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Structuring institutional analysis for urban ecosystems: A key to sustainable urban forest management

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Abstract A decline in urban forest structure and function in the United States jeopardizes the current focus on developing sustainable cities. A number of social dilemmas—for example, free-rider problems—restrict the sustainable production of ecosystem services and the stock of urban trees from which they flow. However, institutions, or the rules, norms, and strategies that affect human decision-making, resolve many such social dilemmas, and thus, institutional analysis is imperative for understanding urban forest management outcomes. Unfortunately, we find that the definition of institutions varies greatly across and within disciplines, and conceptual frameworks in urban forest management and urban ecosystems research often embed institutions as minor variables. Given the significance of institutional analysis to understanding sustainable *rural* resource management, this paper attempts to bring clarity to defining, conceptually framing, and operationally analyzing institutions in *urban* settings with a specific focus on sustainable urban forest management. We conclude that urban ecologists and urban forest management researchers could benefit from applying a working definition of institutions that uniquely defines rules, norms, and

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strategies, by recognizing the nested nature of operational, collective choice, and constitutional institutions, and by applying the Institutional Analysis and Development framework for analysis of urban social-ecological systems (SESs). Such work promises to spur the desired policy-based research agenda of urban forestry and urban ecology and provide cross-disciplinary fertilization of institutional analysis between rural SESs and urban ecosystems.

Keywords Urban forest management · Urban forest policy · Institutional analysis · Ecosystem services · Public goods · Sustainability

Introduction

More than fifty percent of the world's population now lives in urban areas and that figure is projected to increase to sixty percent by 2025 (Wu 2008). Increasing urban populations rely on urban forests which provide important positive externalities through ecosystem services. These services—public goods—include clean air and water, energy conservation, carbon storage and sequestration, cooler and more regulated air temperatures, wildlife habitat, recreational opportunities, social, physical, and psychological well-being, and economic stimuli (Bolund and Hunhammar 1999; McPherson et al. 1997; McPherson 2006; Nowak and Dwyer 2000; Wolf 2004, 2005). Yet, a decline in urban forest structure and related function in the United States has been noted (Nowak and Walton 2005; Wu 2008; Nowak and Greenfield 2012), elevating the importance of research to understand how the interactions between people, their institutions, and the biophysical environment affect the sustainability of urban natural resources. Such research facilitates the current focus on developing sustainable cities (Grove 2009) and is a key future focus in urbanization and human dimensions of global environmental change (IHDP 2010).

To date there has been extensive work developing tools to evaluate coupled human-environment system dynamics in urban ecosystems. Along with comprehensive ecological assessments of vegetative and faunal populations (the ecology *in* cities approach), these methods have included survey instruments to understand how decision-making by individual landowners, non-governmental organization stakeholders and government actors at different scales affect ecological dynamics in urban environments (the ecology *of* cities approach) (Grove 2009). This work has developed particularly robust methods for linking landowner attributes to landscape outcomes on discrete spatial partitions (Pickett et al. 2008), effectively applying analytical approaches from landscape ecology to urban contexts (Wu 2008). Much of this interdisciplinary research has been accomplished by urban ecologists and social scientists; their multi-method approach has been to study urban ecosystems as coupled social-ecological systems (SESs) in which biophysical and social systems, including human institutions, interact.

However, while frameworks for analyzing human institutions have been applied to many predominantly rural SES domains (e.g. fisheries, forests, irrigation networks), there has been less work formalizing institutional dimensions for the study of social-ecological dynamics in urban systems. To be clear, there have been empirical studies of institutions –the rules and norms that influence human decision-making and action (Ostrom 1990) — in urban systems, but a formal structure for institutional analysis has not been developed for urban ecosystem research. While urban ecology's Human Ecosystem Framework includes "institutions" as a social ordering mechanism, among its applications, the use and meaning of the term has been varied. Therefore, given the considerable significance of institutions to sustainable management of community forests (Gibson et al. 2000) which are akin to urban forests

(Nilsson et al. 1999),[1] an exciting opportunity exists for cross-disciplinary fertilization of institutional analysis from rural SESs to urban ecosystems.

More in-depth and structured analysis of institutions in urban SESs promises to help answer why and how individuals are incentivized to conserve or remove urban trees—an imperative question for declining urban forests. While a strong thread of policy analysis exists in urban systems, additional structure is needed for long-term and cross-site analyses to develop the depth of understanding cumulated in rural systems through structured institutional analysis. Herein, we propose a clear definition of "institutions" and a structure for institutional analysis in urban ecosystems through a general institutional framework (Ostrom 1990, 2005). We demonstrate the use of this analytical framework by articulating unique institutional contexts found in urban systems and present approaches for characterizing those institutions and their interactions with urban actors and the resource by considering the management of a specific urban forest type, street trees.

Background on the problem

Urban forests are coupled SESs composed of biophysical components (trees and associated vegetation) and social components, and like other SESs, are complex and adaptive, involving multiple subsystems as well as being embedded in larger systems. SES sustainability is related to both ecological resilience and engineered robustness, the latter being particularly significant for urban forests because they are, in part, engineered by humans (Anderies et al. 2004; Zipperer et al. 1997). A robust SES is able to maintain some desired system characteristic despite changes in the behavior of its components parts, circumstances that contribute to long-enduring or sustainable systems overall (Anderies et al. 2004). Dwyer et al. (2003) argue it is the provision of ecosystem services (public goods) over space and time that constitutes sustainable urban forests.

Sustaining ecosystem services from an urban forest means developing a robust population of trees and associated vegetation across the myriad of subsystems that compose the larger system; street trees, park trees, treed preserves and private parcels constitute some of the subsystems to be managed. Trees are one resource within these sub-systems, and can be considered a stock from which a flow of goods and ecosystem services are obtained (see Lant et al. 2008). Because important ecosystem services are provided via functioning urban forests, and a loss in urban forest structure leads to a loss in function (Nowak et al. 2008), sustainable urban forests are managed for maintenance of structure that does not forfeit long-term or distributional provision of ecosystem services (McPherson 2006). Thus, a number of structural management challenges facing urban forest managers have been empirically explored including maintenance of a sustainable tree population via tree relative age-distribution, native and diverse species distribution, tree condition, as well as aggregate canopy cover at the scale of interest and equitable distribution of canopy cover across spatial scales (Clark et al. 1997).

Because urban forests are human-engineered systems, their structural robustness lies in the collective actions of individuals. Humans at various scales or "subsystems" from

[1] According to Sanesi (query2011: 35), "The term 'Community forestry' (CF) includes all the forest management types that provide both economic and social goals, under the control (or property) of a local community or larger social group. CF management is often set in a larger ecological landscape with other land uses." Urban forests, set in a landscape of variable land use, also include forest management that provides economic and social benefits which are largely controlled by the local community as the majority of the urban forest is privately owned (Clark et al. 1997).

households to city blocks to neighborhoods to governments are part of an urban ecosystem and make decisions that are integral to sustaining it (Grove 2009; Roy Chowdhury et al. 2011). Therefore, urban forest management is polycentric and involves operational-level (or on-the-ground) actors as well as policy-makers that influence urban planning, land use, and development. For instance, city governments are frequently charged with managing "the" urban forest and its canopy cover. While governments may produce a portion of city trees, they rely heavily on tree production from individual private-property parcels which contain the majority of urban trees (Clark et al. 1997).

This scenario may be partly responsible for the noted decline in urban forest structure as few incentives exist for private individuals to produce public goods at levels that are socially optimal. For instance, since there is no effective market for ecosystem services, property owners often manage land and resources for outputs traded in extant markets (e.g., housing development) at the expense of natural capital (e.g., trees) and the flow of functional public benefits (ecosystem services which generally have no market). Related, the incentive for actors to rely on the provision of others without contributing themselves is known as the free-rider problem. If an individual pays to plant or maintain a tree, other individuals benefit as much as the investor without incurring costs. Further, an investor, acting alone, is likely to argue that one individual's efforts may make little to no difference in "the big picture" provision of ecosystem services. However, involving other individuals to avoid this dilemma is costly in terms of transaction time and effort to facilitate collective action for the sustainable provision of services.

For solutions to these social dilemmas, coordinated strategies of action that define how a community provides for, produces, and manages public goods are required involving rules and norms among actors or resource users in a given situation (Ostrom et al. 1994). But for many decades, scholars argued that the appropriate institutions to solve such social dilemmas were property rights alone. More specifically, they argued for privatization (and market solutions) or government command and control, disregarding community management based on the theory that humans are exclusively rational egoists and do not collectively act for the public good as Hardin (1968) defined in the Tragedy of the Commons. But clearly, markets do not always exist where needed—there is no functional market for ecosystem services—and government command and control can fail to incentivize socially beneficial actions, particularly when the target resource setting is as complex and "institutionally thick" as an urban forest (see Hardy and Koontz 2010). Moreover, humans do not always act as rational egoists but are boundedly rational—able to follow norms and rules and learn and adapt to collectively organize institutional arrangements of resource management (Ostrom 2005). From this perspective, institutions "change incentives to enable fallible humans to overcome social dilemmas" (Ostrom 2005: 125). Thus, regardless of tenure regimes, successful institutions in the forms of rules-in-use can help to establish sustainable systems (Moran 2005). Alternatively, misguided institutions can do more harm than good unless there is a coherent understanding of the nature of the resource itself (Ostrom et al. 1994), a real concern in the relatively new field of urban ecology where policy prescriptions abound (Young and Wolf 2006). In either case, institutions appear as a key for integrating social and ecological analyses.

Yet, institutions have received less attention and scrutiny in urban forest management and urban ecosystems research despite recent emphasis on interdisciplinary or integrated research for environmental questions and problems that cut across traditional disciplinary boundaries—arguably the case for urban ecosystem sustainability. Wake (2008) argues that natural and social scientists of the 21st century must address societal needs in new and synthetic ways with integrative attitudes to solve contemporary problems. As in response,

Lowe et al. (2009) track a myriad of recent interdisciplinary efforts pointing to the relatively new and supportive perspective of ecologists that people are a part of nature (and thus, ecology) rather than apart from it. In fact, the "ecology of cities" approach, accepted by many urban ecologists, frames urban ecology in this light. And yet, Grove (2009) argues that we understand very little about the dynamics of urban ecosystem services and human preferences over space and time. In other words, the incentives (based on institutions) that structure human decisions and actions linking community characteristics and biophysical outcomes are not well understood. This failure to cumulate institutional understanding is arguably related to uncommon language among disciplines at work in urban ecosystem sustainability (discussed in the following section). None-the-less, discovering why and how individuals and collective associations of individuals through various social subsystems are incentivized to conserve or remove urban trees is therefore, in part, an *institutional* inquiry—distinct from a more general social inquiry—because institutions are tools that influence the incentives of humans thereby affecting their decisions and actions. They are an important link for integrating social and ecological phenomenon. Moreover, urban environments are prone to rapid change through their emergent properties in response to institutions (Benvie 2005). Thus, to explore the sustainability of urban forests or any urban ecosystem resource, institutions must be well-defined and institutional analysis must to be undertaken to understand the dynamics affecting resource decision-making.

Defining institutions

Failure to cumulate institutional understanding in urban ecosystems, let alone other disciplines, is arguably related to variation in defintions among disciplines. In fact, this is a general problem in interdisciplinary work; Michalos (1997) points to an inability to "get a generally accepted ontology" (222) for the integration of social, economic, and environmental indicators of sustainability. Not surprisingly, competing definitions of "institutions" exist both within and among different academic disciplines even though the idea of institutions dates to Giambattista Vicco's 1725 *Scienza Nuova* (Ostrom 2005; Hodgson 2006). While the term commonly refers to organizations or entities, its academic focus has been governing forces and the majority of these explanations can be placed within two approaches: institutions-as-equilibria and institutions-as-norms/rules.

Scholars that advocate an institutions-as-equilibria study how stability emerges from mutually understood actor preferences as well as optimizing behavior (Menger 1963; Hayek 1945, 1967; Schotter 1981; Riker 1980; and Calvert 1995). Proponents of this approach view stable behavior patterns (equilibrium) as a form of institutions. Calvert (1995) finds "there is, strictly speaking, no separate animal that we can identify as an institution…institution is just a name we give to certain parts of certain kinds of equilibrium" (18). This approach has been critiqued by a number of new institutional economic (NIE) scholars since the definition does not account for the foundations or underpinnings of stable outcomes which tease out different levels of equilibria like "shared advice based on prudence, shared obligations based on normative judgments, and shared commitments based on rules created and enforced by a community" (Crawford and Ostrom 1995, 583).

The institutions-as-norms/rules approach, supported by NIE scholars, argues that behavior patterns are grounded in what a society believes is both correct and improper behavior given a certain stimulus (Lewis 1969; Ullmann-Margalit 1977; Coleman 1988). The study of institutions should not solely be the study of equilibria but go "beyond immediate means-end relationships to analyze the shared beliefs of a group about normative obligations"

(Crawford and Ostrom 1995, 583). This approach stresses that not only norms, but rules such as public policies or laws structure institutions (Hohfeld 1913; Commons 1986; Shepsle 1975, 1979, 1989; Shepsle and Weingast 1984, 1987; Plott 1986; Oakerson and Parks 1988; North 1986, 1990; Ostrom 1986, Ostrom et al. 1994; Ostrom 1980; Williamson 1985; and Knight 1992). Actions outside what a rule proscribes or requires are likely to be discouraged due to sanctions and punishments.

NIE scholars that utilize the Institutional Analysis and Development (IAD) framework originally developed by Kiser and Ostrom (1982) further distinguish between rules, norms, and shared strategies as different kinds of institutions. From this perspective, rules are institutional prescriptions for behavior which require, prohibit, or permit some action or outcome *and* include sanctions (an "or else" statement) if a rule is not abided. Rules can be as formal as law or as informal as common knowledge, so long as the rule also entails an 'or else' clause (Ostrom 2005). The focus is more specifically on "rules-in-use" as rules followed in practice are not always the same as written rules, resulting in variable outcomes. Norms are the values an "individual places on actions or strategies in and of themselves, not as they are connected to immediate consequences" (Ostrom 1990, 35); they are institutional prescriptions for behavior *without* defined sanctions that can be just as important as rules in constraining human behavior due to fear of social censure (Ostrom 1990, 2005). Shared strategies are even less formal as they do not include defined sanctions *or* an operator that "forbids" or "requires" or "permits" an action; instead, strategies are taken by actors based in part on their knowledge of norms and rules.

Institutions in urban ecosystem research

Within their extensive empirical work that considers biophysical qualities and social characteristics of urban communities, urban ecologists have argued that "institutions" are components of urban ecosystems (Grove 2009); yet, given the interdisciplinary nature of urban ecology, a term that truly denotes social-ecological analyses, it is not surprising that some inconsistency exists within the field on how to incorporate this human component into frameworks for urban ecology[2] (McDonnell and Pickett 1993). While urban ecology scholars recognize institutions are related to behavior patterns and that institutions can take both formal and informal forms, they draw largely from the institutions-as-equilibrium approach, and do not always define "rules" or "norms." This points to a difficulty in basing new institutional analysis in urban ecology on existing work, and highlights the rationale for drawing from the extensive institutional research in rural social ecological systems and to build upon those urban studies that have utilized more structured institutional analysis.

A number of frameworks, such as the Human Ecosystem Framework (for an example, see: www.beslter.org/one_pagers/pdf/the_human_ecosystem.pdf), have emerged in urban ecology that link human and natural systems (Boyden 1977; Blood 1994; Pickett et al. 1994; Machlis et al. 1997; Pickett et al. 1997; Grove 2009). These frameworks aim to account for connectivity issues and dynamics that govern social ecological system outcomes. Among them, the prevalence and clarity of "institutions" varies. Those that include

[2] It is important to emphasize here that institutions have been studied in urban areas in general; the urban planning and smart-growth literature emphasize policy solutions, such as zoning and urban growth boundaries, as tools for sustainable development (see Duany et al. 2009). Our point is that in-depth institutional analysis is underutilized and seldom linked to understanding ecological outcomes in research framed as "urban ecosystem" or "urban forest management research," in particular.

institutions frequently embed them as minor exogenous factors. More significantly, variation exists in the definition of institutions. For example, some scholars state that institutions are "rules of the game" and "play a key role in the adjustments or adaption of cities to changing conditions" (Grove 2009, 287; Burch and DeLuca 1984). However, what is meant by "rules" is not clearly stated. Institutions are also commonly described broadly as "dynamic solutions to universal needs, including health, justice, faith, commerce, education, leisure, government, and sustenance" (Grove 2009, 288; Machlis et al. 1997), or inclusive of "kinship, economy, religion, polity, governance, and education" (Beddoe et al. 2009). Such broad definitions, while arguably appropriate for framing scholarship, make institutions difficult to operationally incorporate into empirical analysis.

Without a working definition of institutions, difficulty arises in conducting cumulative and comparative institutional analyses which otherwise have the potential to yield robust policy prescriptions for sustaining trees and related resources in urban ecosystems. This situation may be the reason for the relative scarcity of empirical analysis clearly linking institutional nuances with urban SES outcomes. Yet, surprisingly, Young and Wolf (2006) find urban ecology literature increasingly engaged in policy prescriptions; nearly three quarters of the papers analyzed specified the set of actors best positioned to effect change but without clarity on how institutions were evaluated within the studies.

Examples of empirical institutional research undertaken in urban ecological studies include analysis outside of the United States. In Stockholm, Sweden, urban green areas that are managed by local user groups have been studied to explain what norms and rules support ecological systems within different landscapes and governance regimes (Colding et al. 2006; Barthel et al. 2005; Ernstson et al. 2008). Without explicit analysis of how institutions vary across governance regimes, researchers conclude that "the incorporation of locally managed lands, and their stewards and institutions, into co-management designs holds potential for improving conditions for urban biodiversity […]" (Colding et al. 2006, 237). Researchers in China link institutions with outcomes and have noted that where legal regulations are not enforced or understood by local people, urban forests have been destroyed (Ye 1997 in Li et al. 2005). Similarly, Nagendra and Gopal (2011) infer that the lack of consistent and publicly available tree policies in Bangalore, India may be partly responsible for declining tree diversity within city parks.

Within the U.S., Long Term Ecological Research (LTER) sites situated in Phoenix, Arizona and Baltimore, Maryland, have facilitated a number of studies that link lawn / parcel vegetation management with social variables, legacies, and institutions offering contributions to understanding this previously unexplored component of the urban forest. While these studies have found institutions to be influential factors apart from more general social variables, they stop short of fully exploring them through structured institutional analysis. Larson et al. (2009) have examined lawn management in Phoenix to understand how social and cultural norms and legacies impact urban landscapes. Martin et al. (2003) analyzed how municipal ordinances and home ownership rules shape unique grass-scapes while Jenkins (1994) identified how internalized social censure plays a role in compelling residents to conform to local lawn standards. According to Robbins and Sharp (2003), aesthetic norms and the fear of neighborhood sanctions are among key drivers affecting front yard maintenance. Larsen and Harlan (2006) explore the power of homeowner association (HOA) rules in influencing front yard landscapes in Phoenix and predict their increasing importance as legal prescriptions for landscape management. In Baltimore, building codes that required minimum set-backs from streets and zoning laws that forbade mixed-use development were determined to be important factors that contributed to residential developments of "seas of green grass" (Boone et al. 2009). Access to green areas—an issue of

environmental justice—was impacted by institutional legacies in Baltimore; a neighborhood association that promoted tree planting and a past covenant that reserved properties for white occupancy-only led to racially-biased access to trees within the city (Buckley 2010).

Other researchers, through complimentary work, have argued for in-depth empirical institutional analysis in urban ecosystems. Stewardship mapping and spatial social network analysis in New York, New York is currently characterizing social groups that manage urban forests, with a focus on collective action and social networking (USDA Forest Service 2009). In fact, Tidball et al. (2010) purport that post-9/11 resilience (a concept linked to sustainability) within New York City communities was obtained in part by community civic ecology strategies, and argue that SES resilience should be studied not only in rural communities, but in urban areas which are vital to global sustainability. Research is also being conducted in Chicago, Illinois to connect institutions of urban forest restoration groups to potential biodiversity outcomes utilizing a well developed research program, the International Forestry Resources and Institutions (IFRI) program (see http://www.umich.edu/~ifri/) (Lynne Westphal, personal communication, March 5, 2010). In this case, researchers have made the clear connection between rural and urban institutional analysis and are working to adapt the program's protocols, developed in rural sites, to urban social ecological systems.

Urban forest ecology and management, arguably a sub-discipline of urban ecology, recognizes the importance of institutions in managing urban trees, but bases many widely accepted policy prescriptions on best practices espoused by certification programs such as Arbor Day Foundation's Tree City USA or the enduring "Model of Urban Forest Sustainability" (Clark et al. 1997; Van Wassenaer and Kenney 2010). For example, both define a sustainable urban forest as one governed by a municipal tree care ordinance, a formal institutional arrangement. Clearly, recognition exists that policy is an important tool for sustaining urban forests by adjusting human incentives and actions, but the rich array of institutional types and structures are not well enumerated or studied within the field. Only a handful of empirical works (McPherson 2001; Conway and Urbani 2007; Zhang et al. 2009) consider urban tree care ordinances in detail.

The IAD framework, which we suggest is useful for urban SES institutional analysis, has rarely been applied in urban ecosystem studies although a few exceptions are notable. Benvie (2005) demonstrated that the presence of institutional design principles (see Ostrom 1990) supported successful adaptive management via collective efforts of resource users in a degraded and declining urban water outlet channel, the Las Vegas Wash. Additionally, a recent comparative study of rural and urban collaborative watershed groups utilized the IAD framework and concluded that urbanites took advantage of the institutional nature of urban areas to strengthen and add to top-down local policies protecting the watersheds; while the rural watershed group was equally successful, they utilized more bottom-up institutional approaches, encouraging landowners to engage in voluntary institutional arrangements including conservation easements (Hardy and Koontz 2010). This analysis found that urbanites compared to their rural counterparts incurred higher transaction costs in terms of sharing information, coordinating activities, and coming to agreement on management strategies due to the relatively large number of urban actors and overlapping urban jurisdictions. Such a social dilemma might not otherwise have been empirically uncovered without structured institutional analysis. This previous research lays the ground work upon which we build our case for further use of the IAD framework.

Common institutions influencing urban forest ecosystems

Clearly, urban forestry and urban ecosystem researchers have acknowledged the role of institutions in their field, thus these settings are well suited for more structured institutional

analysis given their biophysical and social complexity and the important role that both formal and informal rules play in land use decisions that have the potential to produce public goods or "bads." Specifically, urban forests are fragmented into a multifaceted matrix of property rights and management strategies subject to a myriad of actors and their associated governance regimes. Within many cities, the majority of private property parcels and their trees are owned and managed by individuals, while some private parcels exist under shared ownership and management, and numerous public property parcels are owned and managed by public entities but often heavily used by the general public. Each of these various governance and use regimes is impacted by diverse and nested institutions given the urban context—a context that Hardy and Koontz (2010) reference as institutionally complex. For instance, municipal zoning laws can influence the area available for urban trees, while these institutions are authorized by state policies. Even federal urban forest management strategies are encouraged through state governments and at local levels through funding from the US Forest Service's State and Private Forestry arm which supports urban and community forestry.

Beyond the complexity of urban property rights, there are numerous, frequently encountered institutions directly related to and impacting urban forest management at the finest scale of management, the private residential parcel (Fig. 1). Municipalities design urban forest conservation codes such as the requirement to obtain a permit to remove trees (even privately-owned ones) above a certain size, the maintenance of a percentage of original canopy cover amidst private

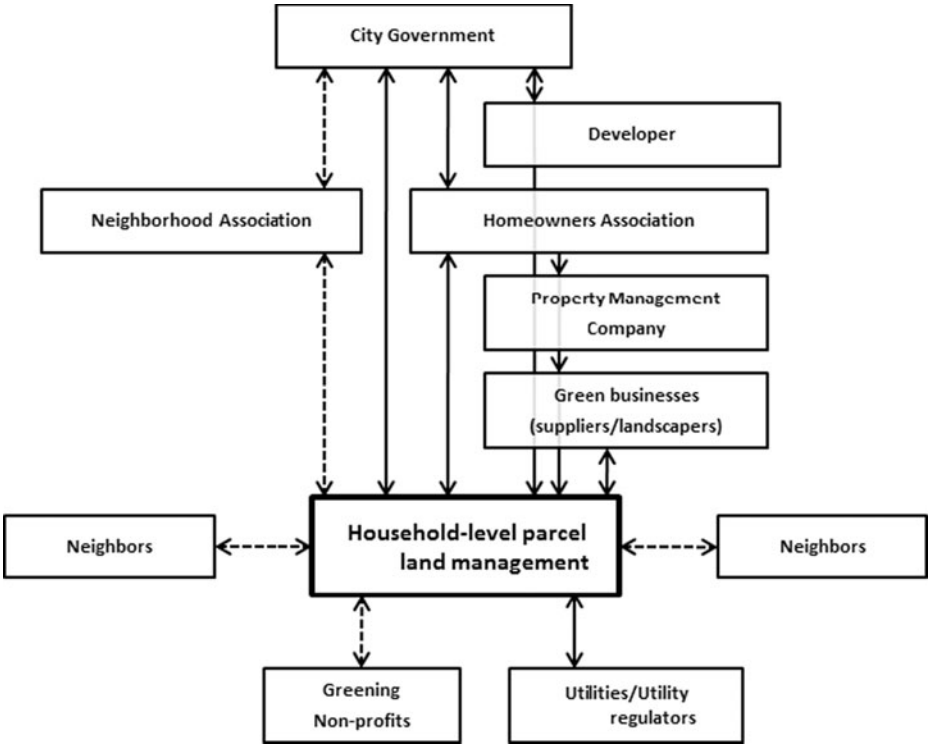

Fig. 1 Common actors and types of institutional arrangements affecting action situations related to urban household land and tree management. Solid lines represent formal institutions or rules while dashed lines represent informal institutions, or norms/strategies. Arrows indicate the primary direction of institutional influence

development, or tree planting requirements within the public right of way adjacent to private parcels. Besides municipal code, cities often enter into agreements with developers during planning stages that establish conservation easements or tree preservation easements, which may then become covenants of the development and can be enforced or forgotten by the city, homeowners associations or neighborhood associations. Thus, the macro-level force of development legacies, as they have been called (Larsen and Harlan 2006), may be altered by subsequent governance forces. For instance, collective residential associations often create their own institutions in terms of by-laws that affect the species that are planted, dead tree removal, or even the acceptable height of vegetation. Moreover, utility easements and their related institutions may overlap with any one of these previously mentioned arrangements. To add even more complexity, informal institutions—norms and strategies—can be quite significant in urban forest management, often incentivizing "popular" landscaping species (also affected by tree nurseries or private industry- landscape contractors) or management strategies—even poor ones, including tree-topping or monoculture plantings. Green non-profits and advocacy organizations may play a role by attempting to influence strategies and norms related to tree management.

Clearly, the nature of the urban forest in terms of governance and institutions is quite complex, facilitating heterogeneous outcomes at the parcel and neighborhood scale across urban landscapes. Unless a community—individual actors, associations, and governments—has established institutions that operate across scales (from parcels to neighborhoods and city-wide) to incentivize sustainable management of urban trees, it may struggle to influence the structure of the urban forest as a whole and its functional provision of ecosystem services. Moreover, unless urban ecosystem researchers have carefully considered institutional forces at play within a research site, their policy prescriptions have the potential to misguide solutions and do more harm than good.

The Institutional Analysis and Development (IAD) framework and lessons from its application

A wealth of institutional analyses that can be adapted to urban ecosystems research have been undertaken largely in *rural* social ecological systems by building upon the IAD framework developed by Kiser and Ostrom (1982). Through this framework, Munger (2010) finds resolution by an exact definition of institutions as rules, norms, and shared strategies that constrain human behavior, each in precise ways (as previously detailed). The importance of institutional analysis in sustaining natural resources is made clear from this perspective: institutions are not minor, embedded components of social systems, but, along with characteristics of the physical world and the community of resource users, are top-tier variables that structure the context in which humans make decisions and act (Ostrom 2005). In fact, from research in numerous *rural* systems, Ostrom (1990) utilized institutional analysis to categorize institutional characteristics, or design principles, associated with long-enduring natural resource management communities that have proven robust across multiple sectors and over time (Cox et al. 2010). In these systems, in-depth institutional analysis has determined how institutions shift individual incentives and actions, directly affecting sustainable outcomes.

This precise perspective of institutions within the context of the IAD framework (Fig. 2) links attributes of the *physical world* (the resource system and resource units), a *community of users*, and the *rules-in-use by that community* as the exogenous variables that incentivize and constrain *actors* in an *action situation*, ultimately leading to *outcomes* (Ostrom 2005). As suggested, an action situation is a setting where two or more individuals are faced with a

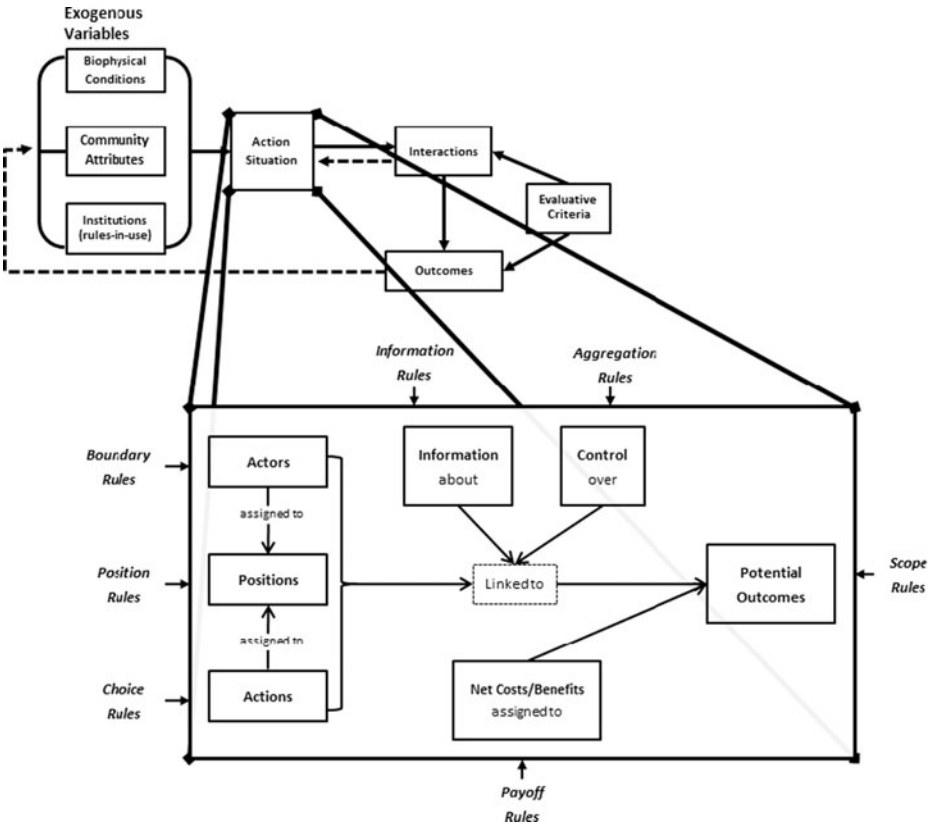

Fig. 2 The IAD framework in the background and the inner-workings of an *action situation* in the foreground. The rules influencing the action situation's component parts are listed around its boundary (Adapted, with permission, from Ostrom 2005: 189)

set of potential actions that jointly produce outcomes representing a snapshot in time in which exogenous variables are held fixed for analysis (Ostrom 2005)[3]; an example includes users of a natural resource managing resource units, such as a forestry agency managing a forest for timber products. "Management" is a broad term for a number of actions related to governance. Ostrom et al. (1961) and McGinnis (2011) define key tasks (or individual action situations) that indicate an effective system of governance—the *provision* for, *production* of, and *consumption* of goods/services, *financing* activities, *rule-making* and *monitoring* related to goods/services, *sanctioning* rule-breakers, *dispute resolution mechanisms*, *information dissemination*, and *coordination* among all relevant actors. Each of these tasks defines an individual action situation that could be modeled in the IAD framework and for which a set of rules apply.

[3] This does not mean that the IAD framework cannot address rapidly changing circumstances. The framework assumes that the action situation is a holon, "[a] nested subassembly of part-whole units in complex adaptive systems" (Ostrom 2005: 11). Holons cannot be reduced to stand alone, but can be dissected for analysis to composite holons that allow for explanations at multiple levels and various spatial and temporal scales. Thus, in a rapidly changing environment for which urban systems are often characterized, iterative analyses may be required, particularly as outcomes may quickly influence and change the exogenous variables that must be fixed to determine outcomes.

Within an action situation, actors (individuals or entities) are assigned to positions through which they choose to act in light of information, the control they have over action-outcome linkages, and the benefits and costs assigned to actions and outcomes (Fig. 2). Each of these variables is affected by institutions. Position rules define the main role or position an actor can take (in the case of forest management, the position could be a "forest manager"), boundary rules define how actors are eligible for this position and how they enter and exit it, choice rules define the allowable actions that actors can take, and information rules affect the level of information available to actors, affecting their decisions among actions. In addition, aggregation rules define whether a single participant or multiple participants must make decisions in the case that multiple actors hold the same position; payoff rules assign rewards or sanctions to actions, and scope rules define allowable outcomes (see further details in Ostrom 2005). This framework clearly "…serves to remind us that each actor's preferences, as well as the choice options available to them, are determined by the institutional arrangements…" (McGinnis 2011: 2).

This approach further defines institutional arrangements as three nested layers of rules: constitutional, collective choice, and operational rules (Ostrom 1990). Operational rules govern day-to-day activities (for example, "The forest manager may not cut down any standing tree or else he/she must pay a fine equivalent to the value of the tree"). Collective choice rules determine how operational level rules are set or changed (for example, "The forest trustees must meet annually to review rules related to tree management; rules must be presented to trustees and voted upon utilizing a majority-rule procedure"). Likewise, constitutional rules determine how collective choice rules are set and changed. Typically, the rules in place in a situation of operational choice are assumed to be determined at the collective choice level and collective choice (or policy) actions are governed by rules at the constitutional level; however, adjacent operational action situations impact one another and can be impacted by multiple processes of collective choice or constitutional interactions (e.g. increased *financing* may lead to increased *production* of a good/service while both management activities can arise from the same operational level) (McGinnis 2011). In addition, actors move between levels—if a day-to-day operational tactic is failing, actors utilize collective choice rules to make changes to operational rules. For instance, if *monitoring* of tree removal has not been effective at preserving a forest for the provision of ecosystem services (the outcome of interest), forest managers and concerned forest users (actors) may act in a collective choice arena to adjust rules defining who operationally monitors the forest and the qualification they must have (boundary rules) and the tactics they use to monitor (choice rules).

The IAD framework has been utilized empirically in a myriad of seemingly disparate settings—across fisheries, forests, and irrigation networks, for example (Ostrom et al. 1994)—and through these studies, design principles (theories) (Ostrom 1990) were built upon the IAD framework that demonstrate key characteristics that yield sustainable SESs. Many of these principles relate directly to institutions and provide reliable theory to be tested in urban systems: 1) resource users must be able to communicate; 2a) boundaries of the resource and 2b) the roles of the resource users must be clear; 3a) rules governing the use of the good must fit the local needs and conditions and 3b) benefits are proportional to inputs; 4) individuals affected by the rules can modify the rules; 5) external authorities respect the rights of users to devise rules; 6a) monitoring of the resource occurs and is undertaken by users and 6b) monitoring of the users occurs; 7) a graduated system of sanctions is used for rule breakers; and 8) a system of nested enterprises and institutions are necessary for complex resource systems (Ostrom

1990, 2005; Cox et al. 2010). Although arising largely from *rural* resource management studies, the design principles have recently been deemed useful for analysis of collective resource management in *urban* settings (Benvie 2005).

Empirical work has confirmed the importance of these institutional characteristics and the IAD framework to important research findings. For instance, Chhatre and Agrawal (2009) used data on 80 forest study sites in 10 countries to show that greater rule-making autonomy at the local level is associated with greater carbon storage and livelihood benefits, outcomes which facilitate sustainability. Another study found that for 220 forest communities, regular, institutionalized monitoring was significantly and positively correlated with forest condition (Gibson et al. 2005). Although not in the realm of social ecological systems research, the framework was also utilized in urban studies related to the provision of policing as a public good in Chicago and Indianapolis (Ostrom and Baugh 1973; Ostrom et al. 1974) which is not dissimilar from the concept of the provision of ecosystem services, as both are essential public goods in urban communities.

Application of institutional analysis to urban forest ecosystems

As a concrete illustration of the application of this kind of institutional analysis to urban ecosystem management, consider one sub-system of the urban forest: street trees. In Figs. 3 and 4 we demonstrate operational and collective choice action situations affecting the

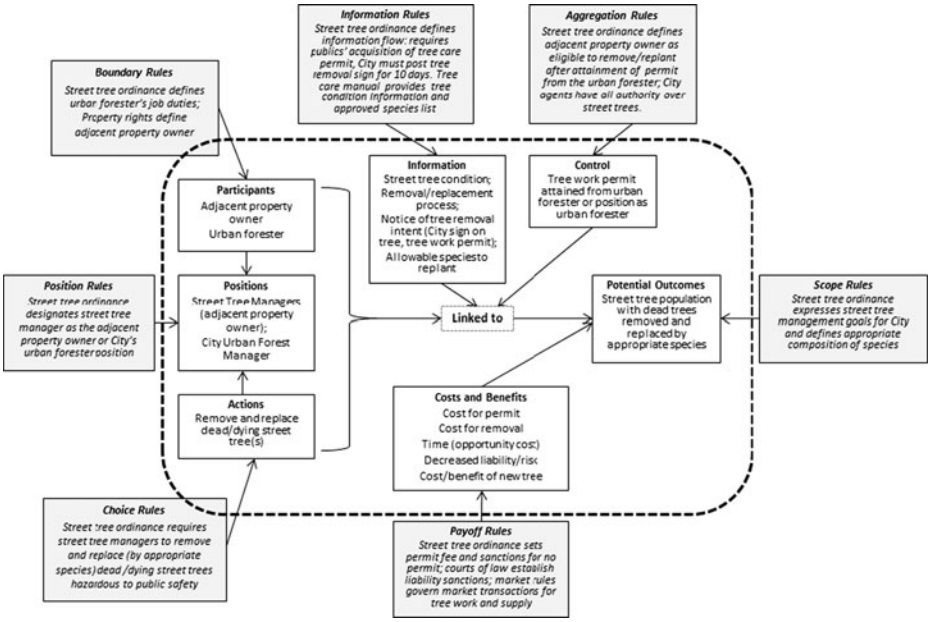

Fig. 3 The institutions impacting the inner workings of an action situation related to operational-level street tree management, specifically, street tree removal and replacement. Adjacent property owners are responsible for street trees but may only take action to remove or replace them when they are dead or dying and after attainment of a tree work permit from the City's urban forester. City foresters may remove or replace street trees but most post signage of the intent for the public unless the situation constitutes an emergency

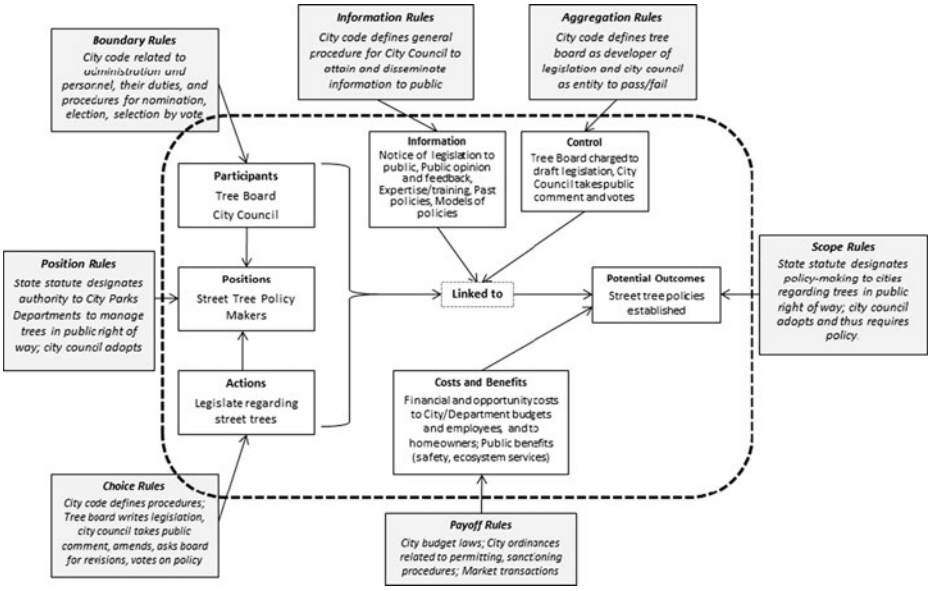

Fig. 4 The institution impacting the inner working of an action situation related to collective choice or policy-making regarding street tree management. State statute designates city parks departments (inclusive of the urban forester) as responsible for street trees in the public right-of-way (PROW). Cities generally turn over legislative development to tree boards or commissions where parks department employees hold one or more seats. The tree board is further composed of volunteer experts that develop street tree management legislation. Draft legislation is then presented to city councils for public feedback, requests for revisions, and ultimately voting

managed structure of a city's street trees.[4] Typically, in the United States, street trees are frequently defined formally in a city's municipal code as the trees in the public right-of-way (PROW). The PROW is also generally described in city code as land beyond the surface of the road pavement to some distance measured from the center of public streets. As described above, municipal governments and adjacent private property owners are generally responsible for the maintenance of street trees in accordance with broad city goals like public safety and aesthetics, or specific aims to plant all available tree spaces. Such information is generally included in code, as well. For example, some cities require adjacent property owners to obtain a permit to remove, plant, or prune trees in the PROW even if the responsibility of its maintenance is relegated to the adjacent property owner while its ownership is relegated to the city. These institutions in city code constitute operational level rules (Fig. 3), impacting the day-to-day management of street trees.

These operational rules are often recommended by tree commissions or boards to executive councils or administrators for enactment in accordance with collective choice (Fig. 4) and constitutional rules that determine policy-making and its procedure. For example, city ordinances frequently define that a city tree board write legislation regarding operational management of city trees, that a city council consider that legislation and take public comment regarding it, amend it as necessary, and vote to reject or pass it as city code.

[4] As presented in the figures, the action situations produce *optimal* outcomes, however, we outline textually the potential for sub-optimal outcomes given theoretical disconnects between exogenous rules and actual components of the action situations.

Unfortunately, perverse incentives and unintended outcomes may result from such common urban forestry institutions meant to aid in the management of street trees and may be linked to the general decline of urban forests, causal links that may not be empirically derived without structured institutional analysis. The failed governance task in this exemplary circumstance is the *production* of healthy street trees (an action situation) which requires urban forest managers (defined by *position rules*) to remove dead or dying trees (with a permit) and replant appropriate species (defined by *choice rules*); the main actors involved are adjacent property owners and urban foresters (*boundary rules*).

Fischer and Steed (2008) argue that the definition of street trees is often unclear to the general public, as is the role of adjacent property owners in their management; attempts to clarify the definition of a street tree, particularly by defining it in the PROW, have led to increased confusion because PROW definitions are embedded in municipal code, which is often unclear or less accessible to the general public. Thus, *information rules* impact the production of street trees, as well. Moreover, when ownership is claimed by the public municipality but management responsibilities are assigned to the adjacent property owner, increased confusion arises about which entity (adjacent property owner or city) is responsible, indicting *aggregation rules*.

If a permit is required of the adjacent property owner to manage trees in the PROW, *payoff rules* are imposed and often increase transaction costs for the actor (in this case, in terms of time and potentially money spent obtaining the permit). If only particular species of street trees are allowed to be planted, *scope rules* are imposed. If municipal code is unclear, unknown or unjustified, actors may not understand the benefits of street trees and cannot consider all the costs of not obtaining a permit to remove and plant trees (potentially including legal sanctions which are classified as *payoff rules*). Thus all benefits and costs are not weighed within the action situation, potentially resulting in inappropriate removal or planting of the wrong species of street tree in the PROW and/or the absence of a tree in a plantable space.

As mentioned, many action situations are influenced by actors within adjacent action situations, as is the case in the above scenario. Even if urban tree production arrangements are understood, outcomes are affected by adjacent action situations including *monitoring* and *sanctioning* related to street tree management. In fact, these adjacent action situations often fail to feed positively into the action of street tree production: limited urban forestry staff (as is commonly the case resulting from *financing* action situations) or uninformed neighbors may be unable to *monitor* street trees, and thus, do not *sanction* rule-breakers, adjusting their costs and benefits (*payoff rules*) in the production of street trees. Why follow a rule to plant or maintain a tree in the PROW if there is no cost to breaking the rule, but there is a cost to following it (the cost of the tree, the cost of the time and effort to obtain a permit and to plant, etc.)?

As demonstrated through this specific example, institutional failure can arise from a variety of nuanced rules that structure an action situation, and likewise, can be resolved by understanding the specific sources of incongruence between policies and outcomes. Thus, in-depth institutional analysis is required to determine the relevant variables influencing the probability of sustainable actions in street tree management. However, to be clear, we do not mean to suggest that adjacent property owners can never sustainably manage street trees; rather, with clarified institutions (e.g., improved information rules about the location of PROW trees through informative mailers, for instance), incentives may be adjusted to allow for optimal street tree management from households. In fact, a major lesson from institutional analysis in rural resource management scenarios is that no particular form of tenure or governance regime is more successful than another (Moran 2005). Tucker (2009) argues that

it is the local context, including history, political economy, social relationships, and biophysical characteristics that establish the appropriate tenure for resource management. Thus there are most certainly scenarios in which well-structured institutions allow for sustainable street tree management by adjacent households. Moreover, because street trees and their associated rules and norms are only one component of an urban forest and its many management policies and strategies, this example underscores that sustainability, as Clark et al. (1997) argues, can only be achieved in comprehensive urban forest management if policies and institutions are well-crafted and respected and are considered across scales, space, and time. More importantly, it points to the fact that structured, repeatable analysis is required of institutional arrangements in order for urban forestry and urban ecosystems scholars to empirically derive a deeper understanding of the roles institutions play in sustaining (or distressing) urban ecosystems and to appropriately advise on policy prescriptions.

Conclusion

There has been much work to test several human ecosystem frameworks and develop a better understanding of urban ecology through institutional exploration (McIntyre et al. 2000). While institutions are recognized as integral to the study of urban ecosystems, theoretical and empirical analysis has been limited in both urban ecology and urban forest management. We argue that the lack of research is not indicative of institutions' relative importance in urban ecological systems; rather, it appears to stem from a lack of clarity regarding how institutions should be defined and analyzed. This has prevented cumulative and comparative research regarding the role of institutions in sustaining urban ecosystems.

Urban ecologists and urban forest management researchers could benefit from applying a working definition of institutions that uniquely defines rules, norms, and strategies, by recognizing the nested nature of operational, collective choice, and constitutional institutions, and by applying the IAD framework to urban SESs such as urban forest systems. Although the IAD framework has not often been applied to urban SESs, it is an ideal paradigm to extend to the urban ecology field given its proven usefulness in understanding the relative role of institutions amidst social and biophysical factors in rural SES sustainability (Hardy and Koontz 2010). Research framed in this manner has provided a foundation of institutional design principles (Ostrom 1990) that work as hypotheses when extended to urban ecosystem research.

A recent study by Wolf and Kruger (2010) determined that urban forestry professionals, academics, and agency-based managers desire a policy based research agenda to help determine adequate policy, code, and regulations for urban forest management. By detailing the role of institutions in the sustainable management of urban forests, we hope to offer direction for analysis in urban ecosystems research that will meet this need and facilitate a key future focus—institutional analysis—in urbanization and human dimensions of global environmental change (IHDP 2010). Opportunity exists for cross-disciplinary fertilization of institutional analysis from rural SESs to urban ecosystems and promises to help answer why and how individuals and their collective associations are incentivized to conserve or remove urban trees.

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