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Research paper

Maximizing pollinator diversity in willow biomass plantings: A comparison between willow sexes and among pedigrees

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ABSTRACT

Shrub willow has potential to be a substantial source of renewable biomass for production of bioenergy, biofuels, and bioproducts. At the same time, scientists and land managers are increasingly challenged to achieve multiple ecosystem functions in bioenergy plantings. Due to willow's early-season bloom period, a time when natural forage for bees can be limited, biomass plantings offer a potential benefit of floral resources for pollinators, some of which are known to be experiencing recent declines. To assess which willow cultivars and sex may provide the most benefit to pollinators, we conducted a common-garden experiment (Northeast U.S.) comparing bee (Hymenoptera: Anthophila) visitation among seven pedigrees and both sexes of short rotation coppice willow. We quantified abundance, richness, diversity, evenness, and species composition in plots planted with each pedigree and sex. Over seven sampling dates, we found an abundant and diverse bee assemblage comprised of 4675 individuals representing > 56 species, at least 10 of which are rare or in decline in the northeastern United States. Willow sex was an important factor in bee visitation differences, with male willows supporting 39% greater abundance, 20% greater richness, and 9% greater diversity of bee visitors. Greater bee richness and diversity on male willows was due to an abundance-driven accumulation of species, as determined via rarefaction. Ordination analyses indicated composition of bee species assemblages differed among both willow pedigree and sex. Thus, our findings suggest male willow of varying pedigrees may be optimal for strategic plantings intended to meet bioenergy goals while also benefiting pollinators.

1. Introduction

Biomass production is an increasingly utilized means for mitigating fossil fuel use and meeting global energy demands [1]. Estimates indicate as of 2010, woody biomass production covered ∼9% of the world primary energy supply and 65% of the world renewable primary energy consumption [2]. Projections show it is possible to accommodate 33% of the world's primary energy consumption with bioenergy and by 2050, 18% of the world's primary energy resources may be solely derived from agriculturally grown woody biomass [2].

Dedicated woody energy crops, such as willow (*Salix spp.*) and poplar (*Populus spp.*), grown in a short rotation coppice (SRC), can be a sustainable way to produce biomass [3]. With development of an expanding bioenergy sector, it is critical to understand how woody crop production affects land-use concerns, such as food production, biodiversity, materials production, and carbon sequestration [1,4,5]. Shrub willow (*Salix* spp.) has several attributes that make it appealing for biomass production, including its ability to produce high yields in a few years, ease of vegetative propagation, broad genetic base, short breeding cycle, and ability to coppice (or re-sprout) after multiple harvests [3].

Woody crops have myriad potential applications [6] including: decreasing soil erosion and mitigating water pollution [7], serving as a wind/snow buffer [8], and bioremediation [9]. Sustainable bioenergy systems can also promote biodiversity [10], featuring reduced biocidal inputs, low management intensity [11], a 3–4 year harvest cycle, and minimal tillage [12]. Various studies have analyzed impacts of SRC willow agroecosystems on various groups of taxa, e.g., birds [13–15], small mammals [16], and general invertebrate assemblages [17,18]; these indicate SRC plantings provide reliable nesting, feeding, and breeding habitat. Rowe et al. [18,19], while not focusing on bees, noted high abundance of visiting Hymenoptera, suggesting willow may provide a resource for pollinators. Manning et al. [20] devised planting strategies featuring second generation bioenergy crops, including SRC

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willow and poplar, interwoven in a multifunctional landscape to maximize ecosystem services and associated biodiversity.

Pollination is a vital ecological service provided by multiple groups of taxa, with recent estimates indicating 87.5% of all flowering plants [21] and 35% of the global plant-based food supply [22] require animal-mediated pollination. Bees (Hymenoptera: Anthophila) are dominant pollinators of wild plants and crops in terrestrial ecosystems and are in need of conservation [23]. Global insect pollinator declines have been documented throughout the 20th century [24,25] and are associated with land-use change, increased pesticide use, persistence of pesticides in the environment, invasive species introductions, and spread of emerging diseases [26,27]. By and large, these land-use changes are due to agricultural intensification [28–30]. Thus, a deeper understanding of land management practices for a given agricultural ecosystem and a broader landscape design perspective can be used to enhance sustainability with regards to pollinator biodiversity. The potential of willow to provide nutrients for pollinators early in the season suggests strategic integration of SRC willow into multifunctional landscapes may promote pollinator health.

It has been proposed that willow provides important early-season nutrient resources for wild pollinator populations in North America [31]. Ostaff et al. [32] provide data indicating frequency of pollinator visitation in willow was notable, with many *Andrena* bees and flower flies (Diptera: Syrphidae) present. Pollinator preferences for male willows were documented, suggesting a protein-rich source of pollen (which is only produced by male flowers) was especially attractive [32,33]. Yet whether this preference for male flowers is generalizable across a full assemblage of pollinator species, and whether particular pedigrees of willow are more attractive than others, is currently unknown. Such information is critical if specific willow pedigrees and sex are being considered for the simultaneous goals of bioenergy production while also maximizing resources for pollinators.

This study assessed presence, abundance, and distribution of a full assemblage of bees among willow sex and several popular cultivars currently being used in bioenergy plantings. Due to known differences in resources provided between willow sexes (i.e. pollen and nectar in male flowers compared to only nectar in female flowers), we expected associated bee abundance and diversity would differ by willow sex. We also hypothesized that physical traits (i.e. relative catkin abundance and estimated biomass) among pedigrees and between willow sexes could potentially influence resources provided and therefore attractiveness to pollinators. Thus, we assessed how variation among these traits were related to pollinator assemblages. Overall, the objective of our study was to provide information to inform how to maximize both bioenergy goals and bee biodiversity in willow bioenergy plantings.

2. Materials and methods

2.1. Study system and design

The Solvay settling basins in Camillus NY are a historically significant site where deposition of waste from soda ash (Na_2CO_3) production occurred from 1881 to 1986. The soda ash facility had profound impacts on local ecosystems as result of high Cl^-, Na^+, and Ca^{2+} ionic waste loading [34]. The site has a range of annual precipitation between 1055 and 1164 mm. In May 2013, a common-garden field experiment was established at the settling basins (lat. 43°04′02.0″, long. 76°15′28.0"). A total of 9360 willows were planted representing 30 willow cultivars, selected for their growth potential to function as an evapotranspiration cover, to prevent percolation and leaching of chloride [35], and to produce biomass for renewable energy.

The shrub willows were coppiced after their first growing season to promote generation of multiple stems on each plant. Shrub willow cultivars were consolidated into seven species-related groupings (hereafter called pedigrees) and sex (Appendix A). Thirty 7.8 m × 7.9 m cultivar plots were randomly assigned in 4 blocks (n = 120). Three double-rows of willow were planted within each plot. Double-rows were 1.8 m apart, contained 13 plants spaced 0.76 m between the double-row and 0.6 m along the row, for a total of 78 willows per plot. The plots' combined total area encompassed 0.74 ha. One cultivar plot (KP x female) was omitted from sampling and analyses due to lack of coppice growth caused by a hardpan forming in places at this site, thus limiting soil depth for plant growth.

2.2. Cultivar characteristics

On the day each cultivar plot was considered to be at "peak flowering," the plot was categorically indexed on a scale of 1–3 with 1 representing plots with < 33% of the willow stems within each sample plot having catkins, 2 with 33–66% of willow with catkins, and 3 having > 66% with catkins as an approximation of proportional catkin abundance in each cultivar plot (adapted from a previously developed scale [33]). Willows are dioecious and so sex of flowering individuals was also noted. Stem diameters were measured at 30 cm height with digital calipers to the nearest 0.01 cm for 10 plants in the middle double-row. Stem diameters and number of stems per plot were used to estimate biomass of each plot. Dry stem biomass of each cultivar plot was estimated by an allometric equation ($R^2 = 0.9760$, $p < 0.0001$), developed for a diverse set of willow cultivars at different locations following procedures from an earlier study [41], using stem diameter and number of stems per plot:

$$\text{Mass (Mg)} = e^{-2.25313+2.62534 * \ln(\text{diameter(mm)})} * (1003 * 10^3)$$

2.3. Bee collection

In 2015, when willows were entering their second year of aboveground coppice growth on a three year old root system, elevated white and blue pan traps were used to collect pollinators on seven collection dates in 2015 over the 3.5 wk willow flowering period (April to May). Pan traps are efficient at providing the greatest abundance and species richness of various passive sampling methods for bees [36]. White was chosen as a color of high reflectance and blue as an alternate color, as it catches bees not caught in white/yellow traps, to optimize collection [37,38]. In each plot, one white and one blue trap were set at catkin level (usually between 1 and 2 m, n = 238), where active pollinator foraging occurs, to capture pollinator visitors throughout willow plots [37].

Pan traps were filled halfway with water and two drops of Dawn© original blue unscented dishwashing detergent were added to break the surface tension. Traps were evenly dispersed in the center double-row of each cultivar plot to avoid decreasing capture rate [39]. Pan traps were deployed between 9:00–10:00 a.m. and left for 24 h. Collection of pollinators occurred every three days from onset of flowering to inflorescence drop-off, as weather permitted. Sampling was conducted on seven dates from 4/19/2015 to 5/15/2015. Specimens were transferred to Whirl-Pak® bags and stored in 95% ethanol. As pan traps were collected, pollinators from white and blue bowls were combined to the plot level (n = 833, 119 plots × 7 days). Plots within the waste beds predominantly contained willow or other plants not yet flowering, and as previous research has documented bees having 150–600 m flight ranges [40], we do not expect bees were flying through to get to other plants during the time period sampled. Thus, the assumption is that bees collected were most likely actively foraging, but by using pan traps, our collection may include a background assemblage of bees that may not have been actively visiting willow catkins.

Collected bees (Hymenoptera: Apoidea: Anthophila) were identified using Discover Life (http://www.discoverlife.org), as well as Mitchell's "Bees of the Eastern United States I" (1960) and "Bees of the Eastern United States II" (1962). *Lasioglossum* (Dialictus) were identified to the subgenus level, with only some individuals identified to species, thus