Distribution and characterization of wild bee nesting sites on San Clemente Island, California Channel Islands

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ABSTRACT.—Wild bees provide the essential ecosystem service of pollination, which may be particularly important in island systems that host rare and endangered plants. Identifying and protecting nesting habitat of wild bees is critical for successfully conserving these pollinators and their pollination services, but characterization and delimitation of nesting habitat receives relatively little attention in the literature compared to description of floral interactions. Such data on wild bee nesting is necessary for creating effective conservation strategies that benefit the stability of ecosystem services, as well as promote the populations of both pollinators and plants. On San Clemente Island, we identified the locations of 50 bee nest sites. Bees from 12 sites were collected and identified as *Diadasia bituberculata* ($n = 9$), *D. opuntiae* ($n = 2$), and *Anthidium collectum* ($n = 1$). We characterized sites by vegetation cover and soil type: half (54%) of the sites were found in maritime desert scrub–prickly pear phase vegetation, and most (82%) were associated with loam-type soil. Here we provide the first descriptions of ground-nesting bee habitats on San Clemente Island and suggest that conservation of bee nesting habitat could be incorporated into existing avian and plant conservation management efforts in these shared habitats.

RESUMEN.—Las abejas silvestres cumplen una función esencial en la polinización del ecosistema, pudiendo ser particularmente importante en los sistemas insulares que albergan plantas exóticas y en peligro de extinción. Es fundamental identificar y proteger el hábitat de anidación de las abejas silvestres para conservarlas y para preservar sus funciones de polinización exitosamente, aunque la caracterización y la delimitación del hábitat de anidación reciben relativamente poca atención en la literatura en comparación con las interacciones florales. Esta información sobre la anidación de las abejas silvestres es necesaria para crear estrategias de conservación efectivas que beneficien la estabilidad de las funciones del ecosistema, así como para promover las poblaciones de los polinizadores y de las plantas. En la isla San Clemente, identificamos la ubicación de 50 sitios de anidación de abejas. Las abejas que se recolectaron en 12 sitios se identificaron como *Diadasia bituberculata* ($n = 9$), *D. opuntiae* ($n = 2$) y *Anthidium collectum* ($n = 1$). Caracterizamos los sitios según su cubierta vegetal y el tipo de suelo: la mitad de los sitios (54%) se encontraron en matorrales desérticos marítimos (tuna en etapa vegetativa), y la mayoría (82%) se asoció a suelos de tipo limosos. En este trabajo, proporcionamos las primeras descripciones de los hábitats de las abejas que anidan en el suelo de la isla San Clemente, y sugerimos que la conservación del hábitat de anidación de las abejas podría incorporarse a los actuales esfuerzos de conservación y de manejo de aves y de plantas en estos hábitats compartidos.

Wild bees provide the critical ecosystem service of pollination in natural and agricultural ecosystems. In efforts to protect rare, endemic plants in biodiversity hotspots (Myers et al. 2000), ecosystem-wide approaches to protecting pollinators of these plants are an integral part of effective conservation (Kearns et al. 1998). There has been great focus on identifying and supplementing floral resources for bee populations, typically in agricultural ecosystems (Haaland et al. 2011, Wratten et al. 2012, Blaauw and Isaacs 2014, M’Gonigle et

al. 2016). However, nutritional resources alone cannot support a species. In addition to flowers, wild bees also require nesting habitat in order to persist in the environment (Potts et al. 2005, Michener 2007, Williams et al. 2010).

Of the 20,000 known bee species worldwide, most are solitary, ground-nesting bees (Cane 1991, Michener 2007). A typical ground-nesting bee spends most of its 1-year lifecycle in the nest from egg through pupation until it emerges as an adult for a short period (typically several weeks) to mate, provision its nest,

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and produce offspring (Michener 2007). Nesting sites are selected by adult female bees after mating. Preference for nesting site soil characteristics varies among bee species, with differences in moisture, composition, and temperature requirements (Cane 1991).

Despite its critical importance, far fewer studies have examined bee nesting habitat relative to studies examining floral resources (Dicks et al. 2013), and nesting requirements are rarely considered in plant conservation strategies or multispecies conservation programs. Overlooking nesting habitat in research and conservation may be due in part to the difficulty and extensive time required in locating nests (O'Connor et al. 2012), particularly in complex landscapes (Cane et al. 2007). Such difficulties may be further compounded by the lack of information about nesting habitat requirements for many species that could otherwise aid in nest searching.

It would therefore be beneficial to identify nesting habitat preferences for bee species and to develop an assessment framework that can be used by researchers and land managers. After key characteristics of nesting sites are identified, habitat management can be recommended in the same manner as floral resource management. Ideally, this information can be used with an understanding of plant–pollinator interactions to protect existing relationships that will contribute to protecting rare or threatened plants and their pollinators (Kearns et al. 1998).

Island systems are of particular interest for conservation due to the relatively high number of endemic species and unique subspecies they host (Kier et al. 2009). Here we show the first mapping of solitary bee nesting sites on San Clemente Island, California. Sites were identified by entomologists, botanists, and ornithologists who surveyed the island for different projects. Associated bees were collected when possible, and nest sites were mapped relative to landform, soil, and vegetation types. This collaborative effort among biologists supports the idea that bee habitat monitoring can be incorporated into existing management plans for other species and serves to benefit overall ecosystem management.

METHODS

San Clemente Island is approximately 34 km long, and 6 km at its widest point, with an area

of 145 km² (TDI 2013). It is approximately 125 km off the coast of San Diego, California, and 35 km from the nearest neighboring Channel Island, Santa Catalina Island. San Clemente Island hosts 23 known bee species (Rust et al. 1985) that are also found on mainland California; however, several subspecies are considered endemic to the island.

Bee nest sites were initially identified when the authors (entomologists) located nest aggregations while collaborating with botanists studying pollination of the island's rare plants. Nest sites were identified as the authors traversed the island in a semisystematic method en route to field sites located across the island but primarily on the western side of the southern half of the island. Sites were identified as aggregations of 25 to 200+ nests at minimum densities of at least 3–5 nest entrances visible per square meter, although denser aggregations were also located. Sites (nest aggregations) were a minimum of 20 m apart. Nest entrances were circular, approximately 1 cm in diameter, and with or without turrets (Fig. 1). Additional nest sites were identified by ornithologists who opportunistically located sites while systematically scouting the island for endemic birds, except in restricted areas of the island, which were dominated by grasslands. The ornithologists were trained to identify nest sites based on search images, and they subsequently logged the geographic coordinates, took pictures of sites, and noted any bee activity. While neither the authors nor collaborators were specifically scouting only for bee nests, all nest locators were involved in projects that required systematic traversal of the island and careful observations and surveys of flora and fauna. Thus we believe that we have a representative sample of nest distributions on the island based on areas scouted, with more effort on the southern half of the island.

Nest sites were identified from January through June 2015. When active nests were found by the authors, bees were collected and brought to the University of California, Riverside (UCR), to be identified using identification keys and the reference collection at the UCR Entomology Research Museum (UCR ERM). All specimens have been deposited at the UCR ERM, Riverside, CA.

Nesting sites were mapped with ArcGIS 10.3 (ESRI, Redlands, CA). Landform, soil, and vegetation layers were used to describe

Fig. 1. Image of nest site aggregation within maritime desert scrub–prickly pear (MDS–PP) phase vegetation in thirst stony fine loam. Circular nest holes are visible, some with turrets and some without.

the habitat of the nesting sites (TDI 2013). Landform types included the following: hills and terraces, sand dunes, escarpments, high plateau clay grassland, and high plateau loamy grassland (Olmstead 1958, Muhs 1982). Soil types included the following: thirst stony fine loam, ustalf cobbly silt loam, Westshore silt loam, Shoba loam, eelpoint clay, and eel-cove fine sandy loam (Muhs 1982). Vegetation types included the following: maritime desert scrub (MDS)–*Lycium* phase, MDS–prickly pear phase, MDS–cholla phase, maritime sage scrub, and none (bare ground) (USDoN SWDIV 2001).

RESULTS

Overall, 50 nest aggregations were located within the 5-month period in 2015 (Table 1). We observed 29 sites with bee activity, and of those, the authors collected and identified bees from 12 sites. The majority (9 bees) were identified as *Diadasia bituberculata* (Cresson),

and 2 were identified as *D. opuntiae* Cockerell. Collectively, *Diadasia* spp. include species commonly known as cactus bees. One bee was identified as *Anthidium collectum* Huard, which is known to use abandoned nests of other bees (Hicks 1929). We also collected and identified an ecotoparasitic fly, *Bombylius major* L. (Boesi et al. 2009), which we observed ovipositing into nesting holes at nest site 20 (Figs. 2, 3).

Although bees nested across the island, identified nests were found on some landforms, vegetation, and soil types more often than others. Just over half (52%) of the nest sites were found on the high plateau loamy grassland landform type. Approximately a quarter (24%) of nest sites were found on hills and terraces. One nest was found in sand dunes and the remaining were found on escarpments or high plateau clay grassland. In relation to vegetation cover, 27 nest sites (54%) were found in MDS–prickly pear phase, 11 (22%) in MDS–*Lycium* phase, 6 (12%) in

TABLE 1. Summary of nest site locations, observations, and other data. MDS = maritime desert scrub, MSS = maritime sage scrub, PP = prickly pear, C = cholla, and L = *Lycium*.

Site	Coordinates	Date observed	Nest activity	Bee collected	Species identification	Soil type	Vegetation community	Landform
1	33.011446, -118.588408	15 Jul 15	active	not collected	<i>Anthidium collectum</i>	Westshore silt loam	MDS-L phase	Hills and terraces
2	33.006047, -118.581825	29 Jul 15	active	not collected		Westshore silt loam	MDS-L phase	Hills and terraces
3	33.005611, -118.573436	8 Jul 15	not active	not collected		San Clemente clay	MDS-L phase	Hills and terraces
4	32.998615, -118.571803	6 Mar 15	active	collected		Eelcove fine sandy loam	MDS-L phase	Hills and terraces
5	32.994639, -118.569826	22 Mar 15	not active	not collected	<i>Diadasia bituberculata</i>	Eelcove fine sandy loam	MDS-L phase	Hills and terraces
6	32.994569, -118.568546	22 Mar 15	not active	not collected		Eelcove fine sandy loam	MDS-L phase	Hills and terraces
7	32.989339, -118.578584	19 May 15	not active	not collected		Psammits Ustalf complex	MDS-L phase	Sand dunes
8	32.913657, -118.481018	26 Feb 15	not active	not collected		Ustalf cobbly silt loams	MSS	Escarments
9	32.905562, -118.474223	29 Mar 15	active	collected	<i>Diadasia bituberculata</i>	Shoba loam	MSS	High plateau loamy grassland
10	32.904325, -118.510269	26 Aug 15	active	collected	<i>Diadasia opuntiae</i>	Shoba loam	MDS-PP phase	High plateau loamy grassland
11	32.887451, -118.484935	20 Mar 15	active	not collected	<i>Diadasia opuntiae</i>	Ustalf cobbly silt loams	none	Escarments
12	32.878270, -118.483572	25 Aug 15	active	collected		Eelpoint clay	MDS-PP phase	High plateau clay grassland
13	32.877573, -118.484443	8 Oct 14	not active	not collected		Shoba loam	MDS-PP phase	High plateau loamy grassland
14	32.876884, -118.485337	25 Aug 15	active	not collected		Shoba loam	MDS-PP phase	High plateau loamy grassland
15	32.876141, -118.506170	5 Jun 15	active	not collected	<i>Diadasia bituberculata</i>	Westshore silt loam	MDS-L phase	Hills and terraces
16	32.876069, -118.506201	27 Mar 15	active	not collected		Westshore silt loam	MDS-L phase	Hills and terraces
17	32.875849, -118.435183	1 Jun 15	not active	not collected		Ustalf cobbly silt loams	MDS-C phase	Escarments
18	32.874770, -118.485233	20 Mar 15	active	collected		Shoba loam	MDS-PP phase	High plateau loamy grassland
19	32.874669, -118.485271	8 Oct 14	not active	not collected	<i>Diadasia bituberculata</i>	Shoba loam	none	High plateau loamy grassland
20	32.874128, -118.485230	20 Mar 15	active	collected		Eelpoint clay	MDS-PP phase	High plateau clay grassland
21	32.873659, -118.485541	25 Aug 15	active	not collected		Eelpoint clay	MDS-PP phase	High plateau clay grassland
22	32.873154, -118.490025	20 Mar 15	active	collected		Eelpoint clay	MDS-PP phase	High plateau clay grassland
23	32.872541, -118.490494	15 May 15	not active	not collected	<i>Diadasia bituberculata</i>	Eelpoint clay	MDS-PP phase	High plateau clay grassland
24	32.872304, -118.488026	8 Oct 14	not active	not collected		Eelpoint clay	MDS-PP phase	High plateau clay grassland
25	32.872014, -118.470274	30 Mar 15	not active	not collected		Thirst stony fine loam	none	High plateau loamy grassland

TABLE 1. Continued.

Site	Coordinates	Date observed	Nest activity	Bee collected	Species identification	Soil type	Vegetation community	Landform
26	32.870764, -118.486968	9 Oct 14	not active	not collected	<i>Diadasia bituberculata</i>	Eelpoint clay	MDS-PP phase	High plateau clay grassland
27	32.870533, -118.495409	25 Aug 15	active	not collected		Eelcove fine sandy loam	MDS-PP phase	Hills and terraces
28	32.870533, -118.495409	25 Aug 15	active	not collected		Eelcove fine sandy loam	MDS-PP phase	Hills and terraces
29	32.869814, -118.474748	30 Mar 15	not active	not collected		Shoba loam	MDS-PP phase	High plateau loamy grassland
30	32.868746, -118.440728	1 Apr 15	active	collected	<i>Diadasia bituberculata</i>	Thirst stony fine loam	MDS-C phase	High plateau loamy grassland
31	32.866102, -118.457555	27 May 15	not active	not collected		Thirst stony fine loam	MDS-PP phase	High plateau loamy grassland
32	32.861033, -118.463670	31 Mar 15	active	collected		Thirst stony fine loam	MDS-PP phase	High plateau loamy grassland
33	32.861017, -118.463727	31 Mar 15	active	collected		Thirst stony fine loam	MDS-PP phase	High plateau loamy grassland
34	32.860981, -118.463552	19 Mar 15	active	not collected	<i>Diadasia bituberculata</i>	Thirst stony fine loam	MDS-PP phase	High plateau loamy grassland
35	32.860924, -118.463507	31 Mar 15	active	collected		Thirst stony fine loam	MDS-PP phase	High plateau loamy grassland
36	32.858247, -118.445789	21 Apr 15	active	not collected		Thirst stony fine loam	MDS-C phase	High plateau loamy grassland
37	32.858167, -118.445807	1 Apr 15	active	collected		Thirst stony fine loam	MDS-C phase	High plateau loamy grassland
38	32.856752, -118.444835	27 Mar 15	not active	not collected	<i>Diadasia bituberculata</i>	Thirst stony fine loam	MDS-PP phase	High plateau loamy grassland
39	32.856451, -118.464724	7 Jul 15	active	not collected		Thirst stony fine loam	MDS-PP phase	High plateau loamy grassland
40	32.855414, -118.445059	27 Mar 15	not active	not collected		Thirst stony fine loam	MDS-PP phase	High plateau loamy grassland
41	32.854959, -118.446185	27 Mar 15	not active	not collected		Thirst stony fine loam	MDS-PP phase	High plateau loamy grassland
42	32.854101, -118.466442	7 Jul 15	active	not collected	<i>Diadasia bituberculata</i>	Thirst stony fine loam	MDS-PP phase	High plateau loamy grassland
43	32.854470, -118.410673	1 Apr 15	not active	not collected		Thirst stony fine loam	Grasslands	High plateau loamy grassland
44	32.853134, -118.460485	30 Mar 15	not active	not collected		Thirst stony fine loam	MDS-PP phase	High plateau loamy grassland
45	32.850780, -118.490280	12 Aug 15	active	not collected		Thirst stony fine loam	MDS-L phase	High plateau loamy grassland
46	32.850981, -118.431310	2 Jun 15	not active	not collected	<i>Diadasia bituberculata</i>	Westshore silt loam	MDS-L phase	Hills and terraces
47	32.848344, -118.426930	2 Jun 15	active	not collected		Thirst stony fine loam	MDS-C phase	High plateau loamy grassland
48	32.845495, -118.477348	7 Jul 15	active	not collected		Thirst stony fine loam	MDS-C phase	High plateau loamy grassland
49	32.842539, -118.463335	22 May 15	active	not collected		Ustalf cobbly silt loams	MDS-L phase	Escarpments
50	32.890997, -118.233641	8 Jul 15	not active	not collected		Eelcove fine sandy loam	MDS-PP phase	Hills and terraces
						Thirst stony fine loam	MDS-PP phase	High plateau loamy grassland

Fig. 2. Map of San Clemente Island vegetation cover. The inset table summarizes the number of sites (nest aggregations) found within each cover type. Site numbers are denoted north to south. Site marks in red indicate where bees were collected; site marks in blue indicate where sites were observed but bees were not collected.

MDS–cholla phase, 2 in maritime sage scrub, 1 in grassland, and 3 in areas lacking vegetation (Fig. 2). In relation to soil type, most nesting sites (82%) were located in a loam-type soil; 38% of nest sites were found in thirst stony fine loam soil, while another 16% were found in clay type soil, and 1 was found in pasamments-ustalf complex soil (Fig. 3).

Of all the nest sites sampled, 42% were inactive at the time of observation, but gregarious nesting patterns and visible fresh turrets are highly suggestive of recent nesting (North and Lillywhite 1980, Ordway 1984). Some of the sites (36%) were large aggregations (>30 nests per m²) found directly on the compacted soil of old ATV trails and dirt roads.

Fig. 3. Map of San Clemente Island soil types. The inset table summarizes the number of sites (nest aggregations) found within each soil type. Site numbers are denoted north to south. Site marks in red indicate where bees were collected; site marks in blue indicate where sites were observed but bees were not collected.

DISCUSSION

To our knowledge, there are very few large-scale solitary bee nesting surveys conducted in natural ecosystems. On San Clemente Island, we were able to find 50 nest sites in 5 months. Our success in locating many nest sites on the island may have resulted from the

low-growing vegetation and numerous bare-ground patches throughout the landscape. Our collaboration with existing personnel and survey efforts involved multiple trained field biologists searching for nests while scouting the island for other species-monitoring projects. We acknowledge the limitations of these opportunistic sampling methods; nevertheless,

our study provides the first mapping of native bee nesting habitat on the island, which may contribute to the growing study of solitary bee nesting habitat.

Nesting habitat patterns emerged, based on sampling effort. Thirst stony fine loam soils cover the highest elevation and upper marine terraces on the west side of the island where approximately half the nest sites were found. Most nesting sites were found within the dominant MDS–prickly pear phase vegetation cover. Almost all (92%) of the *Diadasia* spp. collected were from nest sites located in cactus-related vegetation (prickly pear and cholla), which is an expected association between cactus and cactus bees (Schlising 1972, Ordway 1984), and may suggest that inactive nest sites found in the same vegetation could also belong to *Diadasia* spp. Future and regular surveys of nesting habitat will improve maps and may have predictive potential.

It is interesting to note that 36% of located nest sites were found on human-disturbed, compacted soil. The association of nest sites with compact soil has been observed for several other bee species (Thorp 1969, Wuellner 1999, Sardiñas and Kremen 2014) and has been observed specifically for *D. bituberculata* in California and Arizona (Linsley and Macswain 1952, North and Lillywhite 1980) and for *D. opuntiae* in Arizona (Ordway 1984). Our observations suggest that some types of human-mediated changes in the environment may be beneficial for some bee species by creating preferred habitat (Heneberg et al. 2013). Because solitary ground-nesting bees create nests by tunneling into the soil (Michener 2007), compaction may contribute to nest integrity via improved structural support, which can allow for larger nest aggregations relative to those in undisturbed soil with less compaction, including ground immediately adjacent to trails (Potts and Willmer 1997).

There are recognizable challenges in protecting species *in situ* because of the level of management and monitoring required (Heywood and Iriondo 2003). Logistically, this *in situ* protection may be more difficult to accomplish in natural ecosystems compared to agricultural systems, which can be manipulated to a higher degree (Wade et al. 2008). Protecting bee nesting habitat in natural areas, however, could be incorporated within existing protection plans for the floral species

they pollinate and protection plans for other organisms, such as birds, which may occupy the same habitat. Additional research may show that bees benefit as nontarget species of bird conservation because bees and birds use the same habitat patches (Heneberg 2012), or vice versa. If bees and birds share specific biological requirements such as nest substrate or food sources, areas with both of those resources could be prioritized. Determining habitat and resource needs of multiple species can help to identify overlapping resource requirements, streamline conservation strategies, and contribute to a comprehensive resource management plan that is cost-effective and efficient to implement (Barrows et al. 2005).

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