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Research Article

A survey of pollinator and plant interactions in meadow and grassland habitats of Marin County, California

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Abstract. Bees and other pollinators play an essential role in maintaining the plant biodiversity of our planet's landscape through pollination. Few baseline studies or monitoring programs have addressed concerns over local, regional and even worldwide declines in bee populations. We established 22 collection sites in meadow and grassland habitats in Marin County, California to determine which bee genera were present and which plants they were visiting. Some of these habitats were located in National Park Service natural areas and wildlands, including Golden Gate National Recreation Area and Point Reyes National Seashore. During this study we collected a total of 109 bee, wasp and fly specimens and from among these we identified seven genera of bees. The bees were found on 44 species of plants, only 11 of which were native to Marin County. The European honey bee (*Apis mellifera*), a non-native pollinator, was found on 37 species of plants, 28 of which were non-native.

Introduction

Worldwide concern exists about possible declines of native bee populations (Roulston and Goodell, 2011). In 2007 the U.S. National Research Council pointed out that neither baseline data nor monitoring programs are available to assess this problem. Bees are economically important to agriculture (Morandin and Winston, 2006; Roulston and Goodell, 2011). Insect pollination, mostly by bees, is necessary for 75% of all crops that are used directly for human food worldwide (Potts et al., 2010). The European honey bee, *Apis mellifera*, which has been well studied compared to other bee species, is capable of increasing yield in 96% of animal-pollinated crops (Potts et al., 2010).

How European honey bees affect native bee species diversity through competitive interactions is strongly debated (Huryn, 1997; Sugden et al., 1996) and difficult to examine. While efforts to monitor honey bees are inadequate in managed settings, efforts to monitor the status of wild pollinators in North America are essentially non-existent (Berenbaum, 2007). Droege and Grundel (pers. comm.) note that although many grasses and temperate trees in U.S. National Parks are pollinated mainly

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through wind dispersal, the majority of other herbaceous vegetation in these parks depends on animals, especially bees, for pollination.

We designed this study as a preliminary inventory of bee genera present and of plants which they potentially pollinate. We established sampling sites in meadow and grassland habitats in Marin County, California where stewardship of natural resources is of primary concern. These included Golden Gate National Recreation Area and Point Reyes National Seashore.

Materials and Methods

Collection sites

Sampling was conducted at 22 sites across Marin County, California from April to October, in 2008 and 2009. Four sites were located within Golden Gate National Recreation Area and four within Point Reyes National Seashore. All sites were selected to feature meadow and/or grassland habitats, areas dominated by non-woody plants such as grasses and wildflowers. Table 1 lists the sampling sites and their GPS coordinates, with Figure 1 showing their locations within Marin County. Sites on average were roughly 30 × 30 meters. During each sampling season, two researchers sampled sites on weekends, for an average of four hours per day. We sampled sites on a rotating basis, and each site was sampled at least four times per season, once in April, once in October with the other samplings falling in-between.

Table 1. Collection sites and their coordinates within Marin County, CA.

Golden Gate Recreation Area, Marin County, California
Site 1: 37° 50′23.26″N, 122° 29′53.33″W
Site 2: 37° 49′55.77″N, 122° 30′43.62″W
Site 3: 37° 50′02.34″N, 122° 32′00.00″W
Site 4: 37° 49′53.02″N, 122° 31′30.37″W
Stafford Lake, Marin County Parks, Novato, CA
Site 5: 38° 06′32.85″N, 122° 39′27.64″W
Site 6: 38° 06′33.64″N, 122° 39′12.12″W
Site 7: 38° 06′56.33″N, 122° 38′54.20″W
Site 8: 38° 06′42.08″N, 122° 39′28.32″W
Pt. Reyes National Seashore
Site 9: 38° 02′30.49″N, 122° 47′59.25″W
Site 10: 38° 09′15.69″N, 122° 6′17.10″W
Site 11: 38° 04′55.27″N, 122° 54′51.23″W
Site 12: 38° 02′26.54″N, 122° 47′54.18″W
Robson-Harrington Park, San Anselmo, CA
Site 13: 37° 58′25.79″N, 122° 34′02.75″W
Dominican University of California, San Rafael, CA
Site 14: 37° 58′50.63″N, 122° 30′50.91″W
Sausalito, CA
Site 15: 37° 51′40.00″N, 122° 29′16.67″W
China Camp, California State Park, San Rafael, CA
Site 16: 38° 00′31.73″N, 122° 29′42.36″W
McNear's Beach, Marin County Park, San Rafael, CA
Site 17: 37° 59′31.57″N, 122° 27′04.73″W
San Dominico School, San Anselmo, CA
Site 18: 38° 01′08.77″N, 122° 35′32.76″W
Marin Art and Garden Center, Ross, CA
Site 19: 37° 57′46.88″N, 122° 33′17.61″W
Phoenix Lake, Ross, CA
Site 20: 37° 57′21.36″N, 122° 34′35.44″W
Mill Valley, CA - Downtown
Site 21: 37° 54′21.58″N, 122° 32′52.40″W
Paradise Park, Marin County Parks, Tiburon, CA
Site 22: 37° 53′37.13″N, 122° 27′25.01″W

Collecting techniques for bees and plants

Collections were made from April to October in 2008 and 2009. B.C. and a volunteer assistant made field observations to assess flying insect and flower associations. Bees were captured directly on flowers using collecting jars containing the killing agent ethyl acetate. Diagnostic parts of each associated plant were collected. Specimens were placed in collection bags and labeled (time, date and location). In the laboratory, bees were pinned and labeled, and plant specimens were pressed and preserved. We identified bees to at least the generic level using dissecting microscopes, field guides, and taxonomic keys. Plants were identified to the species level using field guides and keys. Our plant identifications were verified by a local botanist of the Marin Chapter of the California Native Plant Society.

Results

Seven genera of bees and 44 host plant species were identified. Plant species are distinguished as native, non-native, or non-native invasive (Table 2). In the case of invasive species the impact level for the species, as determined by the California Invasive Plant Council, is included. A rating of A designates that a species has severe ecological impact on physical processes, plant and animal communi-

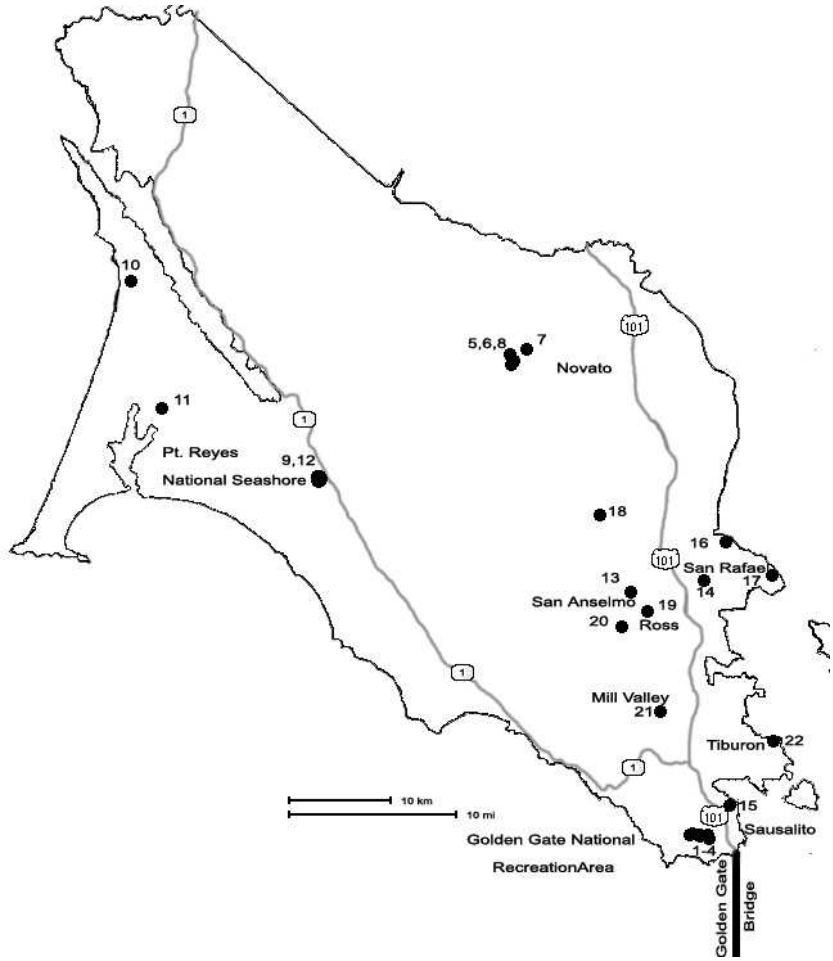

Figure 1. Bee and plant collection sites and landmarks, Marin County, California.

ties, and vegetation structure; a rating of D designates a species that has no potential impact (California Invasive Plant Council, 2006). Some bee taxa were found on a single plant species, while others, such as *A. mellifera* and *Bombus sp*. were found on a broad array of plants, both native and non-native.

The non-native European honey bee, *A. mellifera*, was found on 37 out of 44 species of plants identified in this study. Of the 37 plant species visited by *A. mellifera*, nine were native and 28 were non-native (Figure 2). Bees other than *A. mellifera* also showed a preference for non-native plants. Six genera were found on four native plant species and on 11 non-native plant species.

From our collections we also identified four wasp genera (*Chalybion, Philanthus, Pompilus,* and *Vespula)*, but wasps are not further discussed in this paper as they are not pollinators. In addition we catalogued six fly genera (*Allograpta, Anthrax, Bombylius, Fucellia, Minettia,* and *Pseudodorus*) as well as the plants on which they were found (Table 3). We include this information as some fly taxa are major pollinators, and this information could be useful to future pollination studies conducted in Marin County.

Discussion

These results represent a starting point for comparison with past and future inventories or

Table 2. Identifications of the bee genera and the plant species they were found on. Invasive impact of plant species is noted, if known, with A being high potential impact down to D being no potential impact according to the California Invasive Plant Inventory (2006).

Identified Genus	
Agapostemon sp.	
Identified plants (common name)	**Plant status**
Baccharis pilularis (dwarf chaparral broom)	Native
Cirsium vulgare (bull thistle)	Non-native invasive impact level B
Identified Genus	
Andrena spp.	
Identified plants (common name)	**Plant status**
Calystegia purpurata ssp. purpurata (Pacific false bindweed)	Native
Cirsium vulgare (bull thistle)	Non-native invasive impact level B
Eschscholzia californica (California poppy)	Native
Hirschfeldia incana (summer mustard)	Non-native invasive impact level B
Hypochaeris radicata (hairy dandelion)	Non-native invasive impact level C
Lobularia maritima (sweet alyssum)	Non-native invasive impact level C
Mentha pulegium (pennyroyal)	Non-native invasive impact level C
Identified Genus and Species	
Apis mellifera	
Identified plants (common name)	**Plant status**
Eleocharis macrostachya (common spikerush)	Native
Arctostaphylos tomentosa (woolly leaf manzanita)	Native
Arctotheca calendula (capeweed)	Non-native invasive impact level B
Bellis perennis (English daisy)	Non-native invasive impact level D
Brassica rapa (birdsrape mustard)	Non-native invasive impact level C
Centaurea calcitrapa (purple starthistle)	Non-native invasive impact level B
Centaurea solstitialis (yellow starthistle)	Non-native invasive impact level A
Ceratostigma plumbaginoides (blue leadwort)	Non-native
Cirsium vulgare (bull thistle)	Non-native invasive impact level B
Conium maculatum (poison-hemlock)	Non-native invasive impact level B
Datura stramonium (jimson weed)	Non-native
Echium candicans (pride-of-madeira)	Non-native invasive impact level C
Convolvulus arvensis (bindweed)	Native
Eschscholzia californica (California poppy)	Native
Euryops pectinatus (yellow bush daisy)	Non-native
Hemizonia congesta (hayfield tarweed)	Non-native
Hirschfeldia incana (summer mustard)	Non-native invasive impact level B
Lavandula angustifolia (common lavender)	Non-native
Lolium perenne (perennial ryegrass)	Non-native
Lonicera interrupta (chaparral honeysuckle)	Native
Lotus glaber (narrow-leaf bird's-foot trefoil)	Non-native invasive
Mentha pulegium (pennyroyal)	Non-native invasive impact level C
Perovskia atriplicifolia (Russian sage)	Non-native
Picris echioides (bristly oxtongue)	Non-native invasive impact level C
Plantago coronopus (cutleaf plantain)	Non-native invasive impact level Unknown
Polygonum capitatum (pinkhead smartweed)	Non-native
Raphanus sativus (radish)	Non-native invasive impact level C
Rubus ursinus (California blackberry)	Native
Salvia leucantha (San Luis purple sage)	Non-native
Salvia sp. (sage)	Native
Schinus terebinthifolius (Brazilian peppertree)	Non-native invasive impact level C
Symphyotrichum chilense (pacific aster)	Native
Taraxacum officinale (common dandelion)	Non-native invasive impact level D
Trifolium fragiferum (strawberry clover)	Non-native
Trifolium repens (white clover)	Non-native
Umbellularia californica (California laurel)	Native
Westringia fruticosa (coastal rosemary)	Non-native

Table 2. Continued.

Identified Genus	
Bombus sp.	
Identified plants (common name)	**Plant status**
Carduus pycnocephalus (Italian thistle)	Non-native invasive impact level B
Cirsium vulgare (bull thistle)	Non-native invasive impact level B
Eschscholzia californica (California poppy)	Native
Hirschfeldia incana (summer mustard)	Non-native invasive impact level B
Lotus glaber (narrow-leaf bird's-foot trefoil)	Non-native
Mentha pulegium (pennyroyal)	Non-native invasive impact level C
Oxalis pes-caprae (buttercup oxalis)	Non-native invasive impact level B
Raphanus sativus (radish)	Non-native invasive impact level C
Westringia fruticosa (coastal rosemary)	Non-native
Identified Genus	
Megachile sp.	
Identified plants (common name)	**Plant status**
Not Observed	N/A
Identified Genus	
Nomia sp.	
Identified plants (common name)	**Plant status**
Euryops pectinatus (yellow bush daisy)	Non-native
Identified Genus	
Synhalonia sp.	
Identified plants (common name)	**Plant status**
Hemizonia congesta (hayfield tarweed)	Native

biodiversity studies in and around Marin County, CA. In surveying bee diversity in restored habitats of Presidio, Wood et al. (2005) reported 56 bee species representing 23 genera. The Presidio, a large open space with interspersed forests in north San Francisco, is separated from Marin County to the north by only the span of the Golden Gate Bridge at the inlet to San Francisco Bay. Despite its close proximity to the Marin sites the Wood team reported a considerably higher number of bee species than we found in Marin County. This is likely due to the higher sampling effort (bowl trapping and netting) at the Presidio, with many more specimens having been collected (N=2,418). In addition, this study focused on meadow and grassland habitats, which represent only a subset of total bee diversity in the area.

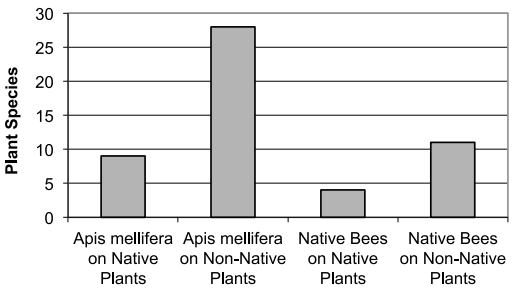

Figure 2. Number of native and non-native plant species on which *Apis mellifera* and six other bee taxa were found on four native plant species and on 11 non-native plant species.

The non-native European honey bee had a high relative abundance and visited a large number of plants in this study. Recovery of native pollinator communities within a few years after the removal of honey bees provides evidence for negative effects of honey bees (Mussen, 2002). Non-native honey bees could negatively influence native bee populations through a number of mechanisms including competition for food, acting as vectors for disease and parasites, and habitat modification. Mussen (2002) noted that proximity to high densities of *A. mellifera* hives reduced colony reproductive success of a native eusocial bumble bee, *Bombus occidentalis* in coastal California, but it is unclear whether the effect is resource-driven. Native pollinators are particular about their environment; if their nesting habitat is disturbed, modified or destroyed they cannot live in an area even when food is

Table 3. Fly genera collected in this study are listed in the table below along with the plants, if applicable, that they were found on, suggesting they may pollinate these plant species. These insects were thought to be bees, based upon behavior and morphology. However, upon further examination they turned out to be true flies (Diptera). Invasive impact of plant species noted, if known, with A being high potential impact down to D being no potential impact according to the California Invasive Plant Inventory.

Identified Genus	
Allograpta sp.	
Identified plants (common name)	**Plant status**
Euryops pectinatus (yellow bush daisy)	Non-native
Hemizonia congesta (hayfield tarweed)	Native
Hirschfeldia incana (summer mustard)	Non-native Invasive impact level B
Salvia leucantha (San Luis purple sage)	Non-native
Schinus terebinthifolius (Brazilian peppertree)	Non-native Invasive impact level C
Identified Genus	
Anthrax sp.	
Identified plants (common name)	**Plant status**
None Observed	N/A
Identified Genus	
Bombylius sp.	
Identified plants (common name)	**Plant status**
Echium candicans (pride of Madeira)	Non-native Invasive impact level C
Identified Genus	
Fucellia sp.	
Identified plants (common name)	**Plant status**
Schinus terebinthifolius (Brazilian peppertree)	Non-native Invasive impact level C
Identified Genus	
Minettia sp.	
Identified plants (common name)	**Plant status**
Bellis perennis (English daisy)	Non-native Invasive impact level D
Ranunculus californicus (Californian buttercup)	Native
Identified Genus	
Pseudodorus sp.	
Identified plants (common name)	**Plant status**
Hypochaeris radicata (hairy dandelion)	Non-native Invasive impact level C

abundant. This suggests that habitat modification may play an important role in declines of native bee populations (Mussen, 2002). The extent to which non-native bees alter native communities is still unclear, as are the underlying mechanisms.

Hives of native bees, that produce honey, range in size from only a handful to a few hundred individuals, up to two orders of magnitude smaller than hives of non-native honey bees that are used in industrial agriculture (Rich, 2005). While native social bees such as the yellow-faced bumblebee, *Bombus vosnesenskii*, are now successfully managed for pollinating small scale crops, such as in greenhouses (Rich, 2005), native plants with few native pollinators may benefit from *A. mellifera* given native pollinator decline (Buchmann and Nabhan, 1996).

While *A. mellifera* may play a role in propagation of non-native plants, the same can be said for native bees. Results of this study suggest that native and non-native bees are assisting in propagating non-native plants. In this context Dohzono and Yokoyama (2010) have suggested that non-native bees may limit native plant biodiversity. Furthermore, the benefits that *A. mellifera* provide, in terms of pollination of native plants, might outweigh the negative effects. Ultimately, the effect of non-native bees on native plant populations depends on bee population densities, visitation rates, and pollinator efficiency, which can vary greatly among plant species (Chamberlain and Schlising, 2008; Westerkamp, 1991). Thus the effect that *A. mellifera* has on native plants likely is species specific and would require more detailed

study. While this study establishes visitation of plants and probable pollination by bees in meadow and grassland habitats within Marin County, it does not demonstrate conclusively that bees pollinated the plants. Future studies could measure pollination success and incorporate additional habitat types for a more comprehensive understanding of the role of *A. mellifera* and other bee species in California flowering plant communities. Also, monitoring for bees in other types of plant communities in Marin County would reveal a dramatically larger number of taxa present.

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