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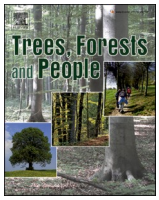

Cost- and biodiversity- "friendly" management: Evaluating conservation behaviors among Vermont maple syrup producers

Daniel F. Pratson [a,b,*], Rachelle K. Gould [b,c], Anthony W. D'Amato [b], Brendan Fisher [b,c]

[a] University of Maryland Extension, Western Maryland Research and Education Center, Keedysville, MD, 21756, USA
[b] University of Vermont, Rubenstein School of Environment and Natural Resources, Burlington, VT, 05405, USA
[c] Gund Institute for Environment, Burlington, VT, 05405, USA

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ABSTRACT

Privately owned forests comprise around 60% of the total forest cover across the contiguous United States and are managed for a range of economic outputs. Such private working forests contribute to large-scale conservation outcomes across the US and the globe. Voluntary conservation programs aim to motivate private forest owners to adopt biodiversity-focused management actions. However, it is often assumed that such management, and by extension, participation in programs, meaningfully increases financial costs borne by forest owners. Thus, these costs may preclude biodiversity-focused management across working forests. We use maple syrup production to test the claim that biodiversity-focused management incurs additional costs, especially for those enrolled in conservation programs. We analyzed reports of forest management actions, management costs, and conservation program enrollment among 70 individuals who manage 5,252 hectares of forest for maple syrup. Our core findings were that 1) most private forest owners engaged with several management actions linked to improved biodiversity outcomes, 2) there was no difference in management costs between those who implemented many "biodiversity friendly" management actions and those with fewer actions. Additionally, relationships between maple syrup yields and management costs did not differ across the number of management actions adopted, nor with producer enrollment in conservation programs. This finding suggests that the maple syrup industry, valued globally at $1.1 billion USD, could play a significant role in delivering habitat at minimal cost to producers. Beyond maple syrup, our study provides a backdrop for future work investigating the opportunity costs of biodiversity-focused forest management in working forests across the globe.

1. Introduction

Working lands refer to areas, including farms, forests, and rangelands, that are managed for combinations of both market and non-market benefits (Abrams and Bliss, 2013). Working lands conservation approaches leverage a range of ecosystem-dependent management practices with the objectives of preserving habitat by creating connectivity across networks of private parcels and protected areas and creating new or restoring former habitat for focal species or ecosystem functions (Eastburn et al., 2017; Kremen and Merenlender, 2018). Given that farms, forests, and rangelands characterize the majority of land use types across the US and the globe (Ramankutty et al., 2018), it is important we understand the roles that working lands, including working forests, may play in supporting broader biodiversity goals.

Highly extractive, single-objective management approaches in working, forested ecosystems have been scrutinized for their contributions to habitat loss and associated global biodiversity declines (e.g., Ehrlich, 1996; Götmark, 2013; Watson et al., 2018). In contrast, multiple-objective forest management approaches that balance resource extraction and biodiversity considerations have the potential to restore and conserve habitat conditions critical for a diversity of forest-dependent species (Franklin et al., 2018; Leak et al., 2014; Puettmann et al., 2012), although such approaches may be net negative for biodiversity if they reduce production of inelastic goods and therefor leak this production elsewhere (Balmford et al., 2025). These approaches can range from relatively intensive, harvest-based interventions (e.g., clearcutting to intentionally establish early seral forest conditions) to more passive considerations (e.g., not removing fallen or standing dead wood in forested stands). In many ways, large-scale biodiversity impacts depend upon management interventions

* Corresponding author.
E-mail address: dpratson@umd.edu (D.F. Pratson).

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implemented across geographic areas that are representative of habitat ranges and are comprised of a patchwork of forest ownership types (Lindenmayer, 2009; Robles et al., 2008). Private forest owners, who collectively own and make management decisions for around 24% of global forestland and nearly 60% of the forestland in the contiguous US, represent a critical population within the mosaic of ownership types that can contribute to multiple-objective forest management approaches across forested ecosystems (Butler et al., 2023; FAO, 2025).

Although private forest owners are poised to play a critical role in large-scale biodiversity conservation, scholars from across the globe (e.g., Butler et al., 2023; Matilainen et al., 2023; Tiebel et al., 2022) have identified how these owners often under-manage their properties, raising concerns around long-term timber supply and forest sustainability (Hatcher et al., 2013). The economic dynamics of private forest management are one of many factors that may lead to this under-utilization, limiting the widespread adoption of impactful conservation approaches across working forest owners and managers (Naidoo et al., 2006; Polasky et al., 2008). Thus, conservation approaches that involve targeted management actions within working forests, and working lands broadly, often rest on the assumption that these approaches increase overall costs. Two main factors help explain these assumed increases: incorporating habitat features among production areas can pose opportunity costs to landowners because land that would otherwise be profitable is managed for non-market ends (e.g., Balmford, 2021), and expanding conservation management across working lands can increase landowners' total management expenditures (e.g., Main et al., 1999). In response to the implications linked to these assumptions, conservation scientists and economists have actively looked to quantify the range of potential costs in the development and implementation of biodiversity-focused initiatives (Adams, 2024; Naidoo et al., 2006). Broadly, this work looks to inform cost-effective management interventions, which, if adopted, can lead to economically optimal benefits for both biodiversity and working lands managers (Ando et al. 1998; Ando and Langpap 2018; Fisher et al. 2011).

In the case of private, working forests, institutions ranging from governments to not-for-profit entities have designed and implemented different voluntary conservation programs that aim to connect forest owners and managers to specific, conservation-focused management practices, and in certain cases, incentivize the uptake of these practices (Floress et al., 2019; Ma et al., 2012). Such programs assume that implementing conservation-focused management can be prohibitively expensive, thus, program incentives (which include direct payments such as payments for ecosystem services or cost-share funding, increased market access through certification schemes, and social recognition, such as awards from professional networks) help to recoup costs, or to provide added benefits to landowners (Börner et al., 2020; Hanley et al., 2012; Ma et al., 2012; Wolff and Schweinle, 2022). However, program effectiveness fundamentally depends on the ability and willingness of forest owners and managers to engage with conservation-based management actions. Furthermore, difficulties around evaluating the conservation and economic outcomes linked to program participation has led to scrutiny around the benefits and costs of program establishment (Börner et al., 2020; Silver et al., 2015; Wolff and Schweinle, 2022).

When implemented effectively, voluntary conservation-focused programming represents a tool for incentivizing multiple-objective management approaches within private working forests in the US and globally. However, it is often unclear how participation in programs, especially those that do not provide explicit financial benefit, relates to on-the-ground management actions (Börner et al., 2020; Nielsen et al., 2018; Potter-Witter, 2005; Silver et al., 2015). Furthermore, there is little information on the relationship between program enrollment and management costs borne by forest owners and managers (Beach et al., 2005). These gaps in knowledge are significant, in that they can perpetuate two important assumptions linked to the design and impacts of voluntary conservation programs in working forests: a) management actions recommended by programming are costly, either by their detrimental impacts to yields (i.e., income), or by the increased expenses associated with management actions; b) landowners and managers enrolled in these programs implement management actions not taken by non-enrolled landowners and managers. It is important to investigate these assumptions in order to improve the design, uptake, and broader ecological and economic impacts of conservation programming (Börner et al., 2020). In our study, we addressed these gaps in knowledge by investigating the relationships among conservation programming participation, management actions, and costs.

We focused our study on maple syrup-producing forests in Vermont, a subset of largely private, working forests owned and managed for multiple objectives. These forests contribute to a wider industry across North America, with annual direct economic contributions of $1.13 billion CAD and $210 million USD to Canada and the US, respectively (Wang et al., 2025). We tracked engagement with a set of biodiversity-focused management practices, annual management costs, and enrollment in conservation programming to broadly answer the following questions: How are Vermont maple syrup producers managing their forests? Are there differences in management practices among conservation program enrollments? Is it costly to engage with biodiversity-focused forest management? Answering these questions allows us to better understand the potential tradeoffs at the producer level between biodiversity-focused management and financial costs to sap and syrup producers. By highlighting the prevalence of specific biodiversity forest management practices across Vermont sugarbushes, we assist local and regional efforts interested in multiple-objective management across private, working forests, and we address aspects of the two assumptions linked to voluntary conservation programming listed previously, contributing to global discourse around the costs of private, working lands conservation (Fisher et al., 2011; Naidoo et al., 2006; Polasky et al., 2008). Finally, we contribute to the growing body of literature on the socio-economic facets of maple syrup production (e.g., Ahmed et al. 2023; Byerly et al. 2019; Hershberger et al. 2023; Velardi et al. 2023).

2. Methods

2.1. Study context

Forested ecosystems cover about 36% of the land area in the US and >59% in the U.S. Northeast (Bigelow and Borchers, 2017). Private landowners own and make management decisions for about 77% of this forestland, including maple syrup producers. Communities in the US northeast refer to these producers as "sugarmakers," a term we adopt here. Sugarmakers are actively involved with collecting sap from sugar maple (*Acer saccharum* M.) and red maple (*Acer rubrum* L.) trees in forested parcels (called "sugarbushes") that collectively contribute to a yearly syrup crop valued at over $170 million USD across seven northeastern US states (i.e., Connecticut, Maine, Massachusetts, New Hampshire, New York, Pennsylvania, and Vermont) (NASS 2025). The long-term sustainability of maple syrup production depends on forested conditions suited to regional climate and disturbance patterns (Chapeskie et al. 2006). Paradoxically, market demand and recent production growth rates have the potential to incentivize management that encourages overstocking and maple monocultures in forests (Lenière and Houle, 2006; Whitney and Upmeyer, 2004), which can diminish forest resilience to disturbances and other climate-exacerbated changes (Rapp et al. 2019).

Our study context, the US state of Vermont, presents a useful case to illustrate the dynamics of conservation programming and forest management outcomes. Forestland covers around 74% of the state, and 78% is privately owned (Caputo and Butler, 2024). Vermont's present working forests, given their historical management regimes and natural community compositions (Forests of Vermont, 2020, 2021; Thompson et al., 2019), support high levels of biodiversity, including a range of both migratory and resident bird species (Bakermans et al., 2012; Long

et al., 2012). Maple syrup operations across Vermont have consistently produced the most maple syrup out of all US states since 1927; the 2023 sugaring season, for example, produced roughly 7.6 million liters, around 50% of total US syrup production (Census of Agriculture. Vermont: State and County Data 2024). Syrup production rates and the total number of trees tapped in Vermont have both consistently increased since 2007, suggesting that the industry will continue to expand (Cannella et al., 2021; Wang et al., 2025). Thus, both the economic and cultural significance of syrup production may exert significant pressures on Vermont's forested landscape and its ability to foster biodiversity over time (Hinrichs, 1998; Whitney and Upmeyer, 2004).

2.2. Survey development and distribution

As part of a larger, multi-faceted, research project, we developed an original survey to assess the management actions of Vermont sugarmakers, as well as the associated costs and values linked to these management actions (Full survey included in Appendix S1). Survey items and responses not linked to this study's research questions will not be discussed in this article. The survey was pre-tested and finalized through several iterations of feedback from maple industry extension professionals, sugarmakers, landowners, and scientists.

Our sampling approach focused on distribution through social and professional networks connected to Vermont sugarmakers, as no comprehensive list of Vermont sugarmakers exists. We distributed the survey, which was made available in both print and online formats, in three main ways. First, we solicited participation in-person during the 2023 Vermont Maple Meeting, an annual trade meeting hosted for sugarmakers. Second, we distributed the survey online via Qualtrics, an online survey host; several organizations who represent maple syrup and forest landowners in Vermont sent the survey URL and an invitation to participate to their email subscribers. Finally, we directly emailed the survey to a subset of USDA Organic certified sugarmaking operations, identified from the USDA INTEGRITY Database; this final approach mirrored that in Byerly et al. (2019) (Appendix S2). Given that we utilized multiple networks to distribute our survey, we are unable to report a unified response rate. In our final sample (n=70), nine questionnaires (13%) were completed by respondents in-person and the remaining 61 questionnaires (87 %) were completed online. Participants who provided their contact information were entered into a raffle to win 1 of 10 gift cards valued at $250 USD to compensate for the value of their time. The University of Vermont's Institutional Review Board reviewed study procedures and determined they were exempt under approved protocol #00001666.

2.3. Management practices and program enrollment

We tracked sugarmaker engagement with eight different forest management actions (hereby termed biodiversity-friendly management) associated with the provision of broad biodiversity outcomes in temperate forest ecosystems (Fig. 1). The eight practices were adapted from guidelines and recommendations outlined by two conservation-adjacent programs relevant to Vermont sugarmakers: USDA Organic Certification (VOF Guidelines for Certification of Organic Maple Sap and Syrup, 2016) and Audubon Vermont's "Bird-Friendly" Maple program (Bird-Friendly Sugarbush Management Guidelines, n.d.). Additionally, these practices are commonly referred by resources informing private forest landowners about forest management aimed to foster or improve biodiversity alongside other objectives (Beattie et al., 1993; Catanzaro and D'Amato, 2026; Long et al., 2012).

We documented sugarmakers' enrollment status in USDA Organic and "Bird-Friendly" programs and established four enrollment categories (i.e., not enrolled in either program, organic only, "bird-friendly" only, both organic and "bird-friendly"). The USDA Organic program and the "Bird-Friendly" program are similar in that the program guidelines of both can influence forest conditions. However, USDA Organic certifications require sugarmakers to participate in annual audits from third-party inspectors to enforce management guidelines, whereas the "Bird-Friendly" program currently has no auditing or enforcement mechanisms. USDA Organic certifications can command increased market

Associated programs	Management Practice	Biodiversity outcome(s)	Financial benefit(s)	Financial Cost(s)
Bird-Friendly + USDA Organic	***State-Certified Forest Management plan***	Uncertain, outcomes determined by plan goals and objectives (Clark & McLeman, 2011)	Access to VT Current use, which reduces property taxes. Access to Organic, which increases syrup market value.	Dependent on plan complexity (e.g., property maps, special management considerations) and property size
Bird-Friendly	***Facilitate Bird Habitat Assessment***	Uncertain, informs future management to encourage birds in sugarbush (*Bird-Friendly Sugarbush Management Guidelines*, n.d)	Uncertain short-term financial benefits	Transaction costs to facilitate assessment with biologist
Bird-Friendly + USDA Organic	***Maintain at least 4 snags per hectare***	Increased habitat opportunities for cavity-dwelling wildlife (Doerfler et al. 2018; Leak et al. 2014)	Uncertain short-term financial benefits, allows for tapped trees to senesce (instead of paying to cut them down)	Damage costs to equipment from falling limbs/snags
Bird-Friendly + USDA Organic	***Leave crowns after harvesting trees***	Creates physical barriers from browse to influence seedling regeneration; provides shelter for smaller invertebrates, reptiles, birds (Lindenmayer et al. 2006; Doerfler et al. 2018)	Reduced damage to sap-producing trees during harvests, less need for heavy felling equipment and contractors	Nuisance costs from navigating around dead wood. Opportunity cost if material was to be sold for energy feedstock
Bird-Friendly	***No harvesting during forest bird nesting season (May-July)***	Increases forest nesting bird survivorship during nesting season (Leak et al. 2014)	Uncertain short-term financial benefits	Transaction costs to negotiate harvests in other seasons. Loss of "non-sugaring" time to complete harvesting
Bird-Friendly	***Promote diverse midstory and understory vegetation***	Provides habitat opportunities for smaller invertebrates, reptiles, birds (Gamfeldt et al., 2013; Lindenmayer et al. 2001)	When achieved through selective cutting, the woody material might be sold for income	Dependent on cutting approach - minimal cost if done in-house. Financial costs if contracted out and timber is not merchantable
Bird-Friendly	***Eradicate non-native, invasive vegetation***	Opportunity for shade-based tree regeneration, which creates future forest habitat for diverse species (Leak et al. 2014)	Uncertain financial benefits, with the exception of NRCS-EQIP (cost-share program) monetary reimbursement	If using chemicals, licensed applicators are required ($ for labor and $ for chemicals.) Mechanical management may be less costly if done in-house
Bird-Friendly + USDA Organic	***Manage/maintain less than 75% sugar maple cover across sugarbush***	Allows for greater habitat opportunities for generalists across the forest (Gamfeldt et al., 2013; Lindenmayer et al. 2006)	Uncertain short-term financial benefits	High management costs if sugarbush is mostly sugar maple. High opportunity costs, given loss of tappable trees. Low/non-existent if sugarbush is already diverse

Less costly ↕ More costly

Fig. 1. List of eight measured biodiversity-friendly management practices, their associations with USDA Organic and Audubon Vermont's "Bird-Friendly" Maple program, proposed biodiversity outcomes, and financial costs and benefits (Gamfeldt et al., 2013; Lindenmayer et al., 2006).

pricing on maple syrup sales (Cannella et al., 2022); Audubon Vermont recognizes sugarmakers participating in their "Bird-Friendly" maple program with promotional signage and materials, but there is no current evidence that a market price premium exists for maple syrup produced in "Bird-Friendly" sugarbushes.

2.4. Annual financial costs and benefits

We collected reports on financial expenditures that represent a range of typical forest management costs associated with sugarmaking operations. Specifically, we measured sugarmakers' direct expenditures for the following: tree-harvesting, invasive and non-native species management, equipment damages from woody vegetation (i.e., falling limbs or snags), and forest management-related hired labor. Our initial goal was to measure direct financial costs associated with each of the eight management practices in Fig. 1. After receiving feedback on our questionnaire, we determined that several practices were best characterized by their opportunity costs, rather than direct financial expenses (See Fig. 1). Opportunity costs associated with private land management can be highly context-dependent, thus, challenging to accurately measure (Adams, 2024; Naidoo et al., 2006).

Several of the biodiversity-friendly management practices that we focused on in this study were also associated with potential financial benefits and lower financial expenditures. For instance, possessing a current, state-certified forest management plan allows Vermont forest owners to participate in the state's land-use tax abatement program, which can significantly decrease annual property taxes (Foster et al., 2008; Maker et al., 2014). Leaving crowns and woody material behind after tree harvests can reduce damage to residual overstory (i.e., sap-producing) trees (Huyler and LeDoux, 1999) and may save time and money (Clark and McLeman, 2012). Given that the magnitude of these potential benefits depends on the scale and biophysical conditions of sugarmaking operations, we did not explicitly measure or approximate their financial benefits. Instead, we accounted for relative benefits through sugarmaker reports of average annual syrup yield in liters, per tapped hectare. We converted annual sap yield responses using a 151 liters: 3.8 liters sap to syrup ratio commonly employed for maple syrup production (Perkins et al., 2022).

2.5. Analysis

We calculated a biodiversity-friendly management index for each sugarmaking operation in our sample. The index ranged from 0 to 1 and represents the proportion of eligible forest management actions (Fig. 1) completed by sugarmakers. We calculated each index score by dividing the reported number of completed management actions by the total number possible. There were several instances when sugarmakers indicated that specific practices were not relevant to their sugarbush; for instance, certain sugarmakers did not manage invasive, non-native plant species because such species reportedly did not exist in their sugarbush. To account for these instances, we calculated the index based on the total number of eligible management practices for each sugarbush. We considered the presence or absence of each practice to represent actions that equally led toward forest conditions supportive of biodiversity, and we did not account for more descriptive attributes (e.g., the extent of invasive species management). Thus, our biodiversity-friendly management indices represent an approximate estimation of management inputs across sugarbushes.

We divided the final distribution of biodiversity-friendly management indices into three groups that represented minimal, moderate, and high engagement with management practices. We determined the cut-off points of the three groups by calculating quartiles of the biodiversity-friendly scores: group 1 (termed minimal management) captured operations that scored below 0.58 (1st quartile), group 2 (termed moderate management) captured operations that scored between 0.58 and 0.85 (2nd, 3rd quartile), and group 3 (termed high management) captured operations that scored higher than 0.85 (4th quartile).

We collected information about both the frequency and total amount spent per of each type of management cost; we converted each cost type to reflect a USD per hectare per year unit to normalize data; in other words, to better compare costs across the range of operational scales found in our final sample. For instance, we calculated the damage cost of a 16-hectare sugarbush that reported $3000 in annual damage expenditures as $187.50/ha/yr. We also calculated a total management cost per sugarbush, which represented the sum of each normalized management cost type. Given that we deployed our survey in 2023–2024, we assume that the respondent reported expenses using that as a base year. Any internal assessment of the next years' inflation of costs likely reflect the acknowledged rates of that time period. We determined relationships between forest management costs and operational benefits by dividing annual syrup production per hectare by annual costs per hectare. Finally, we compared mean biodiversity index scores, management costs, and liter:dollar ratios with one-way ANOVA tests. All statistical analyses were performed using R Statistical Software (v4.0.2, R Core Team 2020).

3. Results

3.1. Sample description

We received 70 complete questionnaire responses. We received an additional 21 incomplete online responses. Online respondents took an average of 33 min to complete the questionnaire. The majority of sugarmakers in our sample were 55 years or older (71%), white (97%), college-educated (59%) and earned more than $75,000 annually (60%). For reference, demographics of private forest owners in Vermont reflect a population that is largely 55 years or older (83%), white (97%), and college-educated (80%) (Caputo and Butler, 2024). Fewer than 20% of sugarmakers reported that maple syrup or value-added maple products (candies, maple sugar, etc.) accounted for a majority of their yearly income.

Our sample represented 5,252 hectares of tapped forestland in 12 of Vermont's 14 counties. Sugarmaking operations ranged in size, averaging 7,689 taps deployed, with a range of 24 to 93,000 taps, and produced an average of 13,623 liters of maple syrup in an average season, with a range of 19 liters to 151,400 liters. Twenty sugarmakers (29%) indicated that they rented sugarbush acreage from others; 17 of these sugarmakers owned a majority of their sugarbush and rented additional acres to add to their operational scale, and three ran operations on strictly rented forestland. The distribution of operations in our sample was roughly equivalent to the 2022 USDA National Agricultural Statistics Service census data of Vermont sugaring operations, with a relatively consistent representation of operations by tap size class and with

Table 1
Comparison of this study sample's operational characteristics against 2022 USDA NASS Census data.

	2022 USDA NASS Census		*Study Data*	
Size Class (# Taps)	Total Operations	Liters Syrup Produced	Total Operations	Liters Syrup Produced*
1–99	69 (5%)	1,722 (0%)	3 (4%)	2,059 (0%)
100–499	279 (19%)	57,823 (0%)	9 (13%)	1,658 (0%)
500–999	197 (14%)	117,789 (1%)	4 (6%)	1344 (0%)
1,000–1,999	179 (12%)	221,457 (2%)	10 (14%)	16,257 (2%)
2,000–2,999	143 (10%)	396,305 (3%)	10 (14%)	37,774 (4%)
3,000–4,999	152 (11%)	676,111 (6%)	8 (11%)	40,878 (5%)
5,000–9,999	191 (13%)	1,851,141 (16%)	13 (19%)	99,920 (11%)
10,000+	223 (16%)	8,578,116 (72%)	13 (19%)	688,113 (77%)

*Six responses omitted due to reporting raw sap yields.

most syrup produced from operations with 10,000 taps or more (NASS 2024) (Table 1). See Appendix S2, Tables S1, S2, and Figure S1 for additional descriptive statistics of the study sample.

3.2. Distribution of biodiversity-friendly management practices across sugarbushes

We found that the average biodiversity index score across all sugarmakers was 0.68 (SEM ±0.02), which indicates that on average, sugarmakers engaged with more than half of the eligible biodiversity-friendly management actions in their sugarbushes. Most sugarmakers (87%) had a state-certified forest management plan, which represented the most common biodiversity-friendly management practice across our entire sample. Sugarmakers also commonly reported that they left crowns and branches after harvesting trees (97% with 12 N/As excluded) and maintained two or more dead standing trees (i.e., snags) per acre of sugarbush (89% with 8 N/As excluded). 64 % of all sugarmakers reported that they managed their forest in a way in order to recruit tree species other than sugar maple. Sixty-one percent (with 3 N/As excluded) of sugarmakers indicated that they employed management to increase the diversity of their sugarbush midstory and understory. Sixty-nine percent (with 15 N/As excluded) of sugarmakers reported managing invasive vegetation, 62% (with 12 N/A's excluded) reported that they focused their tree harvesting activities in months outside of forest bird nesting season, and 47% indicated that they had a bird habitat assessment performed in their sugarbush (Fig. 2).

3.3. Differences in biodiversity-friendly scores across program enrollment

We found significant differences in average biodiversity-friendly management scores across enrollment in USDA-Organic and "Bird-Friendly" maple programs ($F(3, 66)=10.02$, $p<0.001$). Specifically, sugarbushes enrolled in both organic and "bird-friendly" scored significantly higher than non-enrolled sugarbushes and organic sugarbushes. Also, "bird-friendly" sugarbushes scored significantly higher than organic sugarbushes (Table 2).

3.4. Relationships between financial costs and three biodiversity-friendly management groups

We compared mean annual management costs (i.e., the sum of each normalized management cost type) across the three "minimal," "moderate," and "high" groups calculated from the biodiversity-friendly management scores. Given the distribution of the summed management cost data, where maximum management costs were >25 times higher than the median cost of $23.85/ha/yr (IQR: $6.28 - $73.10), we truncated the cost data to exclude below the 5th percentile ($0.01/ha/yr; 11 sugarbushes) and above the 95th percentile ($383.35/ha/yr; 4 sugarbushes),which led to a subset of 55 responses with an average management cost of $71.03/ha/yr (IQR: $12.97 - $72.07). There were no significant differences in average annual management costs across the three management groups ($F(2, 52)=1.05$, $p=0.36$). Median annual management costs were $46.46/ha/yr (IQR: $16.08 - $158.85) in the "minimal" group (17 sugarbushes), $21.96/ha/yr (IQR: $12.02 - $67.44) in the "moderate" group (23 sugarbushes), and $25.47/ha/yr (IQR: $13.83 - $49.85) in the "high" group (15 sugarbushes) (Fig. 3).

Table 2
Differences in mean "biodiversity-friendly" scores across program enrollment types; differences in superscripts represent statistically significant differences in means.

Program enrollment status (*n*)	Mean biodiversity-friendly score (SD)
Not enrolled (25)	0.63 (0.17)[c]
Organic (13)	0.50 (0.19)[bc]
"Bird-Friendly" (13)	0.75 (0.17)[ab]
Organic + "Bird-Friendly" (19)	0.81 (0.15)[a]

3.5. Benefits and costs across three biodiversity-friendly index groups

We compared sugarmakers' annual syrup yields to annual management costs across the three index groups to determine how the costliness of employing increasing degrees of biodiversity-focused forest management practices might interact with productivity. We divided benefits (annual syrup yields, in liters) by costs (annual management costs, in dollars) to produce a liter:dollar ratio. Six sugarmaking operations did not report annual syrup yields, thus, we analyzed 51 responses. There were no significant differences in mean syrup yield and management cost ratios across the three levels of "biodiversity-friendly" scores ($F(2, 49)=0.49$, $p=0.62$). Median ratio values were 3.83 (IQR: 0.71 – 8.56) for the "minimal" group, 4.29 (IQR: 1.38 – 13.8) for the "moderate" group, and 5.71 (IQR: 2.89 – 13.1) for the "high" group (Fig. 4).

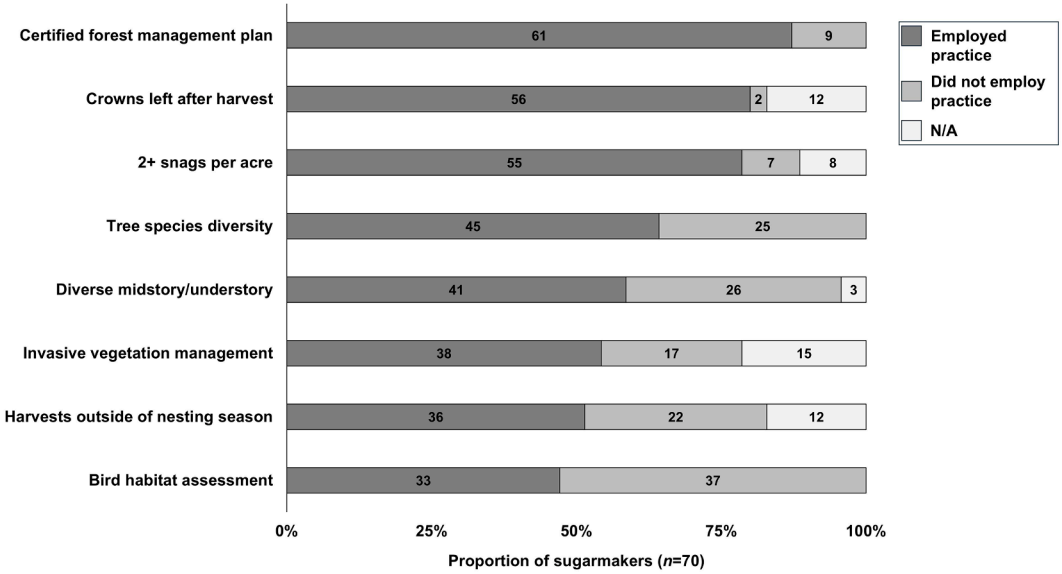

Fig. 2. Distribution of "biodiversity-friendly" management practices across sugarmaking operations in our study sample.

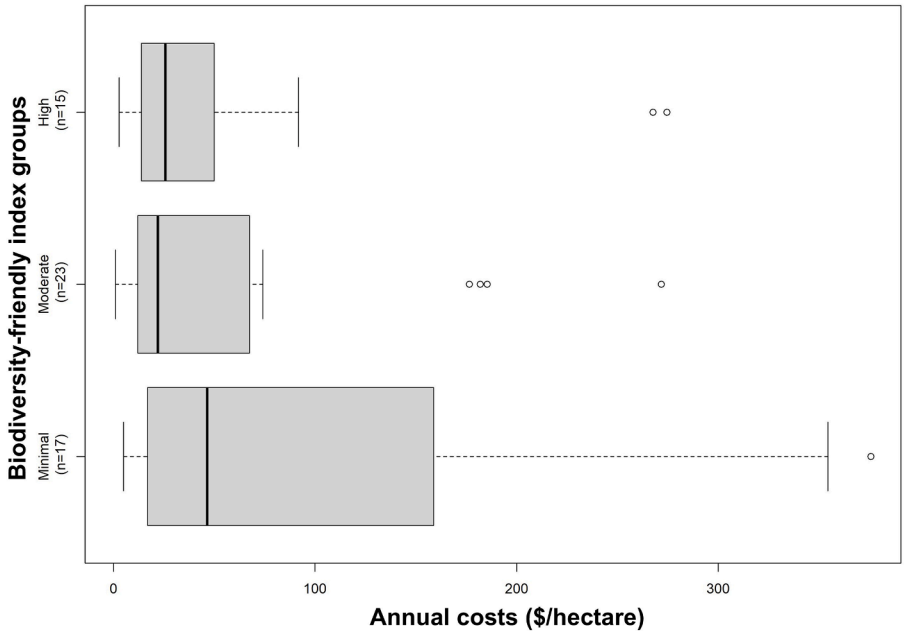

Fig. 3. Annual forest management costs (normalized by dollars spent per hectare of sugarbush) across the three "biodiversity-friendly" index groups.

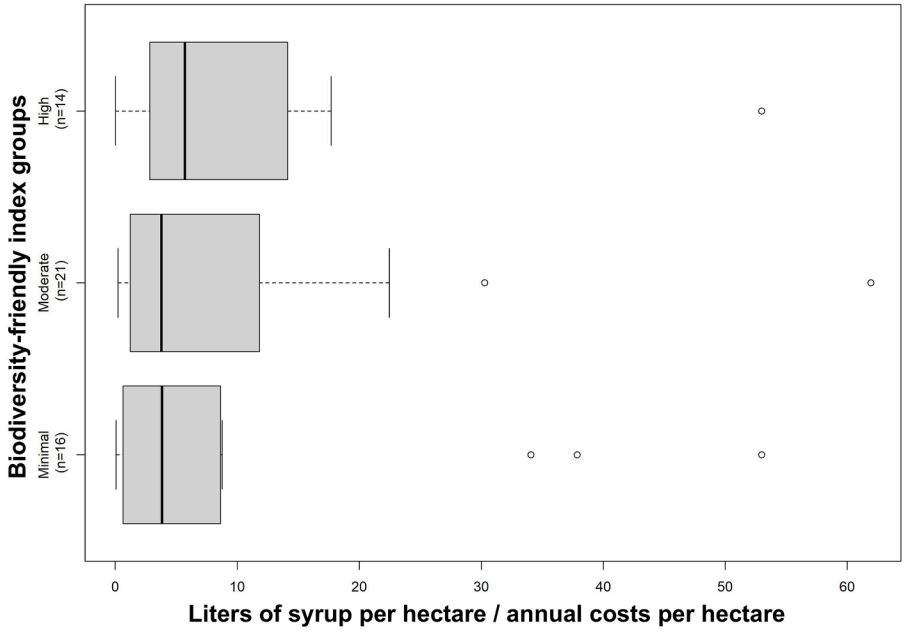

Fig. 4. Ratios representing the relationship between annual syrup yields and management costs distributed across the three "biodiversity-friendly" index groups.

3.6. Benefits and costs across degrees of program enrollment

We compared the average liter:dollar ratios of annual syrup yields to annual management costs across the four different configurations of enrollment (or not) in USDA-Organic and "Bird-Friendly" Maple. There were no significant differences in this average ratio across the four levels of program enrollment ($F(3, 48)=1.77$, $p=0.17$). Median ratio values were 3.41 (IQR: 1.1 – 6.85) for those who were not enrolled in any programming, 8.31 (IQR: 1.53 – 30.1) for those who were enrolled in USDA-Organic, 4.23 (IQR: 1.03 – 15.02) for those who were enrolled in "Bird-Friendly" maple, and 5.34 (IQR: 2.81 – 14.45) for those who were enrolled in both Organic and "Bird-Friendly" (Fig. 5).

4. Discussion

Multiple objective management approaches on private, working lands have been shown to contribute to biodiversity conservation across the globe (Cortés Capano et al., 2019; Hanley et al., 2012; Kremen and Merlander, 2018). Voluntary conservation programs that recommend specific management practices can incentivize actions that lead to the provision of biodiversity outcomes (Börner et al., 2020; Ma et al., 2012; Potter-Witter, 2005). However, gaps in knowledge around the actual costs of, and program-driven uptake of, additional management actions can hinder program design and evaluation (Pierce et al., 2008; Silver et al., 2015; Wolff and Schweinle, 2022).

In our investigation of Vermont sugarmakers, we found that annual management costs did not differ across the levels of biodiversity-friendly

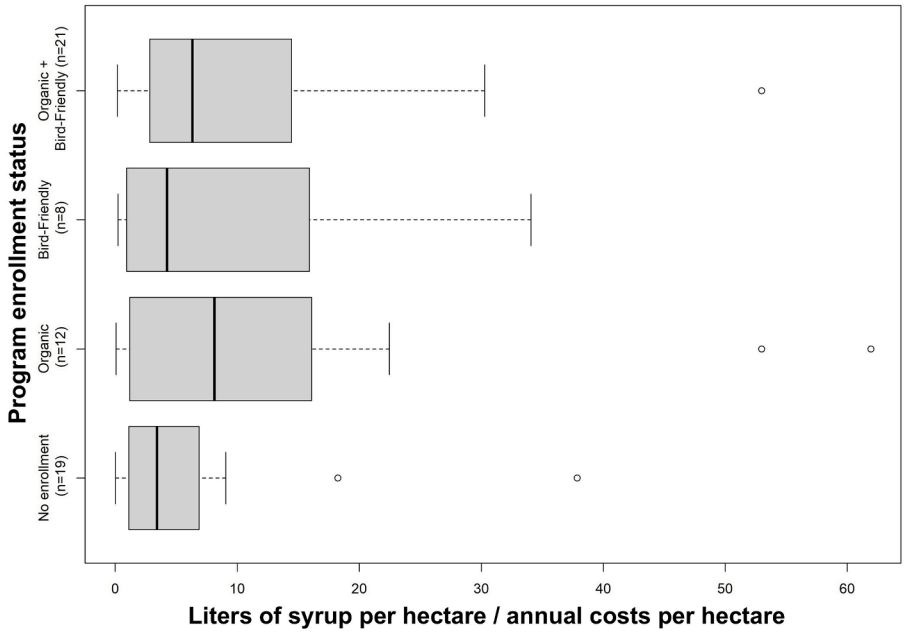

Fig. 5. Ratios representing the relationship between annual syrup yields and management costs distributed across four different degrees of program enrollment.

management, nor did the ratio of annual syrup yields to management costs. This finding challenges the assumption that conservation-focused management automatically leads to high costs, and indicates that, in our study case, financial outcomes are not meaningfully impacted by such management. We also found relatively high engagement with a suite of biodiversity-focused management practices, especially among sugarmakers enrolled in Audubon Vermont's "Bird-Friendly" program. This finding challenges the assumption that program participants "do more management," as solely USDA-Organic producers in our study reported carrying out significantly fewer management actions than "bird-friendly" producers. Taken together, our study suggests that many owners and managers of working maple syrup-producing forests in Vermont managed for biodiversity at low cost, and that management actions differed across degrees of voluntary program engagement. These findings are significant to the broader maple syrup industry, given its potential role in providing both critical habitat for wildlife and economic returns to sugarmakers. Furthermore, these findings contribute nuanced insights to global discussions around the roles of working forests, and working lands, broadly, in biodiversity conservation efforts (Cortés Capano et al., 2019; Fisher et al., 2011).

4.1. *Distribution of forest management practices across sugarbushes*

In our analysis of management practices across Vermont sugarbushes, we found that most sugarmakers engaged with forest management actions linked to lower expected costs, (Fig. 1), such as maintaining a state-certified forest management plan, leaving limbs after tree harvests, and maintaining at least four snags per hectare. Fewer sugarmakers engaged with practices with higher potential costs, such as harvesting trees. Notably, less than half of our total sample of sugarmakers reported that they had hosted a bird habitat assessment in their sugarbush, a practice predicted to come at a minimal cost to sugarmakers, but perhaps also the activity with the least clear benefit to syrup production. We discuss these four specific management actions, selected because uptake in our sample was especially high or low, in relation to their adoption and associated costs in working forests.

A majority of private forest owners in Vermont do not have a formal, certified management plan, a trend consistent among private forest owners across the US (Caputo and Butler, 2024). Our data indicates that maple sugarmakers represent a subset of Vermont forest owners and managers that readily engage with this management tool. Although private forest owners pay fees for forest management plans, both for their development and for periodic renewal, they are required for participation in several programs associated with potential financial benefit, including Vermont's Current Use land tax abatement program, management cost-sharing, and when relevant, USDA Organic. Thus, the benefits linked to forest management plans appear to outweigh initial establishment costs, as highlighted by their high adoption across sugarmakers in our study. The links between forest management plans and biodiversity outcomes, however, are less direct. Forest management plans document forest owner goals and recommend specific practices that can be taken to reach those goals (Beattie et al., 1993; Long et al., 2012). Surprisingly little research evaluates the extent to which forest management plans are carried out on the ground, thus, it remains unclear whether forest management plans are more valuable for their tax savings or for their assistance to landowner management planning.

Most sugarmakers retained or recruited high levels of woody material (i.e., leaving crowns and branches after harvesting trees and maintaining four or more dead standing trees per hectare) in their sugarbushes. Downed woody material can serve as important habitat for vertebrate and invertebrate species in forested ecosystems (Marcot, 2002; McComb and Lindenmayer, 1999); our findings indicate that Vermont sugarbushes likely host an array of habitat via woody material in the understory. Our findings align with Clark and McLeman's (2012) study of sugarmaker management behaviors in Ontario, which noted that many sugarbushes contained high amounts of coarse woody material. The authors attribute leaving woody material to relative ease of adoption; sugarmakers may be more inclined to adopt a management approach (e.g., leaving woody material after a harvest) that does not require additional, potentially costly effort to complete. Woody material can cause costly damage to operational infrastructure in sugarbushes (e.g., disconnecting tubing between trees), which was reflected as a portion of the damage costs borne by sugarmakers in our study. However, benefits linked to time savings, and wildlife habitat (Doerfler et al., 2018) may have motivated the high engagement among sugarmakers in our sample.

Slightly more than half of sugarmakers harvested trees outside of months (May through July) that correspond with forest bird nesting season in the Northeast US (Leak et al., 2014). Sap is generally harvested in early spring (Rapp et al. 2019; Rapp et al. 2020; Whitney and

Upmeyer 2004), and sugarmakers spend significant portions of the months preceding and following the harvesting season tending to their operations, which can include activities such as tapping trees, organizing equipment and maintaining tapping infrastructure. This leaves the summer months as some of the only ones available for timber harvesting, especially with increasingly warm winters that make harvesting in winter often untenable (Rittenhouse and Rissman, 2015). Although timber harvests in the same stand are often spaced over several years to allow for regrowth, shifting harvesting from summer months to other times of the year may allocate time and resources that would have otherwise gone to preparing for sap collection. We also found that slightly under half of sugarmakers had hosted bird habitat surveys in their sugarbushes. Intensive habitat surveys require sugarmaker coordination with, and payment of, trained ecologists. Taken together, these results suggest that sugarmakers may be less inclined to engage with specific management approaches or tools that are logistically onerous, thus, linked to opportunity costs and transaction costs. Broadly, our descriptive findings shed light on specific forest management actions employed across Vermont sugarbushes and improve sparse understandings of discrete, private forest landowner management behaviors (Butler et al., 2023; Clark and McLeman, 2012; Silver et al., 2015).

4.2. Biodiversity-friendly management scores and program enrollment

We found significant differences in average biodiversity-friendly management scores across conservation program enrollments. Sugarmakers involved with both USDA Organic and "bird-friendly" programs scored highest, followed closely by those enrolled only in the "bird-friendly" program. Notably, those enrolled strictly in USDA Organic scored lowest. In general, guidelines associated with conservation programming can assist forest owners by informing clear objectives and identifying the appropriate management approaches to meet those objectives. Our data suggest a positive relationship between conservation program enrollment and higher engagement with biodiversity management, similar to results in two different studies of Michigan private forest owners and their engagement with voluntary landowner-assistance programs (Potter-Witter, 2005; Schram et al., 2021). The fine-grained differences in management across program type contribute nuance to general assumptions of conservation programs (i.e., that those who are enrolled do more), and suggest that differences in conservation program messaging and goals may impact biodiversity-focused management across larger landscapes.

The conservation-focused aims linked to the "bird-friendly" program contrast with the largely market-driven focus of organic certification (VOF Guidelines for Certification of Organic Maple Sap and Syrup 2016; Bird-Friendly Sugarbush Management Guidelines, n.d.). Furthermore, the "bird-friendly" program is able to connect with, and recruit from, forest owners that would otherwise not be eligible for an audit-based certification program based on size or commercial output (Börner et al. 2020). Thus, "bird-friendly" programming and management guidelines appear to appeal to a wide range of environmental values potentially salient with sugarmakers (Himes et al., 2024; Himes and Muraca, 2018; Pratson, 2025). This is consistent with values expressed by a broader sampling of forest landowners, as 88 % of private forest owners across the US indicated that "protecting nature or biological diversity" was of some importance to their management goals (Caputo and Butler, 2024). As private, working forestland is increasingly owned with the intent to reflect diverse environmental values, programs that reflect and express these values can assist owners in working towards biodiversity outcomes.

However, we are unable to claim that program enrollment, and any associated management, led to discrete biodiversity outcomes. This conceptual leap between enrollment and ecological impact has been considered in select reviews and meta-analyses, which collectively indicate that biodiversity outcomes are highly dependent on geographical context, and that program interventions are often carried out in contexts where there exists lower pressure on local natural resources (Börner et al., 2020; van der Ven and Cashore, 2018; Wolff and Schweinle, 2022). Research in Vermont forests, however, has linked enrollment in Forest Stewardship Council certification to forest conditions supportive of biodiversity (e.g., Foster et al., 2008). Similarly, Maker and colleagues found that participation in the state's Current Use tax abatement program was linked to increased "sustainable management practices" (Maker et al., 2014). As such, future research efforts that compare sugarbush biophysical conditions across management regimes may consider connections between enrollment status and on-the-ground management (Faccio et al., 2023).

Given the biodiversity-related benefits linked to participation in Audubon's "Bird-Friendly" program, the opportunity exists to explore how to offset internal program costs. Currently, the program is free for sugarmakers to participate, where external grant funding pays for bird habitat surveys and promotional materials. If the program population and need for third-party auditing expands, financial mechanisms such as syrup price premiums or cost-sharing assistance may be required for the program to be sustainable (Conde, 2023). Thus, future research that evaluates consumer willingness to bear market price premiums attached to "Bird-Friendly" syrup can inform the development of such financial mechanisms.

4.3. Relationships among costs and biodiversity-oriented forest management

Sugarmakers reported spending a yearly average of $71.03/ha/yr (IQR: $6.28 - $73.10) on total forest management expenditures that included harvesting costs, invasive species management costs, paid labor costs, and damage costs. Average costs did not differ across levels of our biodiversity-friendly forest management score, nor did the ratios of annual syrup yields to management costs (i.e., liter:dollar ratios) differ across management levels or program enrollment types. Our findings indicate that certain forest management practices readily accomplished within the context of sugarbushes may positively impact biodiversity at minimal or no additional costs to forest owners. As such, these results challenge assumptions that costs increase with the adoption of biodiversity-focused management actions. Voluntary conservation programming that looks to play a meaningful role in achieving biodiversity outcomes can promote similar management practices to sugarmakers, especially as maple syrup production rates expand across large portions of forest habitat in the Northeast and Midwest US and Canada (Isselhardt, 2023).

Sugarmakers reported a wide range of annual forest management costs, with several indicating that their annual costs were >25 times higher than the median annual management cost ($23.85/ha/yr). The wide range found in our results is consistent with other studies that have looked to quantify the range of management costs borne by private forest owners in the US (Arano et al., 2002; Callaghan et al., 2019). Scoping reviews and meta-analyses of forest management trends almost universally indicate that management is more frequent and less costly per hectare in larger parcels, yet these studies focused their analyses on parcels primarily utilized for timber production (Beach et al., 2005; Londo and Grebner, 2004; Silver et al., 2015). Since most sugarbushes house networks of plastic tubing, total management costs may be tied more to a sugarmaker's capacity to dismantle select sections of tubing and less on parcel size (Sendak et al., 1982). This range may be further explained by potential errors that result from self-reports of management data across relatively large parcels and long time periods (Dang et al., 2020; Winkler-Schor et al., 2024).

As outlined in Fig. 1, specific management behaviors were linked to varying degrees of costs and benefits to sugarmakers. For instance, tree harvesting can yield significant financial benefit relative to costs (Long et al., 2012; Palik and D'Amato, 2017), whereas management of invasive, non-native vegetation has no clear financial benefit. By integrating syrup yields as a measure of benefit, our data suggest annual forest

management expenditures, even in sugarbushes that report high levels of management action, are exceeded by production benefits. When considering the potential financial benefits associated with the eight forest management practices that we tracked across sugarbushes (Fig. 1) alongside syrup production benefits, our study indicates that discrete financial costs may not play a strong role in inhibiting conservation-focused forest management in the context of maple syrup operations. This result is significant, as several previous studies have identified management costs in working lands as significant barriers toward practice adoption, and ultimately, conservation outcomes (e.g., Adams et al., 2012; Main et al., 1999; Naidoo et al., 2006; Polasky et al., 2008).

5. Conclusions

Our study investigated the extent to which Vermont sugarmakers engaged with select biodiversity-focused forest management practices, and whether those practices were associated with meaningful differences in annual management costs. We found that most practices were common across the majority of sugarbushes in our sample, and that costs were not significantly associated with increasing engagement with biodiversity-friendly management. Future research may look to expand considerations of different forest management practices associated with specific conservation-related outcomes. Furthermore, work may look to collect additional information on costs (e.g., opportunity costs, transaction costs) directly associated with practices to better understand the motivators and barriers around biodiversity focused management.

Sugarbushes represent working forested landscapes that can be managed both for financial benefit and the provision of non-market ecosystem services and broader biodiversity conservation (Clark and McLeman, 2012; Kremen and Merenlender, 2018). Our sample of sugarmakers in Vermont demonstrates that management linked to conservation goals can be accomplished at low cost across a range of operational contexts. The maple syrup industry is made up of many sugarmakers that collectively own and manage large expanses of forestland across the northern US and Canada. Our study suggests that collectively, this industry has the potential to contribute to large-scale conservation outcomes by promoting low-cost, biodiversity-focused management practices across sugarbushes. As new markets emerge that aim to incentivize biodiversity conservation (e.g., Croci et al., 2025), the maple syrup industry may be able to further grow in economic value while retaining and managing critical habitat. Voluntary conservation programming can play a key role in motivating sugarmaker engagement with such management approaches; thus, maple syrup industry groups may look to connect sugarmakers with such programs. More broadly, this type of programming may prove useful in other types of working lands across the globe.

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CRediT authorship contribution statement

Daniel F. Pratson: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rachelle K. Gould:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Anthony W. D'Amato:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Brendan Fisher:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.tfp.2026.101223.

Data availability

Data will be made available on request.

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