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An Automated Content Analysis of Forestry Research: Are Socioecological Challenges Being Addressed?

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Forests worldwide are increasingly threatened by a wide range of human-induced socioecological challenges, such as urbanization, invasive species, and climate change. Using automated content analysis, we analyzed 14,855 abstracts published in seven prominent applied forestry journals between 2000 and 2013 to determine the degree to which these publications are providing forest managers with the information needed to address these challenges. We found that most articles still focus on more traditional forestry topics (e.g., silviculture and timber harvesting), with limited evidence of effort to address socioecological challenges. Although these traditional topics are essential to forest management, framing this research within the broader context of contemporary socioecological challenges will improve forest managers' abilities to address these challenges and contribute to the sustainability of forest ecosystems.

Keywords: automated content analysis, literature review, interdisciplinary, research gaps, socioecological challenges, ecosystem services

Forest ecosystems provide many regulating, provisioning, supporting, and cultural services that are closely linked to human well-being (Gonzalez et al. 2005). Despite our reliance on forests, humans have and continue to exert substantial ecological strains on these systems. In the last 200 years, land-use change has resulted in the destruction of nearly 40% of the world's forests (Bryant et al. 1997, Gonzalez et al. 2005). The remaining forests have experienced mounting human-induced stressors such as fragmentation, climate change, and exotic invasion (Riitters et al. 2000, Chornesky et al. 2005, Allen et al. 2010, Oswalt et al. 2015). Decreases in forested areas, in conjunction with multiple human-induced stressors, may greatly diminish society's ability to extract and use the wide range of forest-based services on which it relies (Gonzalez et al. 2005).

These stressors raise obvious concerns for sustainable forest management, i.e., ensuring the long-term social, economic, and ecological benefits of forests. Forestry research can help the forest managers to face these challenges so long as the scope of this research is broad enough to encompass the complexity of these challenges (Winkel and Jump 2014). For instance, forestry research must investigate not only trees but also all other components of forest communities, including the ecosystem services that forests provide (Burley et al. 2001). Forestry research must also contribute to the development of viable management and policy practices to address human-induced stressors (Committee on Forestry Research 1990, Gonzalez et al. 2005, National Research Council [NRC] 2002). Finally, the diversity of resources and ecosystem services derived from forests necessitates the simultaneous management of multiple resources to meet the needs of a diverse range of stakeholders (Tanz and Howard 1991, Selin and Chevez 1995, Burley et al. 2001). This multiservice management paradigm underscores the importance of interdisciplinary research for understanding human-forest interactions and the sustainability of forest resources (NRC 2002, Gonzalez et al. 2005, Innes 2005, Balmford and Cowling 2006). Here we define (sensu Innes (2005)) "interdisciplinary" as interactions among scientists from historically distinct disciplines with the aim of ad-

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Table 1. List of journals (abbreviations) surveyed, their associated impact factor, year of first publication, count of abstracts from each used in our analysis, and link to their webpages stating their aims and scopes.

Journal	Impact factor	First published	Abstract count
Annals of Forest Science (AFS)	1.63	1923	1,212
Canadian Journal of Forest Research (CJFR)	1.56	1971	3,220
European Journal of Forest Research (EJFR)	1.96	1857	721
Forest Ecology and Management (FEM)	2.77	1977	7,145
Forest Science (FS)	1.09	1955	882
Forestry (FOR)	1.68	1927	650
Journal of Forestry (JF)	1.24	1902	1,025

The associated impact factor was from Web of Science (2014). Webpages are as follows: AFS, www.afs-journal.org/about-the-journal/aims-and-scope; CJFR, www.nrcresearchpress.com/page/cjfr/editors; EJFR, www.springer.com/life+sciences/forestry/journal/10342; FEM, www.journals.elsevier.com/forest-ecology-and-management; FS, http://www.eforester.org/Main/Library/Publications/Forest_Science/; FOR, www.oxfordjournals.org/our_journals/foresj/about.html; JF, http://www.eforester.org/Main/Library/Publications/Journal_of_Forestry/.

dressing a problem of common interest and as research that spans multiple research disciplines.

These research directions have been and continue to be recognized as important to the field of forestry (Committee on Forestry Research 1990, Burley et al. 2001, NRC 2002, Gonzalez et al. 2005) and have subsequently been pursued by many research programs. Further illustrating this need is the continued call from academic, government, and private forestry communities for greater incorporation of social and economic training into academic forestry programs (O'Hara and Salwasser 2015, Sample et al. 2015). Given this importance, it is imperative that the findings of the interdisciplinary research programs that address contemporary, human-induced stressors (hereafter referred to as "socioecological challenges") to forest sustainability reach forest managers. This information will help to ensure that managers are equipped with the most up-to-date information when devising management and policy strategies and help to ensure that these strategies are placed in the broader context of the many complex, socioecological challenges impacting forests.

One of the primary ways by which scientific information is disseminated to practitioners is through scientific journals having an applied focus. Many such journals exist in the field of forestry research. These journals aim to transfer scientific information pertaining to a wide range of forestry-related topics to land managers in ways that help to guide management efforts. Evaluating the degree to which research published in these journals addresses the many human-induced stressors impacting forests or the many ecosystem services that forests provide would help to determine whether forest managers are receiving the information needed to address these challenges. Such an evaluation would help forest researchers (i.e., scientists and applied forestry journals) to identify research strengths and gaps and to determine the actions that they may want to take to ensure that managers are provided with the information required to manage forests sustainably in the face of contemporary socioecological challenges.

We conducted an evaluation of the degree to which these elements are included in the abstracts of articles published between 2000 and 2013 in seven prominent applied forestry journals. Our main objectives were to determine: (1) the scope of research being conducted, (2) the prevalence of ecosystem services-related research, (3) the extent to which relevant socioecological challenges are being addressed, and (4) the presence of practical management and policy recommendations. To accomplish these, we used automated content analysis (ACA), a machine learning-based approach that is of great utility for reviewing massive amounts of literature (Smith and Humphreys 2006, Blei 2012, Nunez-Mir et al. 2016). This tool has been used extensively for reviews in other fields (Chen and Bouvain 2009, Cretchley et al. 2010, Travaglia et al. 2011), including forestry (Nunez-Mir et al. 2015). The findings of this review should help researchers better inform forest management and policy.

Methods

Selection of Literature/Journals

In March 2014, we used SCOPUS to obtain a total of 14,855 abstracts published between 2000 and 2013 from the following forest science journals: *Annals of Forest Science* (AFS), *Canadian Journal of Forest Research* (CJFR), *European Journal of Forest Research* (EJFR), *Forest Ecology and Management* (FEM), *Forest Science* (FS), *Journal of Forestry* (JF) and *Forestry* (FOR). We chose these journals based on the criteria described below, with the goal of surveying the literature published in journals with a high potential influence on the forestry community, a long history of publication, and broad self-identified aims and scopes (Table 1). The criteria used for journal selection were the following: (1) high impact factor relative to those of other forestry journals as designated by International Scientific Indexing (ISI), (2) a long history of publication, (3) an explicit aim to attract a diverse readership across the field of forestry, (4) an explicit aim to publish on the wide range of both tradi-

Management and Policy Implications

Forests are impacted by many socioecological challenges (i.e., human-induced stressors, such as urbanization, climate change, invasive species, and others) that hinder their ability to provide important ecosystem services sustainably. A key role of forest researchers is to provide forest managers with the information required to address these challenges, with applied forestry journals potentially serving as a channel for information transfer between these two parties. Nevertheless, we found that much of the research published in these journals focuses on more traditional forestry topics and provides little information/guidance on how to address contemporary socioecological challenges. We recommend three ways in which forest researchers can meet this need while still reporting important traditionally based forestry research: by placing traditionally based research into the broader context of ecosystem services and socioecological challenges, by promoting interdisciplinary thinking through communication of how research findings relate to social and economic aspects of forestry, and by making sure this information is highlighted in the abstracts of research articles to ensure its communication to even those readers just scanning an article. These recommendations will help to communicate still-needed, traditionally based forestry research in a way that helps forest managers to address contemporary socioecological challenges.

tional and emerging issues affecting forestry, and (5) an interest in informing forest management and/or policy. Impact factor values aim to quantify the importance of a journal to the academic community studying a given topic (Garfield 1994). Together with length of publication history, journals that satisfy these criteria are likely to be influential to the field of forestry. These criteria were used as a method of objectively identifying such journals. Certainly, there are other influential applied forestry journals; however, an analysis including all journals, although interesting and potentially revealing, falls beyond the scope of our review. We included the breadth of readership and content in our journal selection criteria as they are likely to identify the most comprehensive venues for forestry research. We made the assumption that managers use such venues to quickly access knowledge on a wide array of topics. For this same reason and to not introduce unwanted bias by inordinately featuring specific topics, we did not include journals having more narrowly focused scopes (e.g., *Forest Pathology* or *Agroforestry Systems*).

Automated Content Analysis (ACA)

Before conducting the ACA, we randomly selected and read a subset of 200 articles distributed equally among the seven surveyed journals to gain a comprehensive understanding of the topics being published in these journals. This understanding ensured that the questions we formulated both helped us to meet our objectives and were germane to the forestry literature (e.g., Fazey et al. 2005). To answer these questions using ACA, we had to designate the categories by which we would classify the reviewed literature. In ACA, these categories are called *concepts* (defined below). As an example, guided by the understanding obtained from our preliminary review, we selected 23 concepts, each representing a distinct research area within forestry, to answer the question "what are the most researched fields in forestry science?" From our preliminary review, we formulated seven questions and 35 corresponding *concepts* that would provide us the necessary information to fulfill our main objectives (Table 2).

We conducted the ACA on all 14,855 abstracts using Leximancer (Leximancer Pty Ltd., Brisbane, Australia). This program is a word mining software system that uses statistical algorithms, machine learning, and bootstrapping methods to discover and define *concepts* and to identify relationships among concepts (Smith and Humphreys 2006). Unlike single words, concepts represent groups of strongly interrelated words that collectively represent a common theme or idea (Smith and Humphreys 2006). By determining whether a concept is or is not in a body of text, ACA can provide quantitative output regarding the abundance and interrelatedness of concepts. There were two key benefits to using ACA over a manual review of articles. First, it allowed us to review a much larger body of literature than is possible with a manual review. Second, it helped us to limit issues associated with human subjectivity that may occur when one is trying to determine whether a particular article addresses a given topic or research question.

ACA is a three-staged process, detailed by Nunez-Mir et al. (2016), as per the following summary:

1. Concept identification—Potential concepts are "identified" through the establishment of *concept seeds*, i.e., frequently used single words that are likely to represent major themes or ideas in the surveyed text (Smith 2003). These concept seeds can be generated automatically by the software used to conduct the ACA (i.e., unsupervised seeding) or can be provided manually by the user (i.e., hand-seeding).
2. Concept definition—Each concept is defined by a group of concept seeds. Using the group of concept seeds established for each concept in the first stage, the software then constructs a thesaurus, i.e., a list of weighted single words that co-occur frequently by which each concept is defined.
3. Text classification—The surveyed text is then classified by concept at high resolutions. The text is divided into segments, each comprising a predetermined number of text lines (usually 2–3 lines). Each text segment is then scanned for concept seeds. If the summed weights of detected seeds for a given concept's thesaurus surpass the classification threshold, the text segment is determined to contain the concept and is therefore classified under it.

To establish the concepts by which the ACA program would classify text segments, we started the ACA process by performing unsupervised automated concept seed identification. In unsupervised automatic concept seed identification, the seeds used to identify the majority of concepts are dictated by the concepts and words already predominantly present within the abstracts reviewed, rather than by our own choosing. On further inspection of concept seeds identified by the program for the concepts listed in Table 2, we found that the program had not automatically identified concept seeds for several concepts of interest to our study, probably because these concepts were either discussed rarely or possessed relatively abstract definitions. We manually added concept seeds (i.e., hand-seeding) to identify these missing concepts. The complete list of concepts and their respective concept seeds used for our analysis can be found in Supplemental Table S1.[S]

Although the accuracy of ACA systems has been confirmed (Grech et al. 2002, Smith and Humphreys 2006, Penn-Edwards 2010), it is still necessary to ensure the correct definition and classification of all concepts, particularly those that are hand-seeded and/or that have abstract definitions (Nunez-Mir et al. 2016). To do so, we implemented a three-stage iterative validation process. First, we retrieved all text segments classified within each of the 35 concepts and randomly selected 10 text segments from each. Next, we manually verified the classification of the text segments. Reviewers were each provided with a random selection of classified text segments and asked to determine whether the segment was classified correctly ("yes") or incorrectly ("no") or whether they could not decide due to either lack of expertise or insufficient information in the text segment ("maybe"). Concepts with less than 90% accuracy were flagged and listed. Concept seeds of flagged concepts were inspected and adjusted accordingly through hand-seeding. Alternatively, if concept seeds appeared to be accurate despite the concept's low accuracy, other classification settings (e.g., the threshold for a segment to be classified for a concept) were adjusted. This validation process was repeated until each concept reached 90% classification accuracy, resulting in 27 of the 35 initially identified concepts relying on some

[S] Supplementary data are available with this article at http://dx.doi.org/10.5849/jof.15-144.

Table 2. Objectives, questions, and concepts used in our ACA to determine the status of forestry research.

Objectives	Question	Concept
Research scope	1. What are the most researched fields in forestry science?	Biomass/Biofuels
		Biometrics
		Community Ecology
		Economics
		Entomology
		Fire Ecology
		Forestry Technology
		Genetics[1]
		Harvesting[1]
		Hydrology
		Landscape Ecology
		Modeling
		Non-Traditional Forest Products
		Nutrient Cycling
		Pathology
		Remote Sensing/GIS
		Restoration Ecology
		Silviculture
		Soil[1]
		Stand Structure and Dynamics
		Sustainability[1]
		Tree Physiology
		Wildlife
Scope of ecosystem services research	2. What is the scope and extent of ecosystem services research in forestry science?	Biodiversity
		Nutrient Cycling
		Timber[1]
		Water Services
Socioecological challenges	3. To what extent has research in forestry science addressed different aspects of/ challenges to forest health?	Management[1]
		Recreation[1]
		Soil Services
		Invasion
		Fragmentation[1]
		Biodiversity
	4. To what extent has research in forestry science addressed urbanization in the context of forestry science?	Urban
	5. To what extent has research in forestry science addressed climate change?	Climate Change
	6. Has the interdisciplinary barrier been crossed in forestry science?	Interdisciplinary
Practical recommendations	7. Are practical management and policy recommendations being provided?	Management[1]
		Policy

[1] These concepts were automatically identified and defined by ACA software. The others were hand-seeded; i.e., we provided the words used to identify and define the concepts in the reviewed text, as described in the Methods section.

degree of hand seeding to be correctly identified (Table 2). Of the 299 concept seeds used to identify concepts (Supplemental Table S1), 71% were hand-seeded.

After validating the accurate identification of concepts, we determined the number of text segments in which all concepts were detected and used this information to assess the proportion of the literature reviewed exploring each concept over time and by journal. This output revealed the scope of the reviewed articles and the degree to which these articles explored topics reflective of ecosystem services, socioecological challenges, and practical management and policy recommendations. This output also allowed for cross-journal comparison and for the detection of temporal trends.

Results

We found seven journals that followed the criteria described in the Methods section (Table 1). The journals selected featured impact factors ranging from 1.24 to 2.77. The oldest journal selected was first published in 1857, whereas the youngest was first published in 1977. From each journal, we harvested between 650 and 7,145 articles, the majority of articles coming from FEM.

Scope of Forestry Research

We found that traditional technical or production-based fields were the predominant focus of the seven applied forestry journals surveyed. On average, the five most frequently studied topics identified in abstracts over time were stand structure (17.3%), silviculture (15%), soil (10.5%), modeling (10.3%), and nutrient cycling (6.2%) (Table 3; Figure 1A). With the exception of fire ecology (5.9%) and harvesting (5.1%), all other general fields were found in less than 5% of the reviewed text. These percentages were consistent across the years, providing little evidence of any temporal shifts in the focus of research topics (Figure 1B). However, we did observe variation among journals in the degree to which they focused on each field (Figure 1C). For instance, text from FS had a greater presence of modeling, text from FOR and EJFR had a greater presence of stand structure, and text from JF had a greater presence of silviculture.

Table 3. Average percentage of text segments from seven reviewed forestry journals (Table 1) in which the top fields of forestry research were detected from 2000 to 2013.

Field studied	Percentage (%)
Stand structure	17.3
Silviculture	15.0
Soil	10.5
Modeling	10.3
Nutrient cycling	6.2
Fire ecology	5.9
Harvesting	5.1
Landscape ecology	4.9
Biomass/biofuel	4.9
Community ecology	4.1
Tree physiology	3.0
Entomology	2.3
Wildlife	2.2
Genetics	2.1
Hydrology	1.9
Biometrics	1.7
Pathology	1.6
Economics	1.5
Restoration ecology	1.3
Sustainability	1.3
Forestry technology	1.1
Remote sensing/geographic information system (GIS)	1.0
Nontraditional forest products	0.1

Scope of Ecosystem Services Research

We found that the study of ecosystem services has largely focused on nutrient cycling (average of 6%), followed by biodiversity and timber (averages of 2.7 and 2.1%, respectively) (Figure 2A). All other ecosystem service categories were addressed in less than 1% of the text reviewed. Research on nutrient cycling has experienced a decline in general; whereas research on biodiversity has increased slightly; research on all other ecosystem services has been temporally consistent (Figure 2B). Noteworthy differences

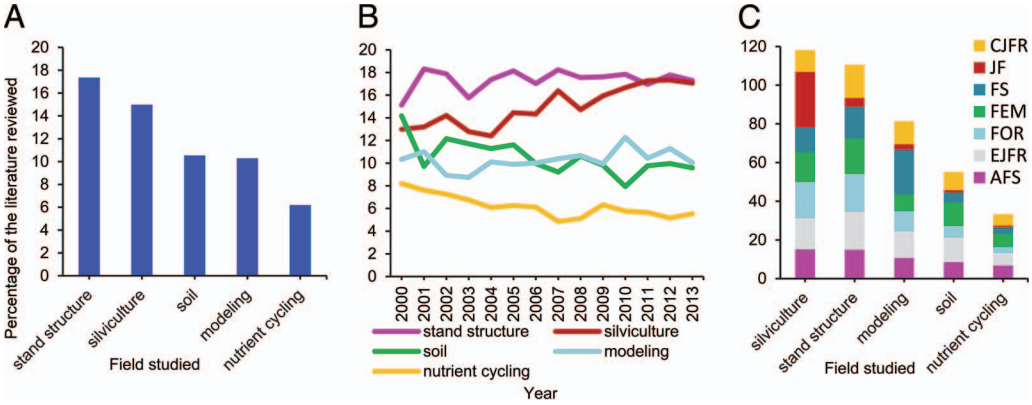

Figure 1. Assessment of the scope of forestry research reviewed as revealed by an ACA of all abstracts published from 2000 to 2013 in seven prominent forestry journals (Table 1). A. Bars represent the percentage of abstract text segments classified under each concept across all journals. B. Lines represent percentage of abstract text segments classified under each concept over time. C. Stacked bars represent the percentage of abstract text segments classified under each concept out of the total number of text segments analyzed for each journal (does not add up to 100%).

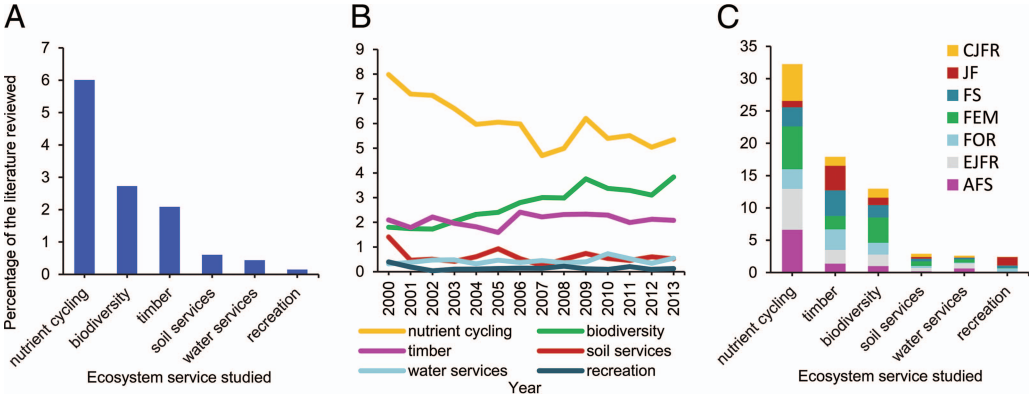

Figure 2. Assessment of the scope and extent of ecosystem services research in the forestry literature reviewed as revealed by an ACA of all abstracts published from 2000 to 2013 in seven prominent forestry journals (Table 1). A. Bars represent the percentage of abstract text segments classified under each concept across all journals. B. Lines represent percentage of abstract text segments classified under each concept over time. C. Stacked bars represent the percentage of abstract text segments classified under each concept out of the total number of text segments analyzed for each journal (does not add up to 100%).

among journals existed regarding the focus and extent of ecosystem services research (Figure 2C). For instance, the presence of the concept of biodiversity was approximately three times greater in FEM than in other journals. Similarly, the presence of the concept of recreation was greater in JF than in all other journals combined.

Extent to Which Socioecological Challenges Have Been Addressed

The presence of concepts reflecting socioecological challenges (e.g., climate change, urbanization, and forest health) was low (Figure 3A). For example, the concepts of climate change and urbanization were present in less than 0.5% of the reviewed text on average each year. In the case of aspects and challenges to forest health, we found biodiversity to be the most common concept, being present in 2.7% of the reviewed text each year. Invasion and fragmentation were found in less than 1% of the reviewed text. Our results also show that many studies are not utilizing interdisciplinary approaches to address socioecological challenges, as evidenced by the percentage of text containing the concept interdisciplinary falling under 0.05% on average for each year. Despite being present in a very small proportion of the reviewed text (less than 0.5%), the concept of climate change seems to be increasing, albeit slowly, with its presence increasing from 0.3 to 0.8% from 2000 to 2010 (Figure 3B). We found similar increases in the concepts of biodiversity (from 1.7 to 3.8%) and biological invasions (from 0.4 to 1.5%). Although the journals reviewed performed comparably for these concepts, a few exceptions are noteworthy (Figure 3C). The concepts of urbanization and interdisciplinary were present in text from JF up to 5 times more frequently than in the text of other journals. Reviewed text from FEM contained the concept of biodiversity twice as much as did the text from other journals.

Policy and Management Recommendations

The proportion of the reviewed text classified under policy was less than 0.7% (Figure 4A), with little annual change (Figure 4B). In contrast, we found that an average of 11.5% of the reviewed text from each year contained the concept of management (Figure 4B). This pattern was found to be consistent over time and across journals, with the notable exception of JF, in which the concept of management was found in 40% of the reviewed text, almost 4 times the proportions found in the other journals

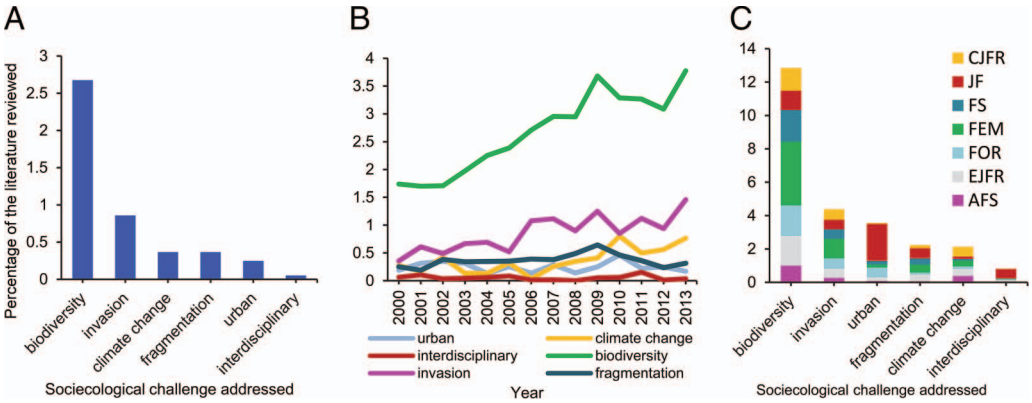

Figure 3. Assessment of the extent of research related to socioecological challenges in the forestry literature reviewed as revealed by an ACA of all abstracts published from 2000 to 2013 in seven prominent forestry journals (Table 1). A. Bars represent the percentage of abstract text segments classified under each concept across all journals. B. Lines represent percentage of abstract text segments classified under each concept over time. C. Stacked bars represent the percentage of abstract text segments classified under each concept out of the total number of text segments analyzed for each journal (does not add up to 100%).

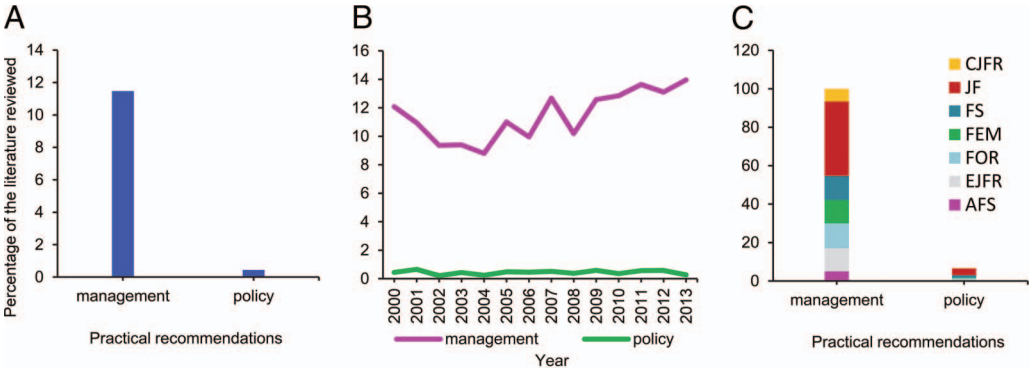

Figure 4. Assessment of the extent to which reviewed article abstracts attempt to provide practical recommendation for forests management and policy as revealed by an ACA of all abstracts published from 2000 to 2013 in seven prominent forestry journals (Table 1). A. Bars represent the percentage of abstract text segments classified under each concept across all journals. B. lines represent percentage of abstract text segments classified under each concept over time. C. Stacked bars represent the percentage of abstract text segments classified under each concept out of the total number of text segments analyzed for each journal (does not add up to 100%).

(Figure 4C). In addition, text from JF and FS also showed slightly higher percentages containing the concept of policy in comparison with other journals (3.5 and 1.3%, respectively).

Discussion

Overall Findings

We found that the majority of the reviewed text from the 14,855 abstracts harvested focused on more traditionally based forestry topics, such as stand structure, silviculture, soil, and harvesting (i.e., on the process of growing and harvesting trees). This finding is not surprising, given that these topics are the cornerstone of forestry. Nevertheless, despite the many socioecological challenges currently impacting forests and forest sustainability and the interest of reviewed journals in addressing these challenges, we found little evidence that the articles to which the abstracts we reviewed belonged to provide such information.

Only a small proportion of abstract text explored the topic of ecosystem services. The ecosystem services that were mentioned again seemed more attuned to traditional forestry research (e.g., nutrient cycling and timber). However, biodiversity was found to be a relatively highly explored ecosystem service, perhaps highlighting an increased recognition by forest scientists of the role that biodiversity plays in maintaining forests or in the importance of conservation. Nonetheless, the overall percentage of reviewed text focusing on biodiversity was still quite low.

Similarly, socioecological challenges were minimally explored in the majority of the abstracts reviewed despite the vast number of socioecological challenges impacting remaining forests (e.g., Riitters et al. 2000, Allen et al. 2010, Oswalt et al. 2015). This finding is perhaps surprising, given the potential negative effects of these challenges on the more traditional aspects and services of forests (e.g., silviculture and timber production). Despite a heightened awareness in the public and scientific community of the potential threat of climate change and invasive species to forest resources, including timber production (Sohngen and Mendelsohn 1998, Holmes et al. 2009), their mention remained low and only exhibited a slight increase over time. The low frequency with which forest fragmentation and urbanization are discussed despite their known negative effect on forests resources (Aizen and Feinsinger 1994, Faulkner 2004, Nowak and Walton 2005, Melo et al. 2010) is another example. Likewise, there was a near absence of the concept of interdisciplinary despite the

recognized need for interdisciplinary research when complex socioecological issues of applied ecological importance are addressed (Innes 2005, Balmford and Cowling 2006).

On the other hand, our results revealed relatively higher proportions of the analyzed abstract text addressing practical recommendations but with some limitations. Management was mentioned across all journals at relatively higher proportions (~11%) compared with the other concepts analyzed, suggesting that the seven targeted journals are in fact providing guidance on how to best manage forests. Nevertheless, given the applied nature of forestry science, one might expect this number to be even higher, as it was, for example, in JF (40%). In contrast to management, we found very little evidence of mention of policy recommendations, revealing a potential new direction for journals—the application of research findings to policy development and decisionmaking.

Our findings suggest that forest researchers could be doing more to communicate the information needed to make informed decisions on how to address the many complex socioecological challenges facing forests and in doing so help to meet the stated goals of applied forestry journals. As pointed out by Pullin et al. (2004) in the highly applied field of conservation biology, practitioners do not often access primary research because it is too time-consuming to locate, access, and read. The forestry journals reviewed here not only have broader scopes and applied relevance but also specifically target these individuals. Therefore, these journals could serve as gateways to integrate socioecological challenges into management practices and policy development. Barriers to the effective communication between researchers and professional foresters and policymakers can greatly hinder the application of scientific knowledge to real-world land management (Wright 2007) and by doing so greatly affect the sustainability of forests. By placing research findings in the context of key socioecological challenges impacting forests and the resolution of these challenges, applied forestry journals and the scientists who publish in these journals have the opportunity to facilitate this integration.

Other Factors Contributing to Findings

Where forest researchers choose to publish may be affecting our findings. For instance, some may choose to publish investigations on particular socioecological challenges, such as climate change, invasive species, and land-use change, in journals more focused on these topics (e.g., *Global Climate Change*, *Biological Invasions*, and *Landscape Ecology*), whereas others may be attempting to reach broader audiences by publishing in more general journals (e.g., *Conservation Biology*, *Ecology*, and *Ecological Applications*). There are also journals more focused on social and policy aspects (e.g., *Ecology and Society* and *Environmental Science and Policy*). The high percentage of abstracts containing the word "forest" or "forests" in the abstracts of some of these journals support this conjecture (Supplemental Table S2). In addition, because of the nature by which researchers are evaluated, researchers may choose to publish in journals having higher impact factors than those of most applied forestry journals. Finally, what some journals chose to publish may impact findings. For instance, FEM directs authors to submit manuscripts having social, economic, policy, or urban focuses to publish in alternative journals (Table 1).

However, we have evidence that our findings are not solely the result of where researchers choose to publish or what journals choose to publish. We conducted a follow-up ACA to determine the degree to which the abstracts from the 2014 International Union of Forest Research Organizations (IUFRO) World Congress revealed findings similar to those of this investigation (Supplement 3). Given the broad focus of the IUFRO Congress, one would expect patterns to differ between published and IUFRO abstracts if publication choice was a leading contributor to the low amount of research focused on ecosystem services and socioecological challenges. However, the results of the follow-up ACA echoed those obtained in the original ACA. Technical or production-based research was also predominantly featured in the IUFRO World Congress abstracts, whereas only a small percentage of abstracts discussed ecosystem services or socioecological challenges. So although forestry research on ecosystem services and contemporary socioecological challenges is certainly being conducted, the frequency with which it is conducted appears to remain low.

Two other factors related to scientific communication may also be affecting our findings. First, forest researchers might not be emphasizing the connections between their research and key socioecological challenges and management and policy implications. For example, literature on silviculture, although being of direct relevance to forest management and policy and to ecosystem services, might simply not be discussed within these contexts. This lack of discussion may reflect researchers' limited recognition of the potential links between traditional research and socioecological challenges (NRC 2002). Alternatively, it may indicate disinterest in these links to socioecological challenges. Second, choices on what to include in an abstract could be contributing to our findings. That is, socioecological challenges and ecosystem services may be discussed in the body of the article, but not in the abstract.

Recommendations

Each of the journals that we reviewed expressed in their statements of scope of interest in linking the findings of broadly focused forestry research, including on the socioecological challenges addressed here, to real-world forest management (Table 1). Achieving this goal is obviously challenging and requires that research papers communicate important information to forest managers regarding not only the socioecological challenges that may hinder forests from providing important ecosystem services but also the interdisciplinary aspects of these challenges and the potential management and policy recommendations for addressing them. Certain journals are already making strides in this direction. For instance, JF requires authors to include a "Management and Policy Implications" section after the abstract in which implications to foresters and policymakers are described in practical terms. On the other hand, FS classifies articles focused on applied research with practical implications for forestry professionals under the "Applied Research articles" designation (as opposed to "Fundamental Research articles"). Ideally, forest managers would be able to access a broad array of journals, including those that specialize or are more likely venues for research on socioecological challenges. However, because of the limited time and resources forest managers may be prone to utilizing mostly or solely applied forestry journals. Therefore, we suggest some approaches by which forest researchers, when publishing in applied forestry journals, may better communicate this information. In turn, these recommendations may help to expand readership beyond more traditionally focused individuals of the

forest management and research communities, for instance, to include social scientists interested in studying the political or cultural aspects of forest management practices. Such an expansion in readership may facilitate the interdisciplinary research needed to address these complex challenges (Innes 2005, Balmford and Cowling 2006, Winkel and Jump 2014). These recommendations are not new, as their need has been noted repeatedly by others (Committee on Forestry Research 1990, Burley et al. 2001, NRC 2002, Gonzalez et al. 2005), including within the scopes and aims of reviewed journals (Table 1). These recommendations are not meant to prompt shifts in research agendas but rather a reframing of ongoing research programs, making these more achievable. We recommend the following:

1. *Place research into the broader context of ecosystem services and the socioecological challenges that may hinder these services.* The fact that we found the majority of reviewed text to be focused on more traditionally based forestry topics, such as stand structure, silviculture, soil, and timber harvesting is not at all surprising given that these topics are important cornerstones of forestry. Nevertheless, these topics are directly related to ecosystem services and to the socioecological challenges that may hinder these services. Making this link more apparent whenever possible may greatly benefit the development of future forest management and policy practices.
2. *Communicate how research findings relate to social and economic aspects of forestry, i.e., promote interdisciplinary thinking.* The multifaceted nature of human-induced, socioecological challenges mandates interdisciplinary approaches to resolve these challenges. Earlier studies in forestry, as well as studies in the similarly applied field of conservation biology, have recognized this need and advocated the crossover of knowledge among disciplines, especially with the social sciences (e.g., Innes 2005, Balmford and Cowling 2006). Acknowledging these links may help forest practitioners to better reflect on the social and economic effects of their management and policy decisions.
3. *Highlight socioecological challenges, ecosystem services, interdisciplinary efforts, and management and policy implications in abstracts.* For better or worse, abstracts are oftentimes the first—or only—encounter of a reader with a scientific article. This may be particularly true for land managers, having to prioritize actual land management efforts over literature reviews. Therefore, it is vital that the abstract of a research article highlights the most salient findings of an investigation accurately to ensure the greatest real-world utility of these findings. This utility will probably be strengthened even further if authors highlight the broader implications of research findings. Journals can assist with this effort by increasing abstract word limits or requesting this information in similarly structured sections (e.g., the Management and Policy Implications section of the JF).

Conclusion

Forest researchers have the opportunity to provide forest managers and policymakers with the knowledge needed to address socioecological challenges. Applied forestry journals provide an important link between forestry researchers and forest managers through which knowledge can be transferred. Nevertheless, our review of article abstracts suggests that the majority of papers published in these journals display limited effort to address these socioecological challenges. The work published in these journals focuses on traditional topics that, although of great importance to forestry, are not being presented in a manner that facilitates the use of this knowledge by managers to address these challenges. Therefore, despite the fact that forest researchers are interested and likely to be pursuing interdisciplinary work and topics related to socioecological challenges, it would be greatly beneficial if researchers and applied forestry journals placed greater emphasis on communicating research findings within the context of these complex socioecological challenges. In this way, the forestry research community may help managers and policymakers to address these challenges and contribute to the sustainability of forests and forest resources.

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