (Wagner et al. 2022), the index simplifies the STEWMAP dataset in NYC to one metric for practitioner use. With this distillation to a single index layer, visualizing stewardship capacity alongside social-ecological conditions (e.g., neighborhood demographics, urban tree canopy, urban heat island, flood risk) and changes is possible. At the same time, the presentation and evaluation of individual variables at multiple scales allows a user to see all variables and their contributions to the final index. Making such data public and interactive can broaden who can contribute to capacity-building solutions in the city, which has the potential to increase equity in how, where, and by whom nature-based solutions are reached.

Capacity Indices Simplify But also Omit Parts of the System

The simplicity and interpretability of an index potentially come at the cost of the omission of components that may indicate key aspects of capacity. As our data are survey-based, they rely on answers groups want to provide Since many environmental groups declined to the answer the question about their annual budget, we were unable to include budget as a variable in the index. Budget is a common measure of capacity (Kaplan 2001), but without the ability to include it, our index relies on labor measures (*Number of members* and *Number of volunteers*) to capture groups' internal capacity. Our index focuses on the group and network levels of capacity for a community, yet individuals that comprise these groups also have varying levels of capacity and interest—in leadership, in networked connections, and in available time and energy (Raetze et al. 2021). This index broadly points to structural differences in capacity but does not include processes and other factors enabling capacity. We also know power dynamics affect capacity, by challenging or reinforcing polycentric governance systems (Morrison et al. 2019), and that groups are often involved in more than one activity or goal (Lubell 2013), which can affect capacity for a specific action at a specific time. Future research focused on measuring stewardship capacity should also consider other key factors that enable groups to succeed in their stewardship missions (Thomas and Romolini 2023), including motivation, communication, political will, strategic planning and monitoring, and group reputation (Kapeller et al. 2022).

Our efforts here are beginning to move beyond a simple count of groups to measure stewardship capacity, which often occurs due to limited data on both capacity and outcomes. Our analyses here have relied upon perceived outcomes, in part because the large breadth of outcomes assessed makes it challenging to conduct fine-scaled assessments for each outcome. As Baird et al. (2021) point out, such approaches work for broad analyses of environmental outcomes, but empirical field data are needed for fine-scale assessments. Further examination of capacity-outcome relationships could focus on more specific outcomes with empirical data in order to understand more mechanistic relationships between capacity and outcomes. While we have derived an index for New York City stewardship capacity, validation elsewhere would be needed to ensure the index's generalizability. A potential option for validation in the future is to first apply this index in another location and then compare to perceived outcome measures, or if available, other empirical outcome measures.

At present, decision-makers seeking to allocate funds to support and build community capacity often lack data and a systematic understanding of community capacity at a

regional scale. Instead, they must rely on preexisting relationships with civic organizations in an area, as well as their own perceived understanding of how much and where capacity is needed. Such shortcuts can result in further supporting known groups at the expense of building new groups and networks, including a tendency toward funding larger, mainstream organizations over grassroots groups (Taylor and Blondell 2023). Currently, a plethora of tools, maps, and indices exist that can support decision-makers, funders, and residents to better understand the spatial pattern of environmental amenities (Plitt et al. 2022). At the same time, existing tools that are available to understand the spatial pattern of civic capacity and help to address stewardship challenges rely on simple count of civic groups, which does not build on existing knowledge about organizational capacity. Capacity indices like this stewardship capacity index allow for comparison of capacity against existing urban social-environmental conditions, to understand where more stewardship capacity is needed—and what elements of capacity those are. For example, this organizational information could pinpoint whether other types of stewardship actions, a larger number of staff members or volunteers, or more stewardship groups are needed. By including capacity data in decision-making, government actors, broker organizations, and funders can more systematically consider what activities to support and direct resources in a systematic way to ensure just solutions.

Conclusion

By furthering an empirical measure of stewardship capacity that builds on existing community capacity and stewardship frameworks, we operationalize an index of stewardship capacity that is grounded in more information than just the number of groups working in an area, a common proxy for civic capacity. Capacity-outcome relationship results highlight that it is not enough to understand the presence of groups but also how they work—their membership size, their networks, their time on task, and the types of work they do. Neighborhoods, where more environmental groups exist, with a larger number of local connections, where more time is spent on stewardship, and where all types of stewardship actions are covered, have better cumulative outcomes. Our results highlight the known role of networks in community capacity and reveal the additional roles of time spent on stewardship and diversity of stewardship actions in achieving stewardship outcomes. We include these additional variables as part of a spatialized stewardship capacity index for application to planning and decision-making. Since the developed index is transparent about all variables included, it supports application by managers and civic groups alike. Stewardship capacity is part of a collective action infrastructure that can facilitate local collective action across issue areas (Chriswell and Huberts 2023). The presented work, focused on understanding and visualizing variability in the existing capacity of stewardship groups and its drivers among neighborhoods, can enable more sustainable actions by environmental managers and stewards in cities.

Data Availability

Original stewardship data used to create these analyses are available for download here: https://www.fs.usda.gov/research/products/dataandtools/datasets/stewardship-mapping-project-new-york-city-data-downloads Neighborhood boundary data are available at NYC Open Data here: https://data.cityofnewyork.us/City-Government/2020-Neighborhood-Tabulation-Areas-NTAs-Mapped/4hft-v355 Derived datasets used to create Table 1, 2a, b and Fig. 2 can be made available upon request. Figure 1 was created using datasets available at NYC Open Data: https://opendata.cityofnewyork.us/.

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Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

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