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Urban forestry and arboriculture as interdisciplinary environmental science: importance and incorporation of other disciplines

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Abstract Urban forests - trees and vegetation in cities - produce numerous benefits for urban residents. The study and practice of urban forestry aims to understand how trees and their benefits are produced and maintained over time. Urban forestry (tree population management) and the related field of arboriculture (single-tree management) are less known outside of the forestry and horticulture disciplines in which these fields developed. Because urban forests are best understood as social-ecological systems, urban forestry research using interdisciplinary methods and theory is beginning to become more common. In this paper, we surveyed educators and leaders of urban forestry and/or arboriculture programs across the world to examine the interdisciplinary basis of these programs. We summarize here the responses of 116 institutions of higher education (85 within the United States) with urban forestry and/or arboriculture coursework. Seventy-four percent of institutions considered urban forestry/arboriculture to be interdisciplinary. Some disciplines (e.g., biology/ecology, forestry) are already very incorporated into their program's current curriculum, and the importance of several other disciplines is recognized even while incorporation is not yet fully realized (e.g., urban planning, natural resource management, environmental science/studies). However, many major disciplines that have relevance to urban forestry/arboriculture are not rated as particularly important to the field, much less incorporated into curriculum (e.g., anthropology/sociology, economics, engineering, public policy/public affairs). Our study serves as a foundation on which to begin strengthening the interdisciplinary ties of urban forestry and arboriculture.

Keywords Interdisciplinary · Higher education · Urban forestry · Arboriculture

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Introduction

Urban forests are the trees and vegetation in the cities, towns, and communities where people live and work. Urban trees and forests produce numerous benefits for individuals and society, including decreased urban temperatures (e.g., Onishi, et al. 2010), improved air quality (e.g., Nowak et al. 2013), and stormwater management (e.g., Xiao et al. 1998), but also stronger ties among neighbors (Kuo 2003) and increased residential property values (Dimke et al. 2013). The field of urban forestry is "a profession encompassing the planning, design, establishment, and management of trees and forest stands" in and around cities, towns, and communities (Elmendorf et al. 2005: p.147, after Nilsson and Randrup 1997). Urban forestry and the related field of arboriculture (single-tree management) are relatively little known outside of the forestry and horticulture programs in

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which these fields were developed (Miller et al. 2015). However, urban forests, like many managed natural resources, are best understood as social-ecological systems of linked human and natural components, and research on urban forests using interdisciplinary environmental science methods and theory is beginning to become more common (Lu et al. 2011; Jack-Scott et al. 2013; Mincey et al. 2013; Pataki et al. 2011; Vogt et al. 2015).

In institutions of higher education, disciplines are nearly always associated with specific departments (e.g., Biology, History, Political Science) that have professors and others trained in a single discipline providing specialized instruction to students in courses within that discipline. However, in today's highly connected, complex and globalized world, single-discipline educational tracks are becoming outmoded, and connecting streams of knowledge across all types of boundaries (political, geographic, social, economic, academic, etc.) is increasingly important (Cash et al. 2006; Spelt et al. 2009). When considering complex dynamic socio-environmental systems (such as cities, including all their constantly changing subsystems with human, social, economic, and environmental components) and problems (such as the challenges of creating an environmentally sustainable world while meeting basic human needs), *interdisciplinary* approaches to scholarship and teaching are crucial to generating a complete and accurate understanding of the entire system or problem (Clark and Dickson 2003; Liu et al. 2007; Spelt et al. 2009).

Internationally, calls for broader notions of education and research using buzzwords like "multidisciplinary," "interdisciplinary," and "transdisciplinary" abound. For instance, the most recent United Nations (UN) Education, Scientific and Cultural Organization (UNESCO) World Conference on Higher Education declared, in part, that institutions of higher education "should increase their *interdisciplinary* focus and promote critical thinking and active citizenship" in order to "contribute to sustainable development, peace, wellbeing and the realization of human rights, including gender equity" (UNESCO 2010, p. 2, *emphasis added*). According to the UN, higher education has a responsibility to prepare current and future generations of students to make contributions toward the new Sustainable Development Goals (SDGs) adopted by the United Nations general assembly in September 2015 (OWG 2015). Within the SDG framework, one of the specific indicators with respect to education states that by 2030, the international community should "ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non- violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development" (SDG 4.7 from the Open Working Group proposal (OWG 2015)). Clearly such ambitious objectives as the SDGs require cultivating types of knowledge and skills beyond those traditionally taught in the siloed halls of academia—that is, taking an interdisciplinary approach (Norström et al. 2014).

An interdisciplinary approach means incorporating knowledge (and methodologies of generating knowledge) from multiple *disciplines* or foci of study. *Interdisciplinary thinking* is, "the ability to change disciplinary perspectives and create meaningful connections across disciplines" (Spelt et al. 2009, p. 366). "Interdisciplinarity is integrative," and in true interdisciplinary teaching and research, knowledge from different disciplines is combined, applied, and changed from its original form (Spelt et al. 2009, p. 366). In the context of urban forestry and/or arboriculture education, interdisciplinary education means teaching students to use knowledge from other disciplines such anthropology, biology, economics, political science, urban planning, and more to manage urban forests and trees. Integration of other disciplines could happen within the context of an entire curriculum or simply within the context of a single course. For example, interdisciplinarity in an urban forestry course might mean that the methods of participatory planning and design charrettes (from the discipline of urban planning) are taught, and students are then asked to create a tree plan for redevelopment of a city block or neighborhood that incorporates the perspectives of various stakeholders. Although such interdisciplinary approaches might not necessarily end with student mastery of other disciplines, it should allow students to interact with many disciplines to develop successful projects.

Past research on urban forestry and arboriculture education

Urban forestry and arboriculture curricula have been examined in previous research (Andresen and Williams 1975; McPherson 1984; Hildebrandt et al. 1993; Miller 1994; Randrup et al. 2002; Andresen and Williams 1975; Elmendorf et al. 2005; Wiseman et al. 2011).[1] A decade ago, Elmendorf and colleagues (2005) surveyed educators in the field of urban forestry (inclusive of arboriculture) and found that topics more typically considered the purview of arboriculture (single-tree care) were considered more important than the broader topical areas that make up urban forestry (population management). They

[1] Elmendorf and colleagues (2005) provide an excellent history and summary of urban forestry and arboriculture educational efforts. Therefore, we will only summarize here studies published more recently.

concluded that although conceptualizations of urban forestry and arboriculture as an interdisciplinary field are common and laudable, these interdisciplinary aspirations are less than realized, as many of the broadest topics (e.g., public relations and volunteer management) are considered either very unimportant or unimportant by less than half of survey respondents (Elmendorf et al. 2005). Furthermore, interdisciplinary topics such as small business management, land use planning, and zoning/subdivision ordinances were inadequately incorporated into curriculum.

More recently, Wiseman and colleagues (2011) reviewed the content of 68 arboriculture courses in the USA and found the most common topics included in course syllabi were related to typical arboriculture tasks such as tree pruning, disorders, physiology and biology, risks and hazards, and soils and nutrition. These tasks emphasize single-tree care and maintenance performed by the practicing arborist (Wiseman et al. 2011). Urban forestry-related topics that might indicate more acknowledgement of arboriculture as "interdisciplinary," such as tree inventories or law and legal issues, were less frequently included in syllabi (Wiseman et al. 2011). They note that "practicing arborists may be consulting on topics well beyond the scope of traditional arboriculture," and advocate for incorporating a greater breadth of topics into arboriculture curriculum (Wiseman et al. 2011, p. 56).

Research objectives

In this study, we investigated institutions of higher education (and programs within these institutions) that contain curriculum or coursework related to urban forestry/arboriculture. This study explicitly examined how interdisciplinary urban forestry/arboriculture curricula (whether single courses or entire degrees) are at institutions, and the importance and incorporation of various key concepts from other disciplines within urban forestry and/or arboriculture. To our knowledge, these aims have not occurred together in a prior study.

Specifically, we asked the following research questions:

1) Do institutions of higher education with coursework in urban forestry and/or arboriculture consider these fields interdisciplinary?
2) What is the perceived *importance* of other major disciplines to the field of urban forestry/arboriculture?
3) To what extent are these other major disciplines *incorporated* into the current urban forestry and/or arboriculture curriculum?
4) To what extent are *key concepts* from within the field of urban forestry/arboriculture and key concepts from other disciplines *incorporated* into the current curriculum?
5) Do answers to these questions differ by *program characteristics* (location of program within the institution, formality of the program, degrees offered, etc.)?

Methods

Survey

To examine the interdisciplinary nature of urban forestry and/or arboriculture curriculum (hereafter, "curriculum"), we designed and implemented an online questionnaire (Supplementary material) to ask individuals in positions most closely aligned with urban forestry and/or arboriculture educational programming (i.e., those who teach courses or are in leadership roles) in these programs across North America and the world. We asked questions about the institution of higher education, the program in which coursework related to the field of urban forestry and/or arboriculture (hereafter, "the field") resided, the degrees granted, and the importance and incorporation of other disciplines into current curriculum. The survey was designed to take respondents no more than 10–15 min to complete.

A list of other disciplines potentially relevant to the field was based on traditional delineations of academic disciplines. We asked respondents about both the *importance* of these disciplines and how well incorporated they were into the current curriculum. Because it was essential to get both importance and incorporation ratings from every respondent, we listed rather broad categories of other disciplines, and only those that might be most closely tied to the field. To not overburden survey respondents, we combined similar disciplines (e.g., anthropology/sociology, biology/ecology) and eliminated those disciplines that we deemed might be most peripheral to the field and curriculum (for instance, physics and geology were excluded).

Lists of key concepts from *within* the field were gleaned from past studies of arboriculture curriculum (e.g., Elmendorf et al. 2005; Wiseman et al. 2011) and from tables of contents of the ISA Certified Arborist study guide (Lilly 2010), the Municipal Specialist Certification study guide (Matheny and Clark 2008), as well as textbooks from the field (e.g., the updated version of the classic urban forestry text by Miller (1988, 1997): Miller et al. 2015; and a widely used arboriculture text: Harris et al. (2004)). Lists of key concepts from other disciplines were generated from tables of contents in textbooks in environmental studies/science, sustainability, etc. Additions and modifications to these key concepts were made based on the authors' experiences and informal discussions with other practitioners and educators with knowledge of the field. We split the final list of key concepts into three categories: urban forestry/arboriculture,

natural sciences, and social sciences. The selected disciplines and key concepts provide a basis for examining interdisciplinarity of curriculum, without ideally overburdening respondents with long lists of terms. As such, we combined some key concepts where appropriate (e.g., combining budgeting and personnel and related issues into a broader concept of administrative issues). To collect any overlooked item, respondents could write-in additional key concepts and rank their importance and incorporation into their curriculum. Write-in responses were analyzed separately from the lists we provided.

We used snowball sampling to survey as many institutions of higher education (universities, colleges, and technical schools) as possible. We conducted a targeted survey of individuals that teach courses and those in leadership roles (e.g., deans, program chairs, department heads) at institutions in the USA that may have coursework in urban forestry or arboriculture. This targeted list of contacts was obtained by cross-referencing lists maintained by the U.S. Forest Service State and Private Forestry regional and sub-regional Urban Forestry Coordinators and the International Society of Arboriculture with information from institutional websites. This list consisted of 267 individuals at 213 institutions of higher education (1–4 individuals per institution) in 49 of 50 United States (Delaware was not represented). To include institutions inadvertently omitted from our original list, we also solicited survey participation using the University of South Florida-maintained URBANFORESTS listserv. Institution recruitment also occurred through e-mail distribution lists through the U.S. Forest Service State & Private regional networks, ISA's Hispanic Committee, and the Alliance for Community Trees Treebune News newsletter.

To capture international institutions, we reached out specifically to individuals in the authors' personal and professional networks with specific regional expertise, and asked them to forward a link to our survey to their regional contacts. Our questionnaire was forwarded to educators and institutions via regional networks in Canada (via the Canadian Urban Forest Network listserv), Northern Europe, Southern Europe, Australia, New Zealand, South America, and Asia. (Note that the survey was only available in English, so knowledge of the English language was a limiting factor for any international survey respondents.)

Targeted solicitations for responses to our questionnaire were administered according to the Dillman Tailored Design Methods adapted for internet surveys (Dillman et al. 2014), using Qualtrics survey software (http://www.qualtrics.com). Requests were sent to potential respondents in our list of individual US contacts as well as via the URBANFORESTS listserv three times on Tuesdays, 1 week apart: 6 January 2015, 13 January 2015, and 20 January 2015. The questionnaire was closed to additional responses on February 20.

Analysis

We summarized responses to the questionnaire per question and make mostly qualitative comparisons of responses to different questions. Chi-square and Fisher's exact (for low cell counts) tests were used to test for differences in the observed and expected frequencies of cases across categorical variables.

Importance and incorporation indices were generated for each discipline by assigning a numeric value of 1.0 to Likert item responses of not at all important (not at all incorporated), 2.0 to slightly important (slightly incorporated), 3.0 to important (mostly incorporated), and 4.0 to very important (very incorporated) and then averaging all responses to obtain an index score.

All data processing and analysis was performed using Stata/SE, version 13.1 (StataCorp, College Station, Texas).

Results and discussion

Survey completion

One of the casualties of conducting an internet survey is that we experienced significant attrition of survey respondents during the completion of the online questionnaire. Our survey software accepted incomplete responses from individuals that answered at least one question on the survey. Of 237 respondents who clicked on the link to respond to the survey, 219 individuals indicated the presence of urban forestry or arboriculture coursework at their institution. Of these 219, only 149 individuals made it far enough into the questionnaire to answer a key question about whether their institution defines the field as interdisciplinary. Of these 149, 128 individuals made it all the way through the questionnaire and provided answers to crucial questions about the importance and incorporation of other disciplines and key concepts into their institution's urban forestry and/or arboriculture curriculum. When summarizing viewpoints on the interdisciplinary of urban forestry and arboriculture, we use only these 128 individual survey responses. We acknowledge that there is potentially an element of bias in this "convenience sample," and some of the inferences made below are limited as such.

Of the 128 complete survey responses, only 12 institutions were represented more than once (with 2 to 4 individuals responding per institution). Since we are primarily interested in the relationship of program and institutional characteristics to interdisciplinarity, we eliminated duplicate responses from the same program as follows: Individual responses from different programs within the same university were kept in the institutional dataset (n=2). Where multiple individuals from the same program responded to our survey, a complete survey response (no missing answers to questions) was kept over an incomplete response; where multiple responses from the same

Table 1 Position of 129 survey respondents within institutions of higher education

Position	Number	Percent
Director/Chair, or similar	39	30.5
Faculty	74	57.8
Adjunct	9	7.0
Non-faculty instructor	8	6.3
Staff member	7	5.4
Other	17	13.2

Percentages add up to more than 100 % since respondents may identify as a program director or chair as well as another position

institution were complete, the set of responses from the most senior-level individual (i.e., a program chair or director) was kept in the institutional dataset. When summarizing institutional and program characteristics, we use this institutional dataset of 115 survey responses. Note that for both individual respondent and institutional datasets, not all respondents answered all questions, so some analyses presented below include slightly fewer than 128 respondents or 115 institutions.

The majority of respondents identified as faculty members (58 %, 74 of 128 respondents), and 31 % (39) identified as having all or part of their job in a leadership role (Table 1).

Institution and program characteristics

One-hundred and fifteen institutions responded to our questionnaire, from across the world, mostly from the USA (74 % of institutions), but also from Canada (7 %), Europe (6 %, including 1 response each from Belgium, Denmark, Italy, Lithuania, Spain, Sweden, and Switzerland), as well as 2 responses (2 %) from Australia (13 programs did not identify their location). Seventy-three (63 %) programs identified as being located within primarily 4-year institutions (including institutions offering graduate degrees of any kind), while 29 (25 %) programs were located within 2-year institutions, 5 programs (4 %) were in institutions offering both 2- and 4-year degrees, and 8 (7 %) programs identified as being part of another type of institution.

The plurality (53 of 115; 46 %) of programs was located within colleges, schools, or departments (or similar) of agriculture, forestry, and/or natural resources (Fig. 1a). Only eight programs (7 %) were located within departments (or similar) of environmental science or studies. Most institutions offered only 1 or 2 courses related to urban forestry and/or arboriculture, but 18 % of institutions (19) offered 5 or more courses (Fig. 1b), with write-in responses as high as 23 for an institution offering an Associate's Applied Science degree as an Urban Forestry Technician. Interestingly, more than a third (36 %) of surveyed programs offered only a single course in urban forestry and/or arboriculture; this is a finding that deserves more investigation as it may relate to interdisciplinarity, and to the placement of students into careers in the field.

Table 2 shows the types of degrees to which coursework in urban forestry and/or arboriculture applied. A majority of institutions indicated that the type of degree that contains urban forestry and/or arboriculture coursework is a bachelors of science (B.S. or BSc.) degree, but institutions granting thesis-

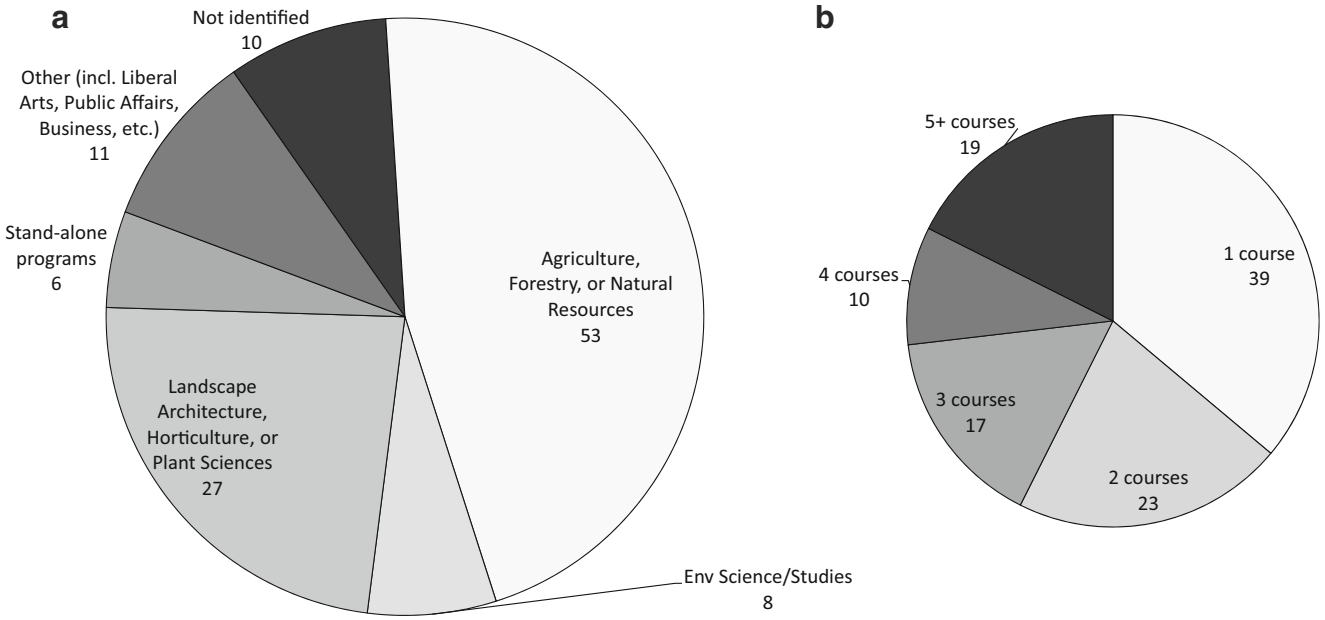


Fig. 1 **a** Institutional location (college, school, department, division, or similar) of urban forestry and/or arboriculture programs within 115 institutions of higher education. **b** Number of courses relating to urban forestry and/or arboriculture at these institutions (note that only 108 institutions answered the questions about the number of courses taught at their instruction)

Table 2 Number of institutions (and percent of 115 total institutions) reporting the types of degrees in which urban forestry and/or arboriculture coursework appears

Degree type	Number	Percent
2-Year degree (incl. associates degree)	33	28.7
Bachelor's of Arts (B.A.)	12	10.4
Bachelor's of Science (B.S.)	65	56.5
Master's degree (with thesis)	34	29.6
Master's degree (no thesis required)	24	20.9
Doctoral degree (Ph.D.)	19	16.5
Other type of degree	21	18.3

Percentages add up to more than 100 % because some institutions have more than one type of degree containing urban forestry and arboriculture coursework

based masters degrees and 2-year degrees (including Associate's degrees) were also common (Table 2). Sixty-three (54 %) of institutions had some type of formal undergraduate or graduate program (a named major, minor, certificate, or emphasis; hereafter, "named" programs) that included coursework related to the field of urban forestry and/or arboriculture; of these named programs, 48 of 60 (80 %) institutions responding to this question indicated that one or more course that included content relating to the field was required. The most common form of named program leading to a degree occurs as an emphasis or concentration within a major or minor (Table 3). Thirty-three institutions (29 %) indicated that no named program existed and coursework was limited (i.e., an elective that does not yield a named major, minor, emphasis, or concentration).

Table 3 Number of institutions (and percent of 116 total institutions) reporting different types of programs in which urban forestry and/or arboriculture coursework is taught

Type of program	Number	Percent
Named undergraduate major	16	13.9
Named undergraduate minor	14	12.2
Named graduate major	13	11.3
Named graduate minor	4	3.5
Certificate	17	14.8
Emphasis or concentration	39	33.9
Informal coursework only[a]	33	28.7
Other type of program	33	28.7

Percentages add up to more than 100 % because some institutions have more than one named program containing urban forestry and arboriculture coursework

[a] Informal coursework only refers to programs that do not have any sort of named major, minor, certificate, or emphasis of any sort relating to urban forestry and/or arboriculture (i.e., only an elective that is not part of a named degree)

Institutions with named urban forestry or arboriculture programs identify their majors, minors, areas of emphasis, and/or concentrations that include coursework in urban forestry and/or arboriculture by a variety of titles (Table 4). The plurality of named programs was titled Urban Forestry, with Horticulture also being a common name. However, 18 named programs had a title other than one specified in our survey. Common write-in responses included titles similar to Natural Resource Management, Landscape Architecture, or Community Forestry. Unique write-in responses included Sustainability Studies, Urban Ecosystems, and Sociology.

Defining urban forestry/arboriculture as an interdisciplinary field

Seventy-four percent of institutions (85 of 115 responding to this question) consider the field of urban forestry/arboriculture to be interdisciplinary. There are no significant differences in defining the field as interdisciplinary by institution geographic location, program location within the institution, named versus unnamed programs, the title of the named program, graduate compared to undergraduate programs, or the number of courses or degrees offered (results not shown). The only significant difference in program characteristics was the type of degree granted that relates to urban forestry/arboriculture. Institutions that offered 2-year Associate's degrees with coursework related to urban forestry and/or arboriculture less frequently defined the field as interdisciplinary compared to institutions that *do not* offer Associate's degrees (chi-square test: $\chi^2=10.524$, $p=0.001$). Institutions that granted B.S. degrees defined the field as interdisciplinary more frequently than expected, while institutions that *do not* grant B.S. degrees identified as interdisciplinary less frequently than expected (chi-square test: $\chi^2=6.039$, $p=0.014$). No other types of degrees were significantly associated with defining the field as interdisciplinary. That Associate's and B.S. programs tend to

Table 4 Number of institutions (and percent of 63 institutions with named urban forestry or arboriculture programs) reporting the titles of different majors, minors, concentrations, or areas of emphasis

Title	Number	Percent
Arboriculture	10	15.9
Urban Forestry	26	41.3
Urban Forestry & Arboriculture	6	9.5
Horticulture	18	28.6
Forestry	14	22.2
Environmental Science	8	12.7
Other	18	28.6

Percentages add up to more than 100 % because some institutions have more than one named program containing urban forestry and arboriculture coursework

differ in considering urban forestry/arboriculture interdisciplinary makes sense. Associate's degrees are specifically focused on applications of science and technology to a specific career. Associate's degree programs might (though need not necessarily) preclude opportunities for inclusion of coursework from other disciplines. On the other hand, B.S. degrees tend to include much coursework from the natural sciences as a whole.

Importance of other disciplines

Survey respondents rated the importance of 13 other major disciplines to the field on a 4-point scale from not at all important to very important, and the degree to which these disciplines were incorporated into their current curriculum on a 4-point scale from not at all incorporated to very incorporated. Results are shown in Fig. 2.

A majority of institutions rated the disciplines of biology/ecology (70 %), forestry (71 %), horticulture (65 %), natural resource management (53 %), and planning/urban planning (55 %) as very important to the field, with nearly a majority of institutions rating environmental science/studies (47 %) very important. These disciplines are the most natural science-oriented of the 13 included in our list, with the exception of planning/urban planning, which has close associations with landscape architecture. Other disciplines were viewed as much less important: A majority of institutions rated the disciplines of anthropology/sociology and medicine/public health as either not at all important (11 %) or slightly important (45 %). Anthropology/sociology are clearly social sciences, while medicine/public health is likely viewed as being only tangentially related to the field of arboriculture. The disciplines of economics, engineering, landscape architecture, public policy/public affairs/political science, and sustainability science were considered of middling importance, with the

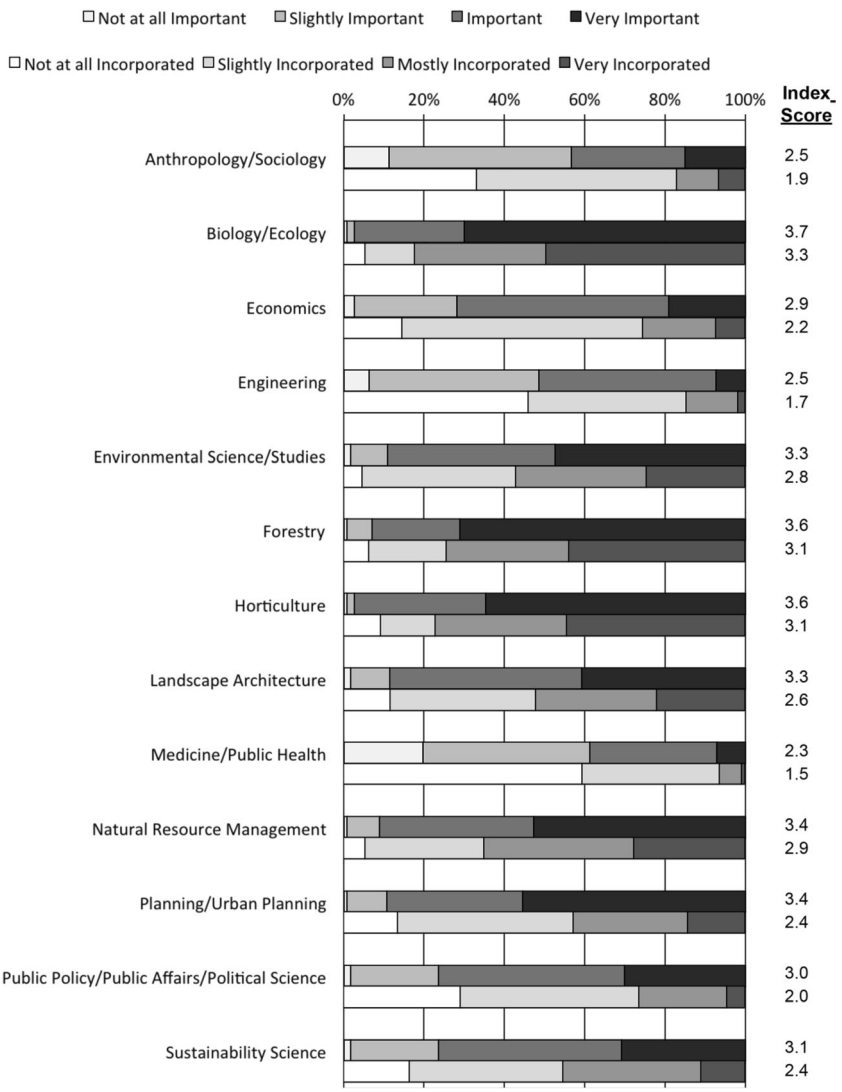


Fig. 2 Importance (*top bars*) of major other disciplines to the field of urban forestry/arboriculture and extent to which responding institutions report that these disciplines are incorporated (*bottom bars*) into their current urban forestry and/or arboriculture curriculum

greatest proportion of institutions responding that these disciplines were slightly important or important.

Incorporation of other disciplines—an attainment gap

Incorporation of other disciplines into urban forestry and/or arboriculture curriculum falls short of the stated importance of these same disciplines. No discipline was rated very incorporated by the majority of institutions, although biology/ecology (50 %) and forestry (44 %) were rated very incorporated by a plurality of institutions (Fig. 2). Index scores for incorporation of all disciplines are far lower than index scores for how important those disciplines are, and the proportion of institutions rating each discipline as mostly incorporated or very incorporated is lower than the proportion of respondents rating each discipline as important or very important (Fig. 2). These lower ratings are consistent across all 13 disciplines included in our survey. Biology, environmental science, forestry, and horticulture were nearest to having incorporation at the level of importance. Planning and public policy had the greatest difference between identified importance and incorporation. Overall, this indicates that institutions are experiencing a significant attainment gap, and that perhaps the desire to be interdisciplinary exceeds institutional capacity.

Figure 3 compares responses to questions about the incorporation of other disciplines in to current curriculum for institutions that do and do not consider the field interdisciplinary. Interestingly, when the field is *not* considered interdisciplinary, incorporation index scores for horticulture, forestry, landscape architecture, and natural resource management disciplines are slightly higher than for institutions where the field is considered to be interdisciplinary (Fig. 3). These disciplines are presumably considered closely related or even already within the field of urban forestry/arboriculture.

Interdisciplinarity is weakly related to the location of the program within the institution. Although there is no significant difference in defining the field as interdisciplinary by

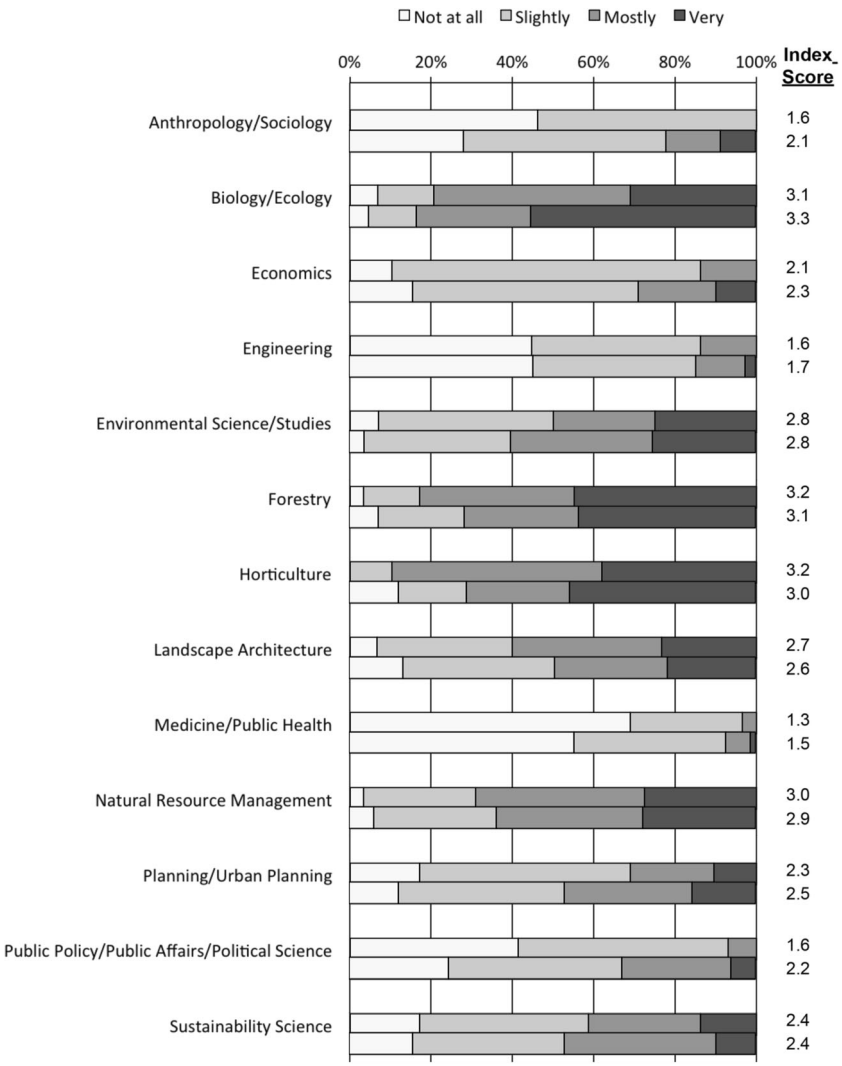


Fig. 3 Comparison of degree of incorporation of interdisciplinary concepts by whether or not respondents identify the field of urban forestry/arboriculture as interdisciplinary (*bottom bars*; $n=34$) or not (*top bars*; $n=94$). Fischer's exact test for significant differences in distribution of incorporation ratings between the two types of institutions reveal significant differences for anthropology/sociology ($p=0.049$), horticulture ($p=0.0295$), and public policy/public affairs/political science ($p=0.0366$). Incorporation index scores are shown to the *right* of bars

location of the program within the institution (Fisher's exact test: $p=0.263$), it is interesting that all 8 programs located within environmental science/studies departments or schools consider urban forestry/arboriculture to be interdisciplinary.

Incorporation ratings by type of degree offering

Based on the significant association between some types of degree offerings and defining the field as interdisciplinary (institutions with 2-year degrees *less* frequently defined the field as interdisciplinary, while institutions with B.S. degrees *more* frequently defined the field as interdisciplinary), we examined the 13 other disciplines to see if any of them were more or less incorporated into curriculum for institutions that do and do not offer a 2-year degree or B.S. degree. Interestingly, for the field of economics, we found a more peaked distribution of responses across incorporation categories for institutions offering 2-year degrees (the discipline was rated slightly incorporated more frequently than expected) and a flatter distribution of responses for institutions *not* offering 2-year degrees (ranked economics ranked either not at all incorporated or very incorporated more frequently than expected; Fig. 4a).

For institutions *with* a B.S. degree program, the distribution of institutional responses across incorporation categories for the discipline of anthropology/sociology was also more peaked than expected (more frequently rated slightly or mostly incorporated), while institutions *without* B.S. degree programs exhibited a flatter distribution of ratings (anthropology/sociology rated not at all or very incorporated more frequently than expected; Fig. 4b). Institutions with B.S. degrees also rated the discipline of public policy/public affairs/political science as slightly or mostly incorporated more frequently than expected (Fig. 4c).

The above results indicate a tendency of institutions *with* 2-year degrees or *without* B.S. degrees to assign middling rankings to some of the most social science-related of the 13 disciplines included in our survey. This could indicate a lack of complete understanding of what these disciplines entail and thus reluctance to make an extreme judgments about the degree to which these disciplines are incorporated into their urban forestry and arboriculture curriculum. Alternatively, the challenge of incorporating many important topical areas leads to exclusion of some areas that do not fit into a confined or credit hour-limited program of study (such as a 2-year degree program).

Incorporation of key concepts from within and outside the field

Figure 5 shows incorporation index scores for key concepts within the field (Fig. 5a), and for key concepts in the broader natural (Fig. 5b) and social (Fig. 5c) sciences. Incorporation index scores for key concepts from within the urban forestry/arboriculture field are the highest (average index score for all key concepts of 3.0), followed by scores for concepts from the natural sciences (2.6 average). Scores for concepts from the social sciences are particularly low (average of 2.2), with no incorporation index score above 2.6 (Fig. 5c).

Key concepts that are considered very incorporated into current curriculum by more than 50 % of institutions are: benefits of trees (71 %), tree identification (71 %), plant/tree biology (68 %), plant/tree selection (65 %), planting/installation technique (60 %), pruning (60 %), planting site selection (57 %), tree diversity (56 %), soil/nutrient management (54 %), and pest/disease management (52 %). No key concepts from the natural or social sciences are very incorporated by more than 50 % of institutions.

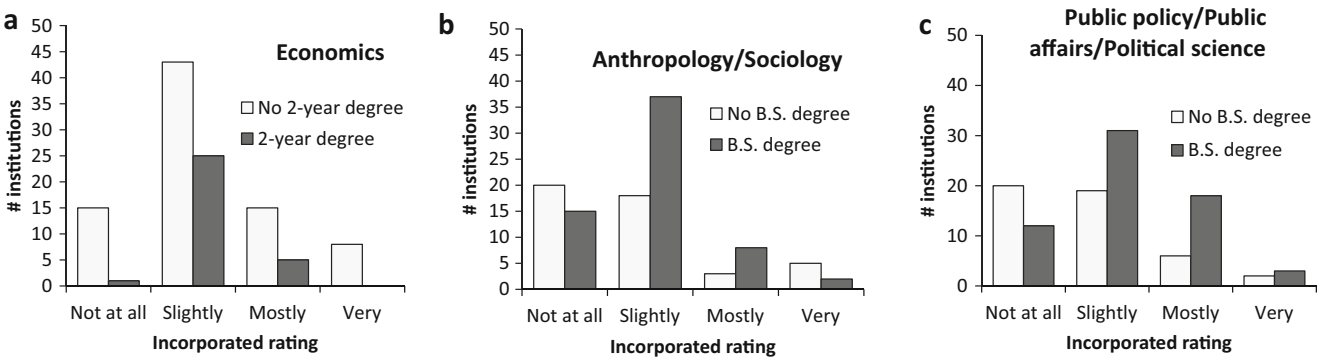


Fig. 4 Comparison of incorporation ratings for the select disciplines for programs with different types of degree offerings. Results shown only for disciplines with significantly different distributions between types of degree offerings. **a** Incorporation of economics for programs with and without 2-year degree offerings (Fisher's exact test: $p=0.019$). **b** Incorporation of anthropology/sociology for programs with and without bachelor's of science (B.S.) degrees (Fisher's exact test: $p=0.034$). **c** Incorporation of public policy/public affairs/political science for programs with and without B.S. degrees (Fisher's exact test: $p=0.030$)

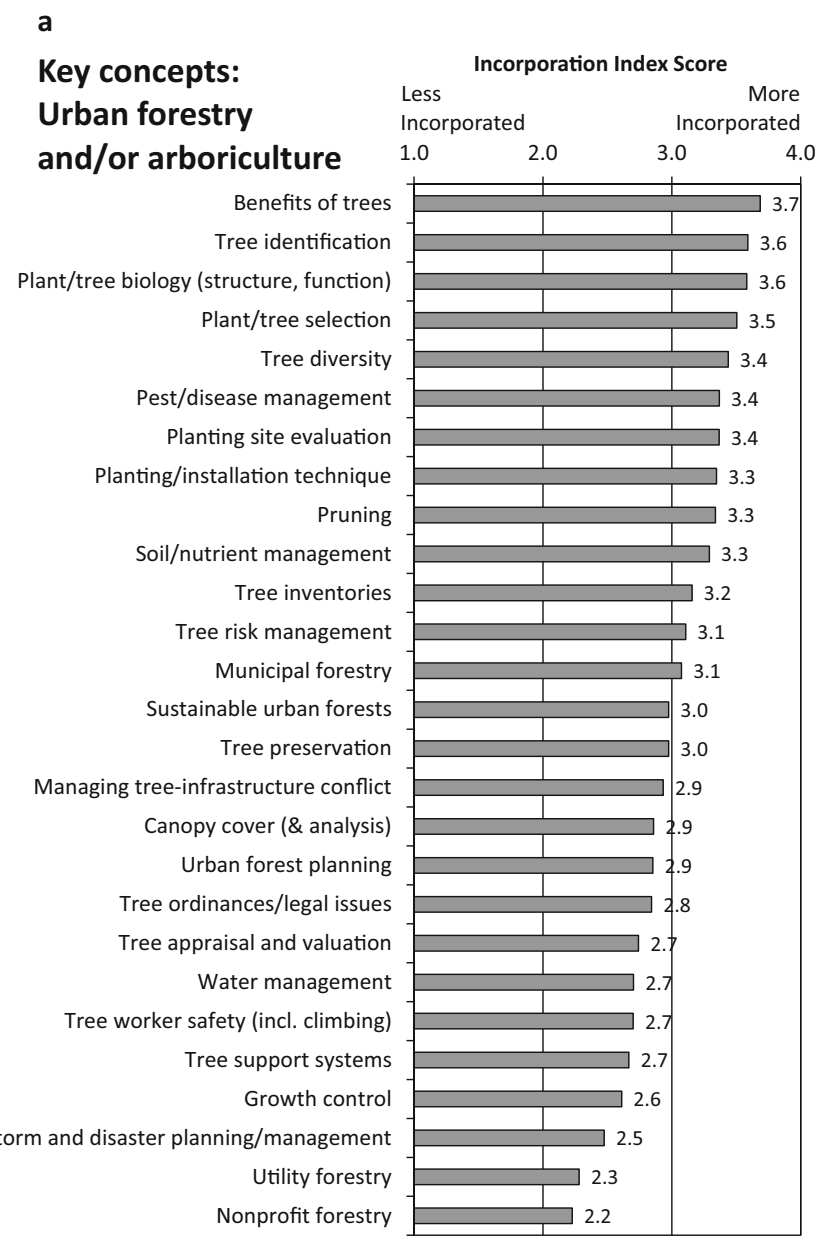
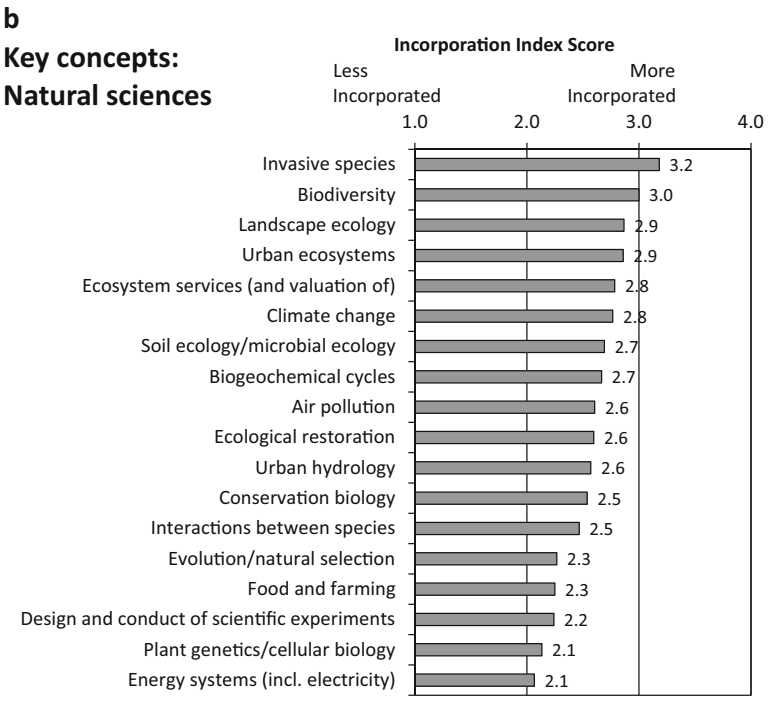


Fig. 5 Index scores for incorporation of key concepts from **a** within the field of urban forestry/arboriculture, **b** the natural sciences, and **c** the social sciences

Table 5 compares the results of this study to the results of the two most recent surveys of urban forestry and/or arboriculture curriculum (Elmendorf et al. 2005; Wiseman et al. 2011). Tree pruning appears on the list of the most incorporated key concepts identified in this study, as well as lists of the most common instructional topics in arboriculture (Wiseman et al. 2011), and the most important and most adequately addressed educational topics in urban forestry (Elmendorf et al. 2005). Tree planting and tree selection appear only on lists of urban forestry-related topics and not as a topic in arboriculture curriculum, which Wiseman and colleagues (2011) as well as others (e.g., Skiera 2014) note may be due to the traditional focus of arborists on care of existing (already planted) landscape trees.

Even the most incorporated natural sciences concepts are not as frequently rated very incorporated into curriculum as are concepts from within the field. Concepts from the natural sciences that are most incorporated are invasive species (38 % of institutions rate the concept as very incorporated), biodiversity (30 %), urban ecology (24 %), ecosystem services (23 %), and landscape ecology (21 %).



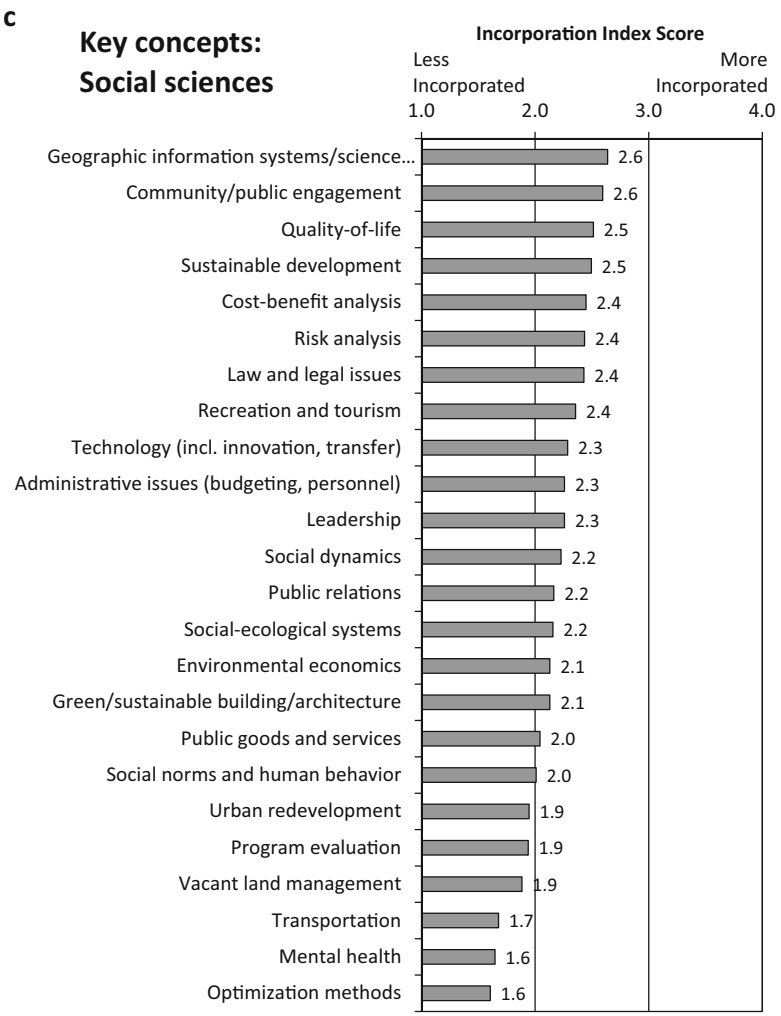


Fig. 5 (continued)

Table 5 Top 5 key concepts from this study (as determined by the greatest percentages of institutions indicating that the concept is very incorporated into their current curriculum) in comparison to results from studies by Wiseman et al. (2011; examined syllabi of arboriculture courses only) and Elmendorf et al. (2005; surveyed educators teaching urban forestry curriculum, inclusive of arboriculture)

	Most incorporated key concepts	Most common instructional topics	Most important educational topics	Most adequately addressed topics
STUDY	Our study	Wiseman et al. 2011	Elmendorf et al. 2005	
SURVEY OF…	Urban forestry and/or arboriculture curriculum	Arboriculture curriculum only	Urban forestry curriculum (potentially inclusive of arboriculture)	
CONCEPTS/ TOPICS	Benefits of trees	Pruning	Planting	Establishment, installation
	Tree identification	Disorders	Pruning	Tree identification
	Plant/tree biology	Physiology/biology	Tree selection	Pruning
	Plant/tree selection	Risks/hazards	Soil, water relations	Tree selection
	Planting *(tied)* Pruning	Soil/nutrition	Tree structure, decay identification	Tree nutrition, fertilization

Note that the fifth ranked key concepts from our study listed in this table is different from the key concept with the fifth highest incorporation index score in Fig. 4 because index scores incorporate the distribution of responses across all rating levels (from not at all incorporated to very incorporated), rather than just the proportion of responses indicating the concept is very incorporated

The top most incorporated social sciences concepts are even less frequently rated as very incorporated into curriculum: geographic information systems/science (GIS; 27 %), community/public engagement (17 %), risk analysis (15 %), quality-of-life issues (14 %), cost-benefit analysis (14 %), and sustainable development (13 %). The five least incorporated concepts from any discipline are all from the social sciences: optimization methods (54 % of institutions rate the concepts as not at all incorporated), transportation (46 %), vacant land management (44 %), mental health (41 %), and program evaluation (40 %).

Trends in urban forestry and broader environmental sciences

The individual and public health benefits of trees are becoming increasingly recognized by the field of urban forestry (Wolf 2008; Nilsson et al. 2011; Nowak et al. 2014; Kardan et al. 2015). In our study, while 39 % of institutions indicated that medicine/public health is important or very important to the field or urban forestry/arboriculture, only 6 % institutions responded that the discipline is either mostly incorporated or very incorporated into their curriculum. It is possible that public health is being incorporated in a curriculum through an overview of tree benefits, which ranked highest in importance in this study. Going into detail of how the array of ecosystem services provided by trees affect human health through physiological and psychological means might be beyond the institutional capacity and faculty knowledge.

Environmental science/studies is a discipline that nearly all institutions rate as important (42 %) or very important (47 %). The vast majority of institutions incorporate the discipline into their curriculum to some degree; only 5 % indicate that environmental science/studies is not at all incorporated. In fact, it may be the case the field of urban forestry/arboriculture is being incorporated into environmental science/studies, rather than the other way around. There is a trend toward traditional forestry schools in the USA to combine with larger units that cover broader areas with natural resource management or environmental science (O'Hara and Redelsheimer 2012).

We were surprised that geographic information systems/science (GIS)—a particular key concept from the environmental sciences but one with substantial interdisciplinary applications—is only very incorporated into the curriculums of 27 % of institutions. GIS knowledge and skill is an increasingly marketable skill for students seeking employment and is being more frequently employed by practicing urban foresters and arborists in maintenance- (Miller et al. 2015), tree inventory- (Nielsen et al. 2014), and planning-/planting- (e.g., Kirnbauer et al. 2009; Morani et al. 2011) related applications. However, the lack of high incorporation into curriculum may reflect the lack of expertise within departments to support GIS curriculum.

Related to (and often cocurricular with) the environmental sciences, sustainability science is a recently formalized (Kates and Parris 2003; Komiyama and Takeuchi 2006) and rapidly growing discipline (Miller 2012). More than three-quarters of institutions indicated that sustainability science is either important (45 %) or very important (31 %) to the field, while a minority of institutions report that sustainability science has been mostly (35 %) or very (11 %) incorporated into their curriculum.

Sustainability of urban forests was first advocated explicitly by Clark and colleagues (1997) in their excellent but rarely applied *Journal of Arboriculture* article, "A model of urban forest sustainability." Clark and colleagues (1997) incorporate

late-1980s/early-1990s notions of sustainability as balancing economic, social, and ecological goals in order to provide for the needs of current generations without compromising the ability of future generations to meet their own needs. Clark and colleagues (1997) purported that a sustainable urban forest must have healthy trees, adequate management, and a supportive community. This broad, three-pillared definition of sustainable urban forests acknowledges the ecological, institutional and social elements of the urban forest as an integrated system. Unfortunately, these multi-faceted and interdisciplinary ideas have not been widely incorporated into urban forestry and/or arboriculture curriculum (although they have been used in some urban forest research and practice: program evaluation: Clark and Matheny (1998), and Vogt et al. (2015); theory: Mincey et al. (2013); data collection methodology: Vogt and Fischer (2014); and, planning: Kenney et al. (2011)).

Conclusions and recommendations

Urban forestry as a field of research and practice aims to ensure the production and maintenance of trees and their benefits in cities. Erik Jorgensen of the University of Toronto, often considered the founding father of the term urban forestry if not the field itself, wrote in 1970 that urban forestry

> …does not deal [solely] with city trees or with single tree management, but rather with tree management in *the entire area* influenced by and utilized by the urban population…[including] the watershed areas and the recreational areas serving the urban population, as well as the areas lying between these service areas and politically designated urban areas [i.e., cities with municipal boundaries] and their trees. (Jorgensen 1970, as quoted in Deneke 1978, p. 499, *emphasis added*)

This original definition of urban forestry is much broader than many would commonly consider the field to be (see, for example, the variety of definitions cited in Konijnendijk et al. (2006)). With such a broad definition of what constitutes urban forestry, it is easy to see how broadly trained professionals who had experienced educational instruction and possess a knowledge and skill base rooted not only in urban forestry/arboriculture but in many different disciplines would be better suited to manage trees in cities than more narrowly trained specialists.

Our survey provides evidence that some disciplines (biology/ecology, forestry) are already very incorporated into the current urban forestry and arboriculture curriculum of 116 institutions, and the importance of several other disciplines is recognized, even while incorporation is not yet fully realized (urban planning, natural resource management, environmental science/studies). However, many major disciplines that have relevance and utility to urban forestry/arboriculture are not rated as particularly important to the field, much less incorporated into curriculum (anthropology/sociology, economics, engineering, public policy/public affairs). Furthermore, key concepts from within the social sciences are particularly lacking in urban forestry and urban forestry curricula, with only two concepts (GIS and community/public engagement) bearing an incorporation index score over 2.5 and closer to "more" than "less" incorporated (Fig. 5c). Our study provides valuable context for examining more closely modern notions of interdisciplinarity among educators in institutions of higher education with urban forestry and/or arboriculture curriculum, and can serve as a foundation on which to begin discussions of strengthening the interdisciplinary ties of the urban forestry field.

A long standing call for interdisciplinarity

Educators and others within the field of urban forestry/arboriculture have long called for an interdisciplinary approach to education, research, and practice in the field (Deneke 1978; Miller 1994; Miller et al. 2015). In 1978, Fred Deneke pointed to the need for a relatively narrow form of multidisciplinary in urban forestry, arguing for urban forestry education that incorporated arboriculture, nursery management, and turf management, as well as horticulture, landscape architecture, and even urban planning. And in the *Journal of Forestry* in 1994, career urban forestry educator Bob Miller advocated for locating urban forestry educational programs as a specialty or concentration within a traditional degree in forestry in order to ensure that graduates entering urban forestry practice are more broadly trained. Cecil Konijnendijk and Thomas Randrup said it most eloquently, in one of the closing chapters of their 2005 text, *Urban Forests and Trees*:

> Professionals are needed with an understanding of both a tree-based natural resource located on high-pressure sites and the *urban society* who is using this resource in many different ways. …When natural resource managers increasingly need to operate in urban environments, new skills are needed…social skills, public relations, communication with different stakeholders, public participation, conflict management, and so forth. … Because of the large variety in knowledge and skills required, no single discipline or profession dominate urban forestry. …[Urban forest professionals] require basic understanding of and openness towards both *the natural and the social science dimension* of their field. They have to learn to speak the language of different professionals and stakeholders, from general public to local politicians to engineers and city planners, and *become true team players.* Urban areas are characterized by high dynamics and urban forestry professionals need

> to keep themselves abreast with developments in their field. (Konijnendijk and Randrup 2005, p. 474, *emphasis added*)

But not all within the field are as supportive. In an essay tracing the evolution of schools of forestry, Miller and Lewis (1999) note that some traditional foresters lament that the environmental movement of the 1960s and 1970s in the USA resulted in the apparent dilution of the traditional forestry discipline by incorporating more environmentally and ecologically oriented coursework in to forestry curriculum, which even resulted in the re-branding of entire schools (e.g., the Yale School of Forestry and Environmental Studies). This trend continues to this day, in part to cope with declining enrollment in traditional forestry programs, at institutions of higher education in both North America and overseas, with forestry programs in the United Kingdom broadening into natural resource management programs and incorporating environmental studies curriculum (Leslie et al. 2006). O'Hara and Redelsheimer (2012) also caution that the identity of a traditional program can be lost when integrated within a larger or more broad discipline. Though neither programs of urban forestry/arboriculture nor related career opportunities are experiencing enrollment problems to quite the same degree, our study and others (e.g., Randrup et al. 2002; Andersen et al. 2002) show that there is apparently increasing recognition of the importance of an interdisciplinary urban forestry education. An interdisciplinary approach is important to the functioning of urban forestry and arboriculture professionals in an increasingly globalized and interconnected world.

Trade-offs

Ultimately, urban forestry/arboriculture programs (as all educational programs) are subject to trade-offs with respect to curriculum design (including the incorporation of interdisciplinary aspects): between depth and breath of coursework, in cost and length of the degree, between adhering to centuries-old tradition and adapting to meet modern developments, between attracting and retaining students and meeting accreditation requirements, adhering to credit limitations (e.g., maximum of 120 required credits) set by policy makers, in building the skills and knowledge required for a specific career and preparing students for broader civic and community life. Curricula are compromises between these factors. A recent student perspective piece in the *Journal of Forestry* spoke to these sentiments in regards to forestry programs (McGown 2015). McGown (2015) acknowledges the "image problem" of forestry and associated difficulties attracting students. Accredited forestry programs may also frequently overly restrictive requirements, including many lab courses, lengthy and potentially financially challenging summer field camps, or simply "too many courses" compared to other similar but "more flexible" degrees such as natural resource management (McGown 2015).

Although these concerns are specifically for forestry programs, as this survey revealed, arboriculture and/or urban forestry programs are commonly located within forestry departments, a potential weakness for these programs. Strengthening the interdisciplinary offerings of urban forestry/arboriculture programs has both positive and negative implications for managing these trade-offs. Increasing interdisciplinary offerings may increase the appeal of urban forestry/arboriculture and aid in student retention. However, increased interdisciplinary may also increase the number of courses required for the degree and thereby increase the length and cost of the degree, unless also accompanied by reductions in more "traditional" curriculum.

Recommendations

Our recommendations with respect to the trade-offs surrounding interdisciplinarity in curricula are twofold.

First, *interdisciplinary education to what purpose*? Practically, program directors and those involved in urban forestry and arboriculture curriculum design should not incorporate interdisciplinary coursework into program or degree requirements simply for the sake of interdisciplinarity. Rather, the goal should be to think about the *purpose* of incorporating interdisciplinary curricula or degree requirements with respect to educational outcomes, institutional mission, employment landscapes, and other specific concerns. Our study revealed that while disciplines and concepts from the natural sciences are relatively well incorporated into existing curricula, concepts from the social sciences are not incorporated into most programs. This perhaps reflects that the social sciences are perceived as most peripheral to the field, and that there is a lack of clear motivations for the need for and purpose of the broadest types of interdisciplinarity.

As educators of the next generation of urban foresters and arborists, we should consider *why* might we seek to cultivate an interdisciplinary ethos in students (and, for that matter, in faculty, staff, or others involved in the program)? If, as the World Conference on Higher Education (UNESCO 2010) and Sustainable Development Goals (OWG 2015) suggest, we seek future arborists and urban foresters that can prepare for and respond to the global sustainability challenges of the Anthropocene, interdisciplinary curricula should endow students with interdisciplinary knowledge and skills to this end. For instance, curricula should draw from environmental and sustainability science to incorporate coursework that teaches about the impacts of climate change on urban forests and trees and how to manage this green infrastructure under the constraints of increasing temperatures and highly variable precipitation. However, only with a clear idea of what we want

students to be able to *know* and *do* with interdisciplinarity ("learning objectives" in the parlance of education) can we begin to designate specific interdisciplinary core competencies for urban forestry and arboriculture education.

Second, *how might we assess whether arboriculture and urban forestry education is interdisciplinary?* This study did not attempt to calculate a metric to indicate the extent to which an institution's urban forestry and arboriculture curriculum is in fact interdisciplinary. Good assessment should evaluate the extent to which its students are achieving the stated learning objectives (Brown et al. 1997; i.e., the stated learning goals or objectives of an interdisciplinary program; see paragraph above). An example of such integrated assessment methods for interdisciplinary education in general is the Targeted Assessment Framework, developed to assess "interdisciplinary understanding," defined as "being well grounded in the disciplines," "showing critical awareness," and "advancing student understanding" (Boix Mansilla and Duraisingh 2007). For urban forestry and arboriculture, future research on interdisciplinary education should aim to synthesize the specific interdisciplinary learning objectives across programs, and then design assessment tools and indicators to evaluate student achievement of these objectives.

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