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Is early pollination to lowbush blueberry an ecosystem service or disservice?

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ABSTRACT

Pollination is frequently identified as an important ecosystem service to agricultural production. In contrast, ecosystem disservices are rarely considered. This study explores pollinator service versus disservice in lowbush blueberry (*Vaccinium angustifolium*) production. This crop is highly managed, requires insect pollination, and has a relatively long bloom; when combined, these characteristics may cause a portion of early season pollination to result in premature ripening and loss. To test this, we exposed early and late flowering clones to early season (wild) pollination only or late season (wild and managed) pollination only. Contrary to our hypothesis of disservice, pre-harvest loss, shatter, and sugar content were consistent across treatments, even though early season pollination plots exhibited heavier berries. Remarkably, early season pollination plots produced over 70% of the total production of late season pollination plots. These results suggest that early season pollination by wild pollinators does not present an ecosystem disservice to lowbush blueberry production.

1. Introduction

Since the 1990s, the idea of ecosystem services has become an increasingly popular way to conceptualize the numerous direct and indirect benefits of ecosystems on human well-being (Costanza et al., 1997; Daily, 1997; MEA, 2005). In contrast, ecosystem disservices are often not acknowledged or considered in the current estimates of service provisioning. Yet the existence of beneficial services to humanity necessitates the recognition that nature also provides disservices that can reduce the productivity of various human systems, increase production costs, and/or pose direct threats to human health (Dunn, 2010; Lyytimaki et al., 2008; Zhang et al., 2007).

Insect-mediated pollination is frequently identified as a regulating ecosystem service (Costanza et al., 1997; Schulp et al., 2014; Winfree et al., 2011), whose role in the production of many agricultural crops is well studied (Klein et al., 2007; Lautenbach et al., 2012) and broadly recognized in popular culture (Walsh, 2013). In certain instances, however, pollination, or a portion of pollination, can be an ecosystem disservice. For example, many insect pollinated crop species set more fruit than optimal from a profitability perspective (Bos et al., 2007a,b). When this occurs, growers may mechanically or chemically thin flowers and/or fruitlets in order to alter resource allocation and increase fruit size, value, and quality at harvest (Free, 1993; Jackson, 1989). Similarly, Klein et al. (2015) found that excess pollination in almond can reduce fruit quality and leaf production, compromising the photosynthetic capacity of trees, while Klatt et al. (2014) found that pollen limitation in commercially important strawberry varieties results in lower amounts of deformed fruit. These crop-specific yield responses to pollination intensity are clear examples of how pollination as an ecosystem service can transform into a disservice that detracts from overall production (Zhang et al., 2007). Yet pollination continues to be commonly viewed as a monotonically positive service, despite recent evidence that what actually happens as a result of management strategies may be a disservice to final production.

Commercial lowbush blueberry (syn. "wild blueberry", Vaccinium angustifolium Aiton) production is an excellent system to explore pollinator service and disservice (Jones et al., 2014). Self-sterile blueberry plants ('clones') are pollinator-dependent, and benefit from the presence of wild pollinators (Javorek et al., 2002; Fulton, 2013). The bloom period of lowbush blueberry lasts approximately four weeks, exceeding that of many pollinator dependent crops like apple (Whiting et al., 2015) or almond (Ortega et al., 2004), but being comparable to other crops like

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canola (oilseed rape) (McGregor, 1981). Bloom is also quite heterogeneous due to considerable clonal diversity within fields, with early and late blooming clones, and a sequential succession of floral bloom and senescence (Bell et al., 2009; Vander Kloet, 1988). Furthermore, although wild pollinators are present throughout the bloom, most growers augment the natural pollinator force with managed honeybees (*Apis mellifera L.)* or bumble bees (*Bombus impatiens Cresson*) at approximately 25% bloom, such that the crop experiences an intense pulse of pollination (Drummond, 2002, 2012; Eaton et al., 2004). In contrast to the prolonged period over which fruit are potentially set, lowbush blueberries in commercial production are harvested from each field during a single mechanized harvest event. We therefore posit that commercial lowbush blueberry crop production may experience significant losses from early season pollination that occurs before the introduction of managed pollinators, which may result in premature berry development, ripening, and pre-harvest berry drop. If this occurs, early season pollination to this crop could constitute an ecosystem disservice that detracts from final yield by reducing the amount of harvested berries, or by reducing berry sweetness should the production of many early-season berries reduce plant resources available to late-season berries. Similar examples of this intra-plant competition for resource allocation can be seen in strawberry (Gardner et al., 1952), almonds (Ortega et al., 2004), and cranberries (Birrenkott and Stang, 1990; Brown and McNeil, 2006). In such cases, as might be the case with lowbush blueberry, developing fruit compete for finite plant resources, such as photosynthates (Gifford and Evans, 1981; Stephenson, 1981). Such intra-plant resource competition may lead early set fruit to produce an inhibitory substance that causes late set flowers and fruit to abort (Van Steveninck, 1959).

We tested whether early pollination by wild pollinators acted as a disservice by excluding early (wild) pollinators and late (wild and managed) pollinators from both early and late blooming clones, and then measured the effects on total and ripe yield at harvest, berry drop both mid-season and during the harvest process, fruit sweetness, and fruit size. Should the hypothesis of disservice be true, we predicted plots exposed to early season pollination to exhibit: (1) lower total yield and ripe yield levels at harvest as a result of (2) higher levels of pre-harvest berry drop and shatter at harvest due to early ripening and fruit drop; (3) increased berry sweetness at harvest as a result of the relatively longer ripening time; and (4) smaller berry size at harvest as a consequence of larger berries being dropped before final yield.

2. Materials and methods

2.1. Pollination exclusion

The experiment was conducted from 12 May to 14 August, 2014 on ten (10) well-established commercial blueberry fields located in the eastern part of the province of Prince Edward Island, Canada. Fields averaged 11.5 ha (max = 27.0 ha, min = 5.4 ha), and all were owned and/or managed by a single company and therefore subjected to consistent management practices. In order to minimize soil and climate variability and their potential influences on the study results, the 10 agricultural fields were all intentionally located on similar agricultural landscapes located within an 80 km radius.

In each field, a 100 m transect was established 25 m from and parallel to the northern field edge. A total of twelve experimental plots measuring 1 m^2 each were established along and within 6 m of each transect. The experimental plots were located on clones of a consistent size class (1–2 m^2 for each clone) with comparable stem densities (690 $\pm$ 135 stems per plot) and no bare patches, with clones identified as unique rhizome systems within the field (MacIsaac, 1997). Criterion used to establish the twelve experimental plots was the relative timing of clonal bloom within each plot, such that six early blooming clones (EC) and six late blooming clones (LC) were selected in each field. Overall flower density and relative flowering phenology of the experimental plots was estimated at the onset of bloom by counting the number of stems in five randomly selected 10 $\times$ 10 cm subplots within each 1 m^2 plot, along with the total number of open flowers present in the subplots.

After six EC and six LC plots were established in each field, plots were randomly assigned to one of two treatments: exposure to early pollination only (EPO) or late pollination only (LPO). This resulted in three replicates of each of the following treatments based on the bloom timing and insect pollinator access: early blooming clone, early pollination only (EC-EPO); early blooming clone, late pollination only (EC-LPO); late blooming clone, early pollination only (LC-EPO); and late blooming clone, late pollination only (LC-LPO). In addition to experimental plots, five control plots were established at approximately 0, 25, 50, 75, and 100 m along the transect. These control plots experienced no pollinator treatment, nor any specific clonal designation based on timing of bloom. That is, control plots mimicked normal pollination of clones in commercial fields. Pollination treatments were established by placing pollinator exclusion tents (Type 2 mesh, Vilutis and Co, Inc., Frankfort, Illinois) over clones at the appropriate time. Exclusion tents were supported by four PVC pipes (1 m long, 2.5 cm diameter) placed vertically into the ground at the corners of the plot. Excess tent material was gathered at the ground and securely pinned to limit insect access. LPO plots were set before bloom began ($\sim$<1% bloom for early and late clones) and remained covered until 3–9 June, just before the introduction of managed bumble bees and honey bees into fields. Tents were then removed from LPO plots and re-installed on EPO plots. Tents remained over EPO plots until the end of bloom (31 June). Throughout the experiment exclusion tents were monitored to ensure bees and other potential pollinators were excluded. Electronic temperature monitors (Onset Corporation HOBO Data loggers) were used inside and outside two randomly selected plots to ensure that the exclusion tents did not adversely affect plot air temperature.

2.2. Flower and fruit development

We collected 25 stem clippings at evenly spaced intervals along the 100 m transect at: (1) the onset of bloom (early June), (2) peak bloom (mid June), (3) initial fruit set (late June – early July; two weeks after bloom), and (4) final fruit set (early to mid August). The number of flowers and fruit per stem were counted and recorded. Additionally, we randomly selected and tagged three ‘typical’ stems in each plot at the beginning of the field experiment and on seven dates from the beginning of June until the day of harvest in mid August counted closed flowers, open flowers, diseased flowers, dropped flowers, green berries, pink berries, and ripe berries. On the day of harvest, berries on these stems were collected, weighed, and frozen.

2.3. Berry drop

Three perforated catchments measuring approximately 28 cm $\times$ 7 cm were installed in each plot. These catchments were made of clear plastic embroidery mesh with 2 mm holes, fastened into half-cylinder shapes using three electrical ties, and then secured into the ground with two agricultural staples. Beginning mid-July until harvest, we recorded the number of dropped flowers, green berries, pink berries, and ripe berries in each catchment on a weekly basis, removing all fallen flowers and berries after counting. After harvest, we estimated berry drop per