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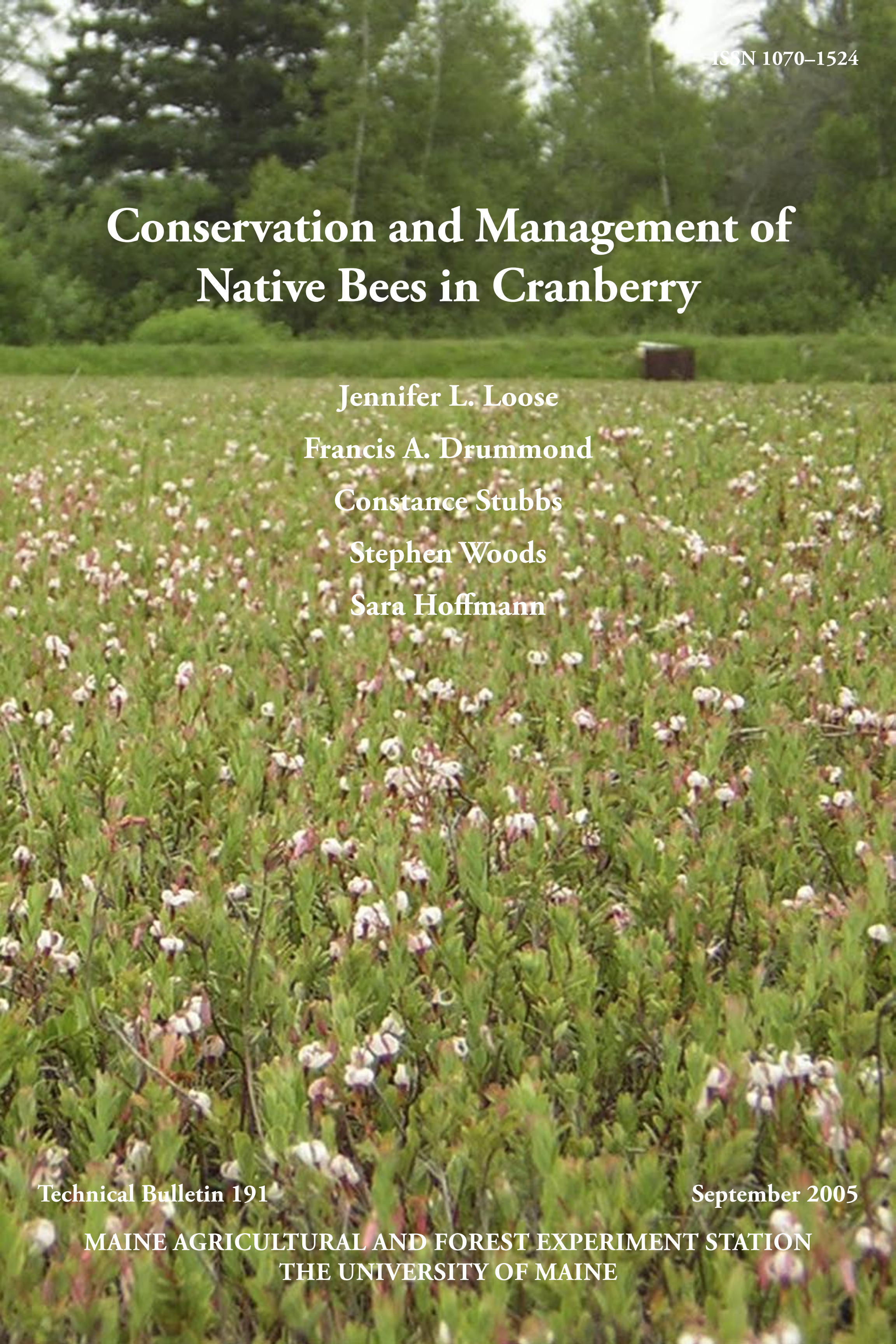

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Conservation and Management of Native Bees in Cranberry

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INTRODUCTION

Animal-mediated pollination is a crucial ecosystem process that is accomplished by a large number of specialist and generalist pollinators. Bees are the most important commercial pollinators (Michener 2000; Proctor et al. 1996), but native pollinator communities are comprised of birds, bats, bees, wasps, beetles, flies, butterflies, and moths (Barth 1985). Pollinator species abundances, and in particular, bee species abundance and diversity are decreasing worldwide (Batra 1984; Buchmann and Nabhan 1996; Day 1991; Falk 1991; Michener 2000, Stubbs and Drummond 2001a; Williams 1982). Declines in bee communities have been attributed to increases in pesticide use, the trend towards monocultural agricultural production systems, and the removal of fencerows and other fallow open areas that provide wild flowering plants and nesting sites (Banaszak 1986, 1992; Free 1993; Johansen 1969; Kevan 1975; Kevan et al. 1990). Similar ecosystem stresses have also been cited as reasons for the declines of other pollinators, especially butterflies and moths (New 1997). Increases in acreage, increases in pollination requirements due to pressure to maximize yield, and decreases in native bee abundance have caused many farmers to become reliant on rented honey bee hives (Apis mellifera L.) (Johansen 1977; Torchio 1990). The decline in pollinator abundance and diversity is accompanied by our lack of knowledge regarding the current contributions by native bees to crop pollination (Kevan et al. 1990; Torchio 1994; Stubbs and Drummond 1997a, 1997b, 2001a; Williams et al. 1991). This lack of understanding of the role of native bees makes it more difficult to make the case for native pollinator conservation to potential funding agencies.

There are more than 3,500 species of native bees in North America (Batra 1994), with almost 2,000 species of bees in California alone (Michener 2000). In North America, most commercially grown fruits and vegetables are pollinated by honey bees, as many current agricultural practices (such as production on large fields and yield-maxmimizing production techniques) render native bees insufficient as pollinators. However, honey bees are threatened by parasitic tracheal mites (*Acarapsis woodi* Rennie), varroa mites (*Varroa jacobsoni* Oudemans), antibiotic resistant foulbrood (*Bacillus larvae* White), and the expanding range of the Africanized honey bee (*Apis mellifera scutellata*) (Allen-Wardell et al. 1998; Delaplane and Mayer 2000; Kearns et al. 1999; Kevan et al. 1990; Stubbs and Drummond 2001a). There has been at least a 50% drop in the number of honey bee hives in the United States since 1950, most of this loss since 1990 (Allen-Wardell et al. 1998; Buchman and Nabhan 1996). The decline in the number of honey bee hives has resulted in decreased hive availability for commercial pollination and in increased hive rental prices (Atkins 1992; Delaplane and Mayer 2000). This, coupled with concern over threats to native bee abundance and diversity, has lead researchers to further explore the role of native bee species in pollination of agricultural crops (Stubbs and Drummond 2001a).

Threats to agriculturally important pollinators have serious implications for human beings. A loss of bees translates to less successful crop pollination, thus reduced yield and poorer quality fruits (Free 1993). Bees are a biological natural resource, in some ways similar to the natural resources that pharmaceutical companies have accessed to develop many of the drugs we commonly use, such as aspirin and penicillin. Native bees have the potential to serve as commercial pollinators, as exemplified by the use of honey bee, bumble bee (*Bombus* spp.), and alfalfa leafcutting bee (*Megachile rotundata*) have been (Bosch and Kemp 2001; Drummond and Stubbs 1997; O'Toole 1993; Stubbs et al. 1994; Stubbs and Drummond 1997a, 1997b, 2000, 2001b; Torchio 1994). A diverse pollinator complex comprised of both honey bees and native bees should result in stable pollination levels and should be resistant to threats such as disease, fluctuating honey and crop prices, and honey bee transportation costs (Stubbs et al. 2001). Adding the goal of native bee conservation to land management increases the ecological integrity of an ecosystem by conserving a unique biological interaction that is the basis for most native wild plant reproduction (Batra 2001; Kim 1993).

POLLINATION IN THE CRANBERRY AGROECOSYSTEM

Cranberry, *Vaccinium macrocarpon* Aiton, is a native fruit that has been cultivated in New England since the early 1800s (Eck 1990). The morphology of the flower (poricidal anthers) necessitates insect mediated pollination (Cane et al. 1996; Delaplane and Mayer 2000; Free 1993; MacKenzie 1994). The cranberry flower is best pollinated by buzz pollination, the process by which the bee dislocates and shivers its flight muscles and vibrates the flower at the frequency of the musical note middle C (Buchmann and Nabhan 1996). This causes the pollen to be dislodged from the terminal pore of the anther and to adhere to the bee. The bee then transports the pollen to the stigma of a receptive flower. Bumble bees are the most common buzz pollinators of cranberry (MacKenzie 1994; MacKenzie and Averill 1995) and are also important pollinators of other *Vaccinium* crops

(Stubbs and Drummond 2000, 2001b). The native bumble bee *Bombus impatiens* has been reared and sold commercially for cranberry pollination during the past decade. Honey bees do not buzz pollinate, rather they collect pollen in a less efficient manner by drumming the anthers with their forelegs or forage solely for nectar and do not collect pollen except by accidental contamination of bee mouthparts and head (Cane et al. 1993).

Cranberry growers once relied solely on native bees for pollination, many of which are evolutionarily adapted to pollinate cranberry (Cane et al. 1993). Although not documented in Massachusetts and the other New England states, many growers and pollination scientists believe that native bee populations associated with cranberry have declined over the past four decades. Marucci and Filmer (1964) reported that growers felt that bumble bee populations were decreasing in New Jersey cranberry beds. This drop in bee abundance and diversity was most likely brought about by habitat destruction and pesticide use, as is the case with bee decline that is associated with other agroecosystems (Banaszak 1986, 1992; Free 1993; Johansen 1969; Kevan 1977; Kevan et al. 1990). This, coupled with increased production pressures to maximize yield, has led growers to their current practice of renting honey bee hives each year during bloom (Johansen 1977; Torchio 1990). Although honey bees are not efficient pollinators of cranberry, a high abundance of honey bees during bloom can meet pollination requirements (Delaplane and Mayer 2000; Free 1993; MacKenzie 1994). Unlike locally adapted native bees such as bumble bees, honey bees do not forage during wet, cool weather (MacKenzie 1994), and if hives are not placed next to the bed when in full bloom, honey bee constancy to the cranberry flower decreases significantly (Free 1993). In addition, male honey bees, unlike males of many native bee species, do not contribute to pollination because they do not forage for pollen (MacKenzie 1994; Stubbs and Drummond 1997b, 2001b). Thus, honey bees have the advantage that they can be temporarily brought in to a crop field in bloom, at extremely high numbers, and even though they may not be well suited individually to a pollinate a crop, their sheer numbers make them an important pollinator. However, because it takes such large numbers of honey bees to pollinate a cranberry field, many growers and scientists think that native bees will never be present in adequate densities for crop pollination. We believe that this is a central problem of bee conservation in agroecosystems.

In southeastern Massachusetts there are approximately 80 species of native bees associated with cranberry (Loose 2000; MacKenzie and Averill 1995) (Table 1). Many of these same species are found in Maine associated with lowbush blueberry (Loose 2000; Stubbs et al. 1992) and are likely to be associated with commercial cranberry bogs in Maine (Table 1). The Apidae is the most species-rich family followed by the Halictidae, Megachilidae, and Andrenidae. Several of these species are effective pollinators of cranberry, but do not exist in high enough densities to be relied upon as the sole pollinators for this crop (Cane et al. 1996; Loose 2000; MacKenzie and Averill 1995). Bumble bees (*Bombus* spp.) and the leaf-cutting bees, primarily represented by *Megachile addenda,* however, represent two groups of bees that have been identified as highly efficient pollinators of cranberry and are common in the cranberry region of southeastern Massachusetts (Cane et al. 1996; Loose 2000; MacKenzie and Averill 1995). Loose (2000) demonstrated that native bees move into cranberry beds during bloom from surrounding habitat and are found in relatively high numbers throughout the bed during this period. Bumble bees and the leafcutting bee *M. addenda* were found to be relatively abundant throughout the 19 cranberry sites sampled in this study. Findings also suggest that native bees can play an important role in cranberry pollination as demonstrated by a correlated increase in yield associated with an increase in native bee abundance. However, this may not always be the case. There was a positive correlation between cranberry yield and native bee relative abundance in only one of the two years studied (Loose 2000). It has been suggested that at least 0.13 bumble bees per m^2 is necessary to provide sufficient pollination of cranberry (Filmer and Doehlert 1959). Native bees do not currently exist in high enough numbers to play a significant role in cranberry pollination in many of the intensively managed cranberry bogs (Cane et al. 1996; Loose 2000; MacKenzie and Averill 1995). Therefore, efforts should be made to enhance their populations.

Native Bee Management and the Cranberry Agroecosystem

Managing land for the purpose of enhancing populations of native bees requires providing adequate bee habitat within the cranberry agroecosystem, including access to nectar and pollen throughout the spring and summer, nesting materials and sites, water, and refuge from insecticides (Batra 2001; Drummond and Stubbs 2003; Goulson 2003; Kremen et al. 2002, 2003; Saure 1996; Westrich 1996). It has been shown in California that farms adjacent to natural unmanaged habitat that also did not use insecticides were characterized by diverse native pollinator communities. These pollinator communities provided the necessary pollination services for crop production (Kremen et al. 2002). Thus conservation of na-

Table 1. Bee taxa (classification after Michener [2000]) and number of individuals collected in cranberry during a two-year study in southeastern Massachusetts. Taxa important to cranberry pollination are in bold (see Loose [2000] for details). Bee taxa denoted with "*" are species collected in southeastern Massachusetts cranberry that were not found during the Loose study (see MacKenzie and Averill [1995] for details), bee taxa denoted with "Δ" are species associated with Vaccinium spp. in Maine reported by Stubbs et al. 1992, and bee taxa denoted by "†" were captured in lowbush blueberry fields in Maine (Loose 2000).

Family	Subfamily	Genus	Species	1997	1998
Andrenidae	Andreninae	*Andrena*	*bradleyi* Δ†	1	0
		Andrena	*carlini* Δ†	1	2
		Andrena	*carolina**Δ†	-	-
		Andrena	*ceanothi*	0	1
		Andrena	*cornelli* †	0	1
		Andrena	*crataegi* Δ†	1	0
		Andrena	*cressonii** Δ	-	-
		Andrena	*ilicis*	1	2
		Andrena	*imitatrix*	17	3
		Andrena	*nivalis* Δ	0	1
		Andrena	*nuda**	-	-
		Andrena	*vicina* Δ†	1	0
		Andrena	*wilkella* Δ†	1	0
Megachilidae	Megachilinae	*Coelioxys*	spp.	16	17
	Megachilinae	*Hoplitis*	*micheneri*	0	1
		Hoplitis	*truncata*	1	1
	Megachilinae	*Megachile*	*addenda*	260	963
		Megachile	*c. companula*	1	3
		Megachile	*deflexa*	0	1
		Megachile	*frigida**	-	-
		Megachile	*frugalis*	0	1
		Megachile	*gemmula* †	4	5
		Megachile	*texana*	0	1
		Megachile	spp.	4	0
	Megachilinae	*Osmia*	*albiventris* Δ†	0	1
		Osmia	*atriventris* Δ†	2	8
		Osmia	*inermis* Δ†	1	0
		Osmia	*proxima* Δ†	0	1
		Osmia	*sandhouseae* †	0	2
		Osmia	*virga* Δ†	1	3
Apidae	Apinae	*Bombus*	*affinis* Δ	14	11
		Bombus	*bimaculatus**Δ†	-	-
		Bombus	*fervidus* Δ†	10	5

Table 1. Continued.

Family	Subfamily	Genus	Species	1997	1998
Apidae	Apinae	*Bombus*	*griseocollis**	-	-
		Bombus	*impatiens* †	25	35
		Bombus	*pennsylvanicus*	2	0
		Bombus	*perplexus**Δ	-	-
		Bombus	*rufocinctus**	-	-
		Bombus	*terricola* Δ†	5	8
		Bombus	*vegans* Δ†	63	49
		Bombus	spp.	18	17
	Apinae	*Psithyrus*	sp.	1	0
Apidae	Anthophorine	*Melissodes*	*apicata*	5	0
	Nomadinae	*Nomada*	spp.	3	16
	Xylocopinae	*Xylocopa*	*virginica**	-	-
	Xylocopinae	*Ceratina*	*calcarata*	1	2
Apidae	Xylocopinae	*Ceratina*	*dupla dupla* Δ	1	0
		Ceratina	*metallica*	4	0
Halictidae	Halictinae	*Agapostemon*	*sericeus**	-	-
		Agapostemon	*texanus* Δ	7	9
		Agapostemon	*virescens*	8	1
		Agapostemon	sp.	0	1
Halictidae	Halictinae	*Augochlora*	*pura*	0	1
		Augochlora	*striata* Δ	8	8
	Halictinae	*Augochloropsis*	*metallica**	-	-
	Halictinae	*Dialictus*	*admirandus**Δ	-	-
		Dialictus	*lineatulus**	-	-
		Dialictus	*marinum**	-	-
		Dialictus	*pilosus*	11	4
		Dialictus	*rohweri**Δ	-	-
		Dialictus	near *obscurus*	2	8
		Dialictus	near *viridatus* Δ	12	5
		Dialictus	near *zephyrus*	4	4
		Dialictus	spp.	87	79
	Halictinae	*Dufourea*	*marginata*	1	0
	Halictinae	*Evylaneus*	*cinctipus**Δ	-	-
	Halictinae	*Halictus*	*confusus**Δ	-	-
		Halictus	*rubicundus* Δ	6	3
	Halictinae	*Lasioglossum*	*acuminatum**Δ	-	-
		Lasioglossum	*athabascense**Δ	-	-
		Lasioglossum	*coriaceum*	7	8
		Lasioglossum	near *quebecensis*	1	0
		Lasioglossum	*zonulum*	3	3
		Lasioglossum	spp.	4	4
	Halictinae	*Sphecodes*	*confertus* Δ	3	0
		Sphecodes	*minor**	-	-
		Sphecodes	spp.	0	3
Melittidae	Melittinae	*Melitta*	*americana*	12	6

tive bees for farm pollination services is an attainable goal. The cranberry agroecosytem is diverse in habitats, having deciduous and coniferous forest, open meadow, wetland and riparian corridors. This diversity of habitats provides nesting sites and wild flowering plants necessary for the conservation and augmentation of native bee communities (Westrich 1996).

In addition to increasing native bee densities, and thus decreasing the need for honey bees, there are other advantages to managing the cranberry landscape for bees. Increasing habitat complexity, by providing wild flowering plants and nesting sites may also benefit predatory and parasitic wasps (Altieri 1994; Altieri and Whitcomb 1979; Andow 1991; Barbosa 1998; Collins and Qualset 1998; Kim 1993) that attack cranberry insect pests. Providing adjacent habitat creates "stepping stones" that enable these predators and bees to disperse between fields (Kruess and Tscharntke 1994; Saure 1996). The findings of Loose (2000) suggest that cranberry bee communities are localized, even between beds less a kilometer apart, and are responding to the amount of wild flowering plants growing immediately around the periphery of cranberry beds. In fact, because of the limited foraging range of bees and other beneficial insects, they have been suggested as good bioindicators that can be measured by trap-nesting (Tscharntke et al. 1998).

If fragmented forests are representative of fragmented wild flowering plant communities within the cranberry agroecosystem, then the study by Murcia (1995) suggests that these corridors of connecting floral resources can have a significant impact on the conservation of bees and natural enemy populations. In addition to increasing the amount of wild flowering plants around beds, increasing the amount of wild flowering plants between beds would lengthen the pathways by which bees may travel, and thus encourage dispersal from beds with abundant bees to beds with a lack of bees. It also suggests that cranberry fruit set and seed set might be enhanced by minimizing fragmentation of floral resources (Steffan-Dewenter and Tscharntke 1997).

Importance of wild flowering plants

Native bees respond positively to the abundance of wild flowering plants surrounding cranberry beds and highbush blueberry (Loose 2000; MacKenzie and Winston 1984). Floral resources around crop peripheries are important to pollinators not only in Vaccinium crops, but in other crops as well such as tree fuits (Scott-Dupree and Watson 1987). Most bees have a flight period that extends beyond cranberry bloom (Mitchell 1960) and require a continuous source of nectar and pollen throughout the season (Goulson 2003; Saure 1996;

Westrich 1996). Macfarlane and Patten (1997) examined the relative attractiveness of perennial floral resources to bumble bees around cranberry beds in the Pacific Northwest throughout the summer. They found a shortage of bumble bee forage resources early and late in the season and suggest that planting for early and late-blooming wild flowering plants may boost bumble bee abundance. In the early spring, emerging queens and new brood require food resources close to the nest and in late summer large colonies have greater food requirements. Bumble bees are one of the most important pollinators of cranberry, and are active from early spring through the end of the summer. This highlights the necessity of a constant source of nectar and pollen from early spring through the fall.

Bees also use plant material for building and provisioning their nests (Krombein 1967). Loose (2000) noted that northern bayberry (*Myrica pennsylvanica*) around cranberry beds with high abundance of the leaf-cutter bee *M. addenda* showed what appeared to be a high degree of use by this bee (leaf-cutters remove circular pieces of leaf and use them to line their nests). Although bees were not observed cutting the leaves, the shape of the damage was consistent with leaf-cutter activity. The leaves of this shrub had been cut by the bees to such a degree as to no longer have their original oblong, lanceolate shape, but became indented and shaped much like oak leaves. Cane et al. (1996) also noted that red maple leaves (*Acer rubrum*) had been used to a great degree by this bee species for nesting material.

The forest understory (in the spring) and open areas around most cranberry beds are habitat for wild flowering plants (Loose 2000; MacKenzie and Averill 1995), several of which are good nectar and pollen resources. Stubbs et al. (1992) compiled a list of alternative forage plants for important pollinators associated with lowbush blueberry in Maine and reported collecting the pollinators on these plants before and after blueberry bloom.

Because alternative forage is so important, we have developed recommendations for encouraging flowering plants around cranberry beds. Honey bee forage manuals were used to create a relative rating of floral resources important to bees found in and around cranberry beds (Ayers and Harman 1992; Lovell 1926; Nye 1971; Pellett 1976, Southwick and Southwick 1986, Tew 1998). The rating is based on the assumption that honey bee resources can be used as an approximate measure of resources for the native bee community. This assumption is probably inaccurate for some native bee species, but in the absence of comparable data for native pollinators, we feel that this list may serve as a useful guideline. Table 2 was constructed by using the rating of 0 to 2 for nectar and for pollen availability to bees: 0 being not a significant nectar or pollen resource, 1 being a minor pollen or nectar resource, 2 being a major resource. Ratings were averaged across references. This table also gives bloom time for all of the plant species. The annual and perennial wild flowering plants in Table 2 are those encountered during the sampling performed by Loose (2000) in and around cranberry beds in Massachusetts.

Red alsike, dutch white, and sweet clovers, birdsfoot trefoil, alfalfa, buckwheat, and commercially available nectar flower mixes are good honey bee forage plants. Goldenrod, thistles, honeysuckle, sweet milkweeds, sages, salvia, sunflowers, and mints are also excellent honey bee plants. These plants are also heavily used by native bees. When managing bee forage plants, it is important to select plants whose bloom won't coincide with cranberry bloom (Ayers and Harmon 1992; Buchman and Nabhan 1996). Common pre-bloom wild flowering plants in cranberry agroecosystems include bunchberry (*Cornus canadensis*), cherry (*Prunus* spp.), blueberry and related taxa (*Vaccinium* spp.), dangleberry and related taxa (*Gaylussacia* spp.), violet (*Viola lanceolata*), *Viburnum* spp., and grape (*Vitis* spp.) Maple (*Acer* spp.), birch (*Betula* spp.), willow (*Salix* spp.), and alder (*Alnus* spp.) are early sources for pollen. After cranberry bloom, dewberry (*Rubus* spp.), *Aster* spp., goldenrod (*Solidago* spp.), fireweed (*Epilobium angustifolium*), sweet pepperbush (*Clethra alnifolia*), toadflax (*Linaria canadensis*), meadowsweet (*Spiraea* spp.), buttonbush (*Cephalanthus occidentalis*), and the non-native hawkweed (*Hieracium* spp.) are all important bee forage plants (Table 2).

Encouraging native wild flowering plants by seeding and not mowing around the beds during bloom will increase plant abundance. The findings of Loose (2000) suggest that this may, in turn, increase native bee abundance by providing necessary floral resources before and after cranberry bloom. Flight range for many bee species is not more than 200 m (Eickwort and Ginsberg 1980). Bumble bee colonies in cranberry have been shown to die out in the early spring if there is little food within 100 m (Macfarlane and Patten 1997). It has been shown by other researchers that having a continuous resource of wild flowering plants is necessary (Aizen and Feinsinger 1994; Didham et al. 1996; Goulson 2003). This could be achieved by not mowing the outside edge (the edge away from the bed) of the roads around cranberry. A strategy of mowing the inside edge of a bed would keep beds neat and help stop dispersal of weeds. Not mowing the outside edge of the bed would be expected to enhance wild flowering plants, thus enhancing floral resources for native bees. Mowing in the fall after the end of wild flowering plant bloom will prevent encroach-

Table 2 Wild flowering plant species identified in vegetation sampling in and around cranberry beds in 1997 and 1998 in Massachusetts and likely to occur around cranberry beds in Maine; relative nectar and pollen resource ranking, as compiled from honey bee forage literature (scale of 0 to 2, 0 being no pollen or nectar, 1 being a minor nectar or pollen source, 2 being a major nectar or pollen source, '•' denotes lack of information in literature) (see Loose 2000 for details). Wild flowering plant species not present in Maine denoted with an asterisk (*) (see Haines and Vining 1998 for details).

Family	Genus species	Common Name	Bloom	Nectar rank	Pollen rank
Aceraceae	*Acer rubrum*	Red Maple	March–May	1.2	1.2
Aceraceae	*Acer* sp.	Maple	March–May	1.25	1.25
Aizoaceae	*Mollugo verticillata*	Carpetwildflower	July–September	•	•
Alismataceae	*Sagittaria latifolia*	Common Arrowhead	July–October	1	1
Anacardiaceae	*Rhus radicans*	Poison Ivy	May–June	1.25	1
Anacardiaceae	*Rhus* spp.	Sumac	June–August	1.6	1.2
Apocynaceae	*Apocynum androsaemifolium*	Spreading Dogbane	June–July	1.67	1.33
Aquifoliaceae	*Ilex glabra*	Ink Berry	April–June	1.33	1
Aquifoliaceae	*Nemopanthus mucronatus*	Mountain Holly	May–June	1	1
Araceae	*Peltandra virginica*	Arrow Arum	May–July	•	•
Araliaceae	*Aralia hispida*	Bristly Sarsaparilla	June–August	•	•
Asclepiadaceae	*Asclepias syriaca*	Milkweed	June–August	1.5	1.25
Balsaminaceae	*Impatiens capensis*	Spotted Touch-me-not	July–September	1	1
Betulaceae	*Alnus rugosa*	Alder	March–May	0.25	1
Betulaceae	*Alnus* spp.	Alder	March–May	0.25	1
Betulaceae	*Betula papyrifera*	Paper Birch	March–May	0	1
Betulaceae	*Betula populifolia*	Grey Birch	March–May	0	1
Betulaceae	*Betula* sp.	Birch	March–May	0	1
Campanulaceae	*Lobelia cardinalis*	Cardinal Flower	July–September	1	1
Caprifoliceae	*Sambucus canadensis*	Common Elderberry	May–August	0.5	1.25
Caprifoliceae	*Sambucus pubens*	Red Elderberry	May–August	0.67	1.33
Caprifoliceae	*Viburnum cassinoides*	Wild Raisin	April–June	1	1
Caprifoliceae	*Viburnum prunifolium**	Black Haw	April–June	1	1
Caprifoliceae	*Viburnum recognitum*	Northern Arrowwood	April–June	1	1
Caprifoliceae	*Viburnum* sp.	Viburnum	May–June	1	1
Carophyllaceae	*Arenaria serpyllifolia*	Thyme-leaved Sandwort	April–August	•	

Table 2 Continued.

Family	Genus species	Common Name	Bloom	Nectar rank	Pollen rank
Caryophyllaceae	*Arenaria* sp.	Sandwort	April–August	•	•
Caryophyllaceae	*Stellaria graminea*	Stichwort	May–October	1	1.2
Caryophyllaceae	*Stellaria vulgatum**	Mouse Eared Chickweed	April–September	1	1.2
Caryophyllaceae	*Spergularia rubra*	Sand Spurrey	June–October	•	•
Cistaceae	*Helianthemum canadense*	Frostweed	May–June	•	•
Clethraceae	*Clethra alnifolia*	Sweet Pepperbush	July–September	1.33	0.75
Compositae	*Achillea millefolium*	Common Yarrow	June–September	•	•
Compositae	*Ambrosia artemisiifolia*	Ragweed	July–October	0	1.5
Compositae	*Aster novi-belgii*	New York Aster	July–October	1.25	1
Compositae	*Aster puniceus*	Purple-stemmed Aster	July–October	1.25	1
Compositae	*Aster* sp.	Aster	July–October	1.25	1
Compositae	*Aster vimineus*	Small White Aster	July–October	1.25	1
Compositae	*Bidens frondosa*	Pitchforks	May–November	1	1
Compositae	*Centaurea cyanus*	Cornflower	June–September	1.33	1
Compositae	*Centaurea maculosa*	Spotted Knapweed	June–September	1.33	1
Compositae	*Chrysanthemum leucanthemum*	Oxeye Daisy	June–July	1	1
Compositae	*Chrysopsis falcate**	Sickle-leaved Golden Aster	July–September	1	2
Compositae	*Erechtites hieraciifolia*	Fireweed	July–October	2	1
Compositae	*Erigeron annuus*	Daisy Fleabane	May–October	•	•
Compositae	*Erigeron canadensis*	Horseweed	July–November	•	•
Compositae	*Eupatorium dubium*	Joe-Pye Weed	July–September	1	1
Compositae	*Hieracium pilosella*	Mouse-eared Hawkweed	June–September	1	1.33
Compositae	*Hieracium* sp.	Hawkweed	May–September	1.33	1.33
Compositae	*Hieracium vulgatum*	Hawkweed	May–September	1.33	1.33
Compositae	*Hypochaeris radicata**	Cat's Ear	June–October	1	1
Compositae	*Krigia virginica*	Dwarf Dandelion	April–August	•	•

Table 2 Continued.

Family	Genus species	Common Name	Bloom	Nectar rank	Pollen rank
Compositae	*Sericocarpus asteroides*	Toothed White-topped Aster	June–October	•	•
Compositae	*Solidago odora**	Sweet Goldenrod	July–August	1.5	1.5
Compositae	*Solidago* sp.	Goldenrod	July–August	1.5	1.5
Compositae	*Taraxacum* sp.	Dandelion	April–September	1.8	1.6
Convolvulaceae	*Convolvulus* sp.	Morning Glory	June–October	1	1.25
Convolvulaceae	*Cuscuta gronovii*	Swamp Dodder	July–October	1	1
Cruciferae	*Lepidium virginicum*	Wild Peppergrass	June–November	0	1
Cruciferae	*Rorippa islandica*	Yellow cress	May–September	•	•
Cruciferae	*Rorippa sylvestris*	Creeping Yellow Cress	May–September	•	•
Cupressaceae	*Thuja occidentalis*	Cedar	March–May	•	•
Ericaceae	*Chamaedaphne calyculata*	Leatherleaf	April–June	1	1
Ericaceae	*Gaultheria procumbens*	Wintergreen	July–August	•	•
Ericaceae	*Gaylussacia baccata*	Huckleberry	May–June	1.33	1
Ericaceae	*Gaylussacia frondosa**	Dangleberry	April–June	1.33	1
Ericaceae	*Kalmia angustifolia*	Sheep Laurel	April–June	1	0.5
Ericaceae	*Lyonia ligustrina*	Maleberry	April–June	•	•
Ericaceae	*Rhododendron nudiflorum**	Pink Azalea	June–August	1	0.5
Ericaceae	*Rhododendron* sp.	Azalea	June–August	1	0.5
Ericaceae	*Rhododendron viscosum*	Clammy Azalea	June–August	1	0.5
Ericaceae	*Vaccinium macrocarpon*	Cranberry	June–July	1	1
Ericaceae	*Vaccinium angustifolium*	Lowbush Blueberry	May–June	1	1
Ericaceae	*Vaccinium corymbosum*	Highbush Blueberry	May–June	1.25	0.75
Ericaceae	*Vaccinium* sp.	•	May–June	1	1
Ericaceae	*Vaccinium vitis-idaea*	Mountain Cranberry	May–June	1	1
Fagaceae	*Quercus alba*	White Oak	April–May	0	1.4
Fagaceae	*Quercus macrocarpa*	Bur Oak	April–May	0	1.4
Fagaceae	*Quercus* sp.	Oak	April–May	0	1.4

Table 2 Continued.

Family	Genus species	Common Name	Bloom	Nectar rank	Pollen rank
Gentianaceae	*Menyanthes trifoliata*	Wild Bean	April–July	•	•
Guttiferae	*Hypericum canadense*	Canada St. Johnswort	July–September	•	•
Guttiferae	*Hypericum gentianoides*	Pineweed	June–October	•	•
Guttiferae	*Hypericum mutilum*	Dwarf St. Johnswort	July–September	•	•
Guttiferae	*Hypericum perforatum*	Common St. Johnswort	June–September	•	•
Guttiferae	*Hypericum virginicum*	Marsh St. Johnswort	July–September	•	•
Haloragaceae	*Proserpinaca palustris*	Mermaid Weed	June–September	•	•
Hamamelidaceae	*Hamemelis virginiana*	Witch Hazel	September–November	•	•
Iridaceae	*Iris setosa*	Iris	May–July	•	•
Iridaceae	*Sisyrinchium atlanticum*	Eastern Blue-eyed Grass	May–July	•	•
Labiatae	*Lycopus* sp.	Bugleweed	June–October	2	1
Labiatae	*Lycopus uniflorus*	Northern Bugleweed	July–October	2	1
Labiatae	*Mentha arvensis*	Wild Mint	July–September	1.67	1
Labiatae	*Mentha* sp.	Mint	July–September	1.67	1
Labiatae	*Prunella vulgaris*	Selfheal	May–September	1	0.75
Labiatae	*Scutellaria lateriflora*	Mad Dog Skullcap	June-September	1	1
Labiatae	*Scutellaria galericulata*	Common Skullcap	June–September	1	1
Lauraceae	*Sassafras albidum*	Sassafras	April-May	0.5	1
Leguminosae	*Apios americana*	Indian Potato	July–September	•	•
Leguminosae	*Baptisia tinctoria*	Wild Indigo	July-August	2	1
Leguminosae	*Melilotus alba*	Sweet Clover	May–October	1.4	1.4
Leguminosae	*Trifolium arvense*	White Clover	June–September	1.5	1.5
Leguminosae	*Trifolium repens*	White Clover	May–September	1.8	1.6
Leguminosae	*Vicia* sp.	Vetch	June–August	1.25	1
Lentibulariaceae	*Utricularia cornuta*	Horned Bladderwort	May–August	•	•
Lentibulariaceae	*Utricularia purpurea*	Purple Bladderwort	May–August	•	•

Table 2 Continued.

Family	Genus species	Common Name	Bloom	Nectar rank	Pollen rank
Lentibulariaceae	Utricularia sp.	Bladderwort sp.	May–August	•	•
Liliaceae	Smilax sp.	Greenbriar	April–June	1	1
Liliaceae	Streptopus amplexifolius	Twisted Stalk	May–June	•	•
Lythraceae	Decodon verticillatus	Swamp Loosestrife	July–August	2	1.5
Malvaceae	Malva neglecta	Mallow	April–October	1	1
Melastomataceae	Rhexia virginica	Meadow Beauty	July–September	•	•
Myricaceae	Myrica pensylvanica	Northern Bayberry	April–May	1	1
Nymphaeaceae	Nuphar lutea	Yellow Waterlily	May–September	•	•
Nymphaeaceae	Nymphaea odorata	Sweet-scented Water Lily	June–September	1	2
Onagraceae	Epilobium angustifolium	Fireweed	July–September	1.25	1
Onagraceae	Oenethera biennis	Evening Primrose	June–September	1	1
Orchidaceae	Calopogon pulchellus	Grass Pink	June–August	•	•
Orchidaceae	Cerastium vulgatum	Mouse-ear Chickweed	May–September	•	•
Orchidaceae	Cypripedium acaule	Ladyslipper	April–June	•	•
Orchidaceae	Habenaria lacera	Ragged Fringed Orchis	June–August	•	•
Oxalidaceae	Oxalis montana	Wood Sorrel	May–July	1	1
Phytolaccaceae	Phytolacca americana	Pokeweed	July–September	•	•
Pinaceae	Pinus spp.	Pine	May–June	0	1
Plantaginaceae	Plantago minor*	Plantain	April–November	0	1.33
Polygonaceae	Polygonum hydropiper	Common Smartweed	July–September	1.2	1.25
Polygonaceae	Polygonum lapathifolium	Nodding Smartweed	July–September	1.2	1.25
Polygonaceae	Polygonum persicaria	Lady's Thumb	July–September	1.2	1.25
Polygonaceae	Polygonum sagittatum	Arrowleaf Tearthumb	July–September	1.2	1.25
Polygonaceae	Rumex acetosella	Sheep Sorrel	May–August	0.67	1.33
Pontederiaceae	Pontederia cordata	Pickerelweed	June–October	1	1
Primulaceae	Lysimachia quadrifolia	Whorled Loosestrife	June–September	•	•

Table 2 Continued.

Family	Genus species	Common Name	Bloom	Nectar rank	Pollen rank
Primulaceae	*Lysimachia terrestris*	Yellow Loosestrife	June–September	•	•
Pyrolaceae	*Chimaphila umbellata*	Pipsissewa	July–August	•	•
Pyrolaceae	*Monotropa uniflora*	Indian Pipe	June–October	•	•
Ranunculaceae	*Anemonella thalictroides*	Rue Anemone	March–May	•	•
Rosaceae	*Amelanchier* spp.	Serviceberry	April–June	1	0.8
Rosaceae	*Aronia melanocarpa*	Chokeberry	May–June	1	0
Rosaceae	*Fragaria ananassa*	Strawberry	May–June	1	1
Rosaceae	*Fragaria virginiana*	Wild Strawberry	May–June	1	1
Rosaceae	*Potentilla canadensis*	Dwarf Cinquefoil	March–June	1	1
Rosaceae	*Potentilla simplex*	Dwarf Cinquefoil	April–June	1	1
Rosaceae	*Prunus pensylvanica*	Fire Cherry	May–June	1.5	1.5
Rosaceae	*Prunus serotina*	Black Cherry	May–June	1.5	1.25
Rosaceae	*Rosa pallustris*	Swamp Rose	June–August	0.75	1.5
Rosaceae	*Rubus* sp.	Dewberry	May–July	1.4	1.2
Rosaceae	*Spiraea latifolia*	Meadowsweet	July–August	1	1
Rosaceae	*Spiraea tomentosa*	Hardhack	July–August	1	1
Rubiaceae	*Cephalanthus occidentalis*	Buttonbush	July–August	2	1.5
Rubiaceae	*Galium* sp.	Bedstraw	June–July	•	•
Rubiaceae	*Galium trifidum*	Small Bedstraw	June–July	•	•
Salicaceae	*Populus* sp.	Aspen	April–May	0	1.25
Salicaceae	*Salix* sp.	Willow	February–April	1.6	1.8
Scrophulariaceae	*Gratiola aurea*	Golden Hedge Hyssop	June–September	•	•
Scrophulariaceae	*Linaria canadensis*	Toadflax	April–September	•	•
Scrophulariaceae	*Melampyrum lineare*	Cow Wheat	July–August	•	•
Scrophulariaceae	*Verbascum* sp.	Mullein	June–September	1	1
Sparganiaceae	*Sparganium androcladum*	Branching Bur Reed	May–August	•	•
Typhaceae	*Typha latifolia*	Cat-tail	May–July	0	1
Violaceae	*Viola lanceolata*	Lance-leaved Violet	April–June	•	•
Vitaceae	*Vitis* sp.	Grape	May–June	1	1

ment by surrounding forest. In addition, continuous strips of wild flowering plants growing along the roads that connect the beds might provide pathways for bees to disperse from areas of high abundance to areas of low abundance (Aizen and Feinsinger 1994; Boller et al. 1997). Despite the sparse data suggesting that increase in flowering plant diversity will enhance bee species diversity and abundance, ecological theory has supported this contention for many decades (Paine 1966; Pimentel et al. 1997).

Nesting sites and bee zones

Most native bee species are ground nesters and nest in a diverse array of soils, from sandy embankments to periodically submerged sites (Cane 1991). Some bees nest in abandoned rodent burrows, slash piles, and hollow plant stems (Batra 2001; Free 1993). Despite the diversity of habitats that bees utilize for nesting, they often share one common behavior in nest site selection: they often nest near flowers (Weislo and Cane 1996).

Specific nesting requirements of most bees are unknown; however, there are nesting site attributes that many bees have in common (Batra 1984). The following discussion presents guidelines on how growers can make changes to their landscapes to encourage bee communities based upon incorporation of bee nesting requirements. It also provides further information on the most important native pollinators in cranberry.

Soil nests. Bees often nest on southerly exposed banks that are well drained and warm. Batra (2001) proposes the term “bee zone” to describe an area that can be maintained by a grower for native bee nesting. The zones should be permanent strips of land along the northern to northwestern edges of the cranberry bed to maximize exposure of nest sites to solar radiation. In most cases the zone should also be protected from cold northwesterly winds that accompany storm fronts in the northeastern USA. Planting a double row of evergreens as a windbreak several meters to the north of the bee zone could also accomplish this. Hummocks and hills are also a part of the landscape that may provide protection to bee nest sites from wind. Bees often select sandy loam banks for nesting, which are common in the cranberry agroecosystem. Clearing banks of vegetation each spring (as vegetation insulates the soil in winter) and keeping them free of insecticide drift will encourage bees. Although, some species of bees can survive submergence under water while in the nest (e.g., *M. addenda*) many are sensitive to waterlogged soils and thus depend upon undisturbed upland soils for nesting. If it is necessary to construct soil nesting banks, they should be 1 to 2 m high, 2 to 3 m wide, and 3 m or more long (Batra 2001). Many species of native bees have short foraging distances (<200 m) (Eickwort and Ginsberg 1980; Frankie et al. 1998). Therefore, the closer the bee zones are to the cranberry bed, the more likely that bees will use them for nesting and the more likely that the bees nesting in them will contribute to cranberry pollination.

The small size of many cranberry beds compliments the foraging range of many bees. Loose (2000) found native bee abundance evenly distributed throughout the cranberry bed during bloom. However, very large beds may need several bee zones. This can be accomplished by managing the dikes that already exist in larger beds as modified bee zones. Most dikes have open exposure to sunlight. Keeping the dikes free from thick vegetation should encourage soil-nesting bees. This can be achieved by mowing and removing detritus in the early spring when the ground is frozen and root systems will not pull up large clumps of soil. Destructive removal of vegetation, such as plowing, should be avoided as it may destroy bee nests. Mowing should be conducted in the evenings when bees are least active.

A common soil-nesting bee in cranberry in southeastern Massachusetts is *M. addenda.* This species was the most abundant bee in southeastern Massachusetts (Loose 2000) and New Jersey (Cane et al. 1996) cranberry beds during bloom. It is common, univoltine, nests in and around cranberry beds, and can withstand the flooding associated with cranberry cultivation. Emergence of the bee in the spring coincides with cranberry bloom, which extends from late June through early July. It is also an efficient pollinator. Cane et al. (1996) found that single nest cell of a female bee of this species contained pollen from at least 1,076 virgin cranberry flowers. Marucci (1967) showed that floral fidelity by this bee to cranberry during bloom appears absolute. *Megachile addenda* has also been collected on Compositae (Asteraceae) and Fabaceae (Cane et al. 1996), and may use these flowers as forage after cranberry bloom.

Non-soil nests. Vegetation that is cleared from bee zones and other areas can be piled elsewhere along the north side of the cranberry bed. Once it is dry, it will provide nesting sites for bee species that nest in hollow stems, twigs, and reeds (Saure 1996). Bumble bees, which are excellent pollinators of cranberry (MacKenzie 1994; Stubbs and Drummond 1997a), nest in slash piles, stone walls, natural fallen vegetative debris and anthropogenic materials, such as old mattresses and farm equipment (Goulson 2003; Kearns and Thompson 2001). *Bombus terricola* and *B. ternarius* generally nest underground, while *B. vagans, B. fervidus,* and *B. impatiens* generally nest in mouse nests and matted grass (Heinrich and Chavarria

2001). Bumble bees can be encouraged to nest in artificial domiciles (upside down pots with cotton fiber inside, wooden boxes, plastic buckets) (Free 1993). Hobbs et al. (1960, 1962) found that bumble bees readily nested in wooden boxes with upholsterers cotton inside. However, artificial nesting sites have not been consistently successful. Providing slash piles for nesting sites and wild flowering plants throughout the season may be adequate to boost bumble bee abundance (Macfarlane and Patten 1997).

Many species of leaf-cutting bees (Megachilidae) nest readily in blocks of wood drilled with holes, called trap nests (Bosch and Kemp 2001; Krombein 1967). Placing trap nests around lowbush blueberry fields in Maine has been shown to increase native bee numbers (Stubbs et al. 1997; Stubbs and Drummond 2001a). Trap nests are inexpensive and easy to make by drilling dry fence posts, logs, or 4x4 in. to 4 x6 in. pieces of seasoned, non-treated wood with 10 to 20 5/16-in. holes 4 to 10 in. deep. Bundles of hollow reeds or bamboo may also be used (Bosch and Kemp 2001). Trap nests can be nailed to trees or posts, or placed in shelters for protection (Stubbs et al. 2000). At least 50 traps should be placed at each site (Stubbs et al. 2000). The shelters should be south facing, to maximize the sun's warmth, of light color but not shiny, and well ventilated. The holes in the nests need to be horizontal to minimize the entrance of rain, and should be at least a 3 ft above the ground. Holes that are used by bees will be capped with dried leaves, resin, or mud. Ants, wasps, and spiders also use the holes for nests. Traps may also be placed under eaves on the southerly side of a structure. Since birds often prey on bees returning to their nests, 2-in. mesh hardware cloth can be placed in front of the trap nest shelter to deter bird predation (Batra 2001).

Judicious Use of Pesticides

Insecticides

Bee poisoning by insecticides was first documented in the United States in the 1870s, but it did not become a problem until after World War II and the advent of large-scale insecticide use on farms. This was facilitated by the availability of inexpensive synthetic organic insecticides and herbicides that could be applied to large areas, which brought about a marked drop in native bee species diversity and abundance (Atkins 1992; Johansen 1977).

Insecticides directly kill bees, but also cause indirect sublethal effects such as reduced fecundity and abnormal foraging behavior (Atkins 1992; Johansen 1977; Johansen and Mayer 1990). Factors such as bee size, density of setae, and behavior all affect a bee's susceptibility to an insecticide (Johansen 1972; Johansen et al. 1983). Smaller bees are often more susceptible to insecticides because of their increased surface area to volume ratio. The use of insecticides is the only production practice in lowbush blueberry cultivation that results in decline of *Osmia* leafcutting bees (Stubbs and Drummond 1997a). In turn, losses of native bees have been shown to have a significant impact on lowbush blueberry yield. Kevan (1977) documented decreases in native bee diversity and abundance, and concomitantly in lowbush blueberry yield, in New Brunswick, Canada, after forest surrounding blueberry barrens was sprayed with Fenitrothionâ during the spruce budworm outbreaks. Unfortunately, no comparable research has been conducted in cranberry to assess effects of insecticides on native resident bee species.

Insecticide applications should be avoided during bloom to minimize insecticide poisoning. Selecting least toxic insecticides for application during other times of the growing season when bees may be exposed should lessen the impact of the insecticide application. A list of insecticides used in many crop production systems and their relative toxicity to bees has been compiled by Delaplane and Mayer (2000) and Drummond and Stubbs (2003). The cranberry agroecosystem is comprised of flowering plant species both within the cranberry bed and also in the surrounding habitat outside of the bed. Both habitats can support alternative forage plants that bees depend upon (Loose 2000). It is also suggested that a weed-free cranberry bed, which prevents attraction of wild bees into the bed during the summer, reduces their exposure to insecticide applications. Loose (2000) found lower native bee densities associated with cranberry beds that had greater within-bed wild plant density. This may be due insecticide poisoning.

Residual pesticides, such as Sevin® and organophosphates can contaminate pollen and nectar and are taken back to the hive or nest by the foraging bee. This contaminated food then kills the brood (Atkins 1992). The insecticides used in cranberry and blueberry that are toxic to honey bees (and probably even more toxic to native bees) constitute a long list. They are azinphos-methyl (Guthion®), phosmet (Imidan®), chlorpyrifos (Lorsban®), malathion (Cythion®), and acephate (Orthene®). The insecticides peperonyl butoxide added as a synergist to pyrethrum (Pyrenone®), spinosad (Spintor®), and carbaryl (Sevin®) are also commonly applied for insect pest management and are categorized as moderately toxic to honey bees. Insecticides not toxic or slightly toxic to honey bees are *B.t.* (Dipel®), tefubenoxide (Confirm®), and neem (Azadirect®)

(Atkins 1992; Delaplane and Mayer 2000; Drummond and Stubbs 2003). When possible, growers should use insecticides that are the least toxic to bees. If highly toxic insecticides are used, then caution should be taken to spray on calm days to minimize drift and in the evening when bee activity is lower and exposure is lessened.

Herbicides

Herbicides are considered relatively nontoxic to honey bees (Atkins 1992), but can have an indirect effect on native bee communities. Herbicide use reduces the amount of nectar and pollen available by killing wild flowering plants and also causes displacement of nectar- and pollen-rich plants by herbicide-tolerant plants that are not rich resources for bees such as yarrow and nightshade (Johansen 1977). The abundance of wild flowering plants in the open edge areas around cranberry beds may mitigate the effect of herbicides within cranberry beds. Loose (2000) showed that wild plant density surrounding beds was positively correlated to the abundance of some species of native bees. This suggests that herbicide use within cranberry beds may not negatively affect native bee communities and may be beneficial as mentioned earlier by eliminating floral resources in the bog where insecticides are sprayed. However, the benefit may only be realized if the habitat complexity of the cranberry agroecosystem provides for alternative forage around the beds.

SUMMARY

Native bee species are a natural resource. The cranberry agroecosystem is a natural landscape that is now intensively managed commercially. Although many species of bees potentially can inhabit this landscape, there are many threats to their existence. Conservation of native bee species is a worthwhile investment for growers because honey bees, the major pollinators of cranberry, are in decline worldwide due to parasites, diseases, and global trade pressures that reduce the profitability of cranberry production, resulting in fewer growers being able to afford honey bee rentals. Bumble bees (*Bombus* spp.) and the leaf-cutter bee *M. addenda* are both common and effective pollinators of cranberry in Massachusetts. Their densities are tied to the abundance of wild flowering plants around the periphery of cranberry beds throughout the season, the availability of nesting sites, and refuge from insecticides. Including considerations for native bees in management plans of the land around cranberry beds may boost their abundance and diversity and increase their contribution to cranberry pollination. Therefore, a management perspective that focuses only on cranberry beds needs to be replaced with a perspective that includes more of the surrounding landscape.

To enhance native pollinator abundance, we recommend the following habitat modifications:.

- Providing sunny, open-edge areas between beds and the surrounding forest to encourage wild flowering plants and to increase suitable nesting sites.
- Planting bee forage and not mowing wild flowering plants while in bloom. Although bees do not appear to be detrimentally affected by herbicide use within cranberry beds, they are more numerous in beds with higher wild flowering plant abundance around the beds. Bees may benefit from alterations in management around beds, such as seeding or encouraging bee forage plants.
- Providing wild flowering plants along roads between beds to provide pathways for bees to disperse between beds.
- Avoiding destructive management practices that tear up the soil or change soil properties to preserve nest sites for soil-nesting bees.
- Leaving piles of debris along the edges of beds, or building trap nests to create more nest sites for bees.
- Using the least-toxic pesticides and timing spraying to avoid times when bees are active in and around the cranberry beds.

Managing land to enhance native bee populations improves the integrity of the ecosystem by conserving plant-pollinator relationships. It also ensures a future source of pollinators, and the continuity of a cultural tradition that evolved around an agricultural system unique to North America and has been in place since the early 1800s.

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