Santa Barbara Botanic Garden

Coelus pacificus (Tenebrionidae) photo by Casey Richart

Channel Islands Invertebrates: A Gap Analysis of Specimen and Observation Data

Final Report

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Channel Islands Invertebrates: A Gap Analysis of Specimen and Observation Data

Final Report

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Acronyms used in this report

ANSP = Academy of Natural Sciences of Drexel Univrsity (in Philadelphia)

Bohart = Bohart Museum of Entomology at the University of California, Davis

CAS = California Academy of Sciences

CHAS = Chicago Academy of Sciences

DMNH = Denver Museum of Natural History

EMEC = Essig Museum of Entomology Collection

KU = University of Kansas Natural History Museum

LACM = Natural History Museum of Los Angeles County, formerly Los Angeles County Museum

MCZ = Museum of Comparative Zoology, Harvard

SDNHM = San Diego Natural History Museum

SBBG = Santa Barbara Botanic Garden

SBMNH = Santa Barbara Museum of Natural History

UCR = University of California, Riverside

UCSB = University of California, Santa Barbara (both University and Museum acronym)

UF = University of Florida

UMMZ = Univeristy of Michigan Museum of Zoology

USNM = U.S. National Museum, at the Smithsonian Institution

YPM = Yale Peabody Museum

INTRODUCTION

"Meaningful studies of island ecology, evolution, and biogeography must be preceded by taxonomic studies of the insects and subsequent publications that provide identification keys. In this regard, entomologists are far behind most other biologists in understanding the fauna of these islands."

- Scott Miller, 1985

Insects and other terrestrial arthropods are the most species-rich animal groups. With no real consensus, the actual number of worldwide species is estimated to total between 3 and 100 million species (Larsen et al. 2017), most of which remain undescribed. Of the approximately 1.4 million species that have so far been described, insects, arthropods, and other invertebrates are some of the groups about which we know the least in terms of body structure, life history, and ecological interactions on a worldwide scale (Wilson 1987, 2000). This same assessment is true for the California Channel Islands. C.L. Hogue (1993) estimated that there were about 3,000–4,000 insect species in nearby mainland Los Angeles, which is far too low given what molecular techniques have revealed. Exploration of micro insects using Malaise traps and other specialized techniques has uncovered unexpectedly large numbers of previously unknown species (Brown & Hartop 2016), such that a total closer to 20,000 species seems more reasonable.

Concurrently, a combination of habitat loss/degradation/fragmentation, pollution, invasive species, global climate change, overexploitation, and extinction of co-dependent species are driving declines of pollinators and other insect species across the globe (Potts et al. 2010, Dirzo et al. 2014, Koh et al. 2016, Seibold et al. 2019, Cardoso et al. 2020, Wagner et al. 2021). This decline is especially apparent for the highly-studied bees and butterflies (Bonebrake & Cooper 2014, Sanchez-Bayo & Wyckhuys 2019), and even common species are affected (Hallmann et al. 2021). Biodiversity conservation has never been more critical, as global climate change and other stressors will demand the resilience and resistance that biodiversity brings (Sakschewski et al. 2016). We'll need to learn what these organisms are while we seek to conserve them.

This study aims to identify the spatial, temporal, and taxonomic gaps in our island terrestrial invertebrate knowledge. Invertebrates are the most difficult to assess group in our gap analyses (which separately include macrofungi, bryophytes, vascular plants, reptiles, amphibians, birds, and mammals). This is because insect and other arthropod collections are massive, containing up to 35 million specimens, but only 1–3% of those specimens are databased. This creates another gap: the digitization gap. To assess this, we compare the number of taxa in the literature versus the number in specimen and observation records.

The following overview of notable collectors and expeditions, invertebrate faunal summaries, general invertebrate surveys, invertebrate genetics, and ecological studies aims to describe the pulses of invertebrate work that have taken place on the islands and the benefits that have been gained, the groups that have been studied, and some of the more notable findings that can inform future work. It will be evident that this work has been idiosyncratic, driven by the topics in vogue at the time and of interest to a given scientist. Added details regarding the institutions of the scientists will illustrate that they come from all over the state and nation – it takes a village when it comes to invertebrate biodiversity studies.

Notable Collectors and Expeditions

While naturalists pursuing other studies occasionally collected insects on the Channel Islands in the last half of the 1800s, "it was not until the 1890s that the first serious entomological collections were made (Miller 1985a)." In 1897 the Pasadena Science Club, led by H.C. Fall, published "A list of the Coleoptera of the southern California islands, with notes and descriptions of new species", resulting from three members' month-long collecting trip to Santa Barbara, San Nicolas, and

San Clemente islands. In 1934, Fall then published "The Coleoptera of Santa Cruz Island" with fellow Club member A.C. Davis. That same decade, Don Meadows, Lepidopterist from Laguna Beach, CA, published two parts of an annotated list of the Lepidoptera of Santa Catalina Island (Meadows 1937, 1938). These were the result of extensive collections made between 1927 and 1934 while living on Catalina Island (Miller 1985a). Meadows reported 167 species of macro-Lepidoptera.

Also in the 1930's, Theodore Dru Alison Cockerell (University of Colorado, Boulder) published accounts of a new sand wasp (genus *Bembix*) on San Nicolas Island (Cockerell 1938) and several new bees from Santa Catalina Island (Cockerell 1939d, e). He also published an overview of the California island insects in 1939 (Cockerell 1939f), with special attention to the island endemic taxa. Cockerell was responsible for naming 51 bee, 4 wasp, and 4 mealybug species found on the Channel Islands (Rust et al. 1985). As described in a tribute by Dan Muhs (2018), T.D.A. Cockerell published 16 papers on the islands from 1937 to 1940, and he played a pivotal role in the establishment of the Channel Islands National Monument.

In 1939, the (then named) Los Angeles County Museum (LACM) launched the Channel Islands Biological Survey, an historic interdisciplinary research expedition investigating the biology, geology, archaeology, and paleontology of all eight islands. The expedition proceeded until 1941, before getting cut short by World War II (Comstock 1939g, 1946). Twenty papers describing new island invertebrates were published by various scientists from that survey in the Bulletin of the Southern California Academy of Sciences between 1939 and 1964. These papers covered the mites (Augustson 1939), fleas (Augustson 1941), beetles (von Bloeker Jr. 1939a, b), butterflies (Clarke 1940, Comstock 1942, Comstock and Dammers 1941, Comstock and Henne 1940, 1942, Meadows 1942), bees (Cockerell 1939a, 1939b, & 1940; Timberlake 1940), wasps (Cockerell 1939a), flies (Wilcox and Martin 1945, Sanders 1964), myriapods (Pierce 1940), strepsipterans (Pierce 1941), and snails (Kanakoff 1950).

The publication of MacArthur and Wilson's insular theory of zoogeography (1963), which relates species richness with island area and distance from the mainland, influenced a generation of scientists on the California Channel Islands. These include Jerry Powell for Lepidoptera (UC Berkeley), David Weissman (Stanford University) and David Rentz (Academy of Natural Sciences of Philadelphia) for Orthoptera, Peter Raven (Stanford University) for plants, and Jared Diamond (UC Los Angeles) for birds. In 1966 and 1969, UC Berkeley personnel made three general collecting trips to the island as part of the larger California Insect Survey initiated by the Agricultural Experiment Station in 1940. This was made more feasible through establishment of the University of California Field Station on Santa Cruz Island in 1965 (Powell 1980, 1985). This Survey entailed 59 full time equivalent (FTE) collector days, and included Dr. Powell, who conducted Lepidoptera surveys in spring and early summer of 1966. Powell reported that some 250 species of butterflies and moths were taken through both diurnal and nocturnal collection of adults as well as by rearing (Powell 1980). These Lepidoptera were recorded in multiple publications summarized in Powell (1985).

In his first island paper in 1967, Powell described an endemic moth, *Cerostoma lyonothamnae*, from Santa Cruz Island that was reared from the Island Ironwood (*Lyonothamnus floribundus floribundus*), and declared that most of the island Lepidoptera fauna were not unique, being found on the mainland as well, with only a few endemics at the species level. Powell then published a preliminary faunal assessment in 1985, giving superfamily-level summaries, species-area graphs, and a list of 24 endemic species and subspecies. He noted that the endemic island Lepidoptera include both neo-endemics (which have differentiated from their near relatives) and paleo-endemics (which are relicts of a past, larger range), and that San Miguel and Santa Rosa Islands are relatively under-surveyed. He also noted that the islands' plant communities had been degraded by the overgrazing of domestic and feral animals for over a century, prior to any Lepidoptera collecting (Powell 1985). Together with David Wagner (University of Connecticut), Powell later declared that Santa Cruz Island's small to minute leaf-mining moth fauna is less depauperate than that of butterflies and larger moths (Powell and Wagner 1993). They hypothesized that this is due to the smaller host plant patches required to maintain effective populations of the more micro Lepidoptera. In the fourth California Islands Symposium (Powell 1994), he reported 750 Lepidoptera species on the islands, with the better-surveyed islands (Anacapa, Santa Cruz, and Santa Catalina) likely no more than 70–75% known. He noted that species numbers show correlations with island area, but are better predicted by the numbers of vascular plants. This stands to reason given the high levels of host plant specialization in Lepidopteran larvae. Powell made new collections on Santa Barbara Island in 2001 and 2003, and reported on that island's Lepidoptera fauna in the Sixth California Islands Symposium (Powell 2005). He noted that much additional effort will be required to complete an inventory of that island, as a species accumulation curve did not reach an asymptote and 31% of the taxa are recorded by a single specimen. He also noted that this island has a higher species richness relative to its size and floral diversity than any of the other Channel Islands.

The first of David Rentz and David Weissman's outstanding evaluations of island orthopteroid insects came out in 1973, with their assessment of the genus *Cnemotettix*. They reported four species on the islands, with three of those found only on the islands. In 1982, they published the most comprehensive analysis of any arthropod group on the islands thus published, in their book "Faunal affinities, systematics, and bionomics of the Orthoptera of the California Channel Islands." Their extensive work included cytology studies, rearing of immatures, song recordings, counting of male cricket file teeth, and wind tunnel tests of adult grasshoppers captured in the field, and includes peripheral taxa including the Phasmatodea, Mantodea, and Blattodea. The book includes assessments of the distribution of Orthoptera on the Channel Islands and adjacent mainland and the zoogeography of the Orthoptera in these areas, a discussion of endemism and species-area relationships, and a key to the orthopteroid insects of the Channel Islands and adjacent mainland, with species descriptions and notes on habitat and distribution. Twelve percent of the 54 orthopteran species on the islands are endemic; these species seem to have radiated and speciated on the islands (Weissman 1985), in contrast to primarily relictual endemics found in botanical studies at that time (Raven 1967, Thorne 1969). Distribution patterns seem congruent with the geological history of the islands, and a high percentage (41%) of Island Orthoptera are flightless, particularly the endemic species (75%; Weissman 1985).

Stephen Bennett, from the Orange County Vector Control District, published five island invertebrate papers between 1983 and 1993. These included four papers describing new island taxa, including a treehole mosquito (Bennett 1983), a biting midge (Bennett 1985b), a whip scorpion (Bennett 1985a), and a mite (Bennett et al. 1989). He also wrote about the effects of feral animals on soil mites in Catalina Ironwood groves (Bennett 1993), noting that "marked decreases in diversity and abundance of species were noted in heavily disturbed areas."

Scott E. Miller (Santa Barbara Museum of Natural History [SBMNH], Harvard, and Smithsonian Institution) is one of the most important contributors to our knowledge of Channel Islands arthropods. He published an entomological bibliography of the California Islands in 1981 with A.S. Menke, followed by solo supplements in 1985 (Miller 1985b) and 1993. These track publications of descriptions and accounts for all of the taxa known from the islands which are not readily discoverable via a literature search, and represents an incredible accumulation of knowledge. Miller maintained his literature database through ~the 1990s, and provided it to us to use in our comparison of taxa known from the literature vs. databased specimens. Miller has also contributed a rich body of his own research. He prepared a report for the U.S. Navy with C.D. Nagano (from LACM) on the insects and related terrestrial arthropods of San Nicolas Island in 1981, and published on the earwigs of the islands in 1984. Also in 1984, he published a list of the butterflies of the Channel Islands, indicating that the island faunas are "depauperate aggregations of mainland species", with limited endemism. In 1985, he produced an account of the beetles of Santa Barbara Island with Pamela Mercer Miller, and published an account of the insects associated with *Malacothrix* flowers on San Miguel Island with W.S. Davis. Later, when at the Smithsonian Institution, he contributed a history of entomological exploration of Santa Rosa Island, in the book *Island of the Cowboys: Santa Rosa Island.* He continues to investigate island arthropods to this day and is a wealth of knowledge.

Our understanding of Channel Island invertebrates took another leap forward with the first Symposium on the Entomology of the California Channel Islands, held in 1981 and published in 1985. SBMNH published the Proceedings, funded by then owner of Santa Cruz Island Dr. Carey Stanton, which was edited by Arnold S. Menke and Douglass R. Miller, both with the USDA. The Proceedings covered a biogeographic comparison of the bees, sphecid wasps, and mealybugs of the Islands (Rust, Menke and Miller 1985), the zoogeography of the Channel Islands Orthoptera (Weissman 1985), the faunal affinities of the Channel Islands Lepidoptera (Powell 1985), the Avalon hairstreak butterfly (Gall 1985), distribution of the tiger beetles (Nagano 1985), the bees of Anacapa Island (Rust 1985), and beetles of Santa Barbara Island (Miller and Miller 1985), as well as a set of maps with place names prepared by Menke. It also included S.E. Miller's summary of island entomology knowledge and endemic species (127 taxa; Miller 1985a), and his first supplement to the entomological bibliography of the California Islands (Miller 1985b).

Rust, Menke, and Miller's 1985 biogeographic comparison of the bees, sphecid wasps, and mealybugs of the islands has been another important contribution to our knowledge of island invertebrates. They described the distribution patterns of these three insect groups, looking for general patterns and investigating inter-island similarities using not only the typical variables used (island size and distance to the mainland), but also maximum elevation, number of plant species and communities, and an index of topographic diversity. While they note that collections had been limited, making their analyses preliminary, they did find some significant relationships. For the mealybugs (typically specialist herbivores), they found four significant relationships, in decreasing order: plant species, elevation, plant communities, and size. No significant relationships were found for the sphecid wasps (predators), but for bees, which feed on pollen and nectar and have a range of specialization levels, the significant relationships were plant species, plant communities, and island elevation. They note that the vast majority of island bees are generalists, with 21% parasitic on other bee species.

Michael Caterino (formerly SBMNH, now Clemson University) and Stylianos Chatzimanolis, with others, published at least seven papers together about island beetles between 2007 and 2015. These included several species descriptions of beetles in the families Staphylinidae (Caterino and Chandler 2010), a conservation genetics study of three flightless beetles (Caterino and Chatzimanolis 2009), and an account of a rare beetle re-discovery (Caterino et al. 2015). They also included a comparative phylogeographic study of island vs. mainland beetles (Caterino et al. 2014), the results of which suggest that "the Channel Islands do not function as a biogeographical unit and … several of the islands exhibit levels of diversity comparable to, or even exceeding, similarly sampled populations on the mainland." The three papers for which Chatzimanolis is the lead author (2007, 2008, and 2010) focus on the phylogeography and conservation of different beetles in the families Carabidae, Histeridae, Hydrophilidae, and Tenebrionidae. Their work reveals that "coastal beetles may be relatively good colonists, and likely to repopulate appropriate areas where management permits habitat to return to natural conditions."

Island Invertebrate Faunal Summaries

A number of other publications greatly advanced our knowledge of different invertebrate groups in the 1980s. Robert Lane (UC Berkeley), Scott Miller, and Paul Collins (SBMNH) published the distributions of the ticks (Acari: Argasidae and Ixodidae) of the Channel Islands in 1982. Ronald Garthwaite (Woods Hole Oceanographic Institution), Frank Hochberg (SBMNH), and C. Sassaman (UC Riverside) provided an account of the occurrence and distribution of island terrestrial isopods in 1985. R.D. Goeden (UC Riverside) reported on the fruit flies (Tephritidae) from Santa Cruz Island in 1986, reporting nineteen new species records from the island and providing host plant information for six of them.

In 2002, Laura Furlong (Westmont College) and Adrian Wenner (UC Santa Barbara [UCSB]) published an account of the aquatic insects of Santa Cruz Island. They reported that the aquatic Diptera and Coleoptera are overrepresented on the island when compared to the mainland, while Trichoptera and Plecoptera were under-represented. They hypothesized that this discrepancy may have resulted from differences in dispersal and colonization abilities, while the depauperate and degraded riparian habitat on the island may have excluded some aquatic groups.

A valuable overview of the land mollusks of the Channel Islands was published in 2018 by Charles Drost (U.S. Geological Survey) and colleagues (Jeffrey Nekola, Barry Roth, and Timothy Pearce). They note that land snails and slugs have the highest level of endemism among all major animal groups on the Channel Islands, with nearly 75% of the species confined to one or more of the islands. Their recent intensive inventories have increased the number of land mollusk species known from San Clemente Island by 50%, while a single survey trip to Santa Rosa Island more than doubled the number of species known on that poorly explored island. They note a strong positive link between native vegetation recovery following nonnative mammal removal and more robust populations of land snails and slugs.

General Invertebrate Surveys

Since 2000, a number of studies have provided comprehensive invertebrate snapshots from the different islands. For example, biologists from Tierra Data, Inc. (Escondido, CA), including Elizabeth Kellogg, Scott Snover, and James Lockman, conducted terrestrial invertebrate surveys on San Clemente Island in 2010 (Tierra Data 2011) at nine sampling sites chosen by representative vegetation types, island fox monitoring grids, and the habitat of the rare San Clemente sage sparrow, San Clemente loggerhead shrike, and island night lizard. These sites were sampled 2–3 times each from May through August, and utilized passive sampling for repeatability. Three pitfall traps and one automated blacklight trap were set at each sampling location, in addition to standardized sweep netting, visual surveys for diurnally active lepidopterans and other large taxa such as grasshoppers and dragonflies, and miscellaneous collections. Specimens were sorted to "morphospecies" (hypothesized species using readily observable morphological features, and voucher specimens, written descriptions, and drawings were used to track these various types across samples. A total of 10,758 arthropods were sorted to 351 distinct taxa in 23 orders and 150 families, and are housed at SBMNH. This survey added 160 taxa to those previously known, indicating how much there still is to learn about island invertebrates.

Ida Naughton (then UC Berkeley), with Mike Caterino, Cause Hanna (Cal State Channel Islands), and David Holway (UC San Diego), published contributions to an arthropod inventory of Santa Cruz Island in 2014, from sampling in island scrub oak (*Quercus pacifica*) woodland and patches of island morning glory (*Calystegia macrostegia* ssp. *macrostegia*). Specimens were sorted to morphotypes and taxonomic specialists identified selected taxa, including the orders Araneae, Scorpiones, Coleoptera (Staphylinidae and Carabidae), honeydew-producing Hemiptera, Psocodea, Orthoptera, Formicidae, and Apoidea. These specimens were deposited at SBMNH and the San Diego Natural History Museum (SDNHM). They recorded 62 species newly known to the island through this effort.

Ken Osborne (independent subcontractor for HDR Inc.) reported on a baseline inventory of terrestrial invertebrates on San Nicolas Island in 2015. On five field trips over 18 days and two years, nocturnal surveys, bait traps, Malaise traps, and pan traps were utilized. A total of 86 species were added to the existing faunal list of 341 species. Many taxa were identified to "Operational Taxonomic Units", or morphospecies. As Mr. Osborne points out, full determination to species level is a process ultimately requiring the attentions of specialist entomologists, therefore the taxonomic inventory presented should be considered tentative. Specimens were deposited at UC Riverside Entomology Research Museum (UCR) and Naval Base Ventura County, and transferred to SBMNH.

Biologists and ecologists from the Santa Barbara Botanic Garden (SBBG), including Casey Richart, Stephanie Calloway, Jenny Hazlehurst, and Denise Knapp, conducted terrestrial invertebrate surveys on San Clemente Island in 2019 (in prep) at seven sampling sites chosen for rare plant populations and habitat type. These sites were sampled over six visits between late February and early July at three-week intervals to capture pollinator turnover. Repeatable techniques were utilized that favored learning opportunities for plant-invertebrate interactions and facilitated future comparisons. These included sweep netting in delineated rare plant plots for pollinator network analysis, pan trapping, beat sheeting off of five plant species at each site, and litter sampling. Specimens are being sorted to morphospecies, imaged from multiple angles, and served online to bugguide.net and iNaturalist.org for identification by experts around the world. Many interns and volunteers are helping to accomplish the huge task of sorting the many thousands of specimens. Those specimens will be distributed to 30 specialist collaborators across the United States and beyond, who will be able to definitively identify these specimens and describe new taxa.

Invertebrate Genetics Studies

With the dawning of the genomics era in the 1970s, island studies have utilized developing techniques to understand the invertebrates. Flies in the genus *Drosophila* have long been model organisms for such studies. In 1978, Lawrence Harshman (State University of New York, Stony Brook) and Charles Taylor (UC Riverside) examined the gene frequencies of an isolated fruit fly (*Drosophila pseudoobscura*) population on San Miguel Island, finding that isolation on this island did not lead to genetic differentiation. Several decades later, in 2008, Sergio Castrezana and Therese Markow from the University of Arizona compared populations of a fruit fly (*Drosophila mettleri*) that breeds in soil soaked by cactus juices on Santa Catalina Island to those in Mexico and Arizona. They found "significant local genetic differentiation, especially when geographical isolation is coupled with host shifts." Maxi Polihronakis Richmond (UC San Diego) and colleagues from both UCSD and the University of Alabama compared the genetic structure of four cactophilic *Drosophila* species that recently colonized Catalina Island (Richmond et al. 2013). They describe how the two species that specialize on columnar cactus species on the mainland underwent a host switch on Catalina to prickly pear cactus, as columnar cacti do not occur there, leading to significant genetic differentiation between mainland and island populations.

A different fly was the subject of Edward Pfeiler et al. (Centro de Investigación en Alimentación y Desarrollo, Sonora MX; 2013), who investigated the genetic differentiation, systematics, and population structure of cactus flies (Diptera: Neriidae: *Odontoloxozus*) from Mexico and south-western USA. They found significant molecular variance between *O. longicornis* on Catalina Island vs. Arizona and Mexico, and stated that most likely this divergence resulted from geographical isolation from the mainland and not a host plant shift, as had previously been posited.

Martin Ramirez (Bucknell University, PA) and Richard Beckwitt (Framingham State College, MA) investigated genetic variability within the spider genus *Lutica* in southern California and Baja California (1995), reporting that the phylogenetic relationships revealed generally correspond with the geologic history of the Channel Islands and adjacent mainland. Ramirez and colleagues (2013) later compared trapdoor spiders (*Bothriocyrtum californicum*) at nine southern California sites, including Santa Catalina and Santa Cruz Islands, finding reduced genetic variability in two of three island populations, "consistent with the loss of variability usually associated with island colonization." They recommended conserving as many populations as possible while creating and restoring habitat to enhance connectivity and colonization.

Marshall Hedin (San Diego State University) and colleagues included California Channel Islands taxa in their study of jumping spiders (Salticidae, *Habronattus tarsalis;* Hedin et al. 2020). Their data show that the islands have been colonized four separate times by this species complex, with southern islands housing genetically and morphologically unique and endemic populations, and the northern islands having limited divergence from the southern California mainland.

The Smithsonian Institution, U.S. Department of Agriculture, Agriculture Canada, and University of Guelph have been building a DNA barcode library for North American Lepidoptera. Scott Miller reports that he has been harvesting island specimens opportunistically. These are mostly from Don Meadows from Catalina, although other specimens are included, like odd specimens that T.D.A. Cockerell sent to the USDA for identification in the 1930s. In addition, the Smithsonian is barcoding the catch from a Malaise trap placed on Santa Cruz Island, which at last count was up to about 14,000 specimens and some 1400 BIN (Biodiversity Index Number)-species. SBBG is also currently conducting DNA barcoding and metabarcoding studies on several islands for the U.S. Navy and The Nature Conservancy, which include the preparation of a specimen library and analysis of invertebrate and vertebrate diets.

Ecological Studies

Invertebrates such as arthropods are excellent indicators of ecosystem health, because they play key roles in nutrient recycling, pollination, seed dispersal, energy flow, and structuring plant and animal communities (Gullan & Cranston 2005). They also respond quickly, sensitively, and locally to environmental changes (Kremen et al. 1993). Analysis of invertebrate responses to invasions can help delineate the drivers of biodiversity and community patterns, thus guiding the conservation and restoration of diverse native ecosystems (Lodge 1993; McMahon et al. 2006). Several studies, or series of studies, illustrate the value of ecological invertebrate work that has occurred on the islands since around the turn of the century.

John F. Barthell (currently at the University of Central Oklahoma) published seven papers with Robbin Thorp (UC Davis), Adrian Wenner (UC Santa Barbara), and John Randall (The Nature Conservancy) about island bees between 1998 and 2009. These included six studies investigating native and European honey bee foraging on the island, and relating honey bee foraging to the success of the invasive yellow star thistle, *Centaurea solstitialis*. Thorp also led two papers with Wenner and Barthell, reporting on the flowers used by honey bees vs. native bees on Santa Cruz Island (Thorp et al. 1994) and reporting that honey bees tend to forage most frequently on introduced plants (Thorp et al. 2002). Wenner (1990) reported on the ecology of honey bee foraging on Santa Cruz, and on the removal of this invasive organism from the island (Wenner and Thorp 1994, Wenner et al. 2002, 2009).

A different invasive species was the focus of James Wetterer (Columbia University in Arizona), Christina Boser (formerly The Nature Conservancy), Korie Merrill, and others (including David Holway, Ida Naughton, and John Randall), who published five papers (between 2000 and 2018) about Argentine ant distribution, impacts, spread, and control on Santa Cruz and San Clemente Islands. Boser, Merrill, Holway, Naughton, and Randall, with others, have been collaborating to remove this invasive ant from those two islands. Wetterer and colleagues published a list of Santa Cruz Island ants in 2000, then outlined the impacts of the Argentine ant in 2001. Cause Hanna (Cal State Channel Islands) and colleagues (including Naughton, Boser, and Holway) published two studies in 2015 outlining the impacts of Argentine ants on flora visitation and plant seed set (2015a) and non-ant arthropods (2015b). Their work also pointed to the importance of adequate information about species identity for such assessments (Hanna et al. 2015b).

Sheena Sidhu and Erin Wilson-Rankin (UC Riverside) and colleagues from the Soil Ecology and Restoration Group in San Diego published an account of the hosts of the generalist moth *Grammia ursina* (Noctuidae) on San Clemente Island (Sidhu et al. 2016). They report rare plant restoration outplantings have been negatively affected by *G. ursina* outbreaks. Sidhu and Wilson-Rankin also described the distribution and nature of wild bee nesting sites on San Clemente Island in 2018, noting that conservation management efforts should consider bee nesting habitat, which is critical to these important pollinators' survival.

Denise Knapp, Fritz Light, and Chris Garoutte (SBBG) investigated the impacts of *Mesembryanthemum crystallinum* invasion (an African succulent plant species) on arthropod abundance, richness, composition, feeding guilds, and functional diversity via impacts on plant diversity, native plant cover, and soil characteristics at three sites on San Nicolas Island (Knapp et al. 2018). They found that arthropod composition was consistently altered by *Mesembryanthemum* invasion at all three sites, and that either species richness or functional diversity (or both) was reduced in *Mesembryanthemum* plots. The larger arthropods found in native plots, including flies, beetles, ants, and moths, are important food for the island fox (Cypher et al. 2014).

Studies_have investigated other invertebrates associated with the endemic island fox. Crooks et al. (2001) studied the ectoparasite fauna for island foxes (*Urocyon littoralis*) on Santa Cruz Island, and identified three ectoparasites: fleas (*Pulex irritans*: Insecta: Siphonaptera: Pulicidae), lice (*Neotrichodectes mephitidis*: Insecta: Phthiraptera: Trichodectidae), and ticks (*Ixodes pacificus*: Arachnida: Ixodida: Ixodidae). They note that island foxes may be especially vulnerable to the introduction of novel disease organisms and their vectors.

METHODS

Island invertebrate literature has been gathered by the lead author over the years, and was supplemented via a Web of Life library search. In that search each island name was searched individually, and all resulting titles inspected, in order to capture the many different taxa and taxonomic levels addressed by this study. Over 200 articles were collected in this manner, and were used both for the introductory materials and to database the taxonomic names contained therein. These were combined with Scott Miller's aforementioned database of island invertebrate names and sources to assess the differences in taxonomic knowledge between the literature, digitized specimens, and iNaturalist observations (**Appendix A**).

Five other data sources were used for these analyses, which are accessible through the Islands of the Californias Biodiversity Information System (Cal-IBIS) symbiota portal at www.cal-ibis.org. This all-taxa portal was created to consolidate Californian and Mexican Channel Islands biodiversity data for ready use by land managers, scientists, and others, and to facilitate the assessment and management of the islands as a whole archipelago (Hoyer et al. 2018). It is one of only a few all-taxa portals created for defined geographic areas in existence. To maintain this portal, data from other sources are periodically searched and data "snapshots" are imported. Other data sets are unique to this portal. Records from other sources are searched via a series of name and spatial searches. Because data coming from different sources can be redundant, a series of operations are then performed to remove duplicates and clean the data prior to posting on the Cal-IBIS portal. Island records that do not contain either geographic coordinates or key island names may not be recovered through this process, as can records that are problematic for one reason or another.

The five specimen and observation data sources used for these analyses were as follows: 1) Global Biodiversity Information Facility data (GBIF: gbif.org), from the Cal-IBIS Symbiota portal, 2) LACM data which are not yet available online and not completely digitized (Hemiptera, Odonata, Orthoptera, and some of the Coleoptera and Lepidoptera remain), 3) iNaturalist observation data, 4) Barcode of Life data system (BOLD) for DNA data (http://www.boldsystems.org/) when available, and 5) Bohart Museum (UC Davis) island bee specimen records, which are also not available online. The AntWeb and PlantBug databases are both served via GBIF and thus were not searched separately.

Although iNaturalist records are a component of GBIF data, we discovered that not all records were being retrieved (likely an issue with the process to remove duplicates), and ultimately downloaded these separately. We will search for a solution to this problem in the future. Here we examine not only "research grade" iNaturalist observations (www.iNaturalist.org), but also non-research grade, due to difficulty of achieving species-level identifications with invertebrates. To be research grade, an observation must have a photographic voucher, a community-supported species-level identification, and date and locality data. All iNaturalist observations data were downloaded in August, 2021.

Furthermore, for iNaturalist data, some observations were "obscured" meaning that available locality data are intentionally offset from the actual observation location. This can occur if the user intentionally changes settings from "open" to "obscured." The iNaturalist platform also automatically obscures all locality data for species of conservation concern. To get access to the unobscured locality data for these observations, researchers would need to contact the individual observers and/or get them to contribute their observations to a project for which the user gives permission to project staff to see unobscured locality data. As a result, getting access to the unobscured locality data is a significant time investment and beyond the scope of the current study.

For all downloaded data (63,306 records), an Island Name field was generated from a combination of place names where given, and coordinates (using scripts in ArcGIS) where not. Year and month fields were standardized, and a Collection Type field was added to standardize the various ways that this was coded in the original data, via the collectionCode and basisOfRecord fields.

Current taxonomic names were accessed via a range of sources, suggested by our collaborators, and listed below. These were then used to synonymize the database by inserting acceptedFamily, acceptedGenus, and acceptedName fields. Endemics data were sourced from (Miller 1985a), the Miller database discussed in the introduction, Powell (1994), the Catalina Island Conservancy website (catalinaconservancy.org), McCoshum et al. (2012), and Drost et al. (2018). Common names, when not available, were generated by combining the distribution with an existing common name for that taxonomic group.

Once the dataset was finalized, summary graphs and tables were generated using R 4.1.0 (R Core Team, 2021), and the tidyverse (v1.3.1; Wickham et. al 2019). Heat maps showing spatial specimen collecting effort were generated using 1 km grid cells overlaid onto each of the islands. Prior to generating those maps, erroneous points using island centroids were removed. These were identified by combining the latitude and longitude of all vertebrate and invertebrate records into one field, calculating how many records had those coordinates, then checking those with large numbers of records to determine if they were centroids. Records removed are summarized in **Appendix B** to facilitate improvement of the original museum data.

- Arachnida (per Casey Richart): World Spider Catalog for spiders (available at https://wsc.nmbe.ch/), World Catalogue of Opiliones for harvestmen (available at https://wcolite.com/), Mite Research for mites (available at http://www.miteresearch.org/aboutme.html), and Harvey's checklist of the world for Pseudoscorpionida.
- Blattodea/Isoptera (no known experts): GBIF (available at gbif.org)
- Chilopoda: GBIF
- Coleoptera (no one best site per Matthew Gimmel): GBIF, Catalog of Life (https://www.catalogueoflife.org), and Discover Life (https://www.discoverlife.org/)
- Dermaptera (no known experts): GBIF
- Diplopoda (via Casey Richart): Shelley, R. M. (2002). Annotated Checklist of The Millipeds of California (Arthropoda: Diplopoda). Monographs of the Western North American Naturalist, 1(1), 90–115. https://doi.org/10.3398/1545-0228-1.1.90
- Diptera (via Brian Brown): Systema Dipterorum, available at http://www.diptera.org/Nomenclator
- Hemiptera: Discover Life
- Hymenoptera (via Katja Seltman): Discover Life
- Lepidoptera (via Scott Miller): Checklist of North American Lepidoptera, available at: https://www.researchgate.net/publication/302570819_Annotated_taxonomic_checklist_of_the_Lepidoptera_of_North_America_North_of_Mexico
- Mollusca (via Casey Richart): MolluscaBase, available at http://www.molluscabase.org/index.php
- Orthoptera (via Jeffrey Cole): Orthoptera Species File Online, available at: http://orthoptera.speciesfile.org/HomePage/Orthoptera/HomePage.aspx
- Phasmida: Phasmida Species File Online, available at: http://phasmida.speciesfile.org

RESULTS

Arachnida

Table Arachnida-1 reveals that spiders (Araneae) make up the majority (67.31%) of Arachnida data points. Araneae are 88.24% of the Arachnida specimens (Cal-IBIS) and 66.15% of the observed Arachnida (iNaturalist). Araneids (orb-weavers) and Salticids (jumping spiders), two of the more obvious and charismatic groups, have the most iNaturalist observations. As spiders are quite difficult to identify, these specimens should also be inspected by an expert before using the species lists from these data.

Table Arachnida-2 shows that 89.7% of specimens in collections are identified to species, while only 32.2% of the research grade iNaturalist observations are identified to species. This is relatively good taxonomic resolution for the specimens relative to other invertebrate taxonomic groups. The overall number of digitized collections is very low, however.

Table Arachnida-3 reveals a digitization gap, between known Arachnida taxa found on the Channel Islands and taxa represented in digitized collections and iNaturalist observations. There are many families (82), genera (149) and species (153) known to occur on the Channel Islands based on the literature that are not represented in the occurrence data (67% at the species level). **Appendix C Table 1** has a complete list of taxa found in the occurrence data and literature.

Figures Arachnida-1a and 1b show the absolute number and proportional number/island size of Arachnida occurrences on each island. The Cal-IBIS records show how under-sampled or undigitized Arachnida are on the Channel Islands, with the majority of the islands having few records, and no records on Anacapa. San Clemente has the most collections, however that total is only 19 specimens. The islands that are more accessible (Santa Cruz and Santa Catalina) or have a lot of working biologists on the island (San Clemente) have the most observations on iNaturalist. The graphs normalized by island size show that Santa Barbara and Anacapa are relatively better sampled for their size.

Figure Arachnida-2 shows the number of specimens by year over time. The first collection recorded is from 1967, which may reveal a digitization gap for past collections of Arachnida on the islands. Specimens from the late 1960s and 1970s are primarily housed at the California Academy of Sciences (CAS) and the Essig Museum of Entomology Collection (EMEC), and were mostly collected by Rentz and Weissman (while surveying Orthoptera) and John Doyen (a Coleopterist from UC Berkeley). Specimens collected between 2004 and 2016 (some of which are hidden by iNaturalist records) were primarily part of jumping spider (Salticidae) studies by M. Hedin, S. Foldi, and B. Boyer at San Diego State University (Hedin et al. 2020). Most of the occurrence records have been recorded in the past decade on iNaturalist.

Figure Arachnida-3 shows the data by month and island. Seasonality can be important for observations of Araneids which are both more discernable and identifiable in the late summer to fall when webs and spiders are at their largest size. Due to the low number of Arachnida data points overall, and the prevalence of iNaturalist data (which is also heavily influenced by accessibility), no seasonal trends can be assessed here.

Figures Arachnida-4a, b, and c show that iNaturalist observations are well-distributed on most islands, except for West and Middle Anacapa Islets, the majority of Santa Rosa Island, and the more remote portions of Santa Cruz and San Miguel. These areas are difficult to access by visitors. San Clemente Island is well-covered, as biologists there are very active on this platform.

Table Arachnida-1. Number of Arachnida data points recorded in each data source by family, showing the relative number of observations (iNaturalist) and specimens (Cal-IBIS). Note: the Los Angeles County Museum has one Arachnida record identified to Scorpiones which is not included in the table for simplicity.

Order	Family	Cal-IBIS	iNaturalist	n	%
Araneae	Agelenidae	0	26	26	1.95%
	Amaurobiidae	1	0	1	0.08%
	Anyphaenidae	0	4	4	0.30%
	Araneidae	6	242	248	18.60%
	Cheiracanthiidae	0	2	2	0.15%
	Clubionidae	0	2	2	0.15%
	Corinnidae	0	3	3	0.23%
	Cybaeidae	0	1	1	0.08%
	Desidae	0	1	1	0.08%
	Dictynidae	0	3	3	0.23%
	Dysderidae	0	12	12	0.90%
	Gnaphosidae	4	26	30	2.25%
	Halonoproctidae	0	7	7	0.53%
	Linyphiidae	0	4	4	0.30%
	Lycosidae	0	51	51	3.83%
	Mimetidae	0	1	1	0.08%
	Oecobiidae	0	3	3	0.23%
	Oonopidae	0	1	1	0.08%
	Oxyopidae	0	8	8	0.60%
	Philodromidae	0	12	12	0.90%
	Pholcidae	0	13	13	0.98%
	Plectreuridae	0	1	1	0.08%
	Salticidae	46	207	253	18.98%
	Scytodidae	0	1	1	0.08%
	Segestriidae	1	3	4	0.30%
	Sparassidae	0	2	2	0.15%
	Tetragnathidae	0	2	2	0.15%
	Theridiidae	0	72	72	5.40%
	Thomisidae	2	91	93	6.98%
	Trachelidae	0	2	2	0.15%
	Zodariidae	0	6	6	0.45%
	Zoropsidae	0	2	2	0.15%
Ixodida	Ixodidae	0	8	8	0.60%
Mesostigmata	Parasitidae	0	1	1	0.08%
Opiliones	Phalangodidae	2	2	4	0.30%
	Protolophidae	5	30	35	2.63%
	Sclerosomatidae	0	1	1	0.08%
Oribatida	Camisiidae	0	1	1	0.08%
	Cymbaeremaeidae	0	2	2	0.15%
Pseudoscorpiones	Cheliferidae	0	2	2	0.15%
Pseudoscorpiones	Chernetidae	0	1	1	0.08%
	Chthoniidae	0	2	2	0.15%
	Garypidae	0	4	4	0.30%
	Garypinidae	1	0	1	0.08%

Order	Family	Cal-IBIS	iNaturalist	n	%
Scorpiones	Hadruridae	0	5	5	0.38%
	Vaejovidae	0	103	103	7.73%
Solifugae	Eremobatidae	0	2	2	0.15%
Trombidiformes	Anystidae	0	6	6	0.45%
	Bdellidae	0	14	14	1.05%
	Caeculidae	0	1	1	0.08%
	Eriophyidae	0	3	3	0.23%
	Erythracaridae	0	1	1	0.08%
	Erythraeidae	0	13	13	0.98%
	Eupodidae	0	4	4	0.30%
	Eutrombidiidae	0	1	1	0.08%
	Microtrombidiidae	0	1	1	0.08%
	Penthaleidae	0	2	2	0.15%
	Rhagidiidae	0	1	1	0.08%
	Smarididae	0	2	2	0.15%
Palpigradi		0	1	1	0.08%
	undetermined Family	0	202	202	15.61%
	total Arachnida	68	1226	1294	
	family diversity	9	57	59	

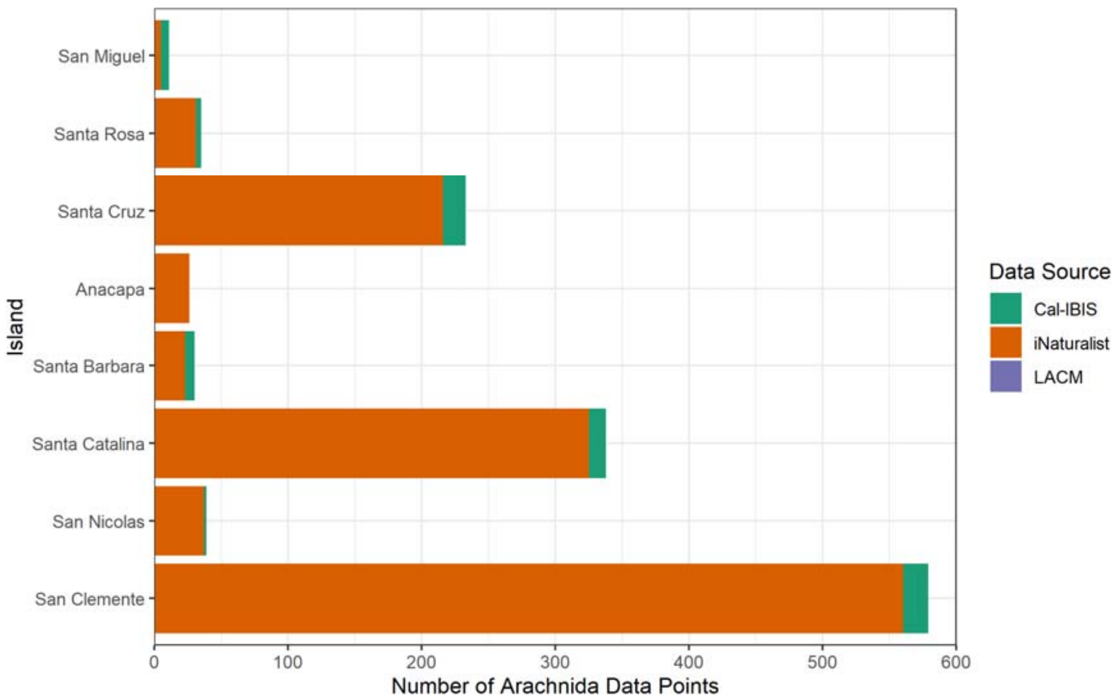
Table Arachnida-2. Taxonomic resolution of island Arachnida records by source. Note: only 395 of the iNaturalist records are Research Grade, likely due to their relatively coarse taxonomic resolution.

Rank	Cal-IBIS	iNaturalist (All)	iNaturalist (RG)	Totals
Class	68	1226		1294
Order	68 (100%)	1202 (98.04%)	395 (32.22%)	1270 (98.15%)
Family	68 (100%)	1024 (83.52%)	395 (32.22%)	1092 (84.39%)
Genus	67 (98.53%)	785 (64.03%)	395 (32.22%)	852 (65.84%)
Species	61 (89.71%)	479 (39.07%)	395 (32.22%)	540 (41.73%)

Table Arachnida-3. Channel Islands Arachnida taxa added by a literature search as compared to those represented in digitized specimen and observation data, revealing the digitization gap.

	# of Families	# of Genera	# of Species
Occurrence Data	59	85	74
Taxa added by Literature	82	149	153
Total Arachnida	141	234	227

(a)



(b)

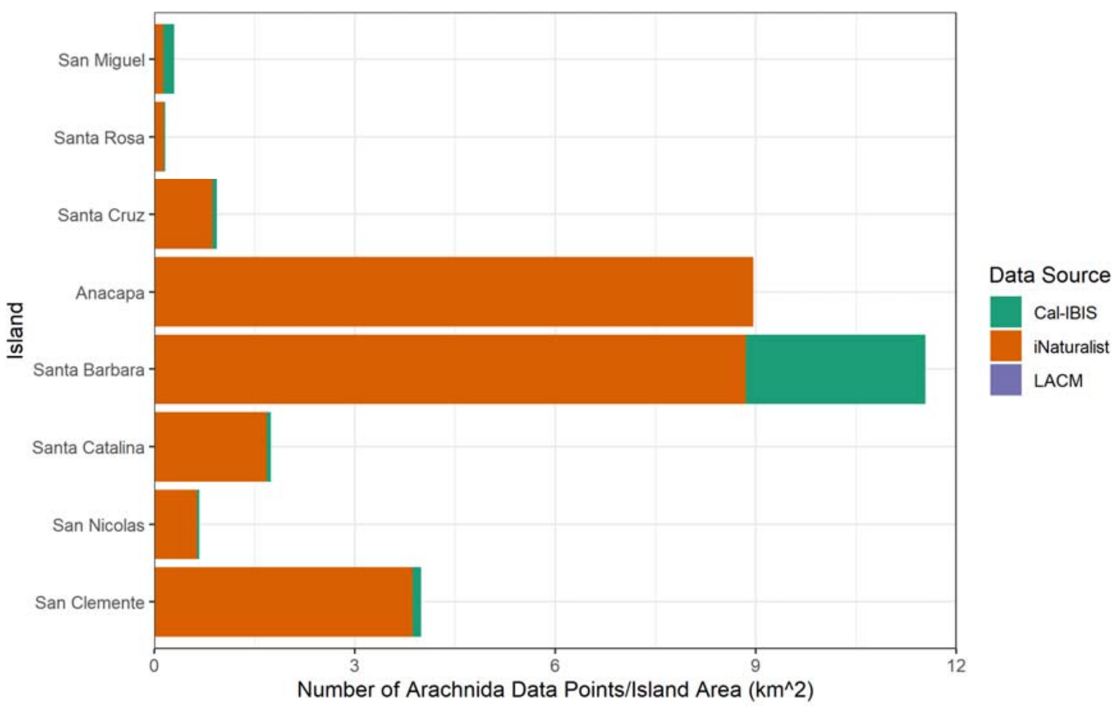


Figure Arachnida-1. The (a) absolute number and (b) proportional number/island size of Arachnid data points on each island by data source reveals spatial gaps in the data. Cal-IBIS represents publicly available specimen data, LACM represents private Los Angeles County Museum data, and iNaturalist represents observation data.

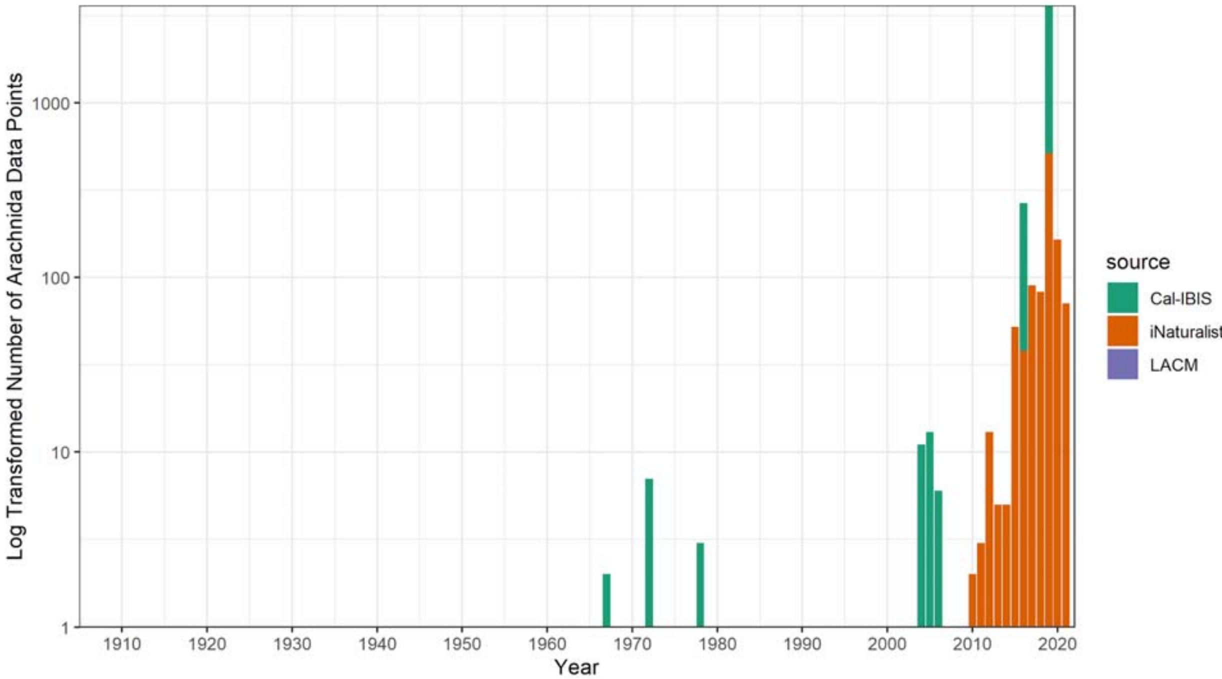


Figure Arachnida-2. The number of island Arachnida data points by year and data source reveals temporal gaps in the data. Cal-IBIS represents publicly available specimen data, LACM represents private data, and iNaturalist represents observation data.

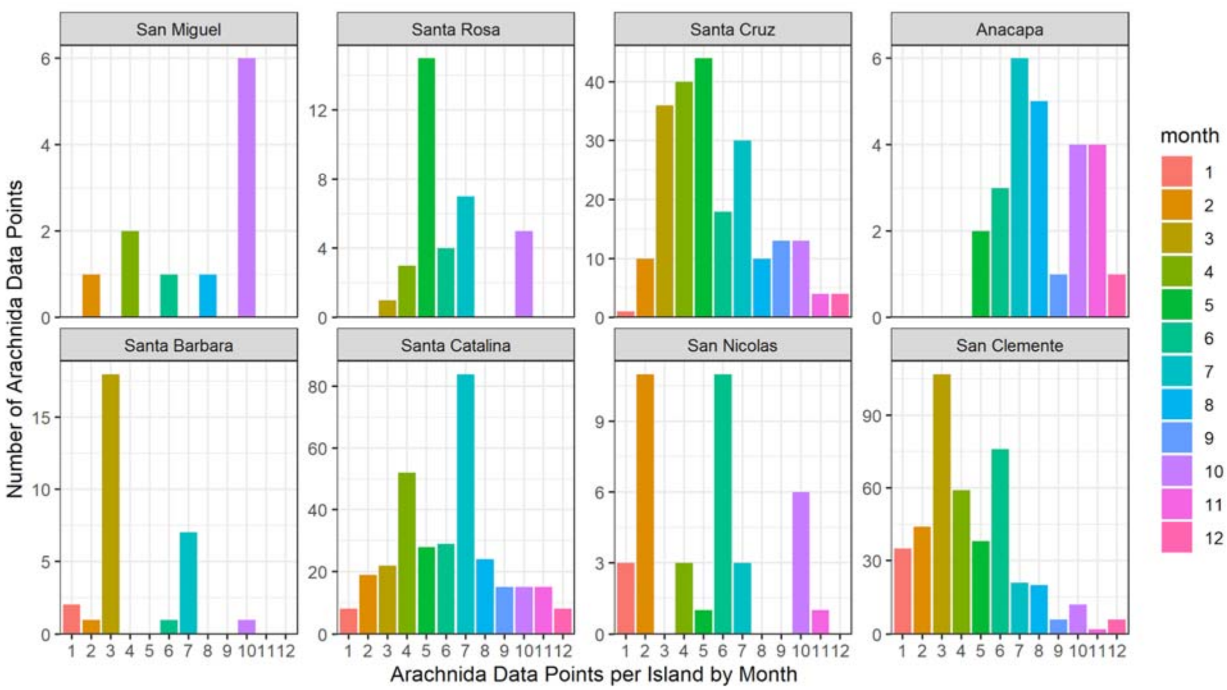


Figure Arachnida-3. The number of Arachnida data points by month, by island, reveals seasonal gaps in the data, which were combined for this analysis.

(a)

(b)

(c)

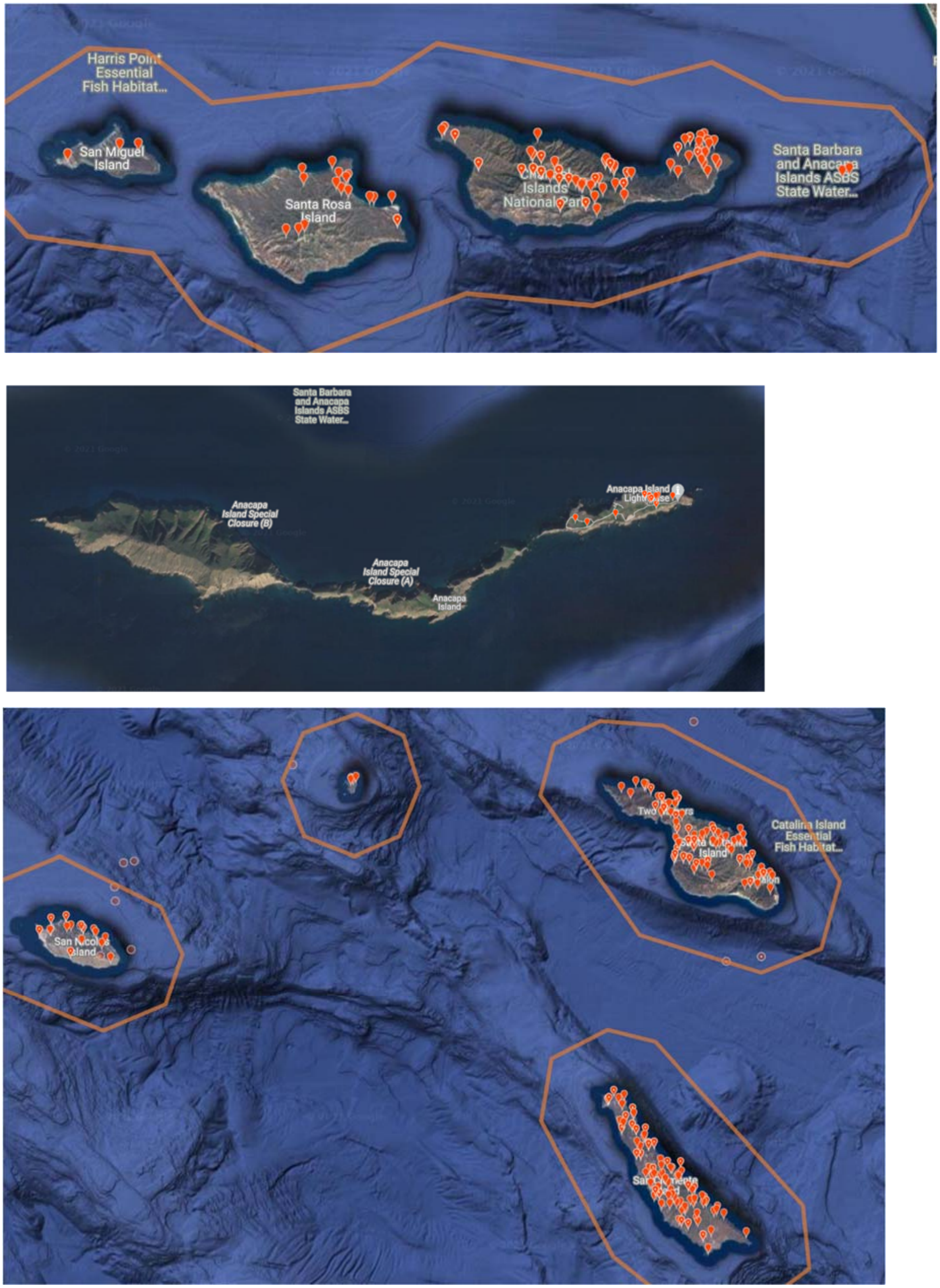


Figure Arachnida-4. Distribution of iNaturalist Arachnida observations on (a) the Northern Islands, (b) Anacapa Islets, and (c) the Southern Islands.

Blattodea (including the former Isoptera)

Tables Blattodea-1 & Blattodea-3 shows there are 17 cockroach and termite occurrences on the island, and only two collected specimens. Four species have been identified, all of which are likely non-native.

Table Blattodea-2 shows that only 7 of the 17 specimens (41%) are identified to species. Similarly, only two of the 15 iNaturalist observations are considered Research Grade, either due to low taxonomic resolution or not enough submitted opinions on the identity of the observations.

Table Blattodea-1. The number of island cockroach and termite occurrences recorded in each data source by family shows the relative number of observations (iNaturalist) and specimens (Cal-IBIS).

Family	Cal-IBIS	iNaturalist	n
Blattidae (cockroaches)	1	3	4
Kalotermitidae (termites)	0	2	2
Rhinotermitidae (termites)	1	7	8
undetermined family	0	3	3
all Blattodea	2	15	17
family diversity	2	3	3

Table Blattodea-2. Taxonomic resolution of island cockroach and termite records by source. Note that only two of the iNaturalist records are Research Grade.

Rank	Cal-IBIS	iNaturalist (All)	iNaturalist (Research Grade)	totals
Order	2	15		17
Family	2 (100%)	13 (86.67%)	2 (13.33%)	15 (88.24%)
Genus	1 (50%)	10 (66.67%)	2 (13.33%)	11 (64.71%)
Species	1 (50%)	6 (40%)	2 (13.33%)	7 (41.18%)

Table Blattodea-3. List of island cockroach/termite species in the occurrence data by data source.

Family	Species	# of Specimens	# of iNat records
Blattidae	*Blatta orientalis* (non-native)	2	1
	Periplaneta americana (non-native)	1	0
	Shelforedella lateralis (non-native)	1	0
Rhinotermitidae	*Reticulitermes hesperus*	2	1

Table Blattodea-4 shows that one species is recorded in the literature and not in the occurrence data: *Blatella germanica,* a non-native species.

Figures Blattodea-1a and 1b show the absolute number and proportional number/island size of Blattodea on each island. Blattodea data points are only recorded on three islands: Santa Cruz, Santa Catalina, and San Clemente. The graphs normalized by island size show that the three islands have very few occurrence records for their size (<1 data point/km^2).

Figure Blattodea-2 shows the number of specimens by year over time. The *Periplaneta americana* was collected in 1930 on Santa Catalina and a Rhinotermitidae sp. was collected in 1977 on Santa Cruz. All recent occurrence data has been collected on iNaturalist.

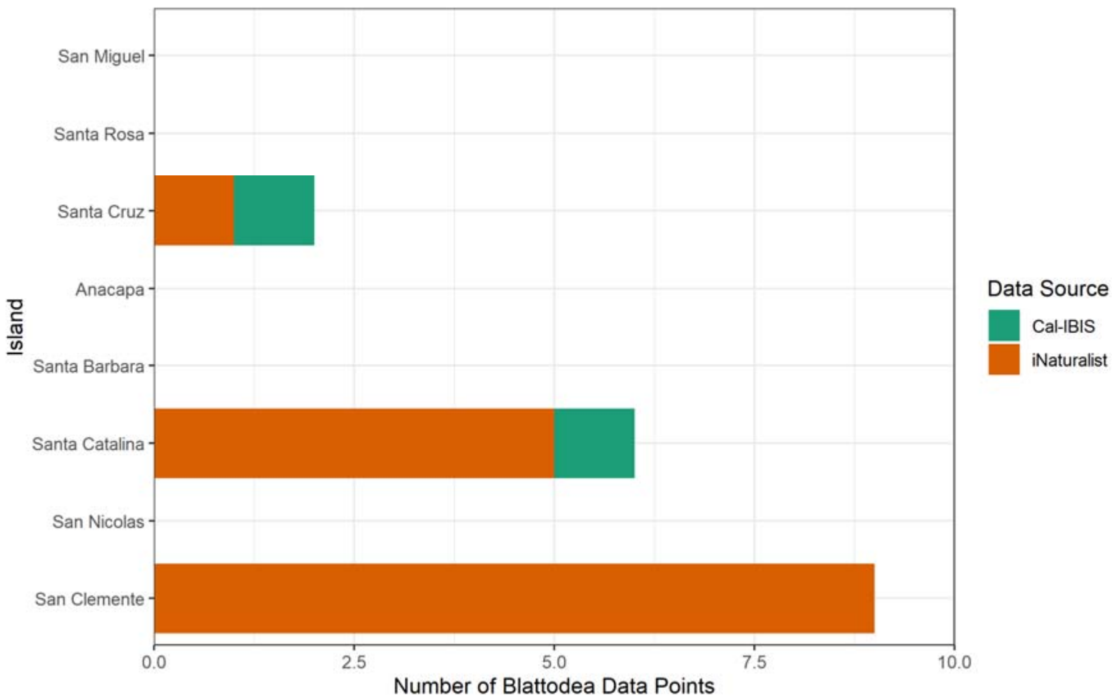
Figure Blattodea-3 shows the data by month and island. Due to the low number of Blattodea data points, no seasonal trends can be assessed.

Figure Blattodea-4 shows the distribution of iNaturalist observations, and reveals that the few areas where these taxa have been observed are in the more developed areas of the islands, like the airfield of San Clemente, Avalon and Middle Ranch of Catalina, and near Scorpion Anchorage on Santa Cruz.

Table Blattodea-4. Island cockroach/termite taxa added by a literature search as compared to those represented in digitized specimen and observation data, revealing the digitization gap.

	# of Families	**# of Genera**	**# of Species**
Occurrence Data	3	4	5
Taxa added by Literature	1	1	1
Total Blattodea	4	5	6

(a)



(b)

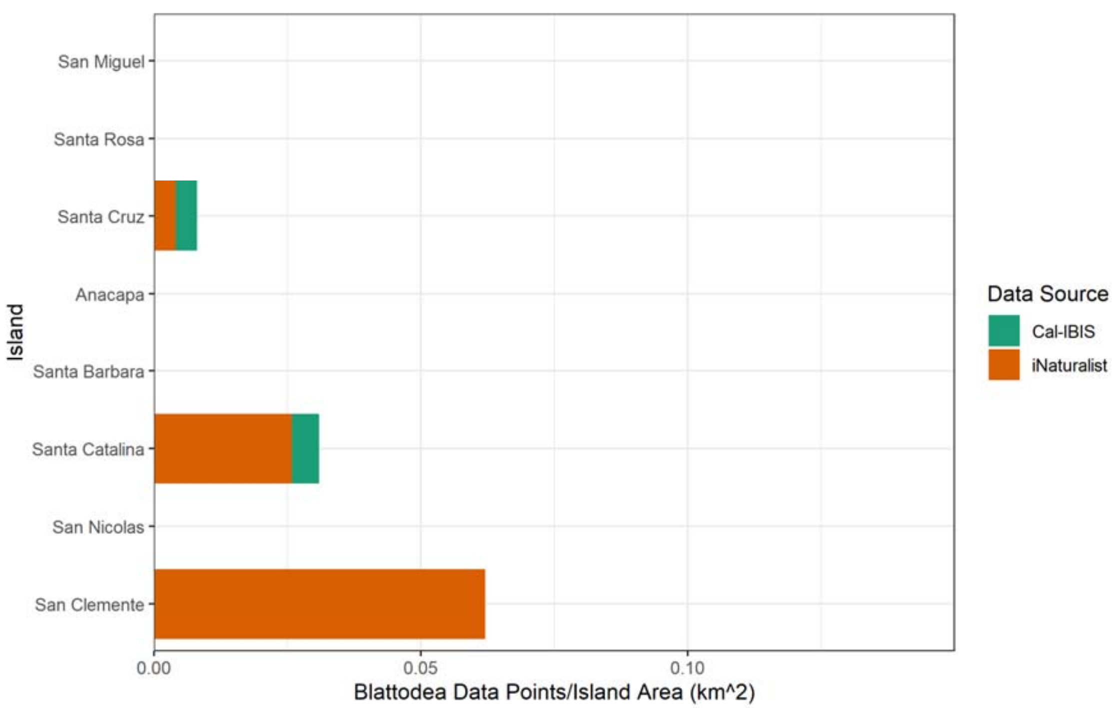


Figure Blattodea-1. The (a) absolute number and (b) proportional number/island size of cockroach/termite occurrences on each island by data source reveal spatial gaps in the data.

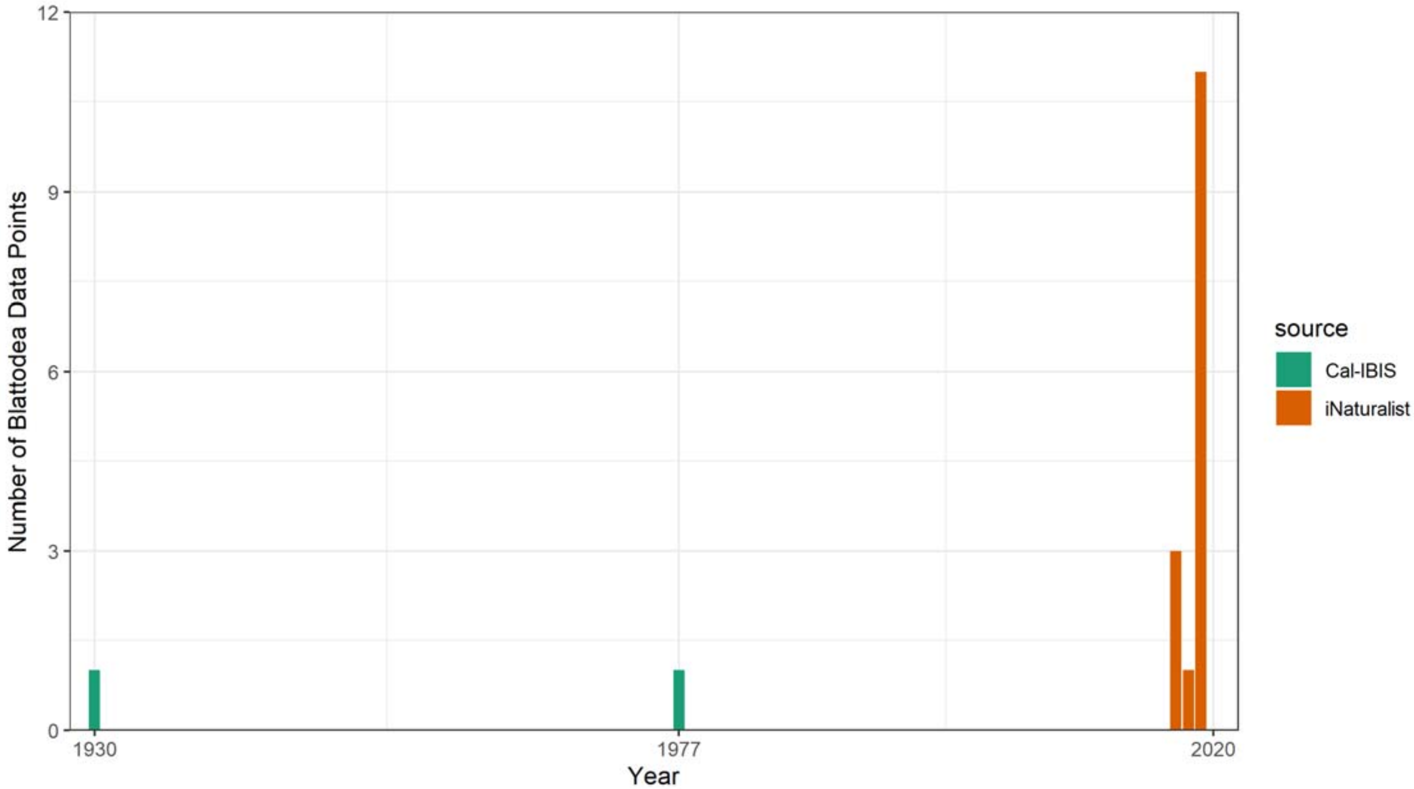


Figure Blattodea-2. The number of island cockroach/termite occurrences by year and data source reveals temporal gaps in the data.

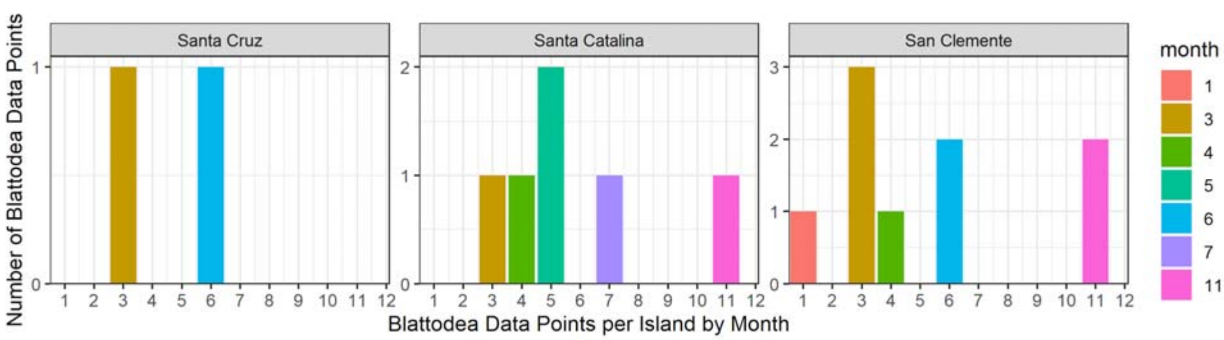
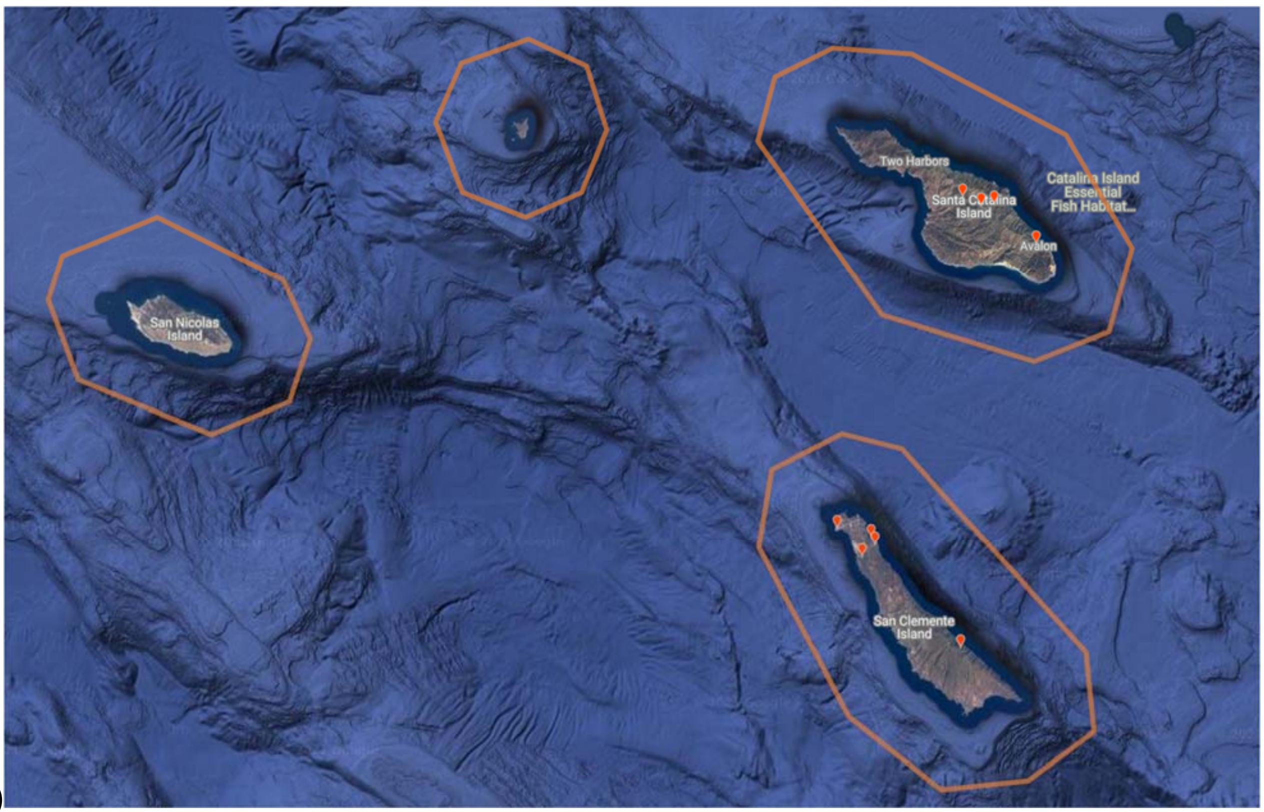


Figure Blattodea-3. The number of cockroach/termite occurrences by month, by island, reveals seasonal gaps in the data. Note that some islands do not have Blattodea data.

(a)



(b)

Figure Blattodea-4. Distribution of iNaturalist centipede observations on (a) the Northern Islands and (b) the Southern Islands.

Chilopoda

Tables Chilopoda-1 & Chilopoda-3 show that no centipede specimens were found in Cal-IBIS. However, there are 84 Chilopoda iNaturalist observations on the Islands. This is somewhat surprising, because most centipedes are quite small and cryptic. Thirty-six (43%) of those observations were made by Cedric Lee, who studies Chilopoda, as part of SBBG surveys on San Clemente Island and subsequent focused surveys. Just over 27 percent of the observations were of the common desert centipede, *Scolopendra polymorpha*. Eight of the observations were of *Scutigera coleoptrata,* the common house centipede.

Table Chilopoda-2 shows that only 36 of the iNaturalist centipede records are research grade. Only 47 of the 84 records (56%) were identified to species.

Table Chilopoda-4 shows that one family, 10 genera and 15 species are present in the literature, but not the occurrence data (60% of the species known from the islands are not in our data). The family added is Cryptopidae. **Appendix C Table 2**. has a complete list of taxa found in the occurrence data and literature.

Figures Chilopoda-1a and 1b show the absolute number and proportional number/island size of Chilopoda observations on each island. Chilopoda observations are only recorded on four islands: Santa Cruz, Santa Barbara, Santa Catalina, and San Clemente. The vast majority of Chilopoda observations were recorded on San Clemente and Santa Catalina, due to active biologists and accessibility, respectively. The figure normalized by island size show that the Santa Cruz Island has particularly few occurrence records for its size (<1 data point/km^2).

Figure Chilopoda-2 shows the number of specimens by year over time. All occurrence records were from iNaturalist, with the oldest Chilopoda data point recorded in 2007.

Figure Chilopoda-3 shows the data by month and island. All the San Clemente observation were recorded in winter to early spring, whereas Santa Catalina observations had greater spread across the seasons.

Figure Chilopoda-4 shows a fairly good spatial distribution of observation points on Santa Catalina and San Clemente Islands, whereas there are very few points on Santa Cruz Island, and those are near access points.

Table Chilopoda-1. Number of centipede observations in iNaturalist by family. Note that no Chilopoda specimens are in public databases, and only about half of the island Chilopoda observations in iNaturalist were identified beyond the family level.

Family	n
Geophilidae	7
Henicopidae	1
Himantariidae	5
Lithobiidae	17
Plutoniumidae	1
Schendylidae	4
Scolopendridae	23
Scolopocryptopidae	2
Scutigeridae	8
undetermined family	16
all Chilopoda	84
family diversity	9

Table Chilopoda-2. Taxonomic resolution of centipede observation records in iNaturalist.

Rank	iNaturalist (All)	iNaturalist (Research Grade)
Class	84	
Order	84 (100%)	36 (42.86%)
Family	68 (80.95%)	36 (42.86%)
Genus	54 (64.29%)	36 (42.86%)
Species	47 (55.95%)	36 (42.86%)

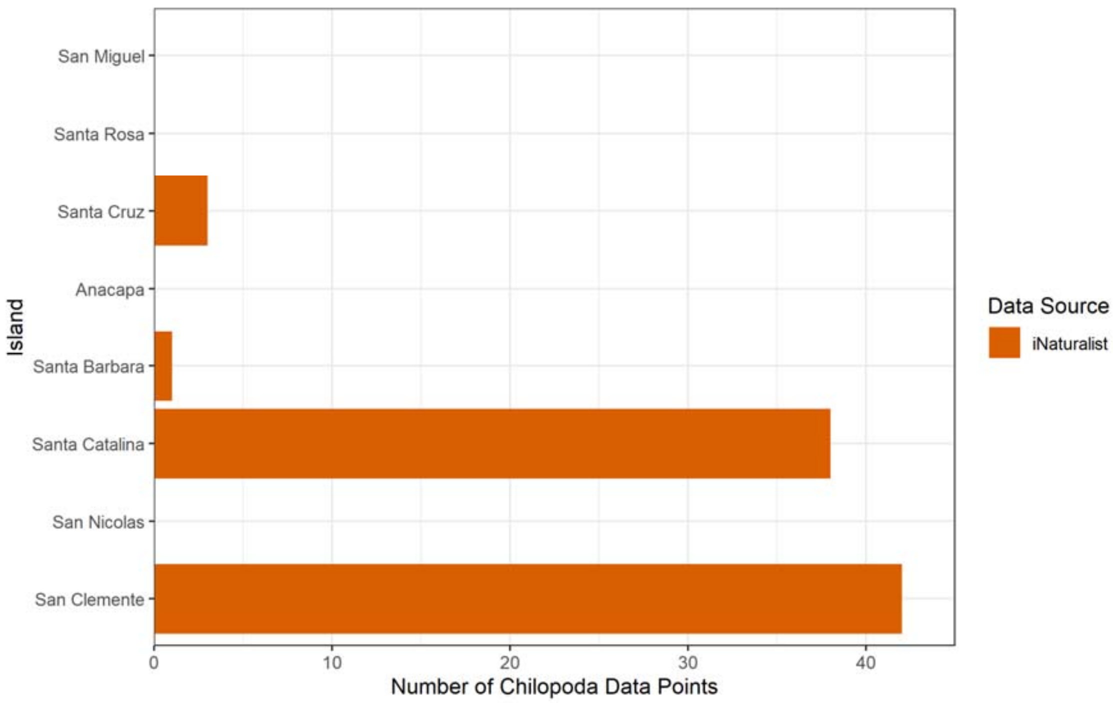
Table Chilopoda-3. Channel Islands centipede species observed via iNaturalist.

Family	Species	# of observations
Geophilidae	*Arenophilus iugans*	1
	Strigamia fuscata	1
	Taiyuna claremontus	3
Lithobiidae	*Bothropolys xanti*	1
	Gosibius monicus	6
	Lithobius obscurus	1
Plutoniumidae	*Theatops posticus*	1
Scolopendridae	*Scolopendra polymorpha*	23
Scolopocryptopidae	*Scolopocryptops gracilis*	2
Scutigeridae	*Scutigera coleoptrata*	8

Table Chilopoda-4. Island centipede taxa added by a literature search as compared to those represented in digitized specimen and observation data, revealing the digitization gap.

	# of Families	# of Genera	# of Species
Occurrence Data	9	13	10
Taxa added by Literature	1	10	15
Total Chilopoda	10	23	25

(a)



(b)

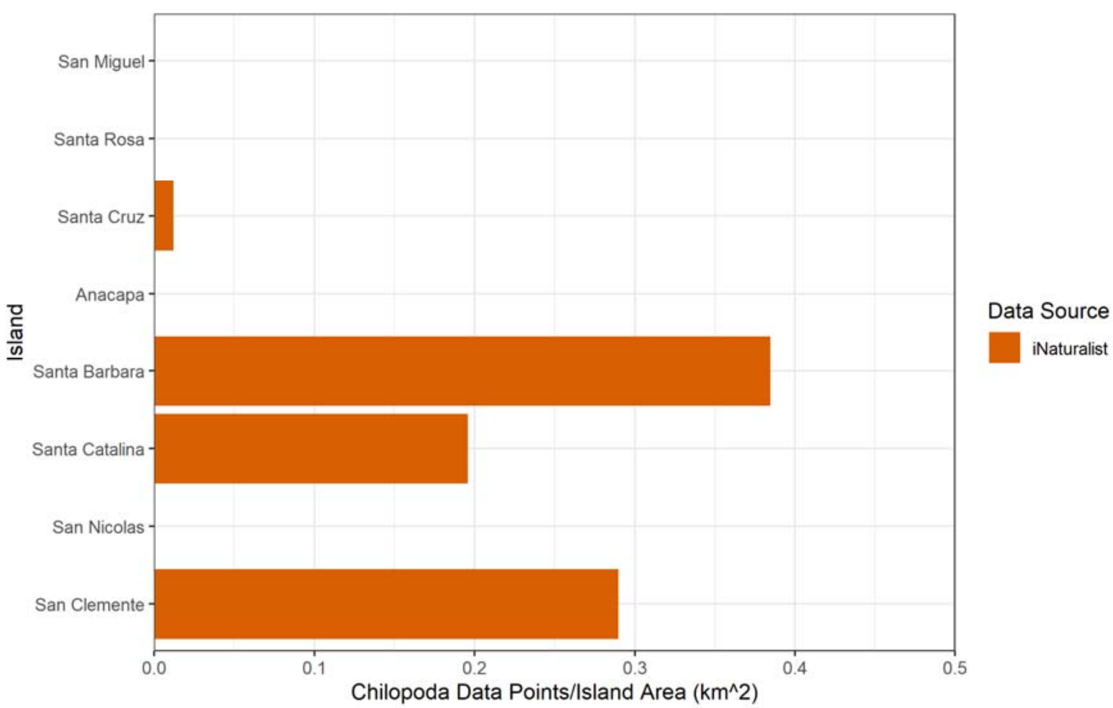


Figure Chilopoda-1. The (a) absolute number and (b) proportional number/island size of centipede occurrences on each island by data source reveals spatial gaps in the data.

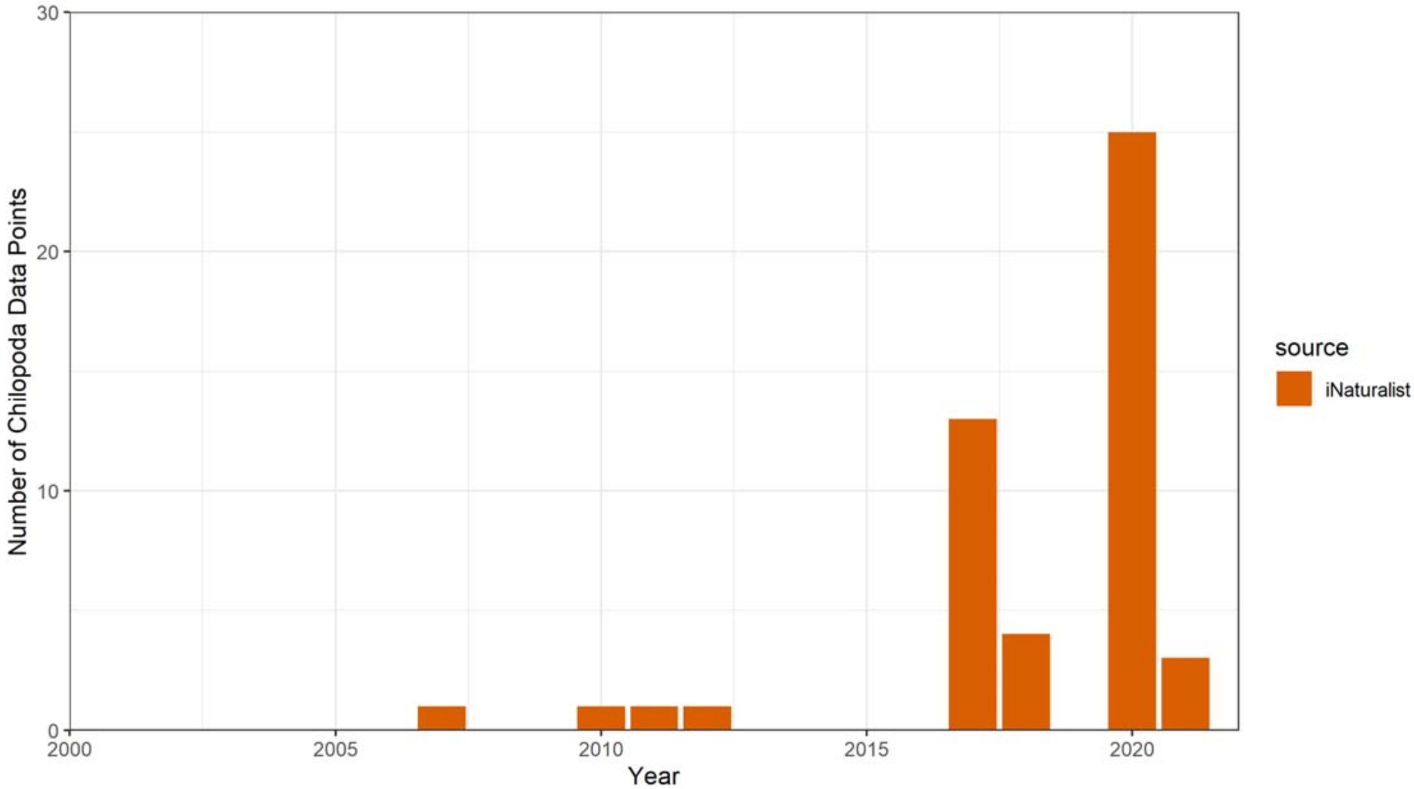


Figure Chilopoda-2. The number of island centipede observations by year and data source reveals temporal gaps in the data.

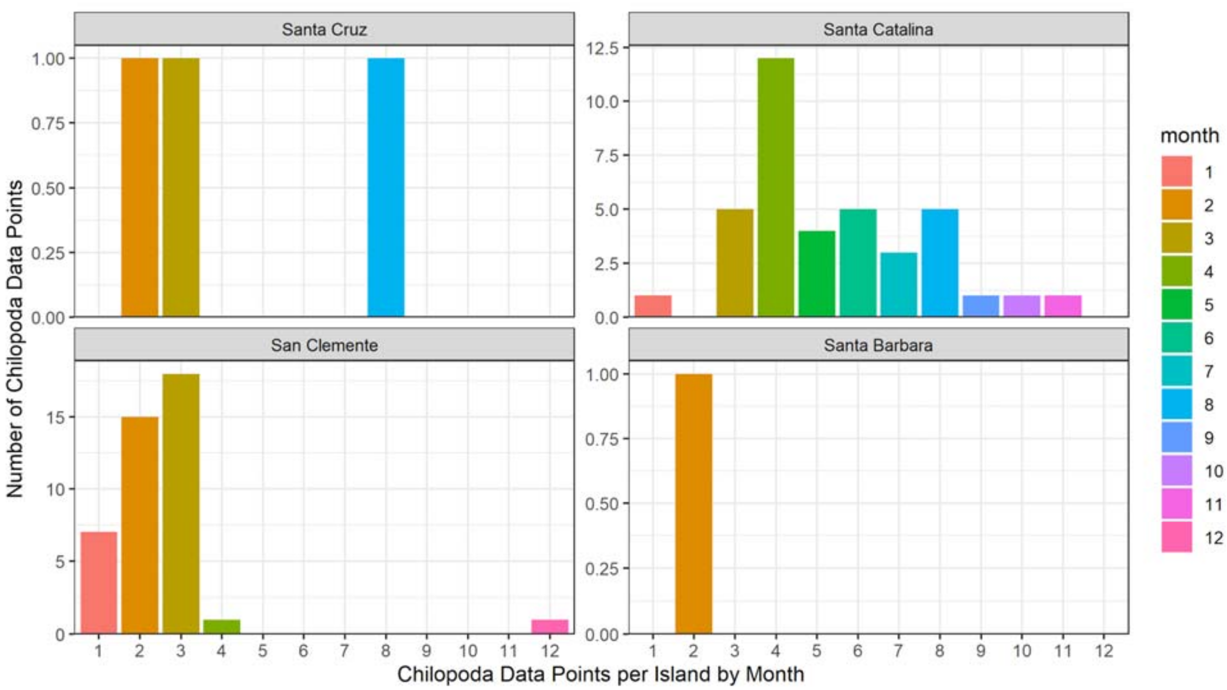


Figure Chilopoda-3. The number of centipede occurrences by month, by island, reveals seasonal gaps in the data. Note that some islands do not have millipede data.

(a)

(b)

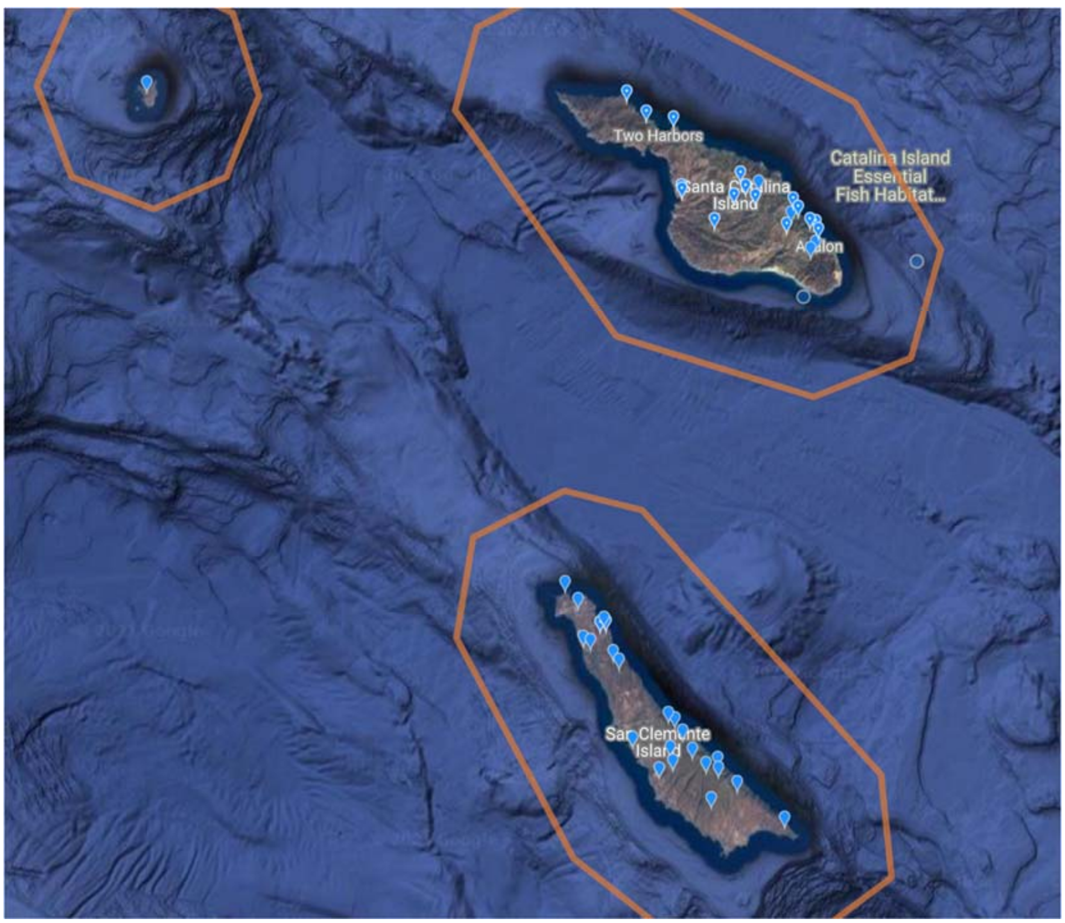


Figure Chilopoda-4. Distribution of iNaturalist centipede observations on (a) Santa Cruz Island and (b) three of the Southern Islands (Santa Barbara, Santa Catalina, and San Clemente).

Coleoptera

Table Coleoptera-1 shows that beetles have been relatively well sampled and digitized – one of the best among the orders investigated here. This relatively good digitization is undoubtedly related to Michael Caterino's California Beetle databasing project, which can be viewed here. A total of 74 families were represented in the occurrence data. The relative representation generally mirrors what we know about the diversity of these groups. This representation is also likely due to the fact that Dwight Pierce, curator at LACM from 1937-1951, was a Coleopterist and worked on Island weevils. Over half of the data points are from the digitized LACM collections. iNaturalist observations make up only 5% of the Coleoptera data points, while the vast majority of the data points are collected specimens.

Table Coleoptera-2 shows that the most of the collected specimens have been identified to genus (Cal-IBIS 94% and LACM 74%), and the majority have been identified to species (Cal-IBIS 55% and LACM 65%). This is much better than is typical for invertebrates. Less than half of the iNaturalist beetle observations are identified to species and research grade (45%), as is more typical.

Table Coleoptera-3 shows that there is a gap between known Coleoptera taxa found on the Channel Islands from the literature and taxa represented in digitized collections and naturalist observations, but not as extreme as is typical for invertebrates. The number of families (9), genera (470) and species (293) in the literature that are not represented in the specimen data are 11%, 17%, and 41% respectively of the totals. **Appendix C Table 3** has a complete list of taxa found in the occurrence data and in the literature.

Figures Coleoptera-1a and 1b show the absolute number and proportional number/island size of Coleoptera occurrences on each island. Beetles have been well collected across the islands, with between 2,000 and 5,000 specimens on each of the larger islands. Although there are many fewer specimens on Anacapa and Santa Barbara Islands, they are well represented for their size. LACM has large beetle collections from all of the islands. The large number of specimens dwarf the number of iNaturalist observations.

Figure Coleoptera-2 shows the number of specimens by year over time. Patterns are more visible in these data due to a greater number of specimens. The first collection recorded was from 1897, made by Adalbert Fenyes and housed at CAS. There are three major pulses in collections visible: 1) the ca. 1940 CA Islands Biological Survey, 2) a myriad of collections between ca 1970 and the mid-1980's (including many made by S.E. Miller and associates and housed at the SBMNH, and many made by C.D. Nagano, J.N. Hogue, G. Challet, and S. Bennett and housed at LACM), and 3) surveys by M.S. Caterino and S. Chatzimanolis in the 2000s (SBMNH). The majority of the datapoints in the past 10 years are iNaturalist observations.

Figure Coleoptera-3 shows the data by month and island. There are seasonal gaps in beetle data points across the islands, and most of the Channel Islands display data peaks in one or two months out of the year.

Figure Coleoptera-4 shows maps of iNaturalist beetle observations. It reveals fairly good coverage across the islands, except for most of Santa Rosa Island, which is relatively inaccessible.

Table Coleoptera-4 and **Figure Coleoptera-5** summarize the spatial specimen collecting effort in 1 km grid cells. They show both that none of the islands has been adequately sampled, and that the collecting has been uneven. None of the islands has fewer than 64% cells with no digitized specimens; the highest percentage of empty cells (88.4%) is on Santa Catalina. Many of the better-sampled areas are easier to access, such as the Central Valley of Santa Cruz Island, Becher's Bay area on Santa Rosa Island, the Airport on Santa Catalina Island, and West Anacapa islet. Others are likely just special areas of interest to individual taxonomists, such as the eastern edge of San Clemente Island and beaches of San Nicolas Island.

Table Coleoptera-1. Number of island beetle occurrences recorded in each data source by family shows the relative number of observations (iNaturalist) and specimens (Cal-IBIS and LACM).

Family	Cal-IBIS	LACM	iNaturalist	n	%
Anobiidae	84	15	6	105	0.50%
Anthicidae	93	14	3	110	0.53%
Aphodiidae	23	394	1	418	2.00%
Attelabidae	17	42	2	61	0.29%
Bostrichidae	28	48	4	80	0.38%
Brachyceridae	1	0	0	1	0.00%
Brentidae	0	0	1	1	0.00%
Buprestidae	39	22	24	85	0.41%
Byturidae	18	2	0	20	0.10%
Cantharidae	102	44	14	160	0.76%
Carabidae	1376	1586	60	3022	14.44%
Cerambycidae	152	174	33	359	1.72%
Cerylonidae	2	0	0	2	0.01%
Cetoniidae	1	0	2	3	0.01%
Chrysomelidae	175	687	31	893	4.27%
Ciidae	11	0	0	11	0.05%
Clambidae	12	0	0	12	0.06%
Cleridae	52	167	2	221	1.06%
Coccinellidae	348	312	351	1011	4.83%
Corylophidae	36	0	1	37	0.18%
Cryptophagidae	30	0	1	31	0.15%
Curculionidae	364	2970	36	3370	16.11%
Dascillidae	0	31	0	31	0.15%
Dermestidae	172	98	5	275	1.31%
Dryophthoridae	6	0	1	7	0.03%
Dynastidae	6	128	0	134	0.64%
Dytiscidae	321	245	9	575	2.75%
Elateridae	65	27	4	96	0.46%
Endomychidae	7	2	0	9	0.04%
Erotylidae	13	0	0	13	0.06%
Eucnemidae	0	1	0	1	0.00%
Gyrinidae	38	0	1	39	0.19%
Haliplidae	30	0	0	30	0.14%
Helophoridae	15	0	0	15	0.07%
Heteroceridae	46	0	0	46	0.22%
Histeridae	47	541	2	590	2.82%
Hydraenidae	310	0	0	310	1.48%
Hydrophilidae	355	461	3	819	3.91%
Hydroscaphidae	18	0	0	18	0.09%
Kateretidae	9	6	1	16	0.08%
Laemophloeidae	1	0	0	1	0.00%
Lampyridae	3	3	0	6	0.03%
Latridiidae	2	0	11	13	0.06%
Leiodidae	86	0	0	86	0.41%
Limnichidae	5	0	0	5	0.02%

Family	Cal-IBIS	LACM	iNaturalist	n	%
Malachiidae	0	0	47	47	0.22%
Meloidae	0	26	1	27	0.13%
Melolonthidae	106	154	13	273	1.30%
Melyridae	63	284	12	359	1.72%
Monotomidae	40	0	0	40	0.19%
Mordellidae	57	15	5	77	0.37%
Mycetophagidae	17	0	1	18	0.09%
Nitidulidae	14	102	5	121	0.58%
Oedemeridae	39	44	0	83	0.40%
Phalacridae	9	0	0	9	0.04%
Phengodidae	0	1	0	1	0.00%
Plastoceridae	0	0	1	1	0.00%
Ptiliidae	146	0	0	146	0.70%
Ptinidae	23	1	3	27	0.13%
Pyrochroidae	2	0	0	2	0.01%
Raymondionymidae	1	0	0	1	0.00%
Rhipiceridae	1	0	0	1	0.00%
Ripiphoridae	0	0	1	1	0.00%
Scarabaeidae	0	61	10	71	0.34%
Scraptiidae	34	0	0	34	0.16%
Silphidae	74	39	8	121	0.58%
Silvanidae	6	0	0	6	0.03%
Sphaeriusidae	15	0	0	15	0.07%
Staphylinidae	1076	295	32	1403	6.70%
Tenebrionidae	140	2288	159	2587	12.36%
Throscidae	3	0	0	3	0.01%
Trogidae	1	7	0	8	0.04%
Trogossitidae	9	1	0	10	0.05%
Zopheridae	41	1	3	45	0.22%
undetermined family	5	2177	58	2240	10.70%
all Coleoptera	6441	13516	968	20925	
family diversity	65	40	41	74	

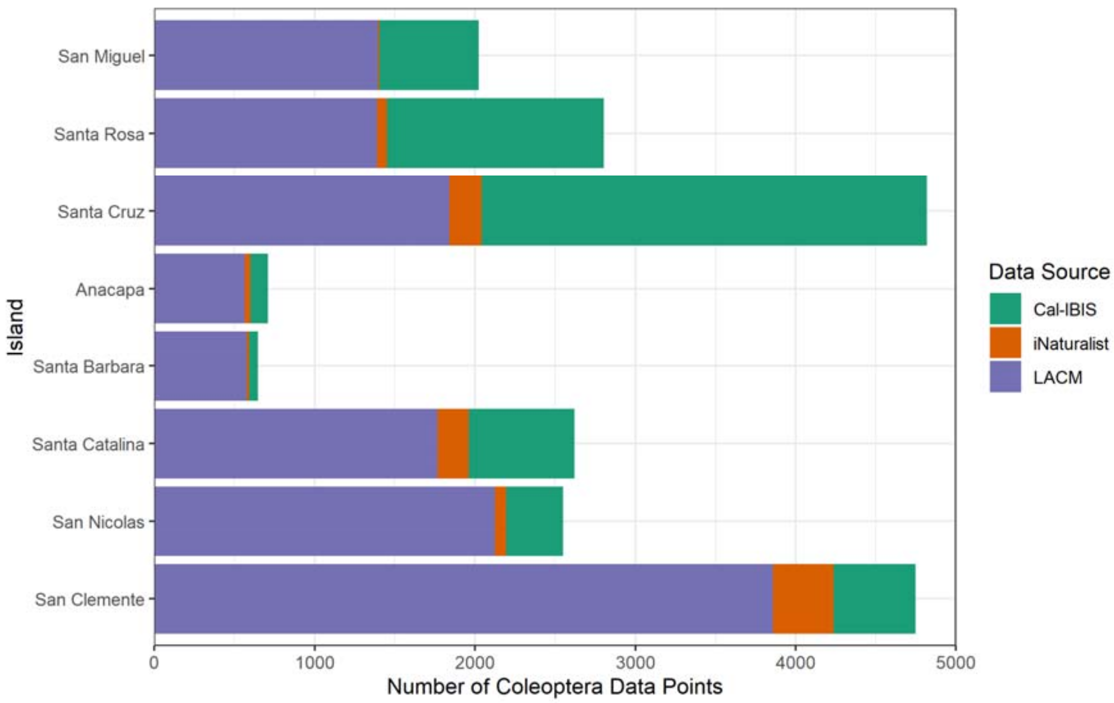
Table Coleoptera-2. Taxonomic resolution of island beetle records by source. Note that only 436 of the iNaturalist records are Research Grade.

Rank	Cal-IBIS	LACM	iNaturalist (all)	iNaturalist (RG)	Totals
Order	6441	13516	968		20925
Family	6436 (99.92%)	11339 (83.89%)	910 (94.01%)	436 (45.04%)	18685 (89.30%)
Genus	6046 (93.87%)	9930 (73.47%)	719 (74.28%)	436 (45.04%)	16695 (79.78%)
Species	3516 (54.59%)	8748 (64.72%)	524 (54.13%)	418 (43.18%)	12788 (61.11%)

Table Coleoptera-3. Island beetle taxa added by a literature search as compared to those represented in digitized specimen and observation data, revealing the digitization gap.

	# of Families	# of Genera	# of Species
Occurrence Data	74	386	428
Taxa added by Literature	9	82	293
Total Coleoptera	85	470	721

(a)



(b)

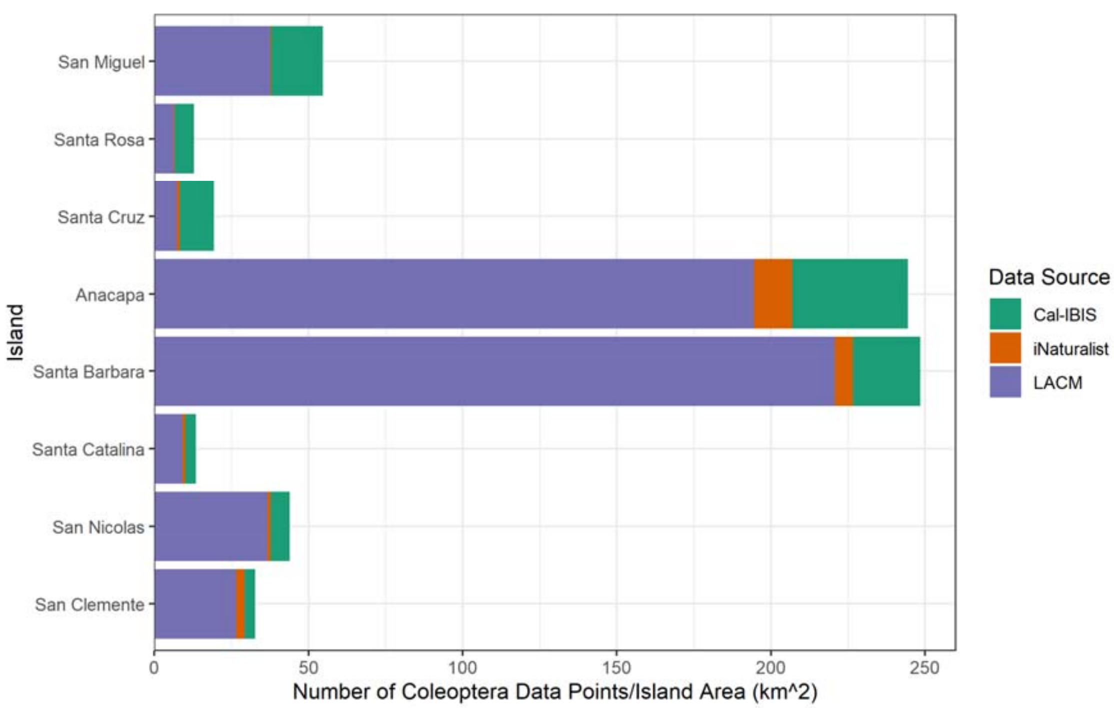


Figure Coleoptera-1. The (a) absolute number and (b) proportional number/island size of beetle occurrences on each island by data source reveal spatial gaps in the data.

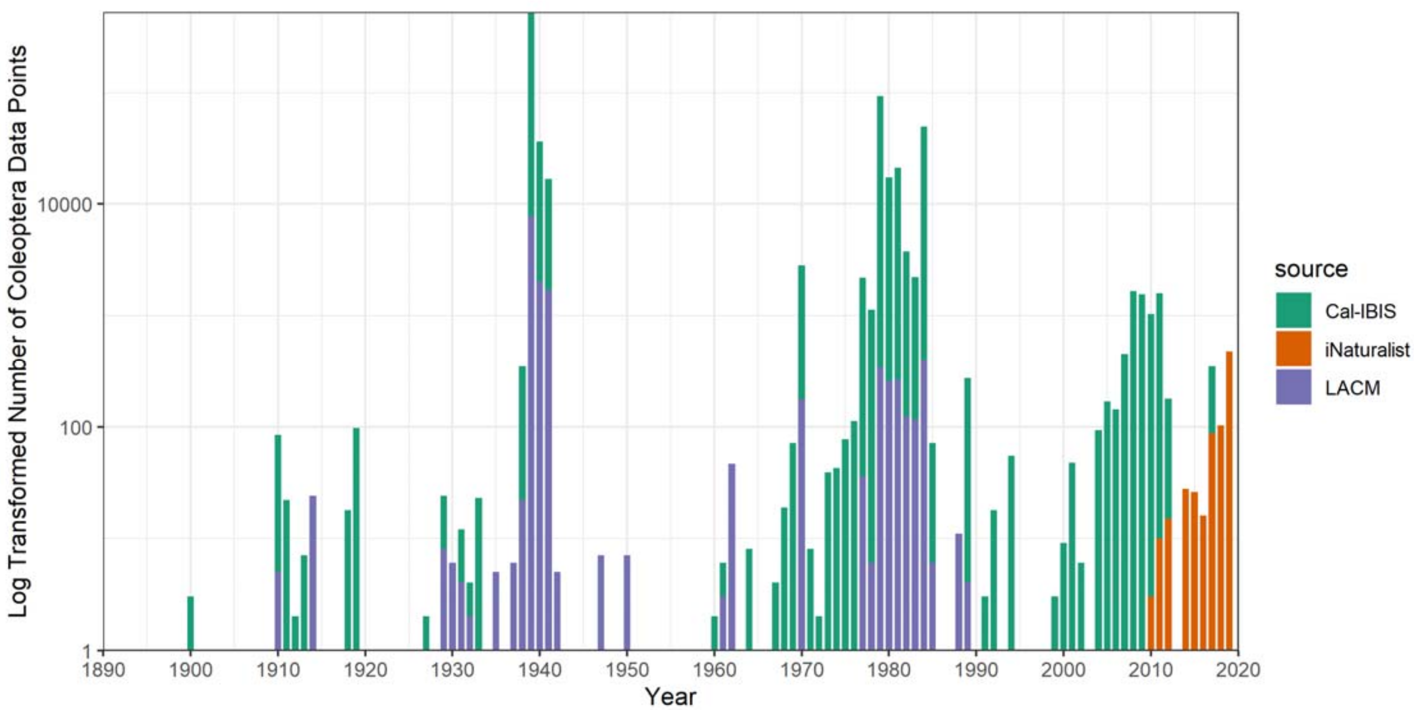


Figure Coleoptera-2. The log transformed number of island beetle occurrences by year and data source reveals temporal gaps in the data.

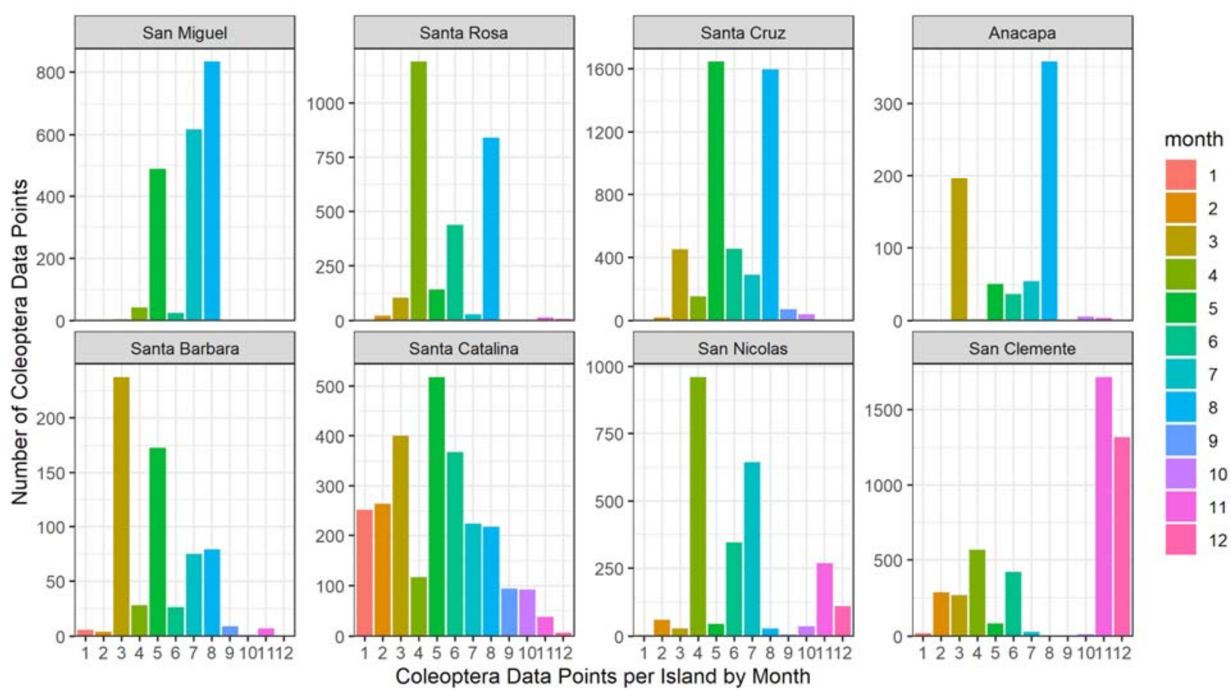


Figure Coleoptera-3. The number of beetle occurrences by month, by island, reveals seasonal gaps in the data.

(a)

(b)

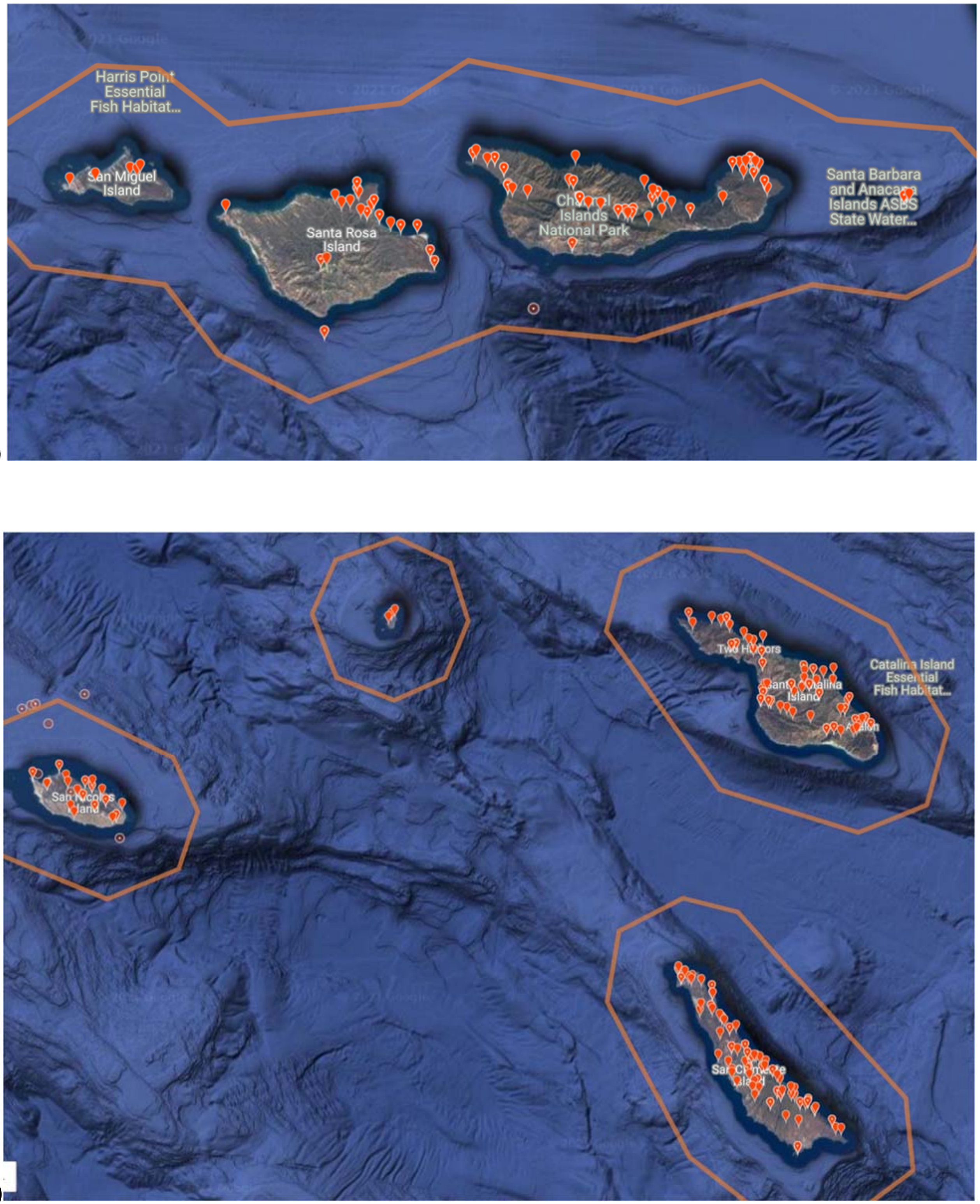
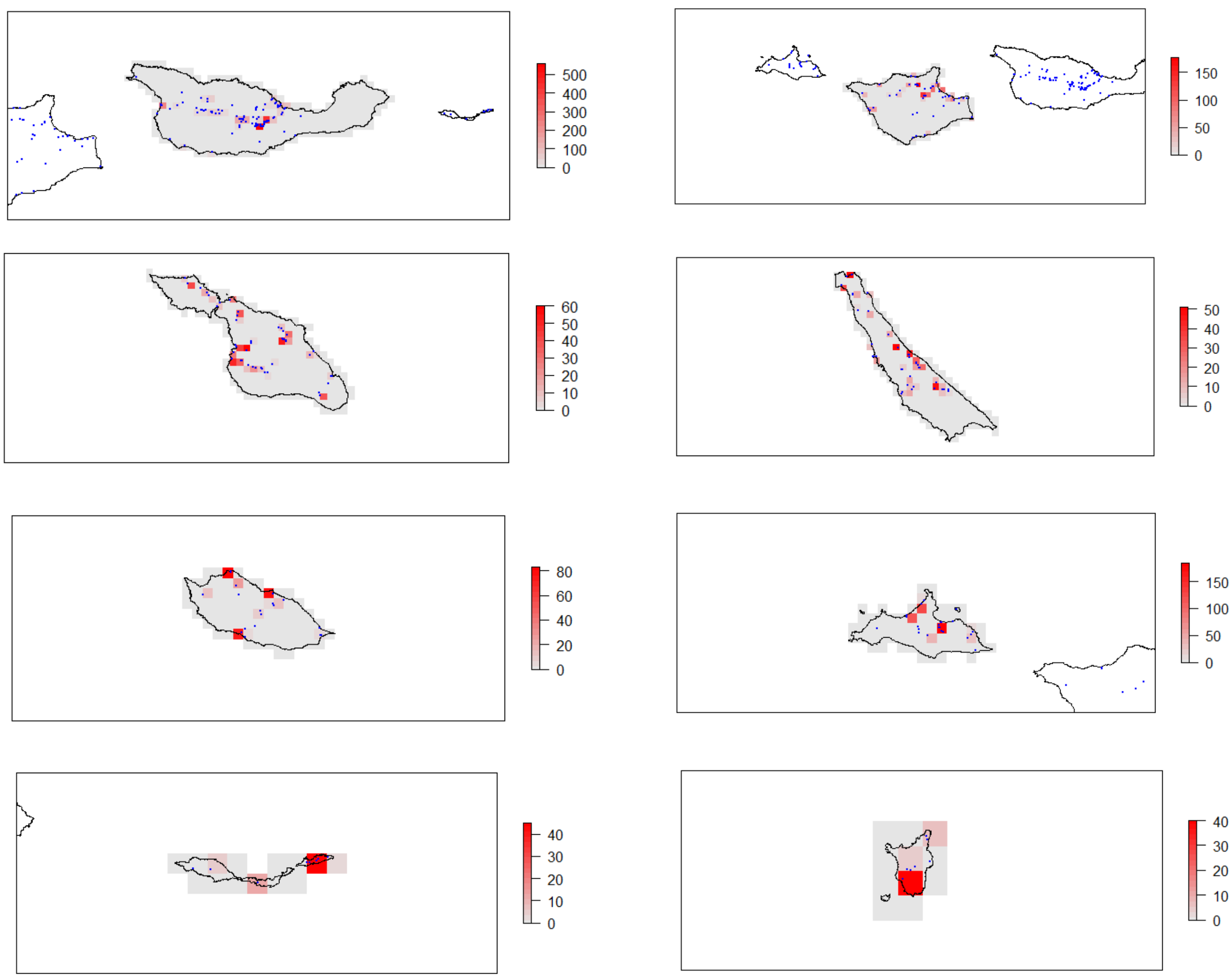


Figure Coeloptera-4. Distribution of iNaturalist beetle observations on (a) the Northern Islands and (b) the Southern Islands.

Table-Coleoptera-4 & Figure-Coleoptera-5. Spatial collecting effort based on 1 km grid cells overlaid onto each of the eight California Channel Islands. Of 6,057 (out of 19,957) specimens with coordinates (30%), 5,767 were used for these maps after records using island centroids were removed.

Island	Island Collections	1 km^2 cells	Empty 1 km^2 cells	% empty cells	Mean records/cell
Anacapa	66	14	9	64.3%	13.2
Santa Cruz	2473	313	269	85.9%	56.2
Santa Rosa	1278	263	229	87.1%	37.6
San Miguel	545	61	48	78.7%	41.9
Santa Catalina	596	250	221	88.4%	20.6
San Clemente	448	198	172	86.9%	17.2
San Nicolas	307	81	69	85.2%	25.6
Santa Barbara	53	11	7	63.6%	13.3



Dermaptera

Table Dermaptera-1 shows that there are 44 earwig occurrences on the island, but only 7 collected specimens. Two species have been identified, *Euborellia annulipes* and *Forficula auricularia*, both of them non-native; no other species are known to occur on the Channel Islands. Eighty-four percent of the earwig data points are iNaturalist observations.

Robert Langston and Scott Miller (1977) reported two types of earwig on the Channel Islands, both introduced: the ring-legged earwig (*Euborellia annulipes*) on San Clemente, Santa Catalina, and Santa Rosa, and the European earwig (*Forficula auricularia*) on Santa Rosa Island. Jerry Powell reported *Forficula auricularia* on Santa Cruz Island in 1980, then Miller published "Earwigs of the California Channel Islands, with notes on other species in California" in 1984, which included newly accumulated records of *Forficula auricularia* on Santa Cruz, Santa Catalina, San Clemente, San Nicolas, and Santa Barbara islands that he believed represented range expansion with increased human activity on the islands. In 2020, Rubén González-Miguens (Museo Nacional de Ciencias Naturales in Madrid, Spain) et al. reported that the European earwig, *Forficula auricularia*, is a complex of at least four species. This calls into question the identity of earwigs on the Channel Islands, which have been reported from all eight islands. New collections and genetic work would be revealing.

Table Dermaptera-2 shows that all of the earwig specimens and most (89%) of the earwig observations have been identified to species, *Euborellia annulipes* or *Forficula auricularia.* These taxa are well known and readily identifiable.

Figures Dermpatera-1a and 1b show the absolute number and proportional number/island size of earwigs on each island, and shows the prevalence of iNaturalist observations over specimen records. The most observations have been on San Clemente Island, where biologists are very active on this platform. Earwigs have been recorded on all of the islands, except for Santa Barbara Island. The graphs normalized by island size show that the seven islands have very few occurrence records for their size (<1 data point/km^2), but Anacapa has the most occurrence records by size.

Figure Dermaptera-2 shows the number of specimens by year over time. The earliest record of an earwig on the Channel Islands was in 1931, by Walter Conrad (housed at CAS). All digitized specimens since then (the last of which was in 1991) are housed at UCSB, with no collector information provided. All of the recent earwig data points were iNaturalist observations.

Figure Dermaptera-3 shows the data by month and island. Due to the low number of Dermaptera data points, no seasonal trends can be assessed.

Figure Dermaptera-4 shows the locations of iNaturalist Dermaptera observations. These are sparse but relatively well-distributed except for Santa Rosa Island, which is relatively inaccessible.

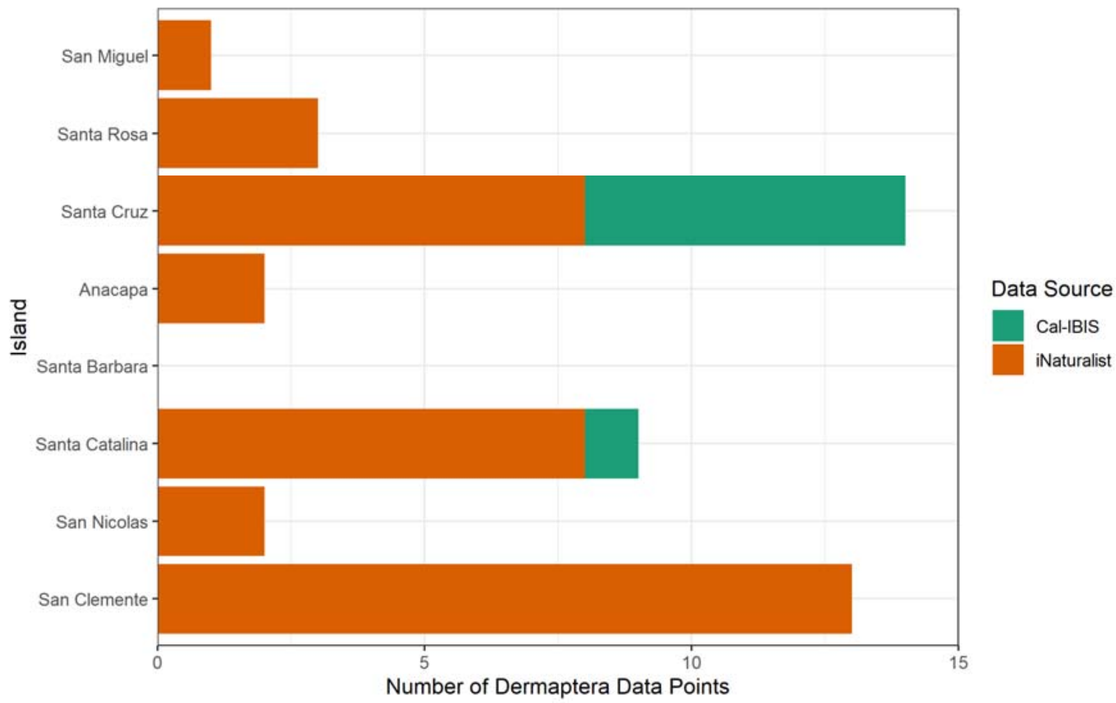
Table Dermaptera-1. Number of Dermaptera data points recorded in each data source by species, showing the relative number of observations (iNaturalist) and specimens (Cal-IBIS).

Family	**Species**	**Cal-IBIS**	**iNaturalist**	**total**	**%**
Anisolabididae	*Euborellia annulipes*	1	2	3	6.82%
Forficulidae	*Forficula auricularia*	6	30	36	81.82%
undetermined species		0	5	5	11.36%
all Dermaptera		7	37	44	
species diversity		2	2	2	

Table Dermapetra-2. Taxonomic resolution of island Dermaptera records by source.

Rank	**Cal-IBIS**	**iNaturalist (All)**	**iNaturalist (RG)**	**Totals**
Order	7	37	25 (67.57%)	44
Family	7 (100%)	33 (89.19%)	25 (67.57%)	40 (90.91%)
Genus	7 (100%)	33 (89.19%)	25 (67.57%)	40 (90.91%)
Species	7 (100%)	33 (89.19%)	25 (67.57%)	39 (88.64%)

(a)



(b)

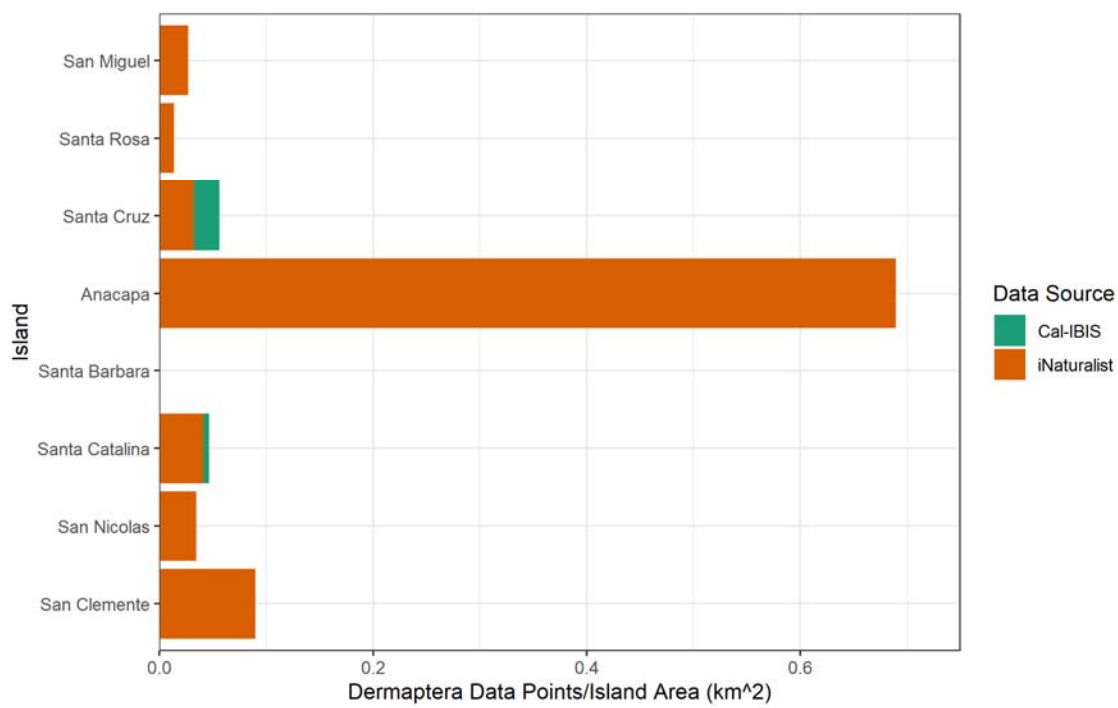


Figure Dermaptera-1. The (a) absolute number and (b) proportional number/island size of Dermaptera data points on each island by data source reveals spatial gaps in the data. Cal-IBIS represents publicly available specimen data, and iNaturalist represents observation data.

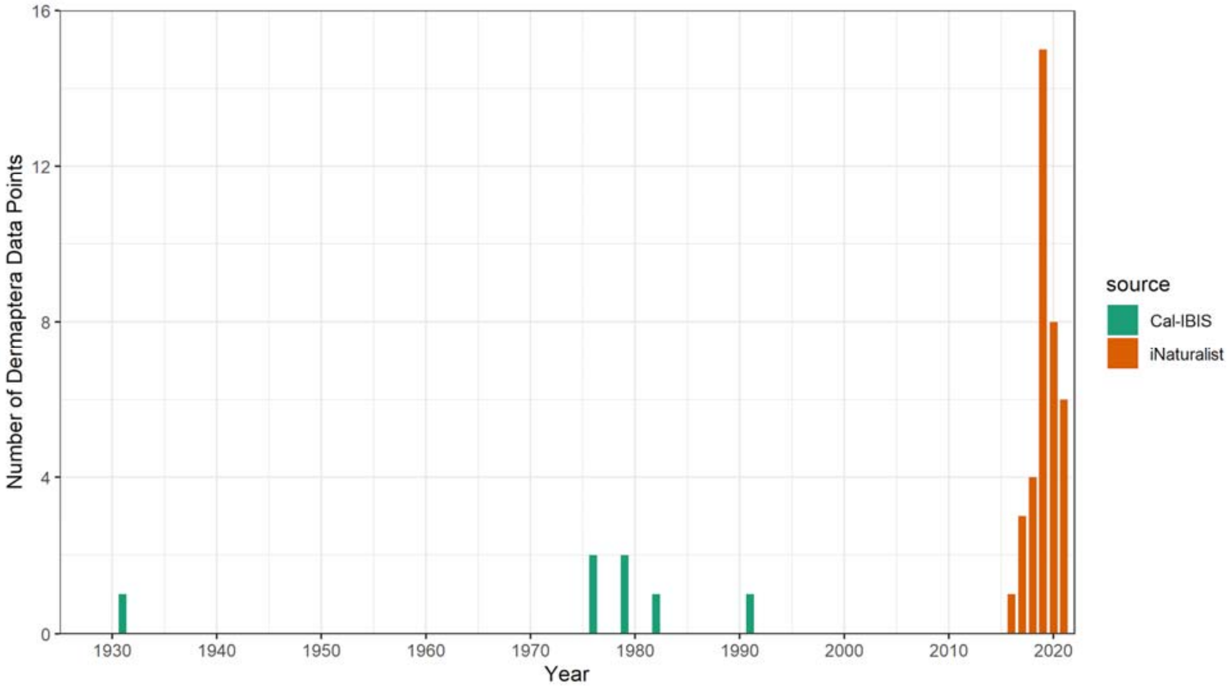


Figure Dermaptera-2. The number of island Dermaptera data points by year and data source reveals temporal gaps in the data. Cal-IBIS represents publicly available specimen data, and iNaturalist represents observation data.

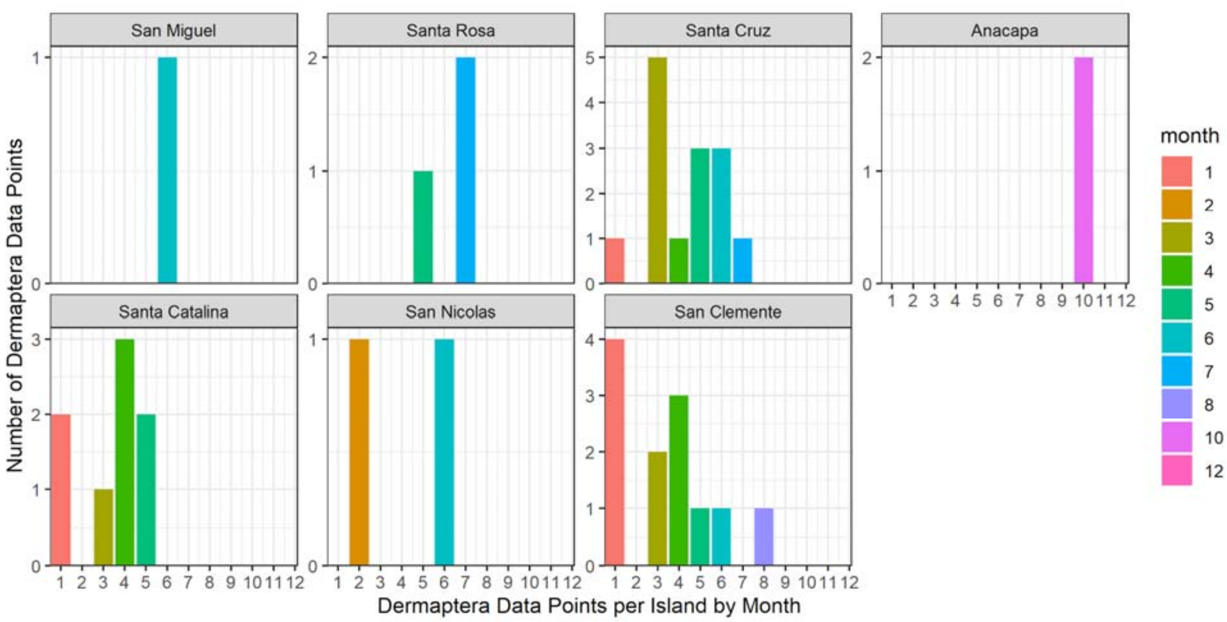


Figure Dermaptera-3. The number of Dermaptera data points by month, by island, reveals seasonal gaps in the data, which were combined for this analysis.

(a) 

(b)

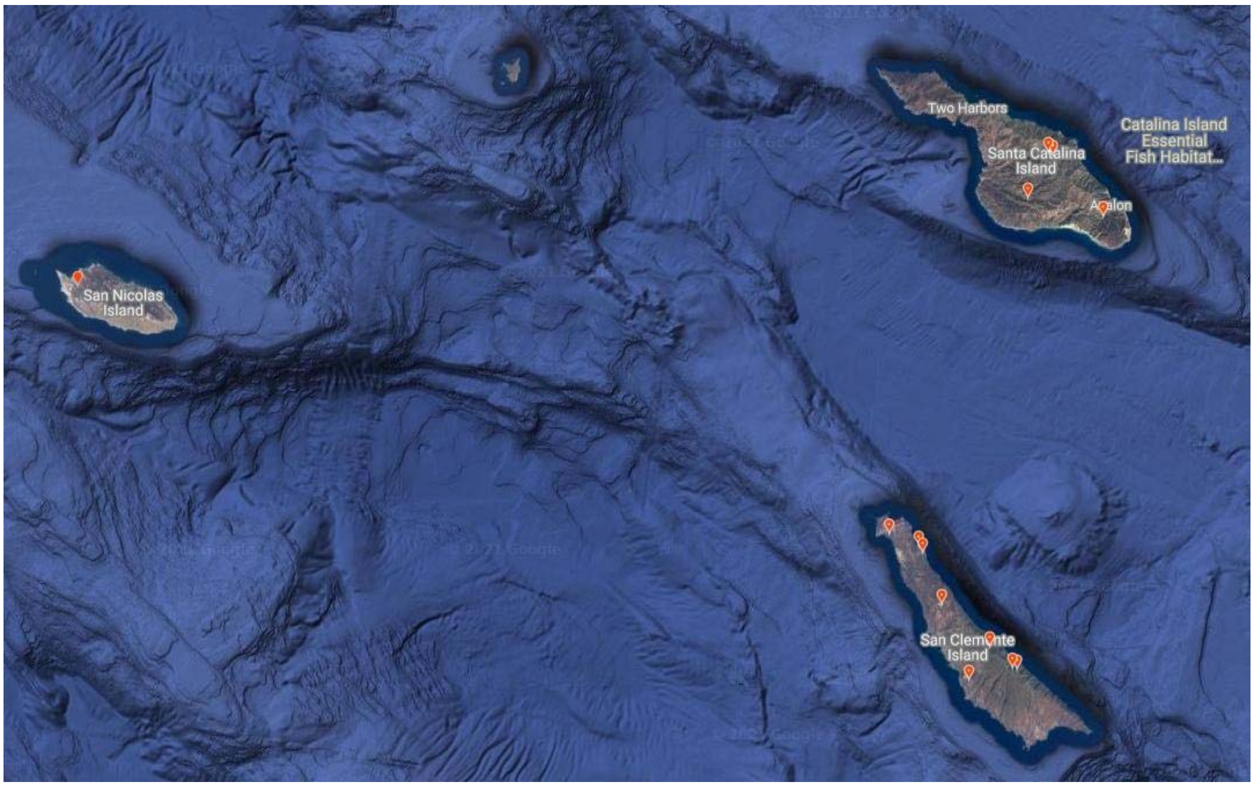


Figure Dermaptera-4. Distribution of iNaturalist Dermaptera observations on (a) the Northern Islands and (b) the Southern Islands.

Diplopoda

Tables Diplopoda-1 & Diplopoda-3 shows there are 38 millipede data points on the islands, and 66% of those are iNaturalist observations. Four millipede families are represented in the data, with 5 different species identified; half of those are *Tigolene clementinus.*

Table Diplopoda-2 shows that most of the millipede specimens and observations have been identified to the family level (92%). All of the specimens were identified to species, whereas only 6 of the 25 (24%) iNaturalist observations have been identified to species (and only 3 of those are research grade).

Table Diplopoda-4 shows that there are no millipede taxa in the literature that are not in the occurrence data. **Appendix C Table 4** has a complete list of taxa found in the occurrence data and literature.

Figures Diplopoda-1a and 1b show the absolute number and proportional number/island size of millipede data points on each island. Millipedes have only been recorded on five islands: Santa Cruz, Anacapa, Santa Catalina, San Nicolas, and San Clemente. Interestingly, Anacapa Island data is all from specimens (mostly housed at LACM) whereas the other islands have mostly iNaturalist observations. The most millipede data points were recorded on San Clemente (11), Santa Catalina (10), and Anacapa (10) islands, whereas fewer were recorded on Santa Cruz (4), and San Nicoloas (2). The figure normalized by island size show that four of the islands have very few occurrence records for their size (<1 data point/km^2), while Anacapa has the most data points by island size.

Figure Diplopoda-2 shows the number of specimens by year over time. The first millipede data point was recorded in 1927 (*Nannolene catalina* on Santa Catalina, housed at USNM with no collector information provided). Millipedes were next collected during the 1940s LACM expeditions by C. Henne. All of the recent millipede data points are iNaturalist observations, with 44% of those being from two specialists, C.H. Richart and C. Lee. Those observations were made during 2019 SBBG surveys on San Clemente Island and subsequent focused surveys.

Figure Diplopoda-3 shows the data by month and island. Due to the low number of millipede data points, no seasonal trends can be assessed.

Figure Diplopoda-4 shows the distribution of iNaturalist observations, which are sparse on the five islands where millipedes were recorded.

Table Diplopoda-1. The number of island millipede occurrences by order and family, and by data source, reveals the relative number of observations (iNaturalist) and specimens (Cal-IBIS, LACM).

Order	Family	Cal-IBIS	iNaturalist	LACM	n
Julida	Parajulidae	0	10	0	10
Polyxenida	Paradoxosomatidae	0	2	0	2
Polyxenida	Polyxenidae	1	5	9	15
Spirostreptida	Cambalidae	3	5	0	8
	undetermined family	0	3	0	3
	all Diplopoda	4	25	9	38
	family diversity	2	4	1	4

Table Diplopoda-2. Taxonomic resolution of island millipede occurrence records by source. Note iNaturalist RG = Research Grade.

Rank	Cal-IBIS	iNaturalist (All)	iNaturalist (RG)	LACM	totals
Order	4 (100%)	25 (100%)		9 (100%)	38 (100%)
Family	4 (100%)	22 (88%)	3 (12%)	9 (100%)	35 (92.11%)
Genus	4 (100%)	13 (52%)	3 (12%)	0 (0%)	17 (44.74%)
Species	4 (100%)	6 (24%)	3 (12%)	0 (0%)	10 (26.32%)

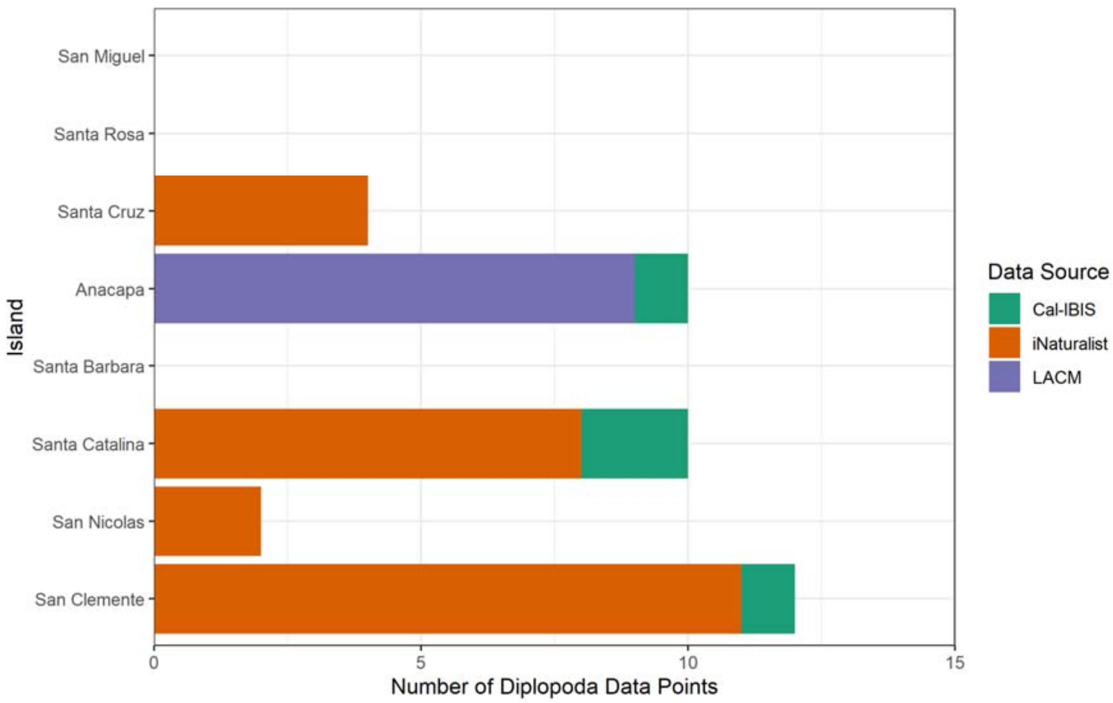
Table Diplopoda-3. Island millipede species in the occurrence data by data source.

Family	Species	# of Specimens	source
Cambalidae	*Nannolene catalina*	1	Cal-IBIS
	Paiteya errans	1	Cal-IBIS
	Tigolene clementinus	5	Cal-IBIS, iNaturalist
Paradoxosomatidae	*Oxidus gracilis*	2	iNaturalist
Polyxenidae	*Polyxenus anacapensis*	1	Cal-IBIS

Table Diplopoda-4. Island millipede taxa added by a literature search as compared to those represented in digitized specimen and observation data.

	# of Families	# of Genera	# of Species
Occurrence Data	4	6	5
Taxa added by Literature	0	0	0
Total Diplopoda	4	6	5

(a)



(b)

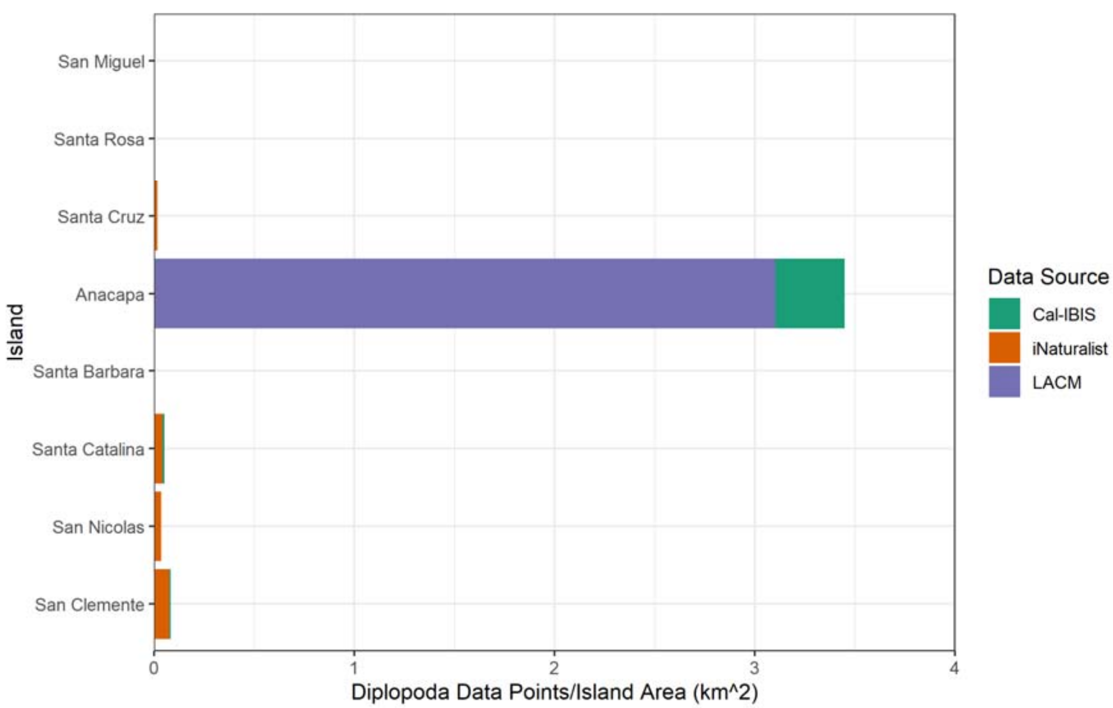


Figure Diplopoda-1. The (a) absolute number and (b) proportional number/island size of millipede occurrences on each island by data source reveal spatial gaps in the data.

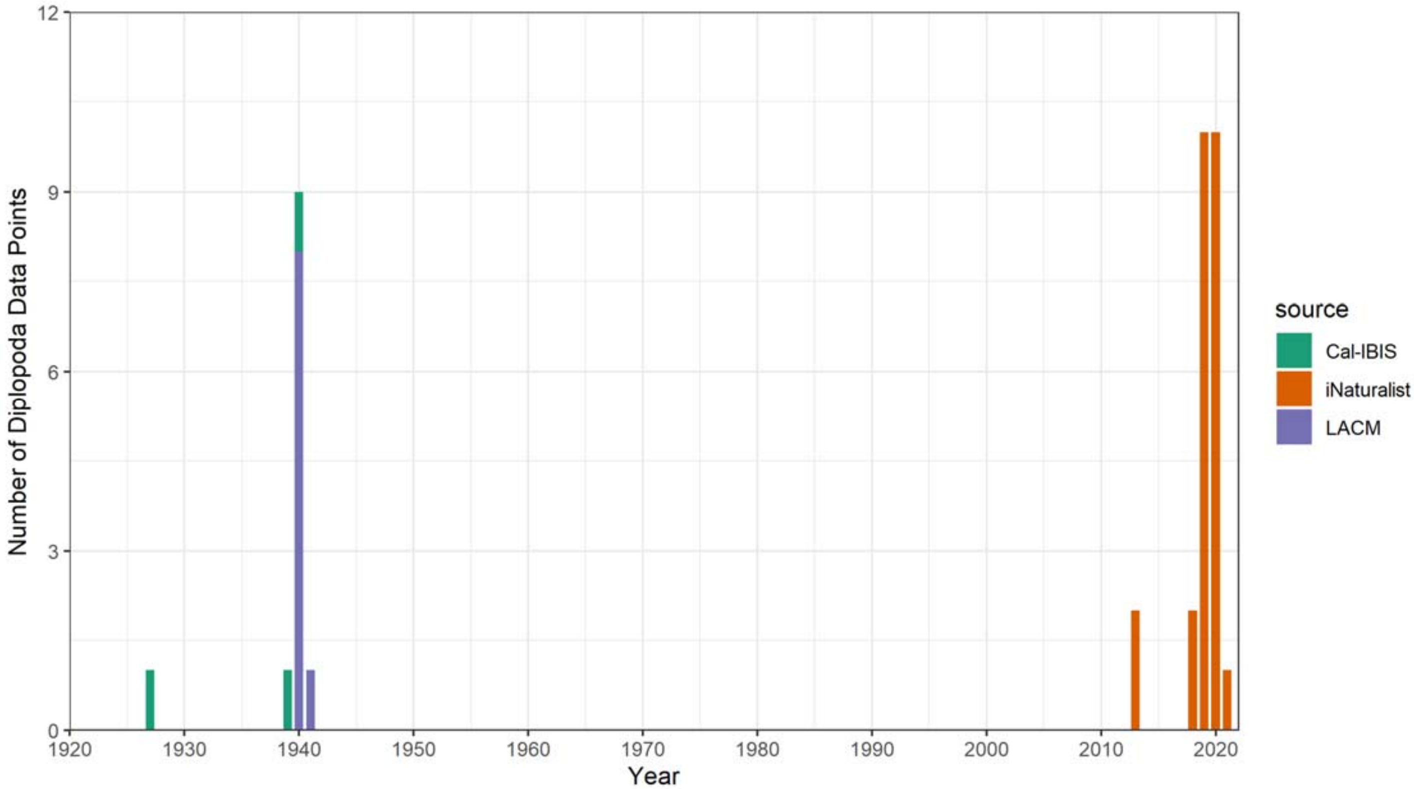
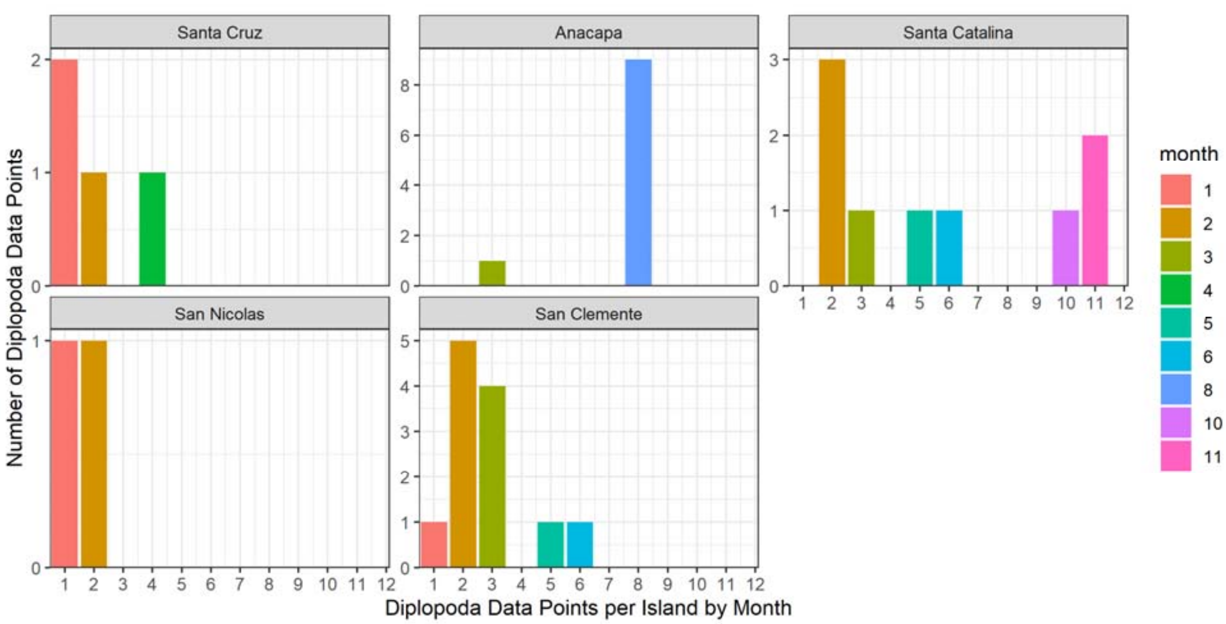


Figure Diplopoda-2. The number of island millipede occurrences by year and data source reveals temporal gaps in the data.



Diplopoda Figure 3. The number of millipede occurrences sampled by month, by island, reveals seasonal gaps in the data. Note that some islands do not have millipede data.

(a)

(b)

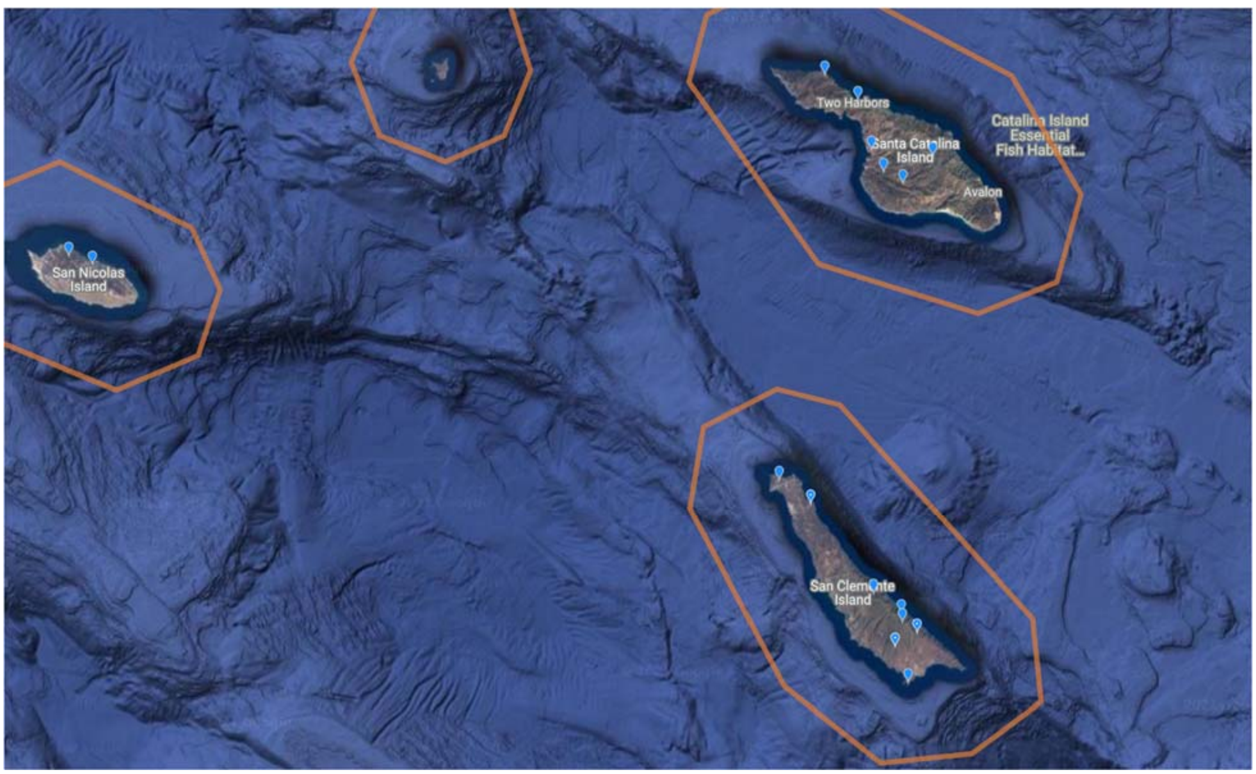


Figure Diplopoda-4. Distribution of iNaturalist millipede observations on (a) Santa Cruz Island and (b) the Southern Islands.

Diptera

Table Diptera-1 reveals that fly families that are physically smaller, such as the Cecidomyiidae, Ceratopogonidae, Chironomidae, and Phoridae, have been under-collected. These are four huge families that have relatively few data points recorded. There is also a notable absence of Drosophilidae. A total of 56 families were represented in the data. Syrphids (flower flies) and Bombyliids (bee flies) make up 50% of the iNaturalist observations, and 22% of all data points. This makes sense, as they are larger, charismatic pollinators. In addition, a previous scientist (Andy Calderwood) at SBMNH worked on the Bombyliidae. Collected specimens (Cal-IBIS and LACM) make up 82% of the fly data points and observations (iNaturalist) make up 18%. LACM represents the majority of the fly data points (73%), likely influenced by their current Curator (Brian Brown) being a Dipterist.

Table Diptera-2 shows that the taxonomic resolution for fly data points is low: an average 55% are identified to family, 29% are identified to genus, and 23% are identified to species.

Table Diptera-3 shows that there is a gap between known fly taxa found on the Channel Islands from the literature and taxa represented in digitized collections and naturalist observations. There are 6 familes, 78 genera, and 162 species known to occur on the Channel Islands based on the literature that are not represented in the occurrence data (61% of the taxa in the literature are not in the occurrence data). **Appendix C Table 5** has a complete list of taxa found in the occurrence data and literature.

Figures Diptera-1a and 1b show the absolute number and proportional number/island size of fly occurrences on each island (between 88 and 1168 data points). LACM fly collections are the majority of fly occurences on most of the islands. San Nicolas has been sampled the most in absolute number (1,168 flies) and proportion to island size. This is due to the SBBG 2016 survey (Knapp et al. 2018).

Figure Diptera-2 shows the number of specimens by year over time. The first collection recorded is from 1913, by G. Heisermann on Santa Cruz Island (housed at UCSB). There are three pulses visible in the digitized collections: 1) the 1940s Channel Islands Biological Survey, 2) collections made by a myriad of scientists including C.L. Hogue, C.D. Nagano, S.E. Miller, J.N. Hogue, and S. Bennett between ca. 1975 and 1984 (housed at LACM), and 3) the 2016 SBBG *Mesembryanthemum* study on San Nicolas Island (Knapp et al. 2018). The majority of the datapoints in the past 10 years are iNaturalist observations. Those are predominated by larger, more charismatic flower-visiting flies (Bombyliidae, Syrphidae, Tachinidae, Acroceridae) and other more obvious taxa like crane flies (Tipulidae), flesh flies (Sarcophagidae), house flies (Muscidae), robber flies (Asilidae), and bottle flies (Calliphoridae).

Figure Diptera-3 shows the data by month and island. There are seasonal gaps in fly data points on all of the islands, with little to no data points recorded from some months. San Nicolas has a peak in occurences in April because of the SBBG survey.

Figure Diptera-4 shows a variable distribution of iNaturalist data points, with Santa Catalina and San Clemente being well covered due to relative accessibility and active biologists on this platform, respectively. Santa Rosa Island points are mainly restricted to the area closer to the island entry point on that relatively inaccessible island.

Table Diptera-4 and **Figure Diptera-5** show the spatial collecting effort in 1 km gid cells. They show that Diptera collection on the islands has been very sparse on all islands except for Santa Barbara. Surprisingly, the better-collected areas are not always the easiest to access, but are likely related to the target organisms of the individual collector. Middle Anacapa Islet and the southeastern end of San Nicolas Island are two examples of this.

Table Diptera-1. Number of island fly occurrences recorded in each data source by family shows the relative number of observations (iNaturalist) and specimens (Cal-IBIS, LACM, [LACM includes San Nicolas Island specimens collected by SBBG and reposited at LACM]).

Family	Cal-IBIS	LACM	iNaturalist	n	%
Acroceridae	1	0	2	3	0.07%
Agromyzidae	8	0	4	12	0.28%
Anthomyiidae	30	148	8	186	4.34%
Asilidae	35	46	11	92	2.15%
Asteiidae	0	0	1	1	0.02%
Bibionidae	8	0	6	14	0.33%
Bombyliidae	57	40	75	172	4.01%
Calliphoridae	15	1	25	41	0.96%
Camiliidae	0	0	1	1	0.02%
Cecidomyiidae	0	3	25	28	0.65%
Ceratopogonidae	0	0	2	2	0.05%
Chironomidae	1	33	2	36	0.84%
Chloropidae	0	164	3	167	3.90%
Chyromyidae	0	0	1	1	0.02%
Coelopidae	5	23	3	31	0.72%
Conopidae	1	0	2	3	0.07%
Culicidae	2	11	4	17	0.40%
Dolichopodidae	9	33	4	46	1.07%
Drosophilidae	0	0	1	1	0.02%
Empididae	0	0	7	7	0.16%
Ephydridae	3	39	6	48	1.12%
Fanniidae	2	0	0	2	0.05%
Heleomyzidae	3	146	1	150	3.50%
Hippoboscidae	0	0	2	2	0.05%
Lauxaniidae	6	0	0	6	0.14%
Limoniidae	0	15	1	16	0.37%
Lonchaeidae	0	0	1	1	0.02%
Milichiidae	0	0	2	2	0.05%
Muscidae	4	0	9	13	0.30%
Mycetophilidae	2	0	0	2	0.05%
Mythicomyiidae	0	0	1	1	0.02%
Neriidae	0	5	5	10	0.23%
Oestridae	0	0	2	2	0.05%
Phoridae	2	114	7	123	2.87%
Piophilidae	0	2	0	2	0.05%
Pipunculidae	1	0	0	1	0.02%
Platypezidae	1	0	0	1	0.02%
Psychodidae	0	0	3	3	0.07%
Rhagionidae	3	0	0	3	0.07%
Rhinophoridae	0	0	1	1	0.02%
Sarcophagidae	13	2	17	32	0.75%
Scathophagidae	5	0	0	5	0.12%
Scatopsidae	0	0	1	1	0.02%
Sciaridae	0	11	7	18	0.42%

Family	Cal-IBIS	LACM	iNaturalist	n	%
Sepsidae	2	1	0	3	0.07%
Simuliidae	0	0	1	1	0.02%
Sphaeroceridae	0	6	0	6	0.14%
Stratiomyidae	13	5	2	20	0.46%
Syrphidae	47	406	309	762	17.79%
Tabanidae	4	10	1	15	0.35%
Tachinidae	23	12	16	51	1.19%
Tephritidae	59	24	12	95	2.22%
Therevidae	12	5	3	20	0.47%
Tipulidae	8	52	27	87	2.03%
Ulidiidae	1	0	0	1	0.02%
undetermined family	26	1752	139	1917	44.75%
all Diptera	412	3109	763	4284	
family diversity	34	27	45	56	

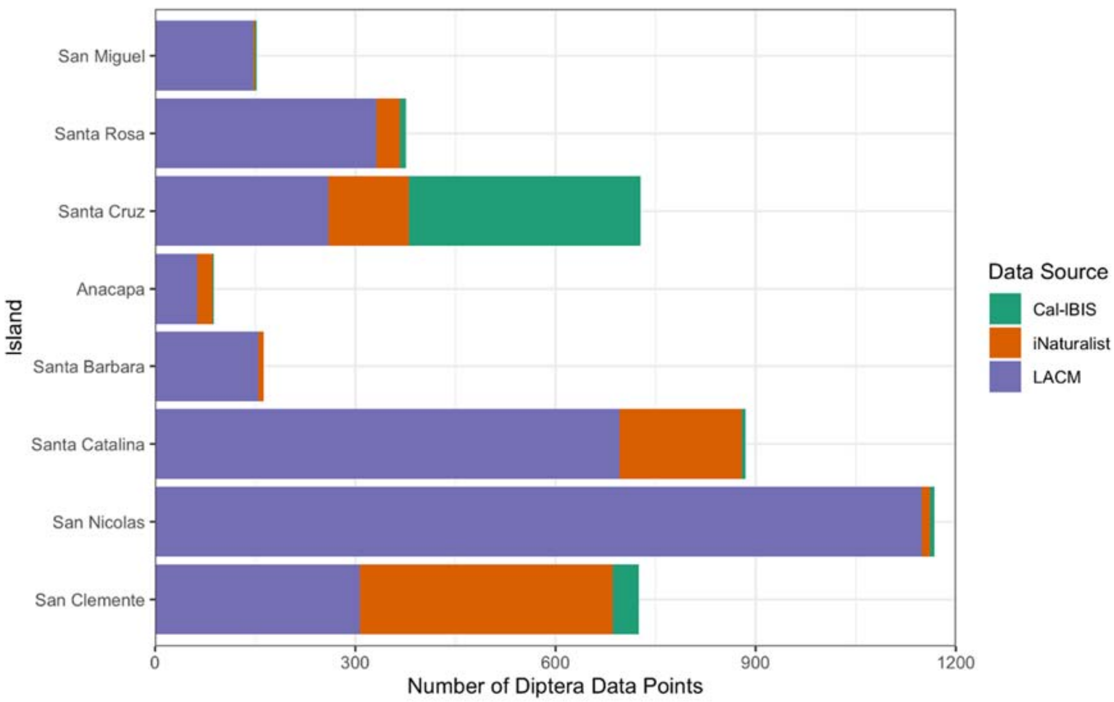
Table Diptera-2. Taxonomic resolution of island fly records by source. Note that only 212 of the iNaturalist records are Research Grade.

Rank	Cal-IBIS	LACM	iNaturalist	iNaturalist (RG)	SNI	Totals
Order	412	2636	763		473	4284
Family	386 (93.69%)	884 (33.54%)	624 (81.78%)	212 (27.78%)	473 (100%)	2368 (55.26%)
Genus	183 (44.42%)	594 (22.53%)	476 (62.39%)	211 (27.65%)	0 (0%)	1253 (29.24%)
Species	122 (29.61%)	527 (19.99%)	352 (46.13%)	209 (27.39%)	0 (0%)	996 (23.24%)

Table Diptera-3. Island fly taxa added by a literature search as compared to those represented in digitized specimen and observation data, revealing the digitization gap.

	# of Families	# of Genera	# of Species
Occurrence Data	56	102	103
Taxa added by Literature	6	78	162
Total Diptera	62	180	265

(a)



(b)

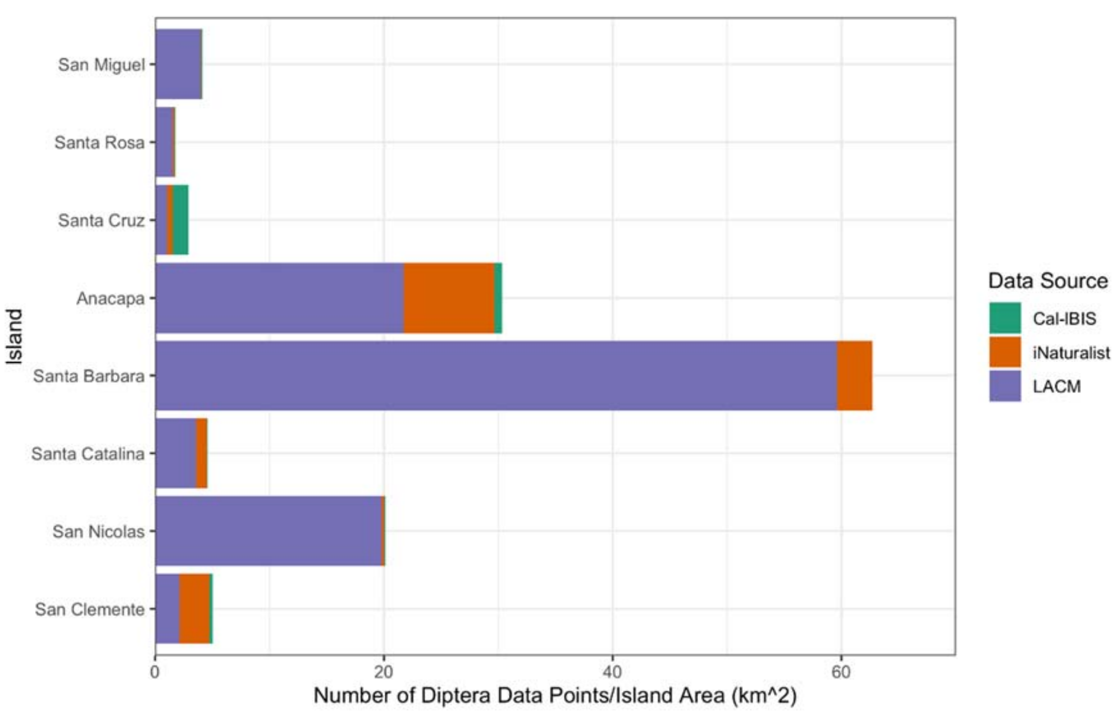


Figure Diptera-1. The (a) absolute number and (b) proportional number/island size of fly occurrences on each island by data source reveal spatial gaps in the data.

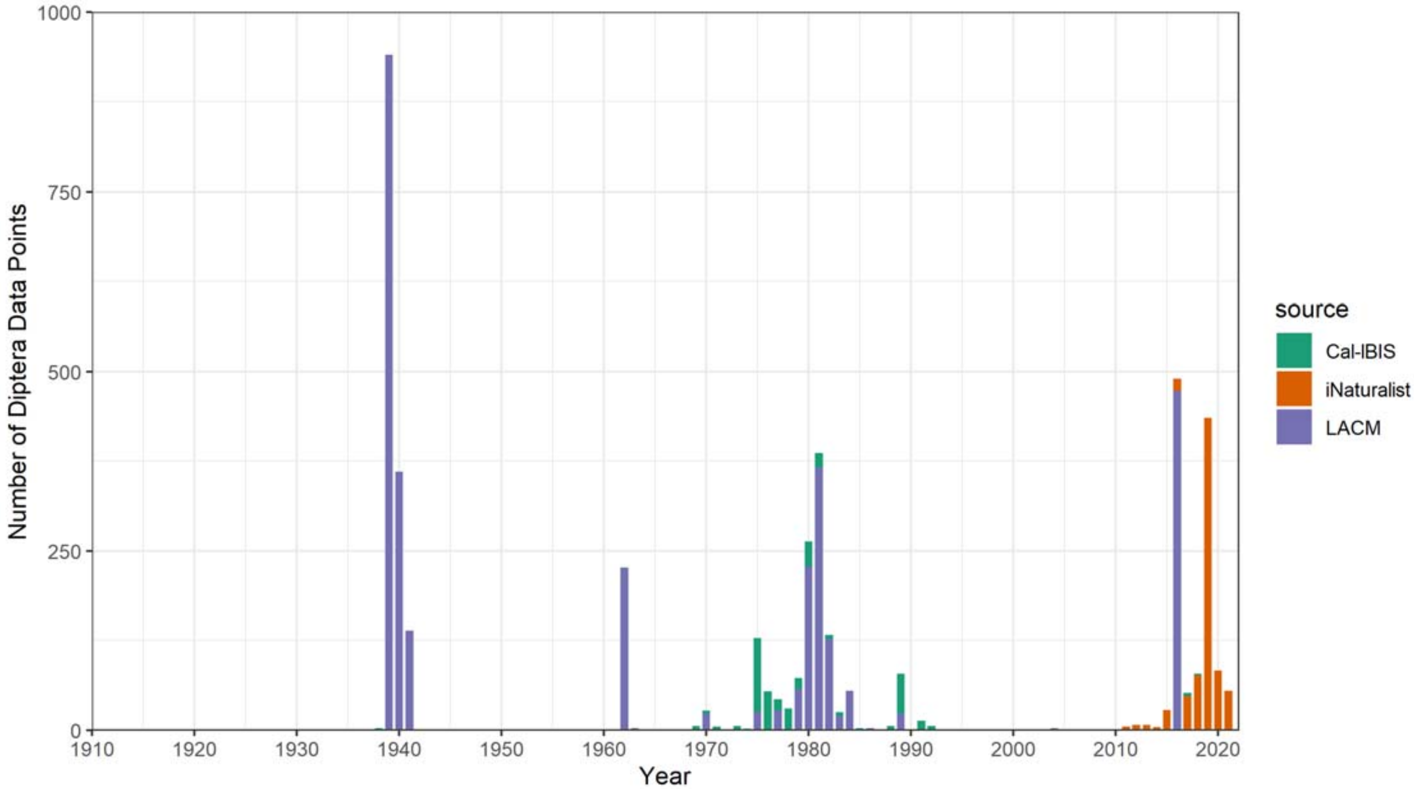


Figure Diptera-2. The number of island fly occurrences by year and data source reveals temporal gaps in the data.

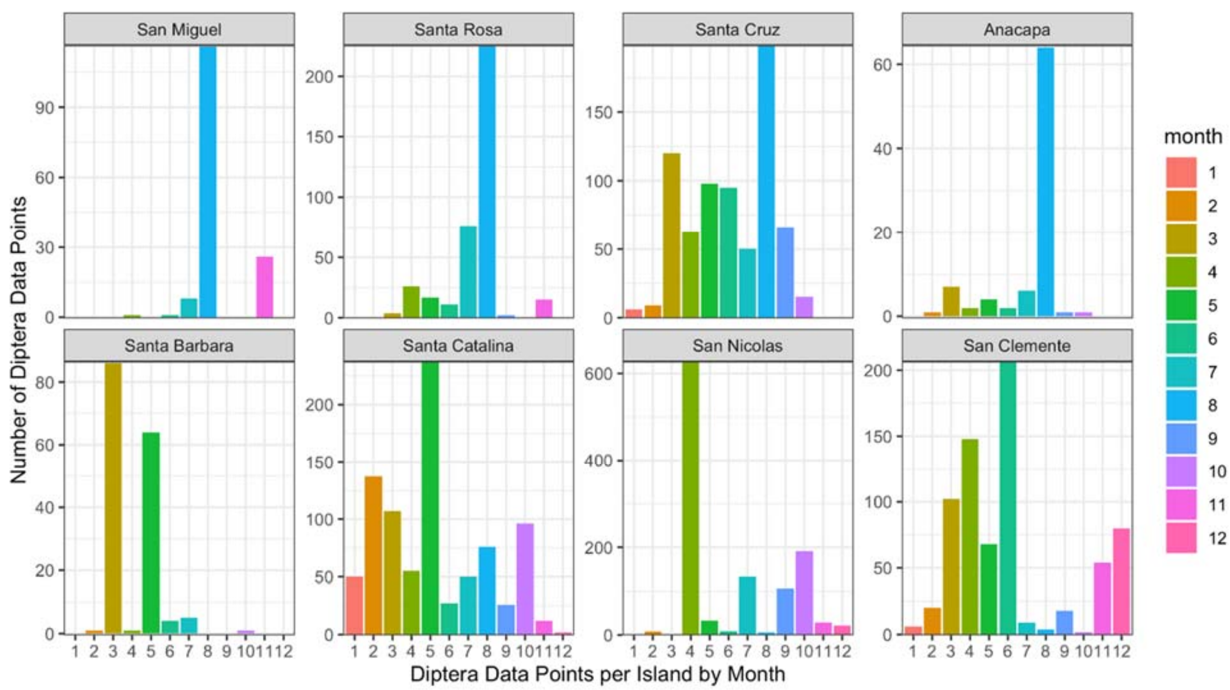


Figure Diptera-3. The number of fly occurrences by month, by island, reveals seasonal gaps in the data.

(a)

(b)

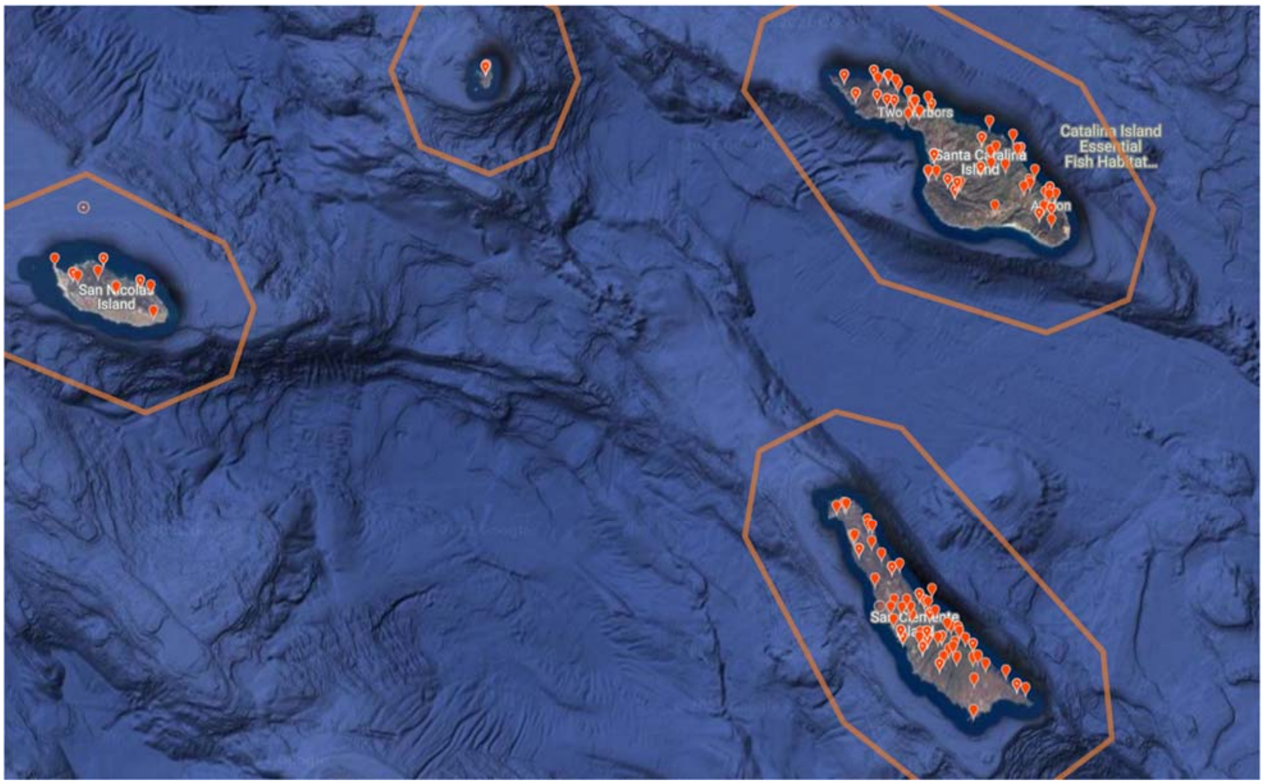
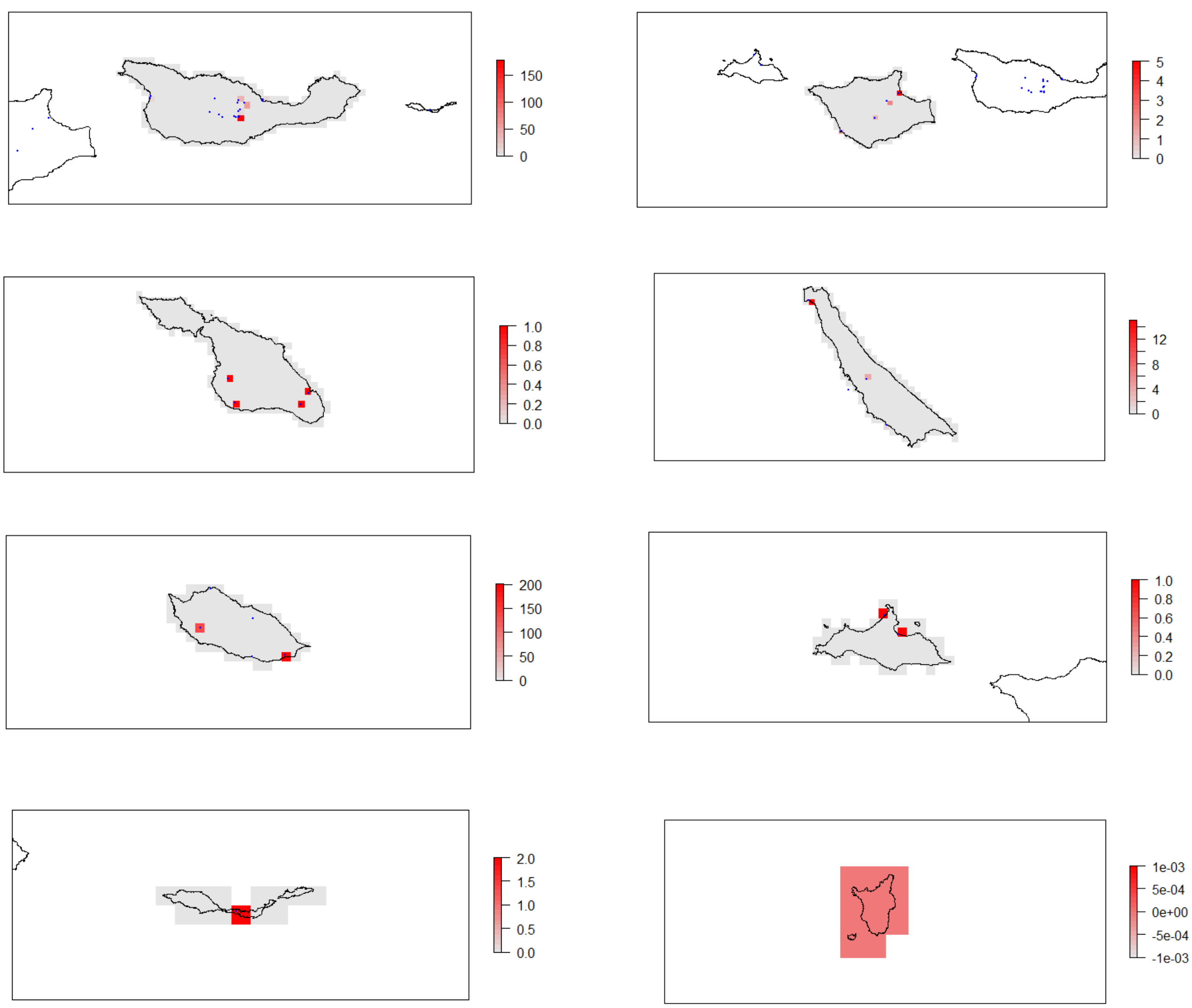


Figure Diptera-4. Distribution of iNaturalist fly observations on (a) the Northern Islands and (b) the Southern Islands.

Table-Diptera 4 & Figure-Diptera 5. Spatial collecting effort based on 1 km grid cells overlaid onto each of the eight California Channel Islands. Only 694 records had legitimate coordinates for these heat maps. Of 830 (out of 3,522) specimens with coordinates (24%), 699 were used for these maps after records using island centroids were removed.

Island	Island Collections	1 km^2 cells	Empty 1 km^2 cells	% empty cells	Mean records/cell
Anacapa	2	14	13	92.9%	2.0
Santa Cruz	310	313	302	96.5%	28.2
Santa Rosa	9	263	259	98.5%	2.3
San Miguel	2	61	59	96.7%	
Santa Catalina	4	250	246	98.4%	
San Clemente	20	198	195	98.5%	6.7
San Nicolas	347	81	76	93.8%	69.4



Hemiptera

Table Hemiptera-1 shows that Hemiptera are under represented in island collections (a taxonomic gap), with only 695 specimens. There are no Aphididae specimens in the collected records (Cal-IBIS and LACM). Collected specimens (Cal-IBIS, LACM and BOLD) make up 50% of the true bug data points and observations (iNaturalist) make up 50%. The LACM specimen collection only contains Gerridae (water-striders).

Table Hemiptera-2 shows that the taxonomic resolution for true bug data points is low: 68% of all data points are identified to family, 46% are identified to genus and 36% are identified to species. These numbers are better for LACM specimens, where 72% of specimens have been identified to species level, than for collective specimens in Cal-IBIS. Only 38% of the 688 iNaturalist records are research grade.

Table Hemiptera-3 shows that there is a gap between the known Hemiptera taxa found on the Channel Islands from the literature and the taxa represented in digitized collections and naturalist observations. There are 1 family, 22 genera, and 24 species known to occur on the Channel Islands based on the literature that were not represented in the occurrence data (in other words, 17% of the known island Hemiptera species are not represented by digitized specimens). Douglass Miller published about island mealybugs in 1973 and 1974, for instance, yet there are no digitized Pseudococcidae specimens. **Appendix C Table 6** has a complete list of taxa found in the occurrence data and literature.

Figures Hemiptera-1a and 1b show the absolute number and proportional number/island size of Hemiptera occurrences on each island. The only data points on Santa Barbara and Anacapa are iNaturalist observations. All 8 islands had at least a few Hemiptera occurrence records: San Miguel 2, Santa Rosa 50, Santa Cruz 811, Anacapa 34, Santa Cata lina 245, San Nicolas 20, and San Clemente 221. The relatively large number of specimens at LACM are all water striders. The graph that has been normalized by island size show that Anacapa Island has been relatively better sampled for its size.

Figure Hemiptera-2 shows the number of specimens by year over time. The first collections recorded were from 1914 (one specimen at UCSB, no collector recorded) and 1915 (nine specimens collected by C.H. Kennedy, housed at CAS and University of Kansas Natural History Museum [KU]). There were some Hemiptera collected during the 1940s Channel Islands Biological Survey (all water striders), but many more were collected in the 1970s and early 1980s. Those were collected by a variety of scientists including R.W. Goeden and D.W. Ricker from UC Riverside (UCR). The majority of the datapoints in the past 10 years are iNaturalist observations, which make up almost half of all Hemiptera occurrence records.

Figure Hemiptera-3 shows the data by month and island. There are seasonal gaps in Hemiptera data points on all islands, with few being collected during the winter on any island.

Figure Hemiptera-4 shows a relatively good distribution of observations on the islands except for Santa Rosa Island, on which transportation is limited.

Table Hemiptera-1. Number of Hemiptera data points recorded in each data source by family, showing the relative number of observations (iNaturalist) and specimens (Cal-IBIS, LACM and BOLD).

Family	Cal-IBIS	LACM	iNaturalist	BOLD	total	%
Achilidae	0	0	1	0	1	0.07%
Aleyrodidae	0	0	17	0	17	1.23%
Alydidae	2	0	0	0	2	0.14%
Anthocoridae	0	0	8	0	8	0.58%
Aphalaridae	0	0	4	0	4	0.29%
Aphididae	0	0	51	1	52	3.75%
Aphrophoridae	11	0	0	0	11	0.79%
Berytidae	2	0	1	0	3	0.22%
Calophyidae	0	0	9	0	9	0.65%
Cercopidae	6	0	0	0	6	0.43%
Cicadellidae	28	0	36	0	64	4.61%
Cicadidae	11	0	1	0	12	0.87%
Cimicidae	1	0	1	0	2	0.14%
Cixiidae	0	0	2	2	4	0.29%
Clastopteridae	0	0	1	0	1	0.07%
Coccidae	0	0	11	0	11	0.79%
Coreidae	20	0	19	0	39	2.81%
Corixidae	15	0	3	0	18	1.30%
Cydnidae	0	0	1	0	1	0.07%
Dactylopiidae	0	0	5	0	5	0.36%
Delphacidae	1	0	1	0	2	0.14%
Dictyopharidae	0	0	1	0	1	0.07%
Flatidae	0	0	1	0	1	0.07%
Gerridae	9	25	4	0	13	0.94%
Issidae	0	0	1	0	1	0.07%
Largidae	14	0	52	0	66	4.76%
Liviidae	0	0	1	0	1	0.07%
Lygaeidae	43	0	41	0	84	6.06%
Membracidae	10	0	5	0	15	1.08%
Miridae	131	0	40	0	171	12.33%
Nabidae	0	0	1	0	1	0.07%
Notonectidae	7	0	5	0	12	0.87%
Oxycarenidae	0	0	1	0	1	0.07%
Pentatomidae	11	0	33	0	44	3.17%
Polymerus	0	0	1	0	1	0.07%
Pseudococcidae	0	0	1	0	1	0.07%
Psyllidae	0	0	4	0	4	0.29%
Pyrrhocoridae	2	0	62	0	64	4.61%
Reduviidae	44	0	36	0	80	5.77%
Rhopalidae	1	0	7	0	8	0.58%
Rhyparochromidae	0	0	11	0	11	0.79%
Saldidae	4	0	2	0	6	0.43%

Family	Cal-IBIS	LACM	iNaturalist	BOLD	total	%
Scutelleridae	0	0	3	0	3	0.22%
Thyreocoridae	1	0	0	0	1	0.07%
Tingidae	0	0	13	0	13	0.94%
Triozidae	0	0	18	0	18	1.30%
Tropiduchidae	19	0	11	0	30	2.16%
undetermined family	277	0	161	1	439	31.65%
all Hemiptera	670	25	688	4	1387	
family diversity	23	1	43	2	47	

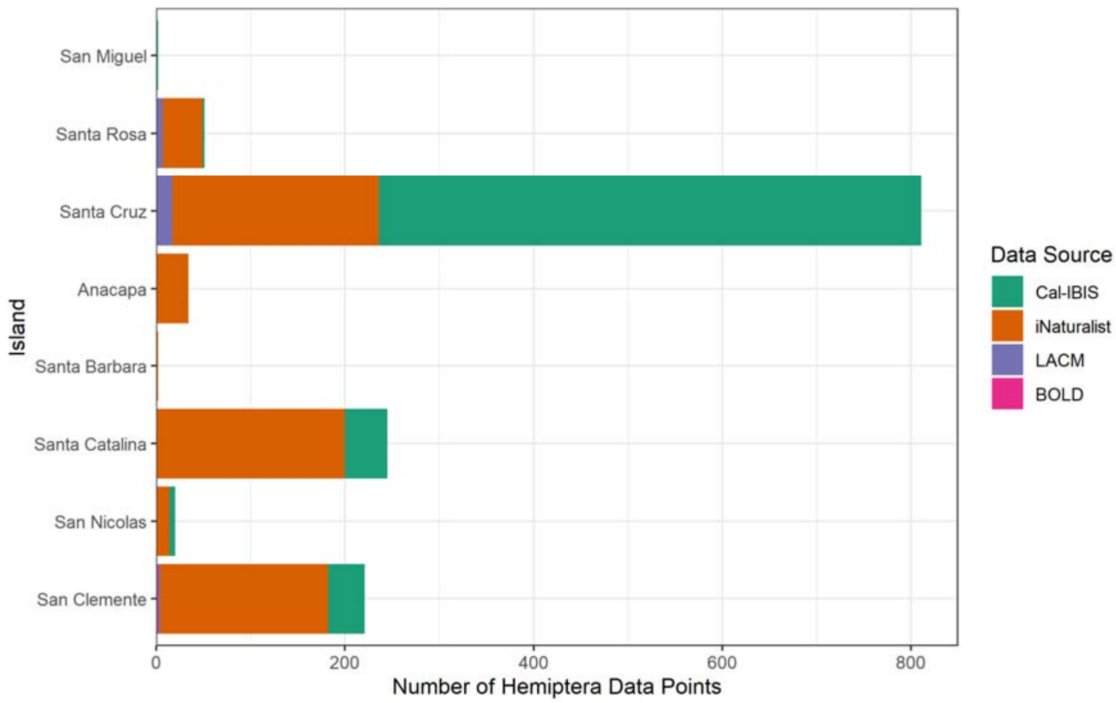
Table Hemiptera-2. Taxonomic resolution of island Hemiptera records by source. Note: only 261 of the iNaturalist records are Research Grade.

Rank	Cal-IBIS	LACM	iNaturalist (All)	iNaturalist (RG)	Totals
Order	670	25	688	261 (37.84%)	1387
Family	393 (58.66%)	25 (100%)	527 (76.60%)	197 (28.63%)	945 (68.13%)
Genus	216 (32.24%)	25 (100%)	398 (57.85%)	193 (28.05%)	639 (46.07%)
Species	19 (2.84%)	18 (72%)	273 (39.68%)	191 (27.76%)	501 (36.12%)

Table Hemiptera-3. Island Hemiptera taxa added by a literature search as compared to those represented in digitized specimen and observation data, revealing the digitization gap. Note: a recording of “Naucordiae?” was not included in the count because of its uncertainty.

	# of Families	# of Genera	# of Species
Occurrence Data	47	135	114
Taxa added by Literature	1	22	24
Total Hemiptera	48	157	138

(a)



(b)

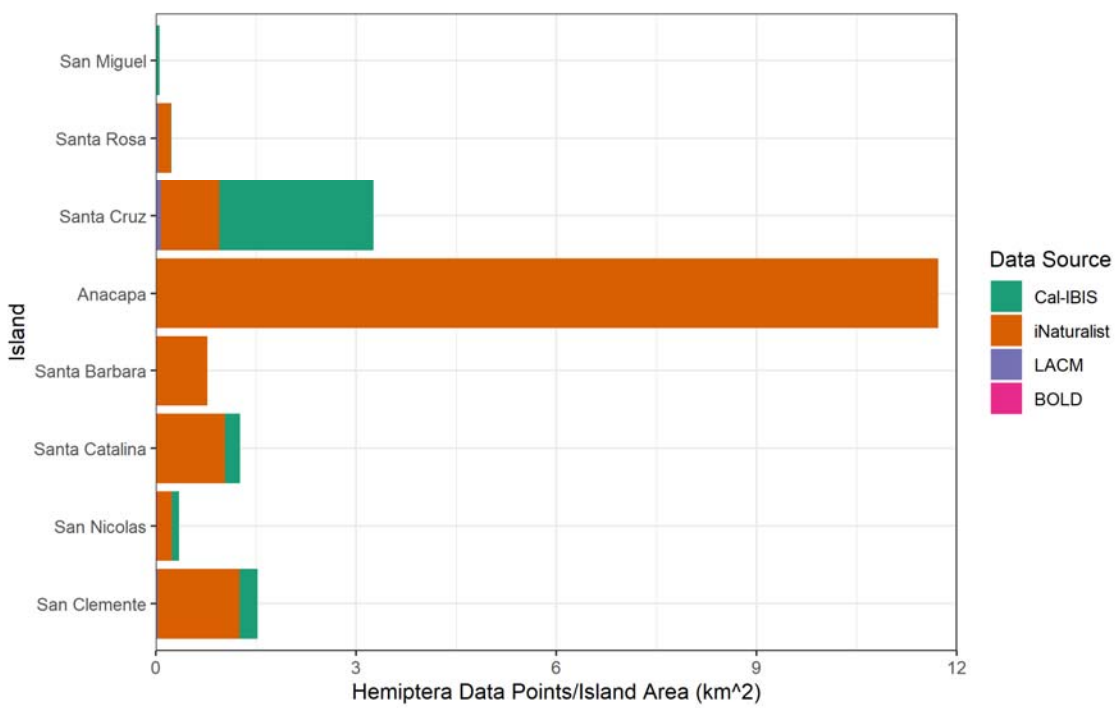


Figure Hemiptera-1. The (a) absolute number and (b) proportional number/island size of Hemiptera data points on each island by data source reveal spatial gaps in the data. Cal-IBIS represents publicly available specimen data, LACM represents private Los Angeles County Museum data, and iNaturalist represents observation data.

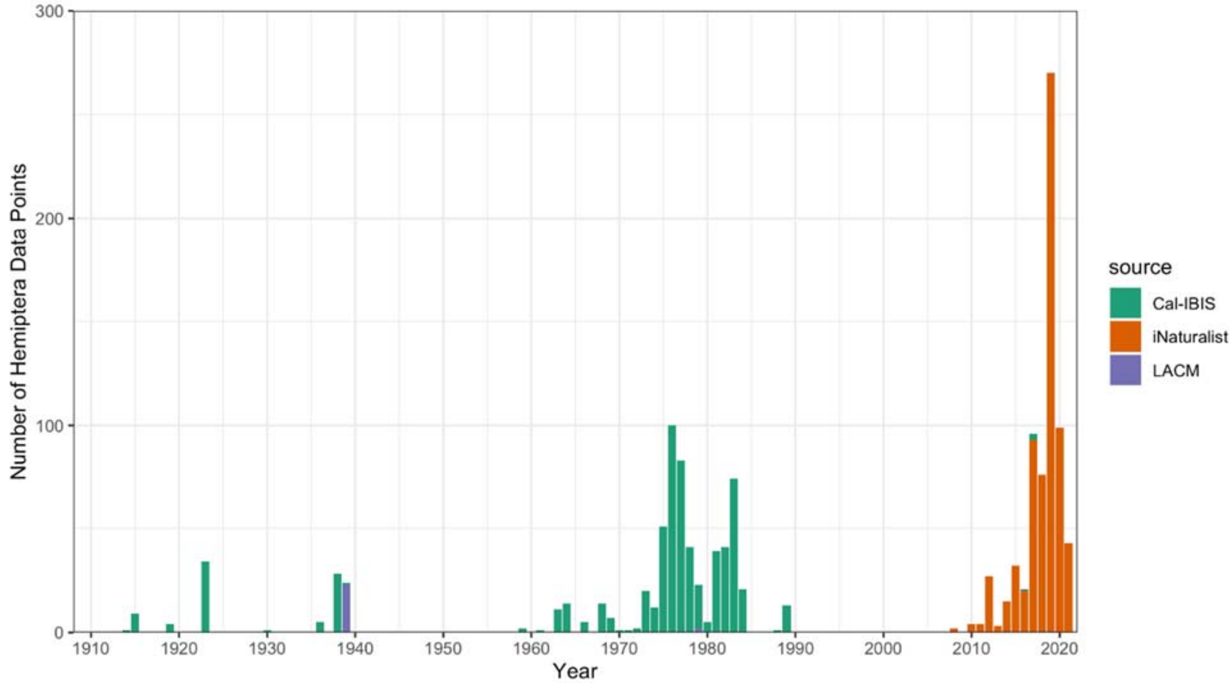


Figure Hemiptera-2. The number of island Hemiptera data points by year and data source reveals temporal gaps in the data. Cal-IBIS represents publicly available specimen data, LACM represents private Los Angeles County Museum data, and iNaturalist represents observation data.

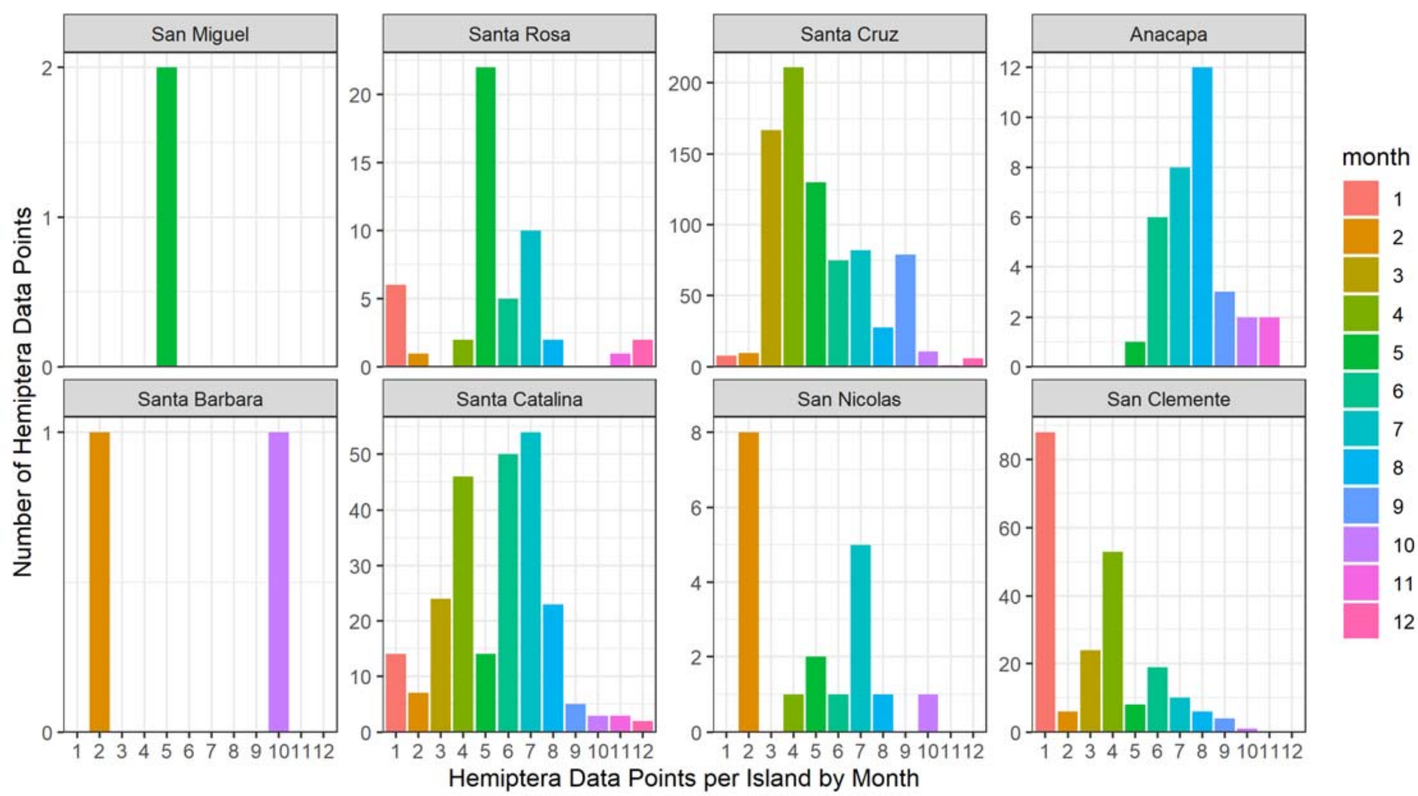


Figure Hemiptera-3. The number of Hemiptera data points by month, by island, reveals seasonal gaps in the data, which were combined for this analysis.

(a) 

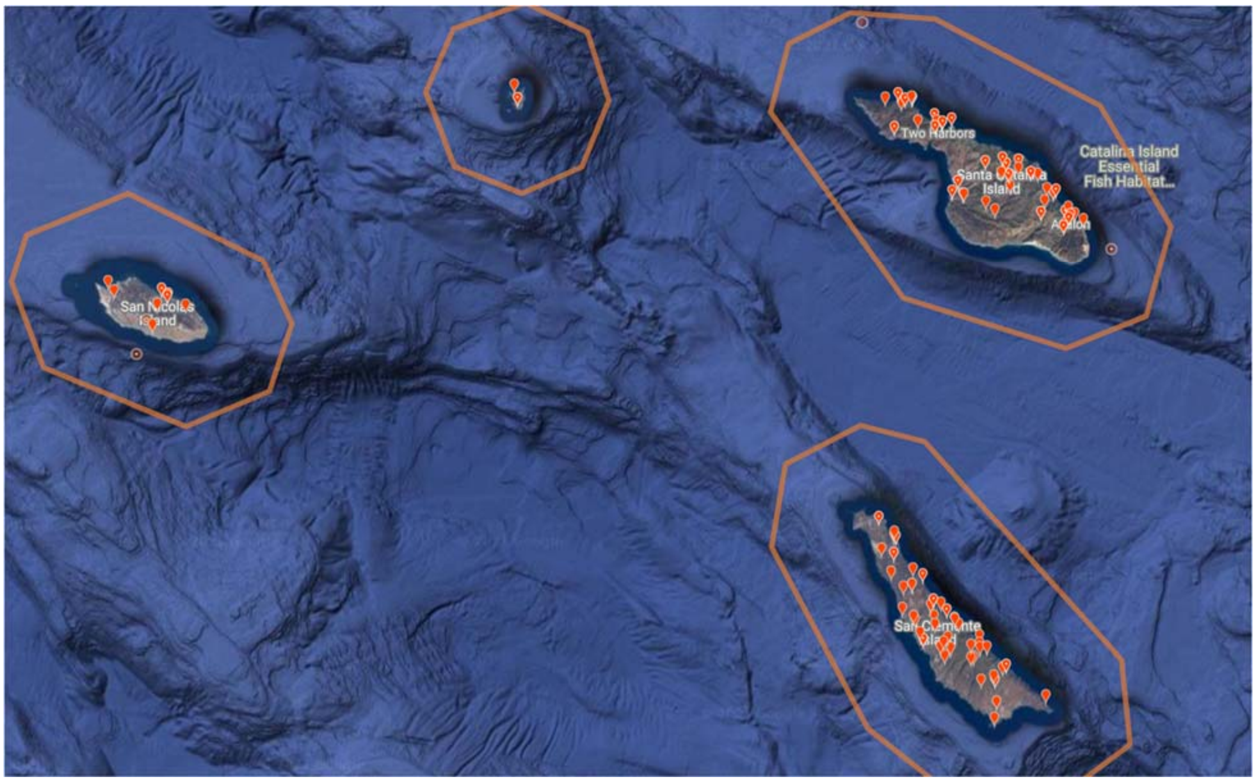
(b) 

Figure Hemiptera-4. Distribution of iNaturalist Hemiptera observations on (a) the Northern Islands and (b) the Southern Islands. There were no iNaturalist observations of Hemiptera on San Miguel.

Hymenoptera

Table Hymenoptera-1 shows that the occurrence data is heavily skewed toward the bees (75%), with half of those records in the family Halictidae. The Bohart database is solely bee specimens. Ants are 10% of the occurrence records and all wasp families only make up 10% of the occurrence records. Parasitic microhymenoptera are grossly under-represented. Platygastridae and Scelionidae are two of the most species-rich groups in the order, but only have one 1 specimen and 2 specimens in the data, respectively. Ichneumonids, Vespids, and Crabronids are the biggest wasp families represented proportionally in the occurrence data; these are larger, more obvious taxa. Collected specimens (Cal-IBIS, LACM and Bohart) are 92% of the Hymenoptera data points, and observations (iNaturalist) are 8%. A total of 35 families appear in the occurrence data. **Appendix C Table 7** has a complete list of taxa found in the occurrence data and literature.

Table Hymenoptera-2 shows that the taxonomic resolution for Hymenoptera data points is relatively high, with 83% identified to family. This is likely driven by the huge number of bee specimens in the data set, which were identified by specialists. Of the 625 Cal-IBIS "parastica" records, however, 476 are identified to genus, and only 97 are identified to species.

Figures Hymenoptera-1a and 1b show the absolute number and proportional number/island size of Hymenoptera occurrences on each island (between 346 on Santa Barbara Island and 10,002 on Santa Cruz). Santa Cruz Island is very well represented in the specimen data (61%), likely due to studies by Thorp, Barthell, Wenner, and Randall. The graph that has been normalized by island size show that Santa Barbara and Anacapa islands have been relatively more sampled for their size.

Figure Hymenoptera-2 shows the number of specimens by year over time. The first collection recorded of an ant was from 1900 (from Santa Catalina, collector unknown), the first bee collection was from 1909 (from Santa Catalina, collected by W. Bather), and the first wasp (an Ichneumonid) was from 1935 (from San Clemente Island, collector unknown, housed at LACM). There was a small peak in collections around 1940, associated with the Channel Islands Biological Survey. The 1970s and 1980s were dominated by bee collections, from scientists including R.W. Thorp, R.W. Rust, and J.S. Ascher. Many of these are housed at the UC Davis Bohart Museum. Between 2002 and 2004, a pulse of ant collections by P. Ward, D.A. Holway, and R.N. Fisher for a review of California ant taxa (Ward 2005) contributed many ant specimens to the CAS and LACM collections. The peak in 2012 reflects collections made by USGS PWRC - Native Bee Inventory and Monitoring Lab (BIML), while a peak in 2019 is due to the UCSBees project at UCSB. iNaturalist observations have been the main source of data in recent years.

Figure Hymenoptera-3 shows the data by month and island. There are seasonal gaps in the occurrence record collections, and the majority of specimen were collected in spring or summer (97%), which is probably due to bees making up the vast majority of the collections.

Figure Hymenoptera-4 shows the spatial distribution of iNaturalist observations. It shows relatively good coverage, except for much of Santa Rosa and the western islets of Anacapa.

Table Hymenoptera-3 and **Figure Hymenoptera-5** address the spatial distribution of island Hymenoptera collections via heat maps on 1 km grid cells. The figure shows that island Hymenoptera collecting has been concentrated in a few areas on each of the islands, with scattered collections elsewhere. In general, the best-collected locations are those that are more easily accessible, like Prisoner's Harbor and the Central Valley on Santa Cruz island, the Becher's Bay area on Santa Rosa Island, and East Anacapa islet. Some more remote yet ecologically interesting areas have also been sampled relatively well, including Christy Beach on Santa Cruz island and the Daytona Beach area on San Nicolas Island. Between 57.1% (Anacapa) and 80.6% (Santa Rosa) of the grid cells have not been collected on the islands.

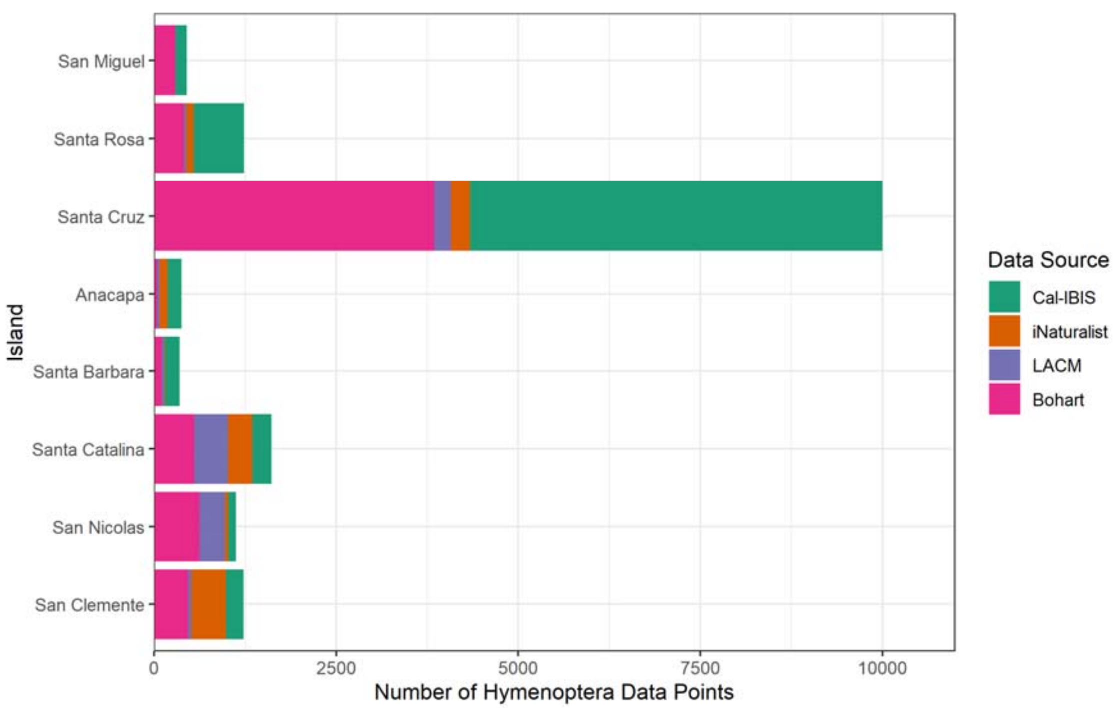
Table Hymenoptera-1. Number of specimens recorded in each data source by family. Note: the Bohart database only contains bee family records.

Family	Cal-IBIS	LACM	iNaturalist	Bohart*	n	%
Andrenidae	589	1	15	590	1195	7.24%
Apidae	770	139	387	1784	3080	18.65%
Colletidae	174	15	28	1114	1331	8.06%
Halictidae	3738	61	224	2245	6268	37.95%
Megachilidae	146	1	42	594	783	4.74%
Bees	**5417**	**217**	**696**	**6327**	**12657**	**76.64%**
Formicidae **Ants**	**1300**	**180**	**195**		**1675**	**10.14%**
Crabronidae	172	21	39		239	1.40%
Sphecidae	118	12	80		210	1.27%
Bethylidae	1	0	1		2	0.01%
Family	**Cal-IBIS**	**LACM**	**iNaturalist**	**Bohart***	**n**	**%**
Chrysididae	20	0	5		25	0.15%
Mutillidae	2	42	36		80	0.48%
Pompilidae	8	21	36		65	0.39%
Chyphotidae	0	2	0		2	0.01%
Tiphiidae	13	17	1		31	0.19%
Vespidae	155	79	67		301	1.82%
Aphelinidae	0	0	3		3	0.02%
Braconidae	27	2	5		34	0.21%
Ceraphronidae	1	0	0		1	< 0.01%
Chalcididae	6	0	0		6	0.04%
Cynipidae	19	0	72		91	0.55%
Diapriidae	1	0	0		1	< 0.01%
Encrytidae	5	0	2		7	0.04%
Eulophidae	9	0	9		18	0.11%
Eupelmidae	2	0	1		3	0.02%
Eurytomidae	15	0	1		16	0.10%
Gasteruptiidae	3	0	0		3	0.02%
Ichneumonidae	12	346	49		407	2.46%
Mymaridae	11	0	0		11	0.07%
Perilampidae	0	0	2		2	0.01%
Platygastridae	1	0	0		1	<0.01%
Pteromalidae	13	0	1		14	0.08%
Scelionidae	2	0	0		2	0.01%
Torymidae	5	0	0		5	0.03%
Wasps	**621**	**542**	**410**		**1573**	**9.52%**
Cephidae	1	0	0		1	<0.01%
Tenthredinidae	0	0	4		4	0.02%
Sawflies	**1**	**0**	**4**		**5**	**0.03%**
undetermined family	282	247	67	9	605	3.66%
all Hymenoptera	7621	1186	1372	6336	16515	
family diversity	31	15	26	5*	35	

Table Hymenoptera-2. Taxonomic resolution of occurrence records by source. Note only 508 of the iNaturalist records are Research Grade.

Rank	Cal-IBIS	LACM	iNaturalist	Bohart	totals
Order	7621	1186	1372	6326	16505
Family	7339 (96.30%)	940 (79.26%)	1304 (95.04%)	6326 (100%)	15909 (96.39%)
Genus	7069 (92.76%)	940 (79.26%)	1116 (81.34%)	6326 (100%)	15452 (93.36%)
Species	6293 (82.57%)	625 (52.70%)	614 (44.75%)	6227 (98.44%)	13760 (83.37%)

(a)



(b)

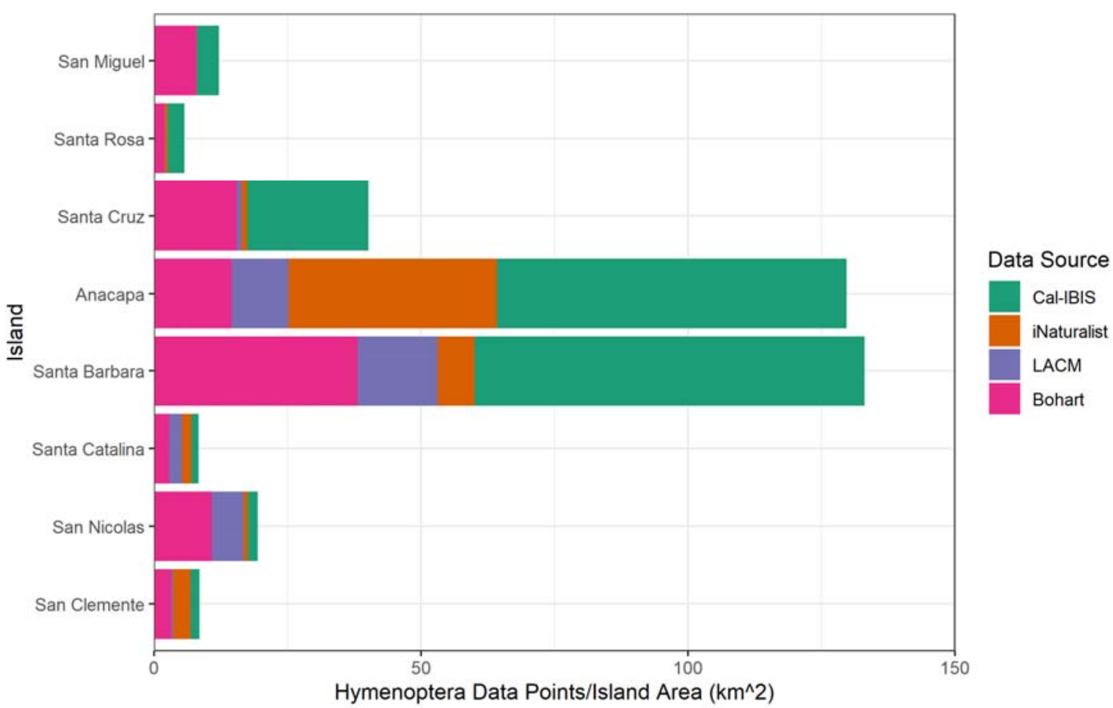


Figure Hymenoptera-1. The number of specimens in the occurrence data collected on each island by data source.

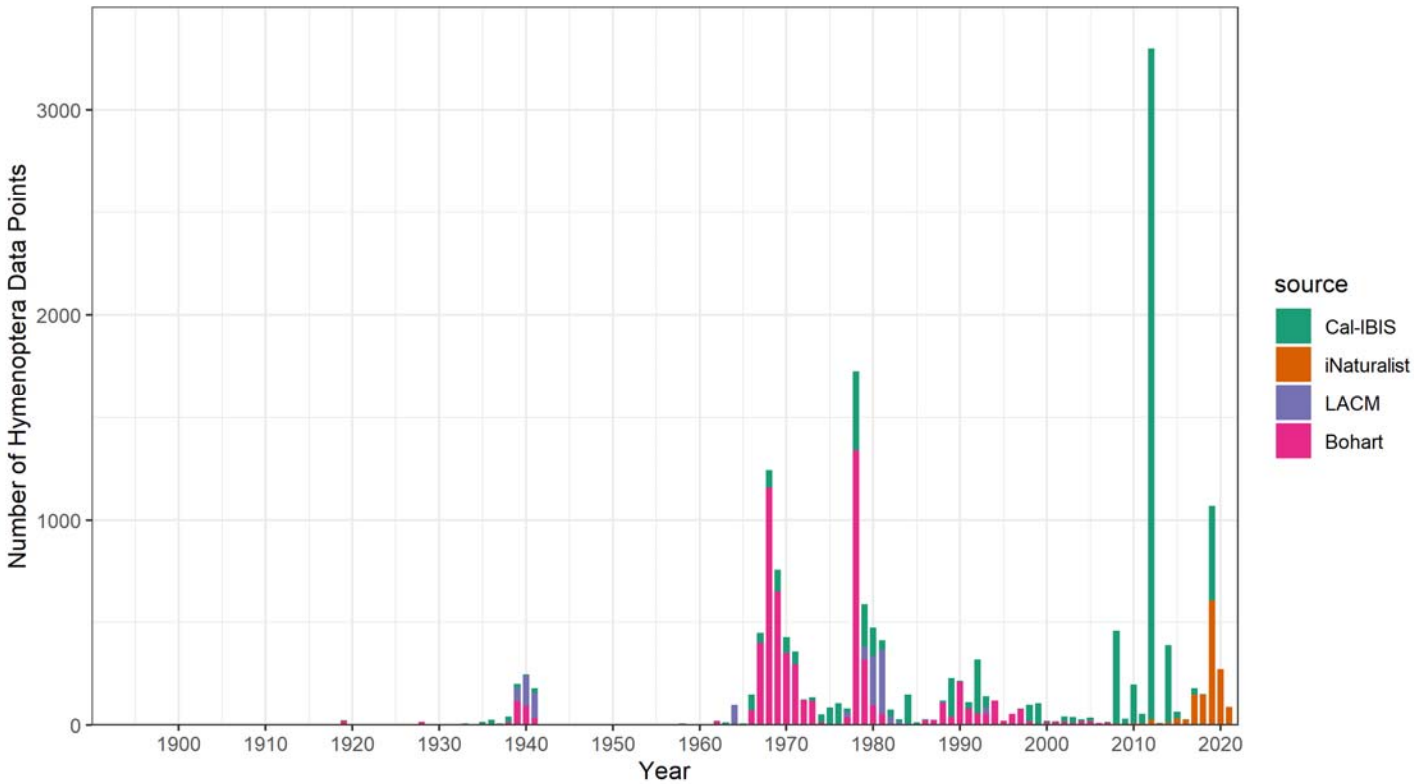


Figure Hymenoptera-2. The number of island Hymenoptera data points by year and data source reveals temporal gaps in the data. Cal-IBIS represents publicly available specimen data, LACM represents private Los Angeles County Museum data, Bohart represents UC Davis bee specimen data, and iNaturalist represents observation data.

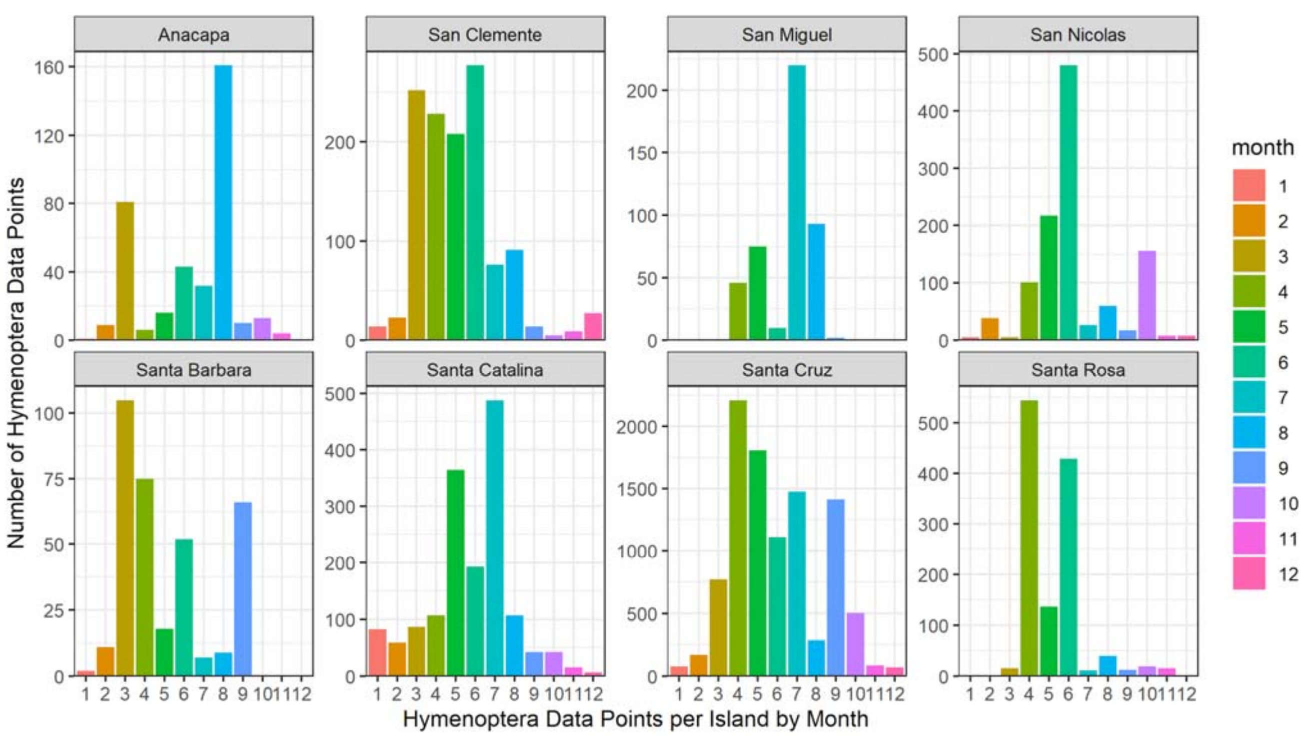


Figure Hymenoptera-3. The number of Hymenoptera data points by month, by island reveals seasonal gaps in the occurrence data.

a)

b)

c)

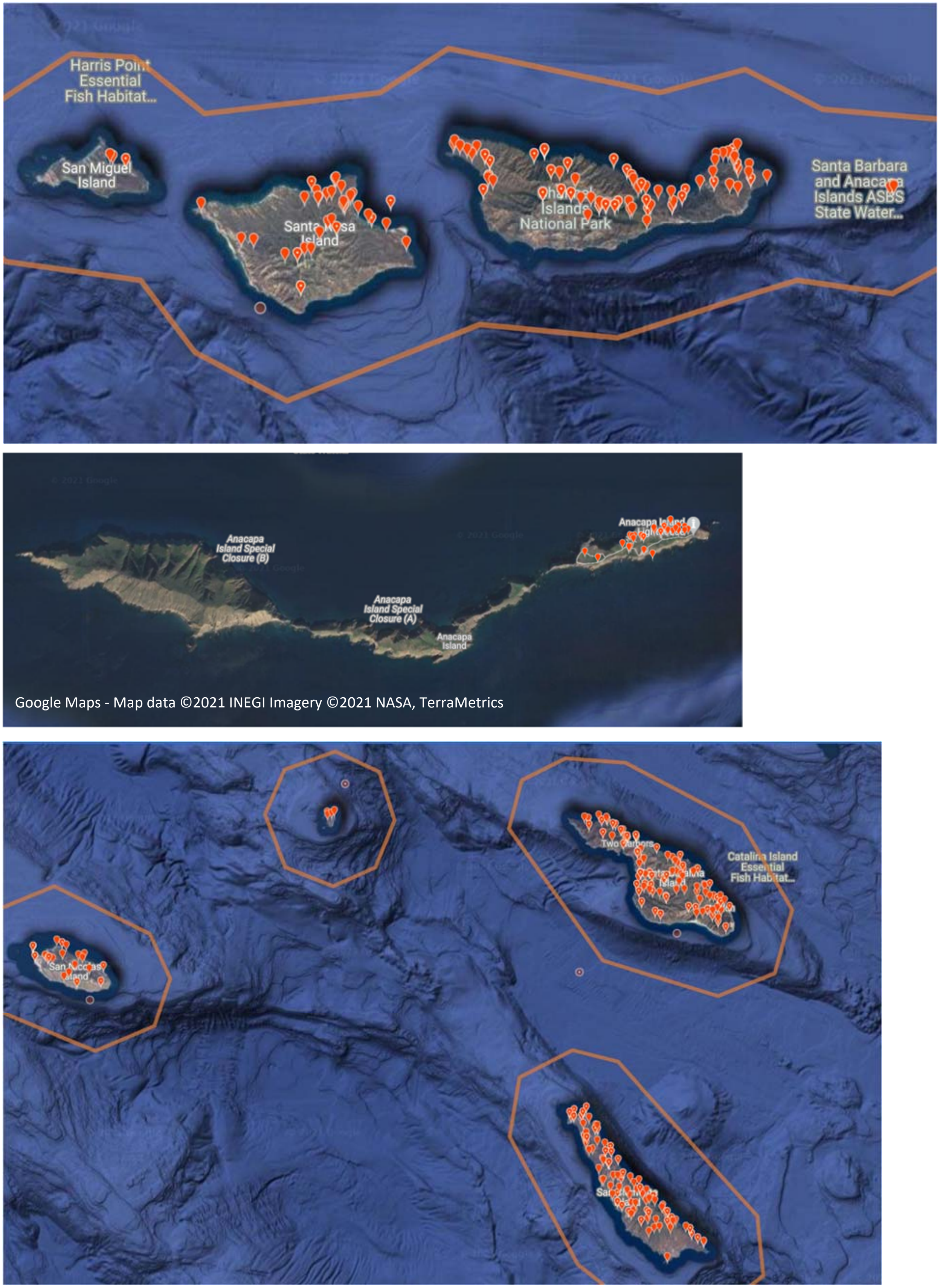
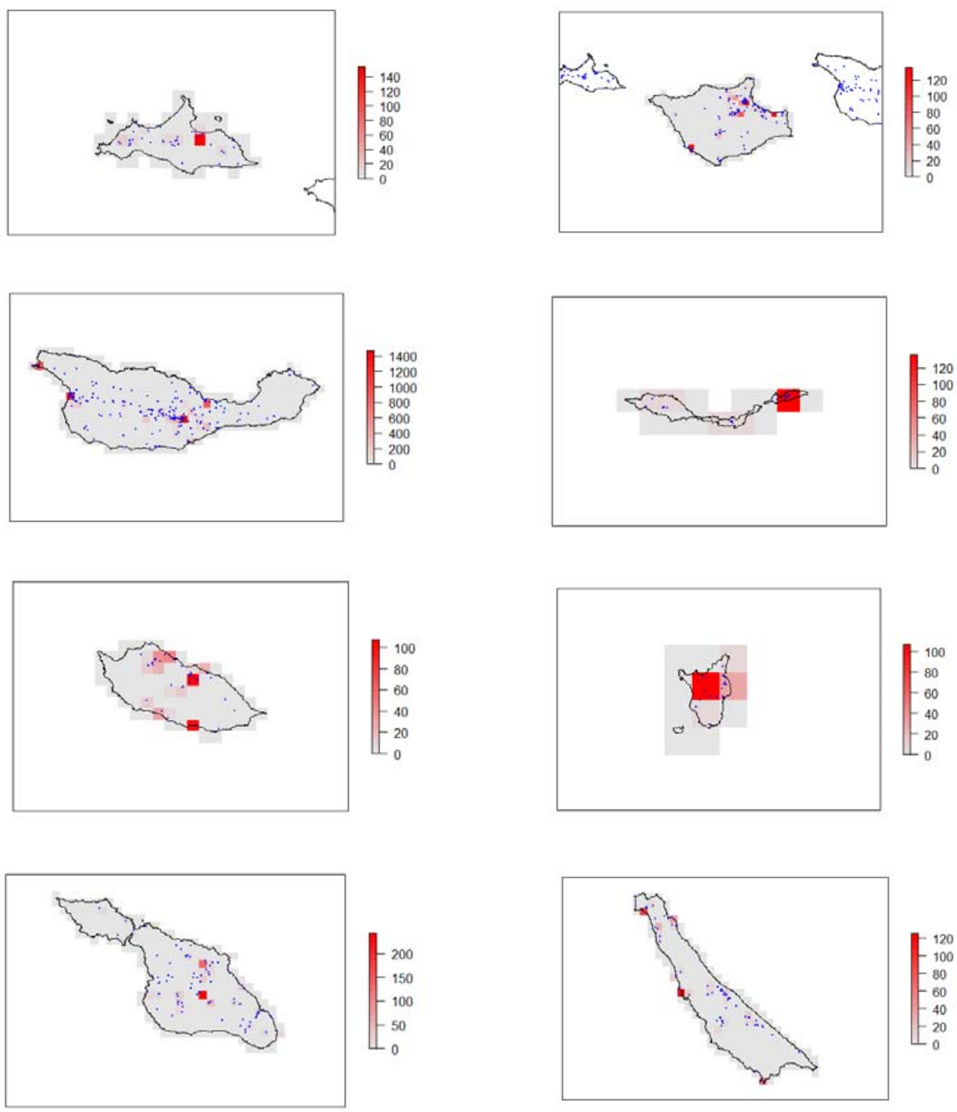


Figure Hymenoptera-4. Distribution of iNaturalist Observations on (a) the Northern Islands, (b) Anacapa, and (c) the Southern Islands

Table-Hymenoptera 3 & Figure-Hymenoptera 5. Spatial collecting effort based on 1 km grid cells overlaid onto each of the eight California Channel Islands. Of 13,480 (out of 15,164) specimens with coordinates (89%), 10,492 were used for these maps after records using island centroids were removed.

Island	Island Collections	1 km^2 cells	Empty 1 km^2 cells	% empty cells	Mean records/cell
Anacapa	167	14	8	57.1%	27.8
Santa Cruz	7414	313	218	69.6%	78.0
Santa Rosa	861	263	212	80.6%	16.9
San Miguel	249	61	39	63.9%	11.3
Santa Catalina	719	250	198	79.2%	13.8
San Clemente	504	198	157	79.3%	12.3
San Nicolas	432	81	61	75.3%	21.6
Santa Barbara	144	11	7	63.6%	36.0



Lepidoptera

Table Lepidoptera-1 shows that microlepidoptera families are under-represented. Collected specimens (Cal-IBIS, LACM and BOLD) make up 78% of the Lepidoptera data points and observations (iNaturalist) make up 22%.

Table Lepidoptera-2 shows that the taxonomic resolution for Lepidoptera data points is relatively high: 98% are identified to family, 91% are identified to genus and 85% are identified to species. More than half (54%) of the research grade iNaturalist observations are identified to species.

Table Lepidoptera-3 shows that there is a gap between known Lepidoptera taxa found on the Channel Islands from the literature and taxa represented in digitized collections and naturalist observations, but it's relatively small. There are 3 families, 31 genera, and 58 species known to occur on the Channel Islands based on the literature that were not represented in the occurrence data. Only 10% of the known species are not represented by digitized specimens. **Appendix C Table 8** has a complete list of taxa found in the occurrence data and literature.

Figures Lepidoptera-1a and 1b show the absolute number and proportional number/island size of Lepidoptera occurrences on each island. Santa Cruz and Santa Catalina have been by far the best sampled, whereas San Miguel Island has been the most poorly sampled (there are 183 occurrences on San Miguel Island and 3,715 on Santa Cruz Island). Lepidoptera have been collected (Cal-IBIS and LACM) and observed (iNaturalist) on all of the Channel Islands. The graph that has been normalized by island size show that Anacapa and Santa Barbara Islands have been relatively more sampled for their size.

Figure Lepidoptera-2 shows the number of specimens by year over time. The first collection recorded was an Avalon Hairstreak (*Strymon avalona*) collected by V.L. Clemence on Santa Catalina in 1906. Two general peaks in Lepidoptera specimen data are evident: 1) the 1940's CA Island Biological Survey and 2) the late 1960s to early 1980s, from such collectors as C.L. Remington, G.A. Gorelick, C.D. Nagano, S. Bennett, R. Holland, and S.E. Miller. The majority of digitized specimens are housed at LACM, while a significant collection from C.L., E.E., and S.T. Remington is housed at the Yale Peabody Museum (YPM). The majority of the data points in the past 10 years are iNaturalist observations.

Figure Lepidoptera-3 shows the data by month and island. There are peaks in collections in certain months on each of the islands which probably represent specific collection events.

Figure Lepidoptera-4 shows the spatial distribution of iNaturalist data on the islands. It shows relatively good coverage, except for a large part of Santa Rosa Island, which is relatively inaccessible.

Table Lepidoptera-1. Number of island butterfly and moth occurrences recorded in each data source by family. Showing the relative number of observations (iNaturalist) and specimens (Cal-IBIS and LACM).

Family	Cal-IBIS	LACM	iNaturalist	n	%
Hesperiidae	104	133	126	363	3.98%
Lycaenidae	246	695	291	1232	13.50%
Nymphalidae	203	70	236	509	5.58%
Papilionidae	5	12	56	73	0.80%
Pieridae	143	28	58	229	2.51%
Butterflies	**701**	**938**	**767**	**2406**	**26.36%**
Adelidae	0	214	4	218	2.39%
Alucitidae	0	1	1	2	0.02%
Autostichidae	0	0	3	3	0.03%
Bedelliidae	0	8	0	8	0.09%
Blastobasidae	1	6	4	11	0.12%
Bucculatricidae	0	0	2	2	0.02%
Carposinidae	0	3	2	5	0.05%
Choreutidae	0	0	1	1	0.01%
Coleophoridae	0	18	4	22	0.24%
Cosmopterigidae	0	2	3	5	0.05%
Cossidae	0	9	2	11	0.12%
Crambidae	1	772	73	846	9.27%
Depressariidae	0	60	8	68	0.75%
Elachistidae	0	1	1	2	0.02%
Erebidae	497	571	241	1309	14.34%
Euteliidae	1	0	1	2	0.02%
Gelechiidae	0	465	35	500	5.48%
Geometridae	880	0	200	1080	11.83%
Gracillariidae	0	6	31	37	0.41%
Heliodinidae	0	0	1	1	0.01%
Lasiocampidae	14	0	0	14	0.15%
Momphidae	0	0	1	1	0.01%
Nepticulidae	0	0	15	15	0.16%
Noctuidae	744	0	169	913	10.00%
Nolidae	3	0	2	5	0.05%
Notodontidae	68	33	2	103	1.13%
Oecophoridae	0	5	4	9	0.10%
Plutellidae	0	126	2	128	1.40%
Prodoxidae	0	0	1	1	0.01%
Pterophoridae	31	1	22	54	0.59%
Pyralidae	10	215	50	275	3.01%
Saturniidae	17	1	1	19	0.21%
Schreckensteiniidae	0	1	0	1	0.01%
Scythrididae	0	2	3	5	0.05%
Sesiidae	2	15	6	23	0.25%
Sphingidae	56	108	75	239	2.62%
Tineidae	0	193	15	208	2.28%
Tischeriidae	0	0	3	3	0.03%
Tortricidae	0	339	51	390	4.27%

Ypsolophidae	0	0	1	1	0.01%
Moths	**2325**	**3175**	**1041**	**6541**	**71.67%**
Family	**Cal-IBIS**	**LACM**	**iNaturalist**	**n**	**%**
undetermined family	7	12	162	181	1.98%
all Lepidoptera	3033	4125	1969	9127	
family diversity	19	31	42	45	

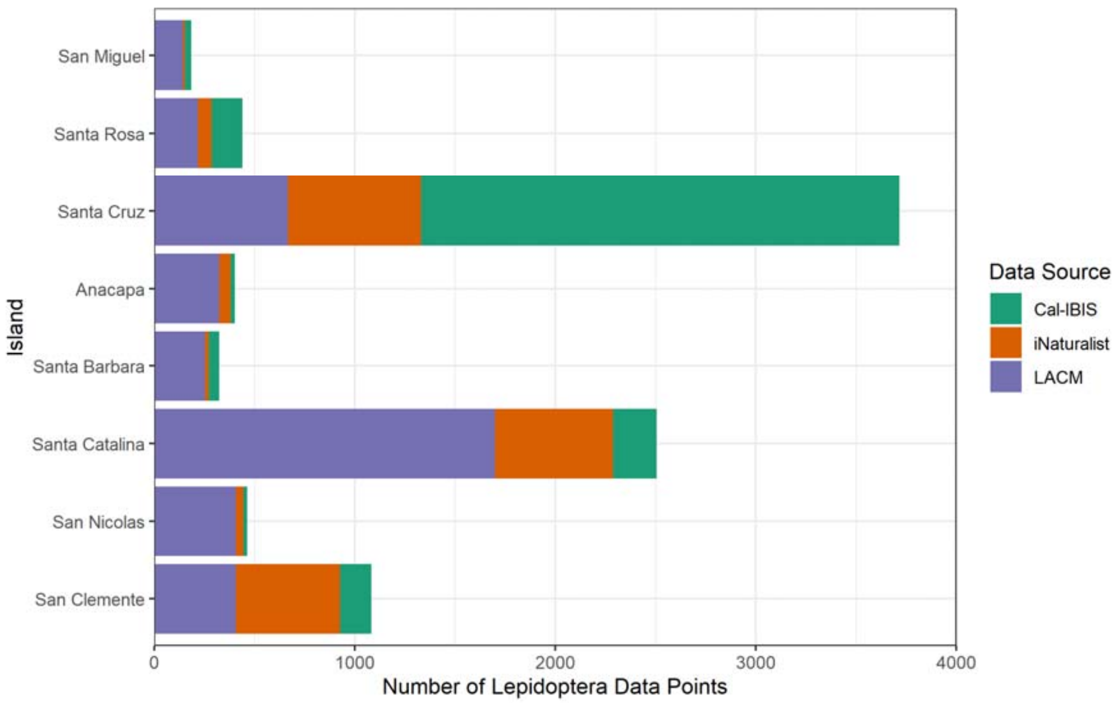
Table Lepidoptera-2. Taxonomic resolution of island butterfly and moth records by source. Note that only 1066 of the iNaturalist records are Research Grade.

Rank	Cal-IBIS	LACM	iNaturalist (All)	iNaturalist (RG)	Totals
Order	3033	4125	1969		9127
Family	3026 (99.77%)	4113 (99.71%)	1807 (91.77%)	1066 (54.14%)	8946 (98.02%)
Genus	2937 (96.83%)	3898 (94.50%)	1496 (75.98%)	1064 (54.04%)	8331 (91.28%)
Species	2859 (94.26%)	3578 (86.74%)	1291 (65.57%)	1061 (53.89%)	7728 (84.67%)

Table Lepidoptera-3. Island butterfly and moth taxa added by a literature search as compared to those represented in digitized specimen and observation data, revealing the digitization gap.

	# of Families	# of Genera	# of Species
Occurrence Data	45	322	500
Taxa added by Literature	3	31	58
Total Lepidoptera	48	353	558

(a)



(b)

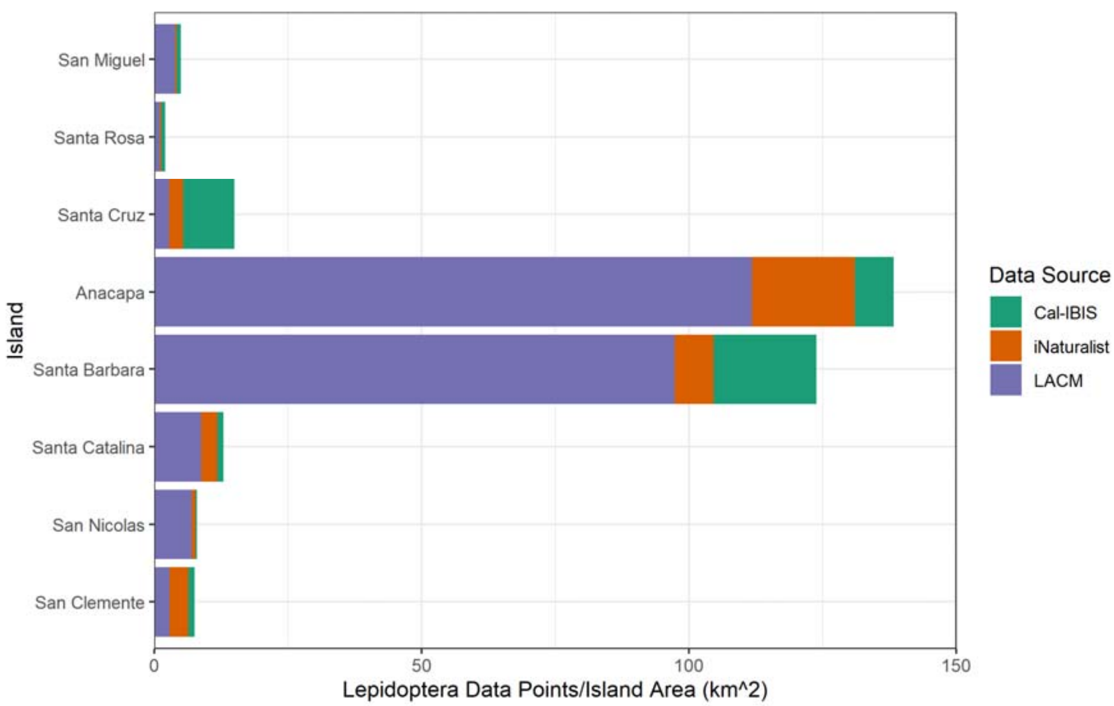


Figure Lepidoptera-1. The (a) absolute number and (b) proportional number/island size of butterfly and moth occurrences on each island by data source reveal spatial gaps in the data.

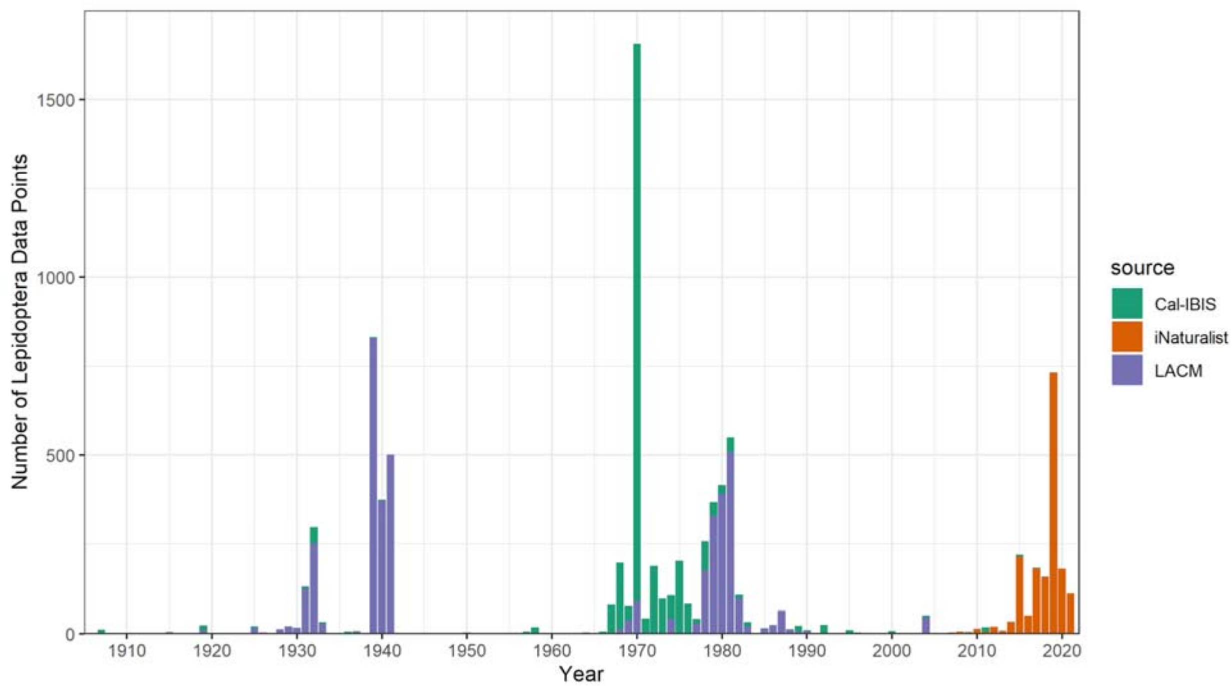


Figure Lepidoptera-2. The number of island butterfly and moth occurrences by year and data source reveals temporal gaps in the data. Cal-IBIS represents publicly available specimen data, LACM represents private Los Angeles County Museum data, and iNaturalist represents observation data.

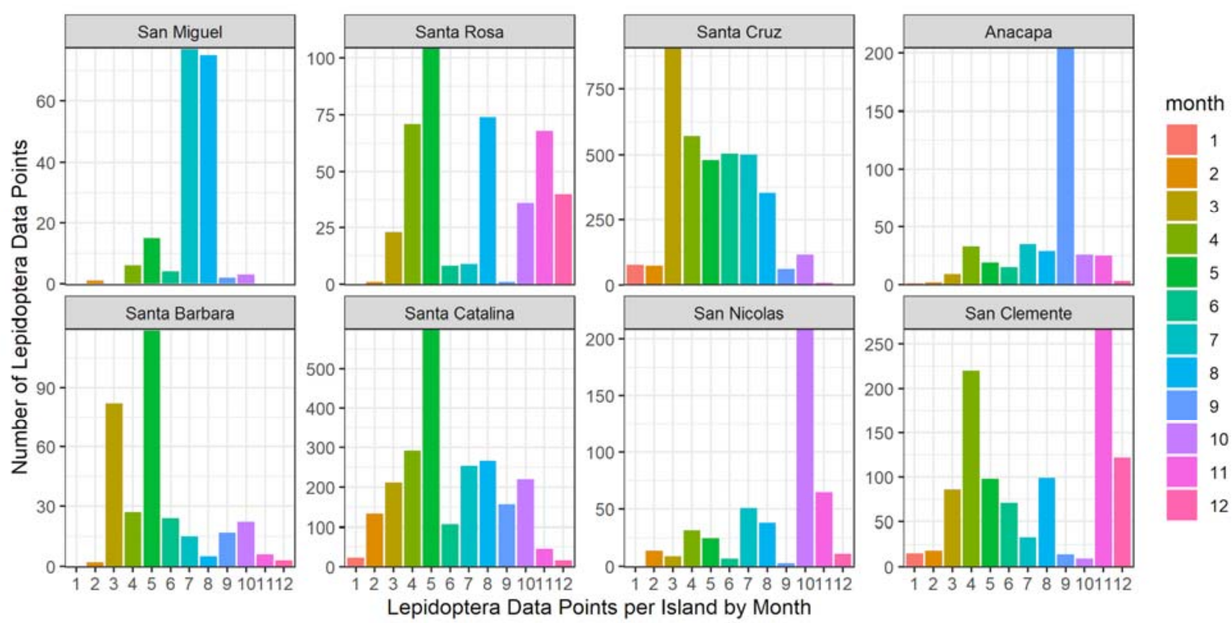


Figure Lepidoptera-3. The number of butterfly and moth occurrences by month, by island, reveals seasonal gaps in the data.

(a)

(b)

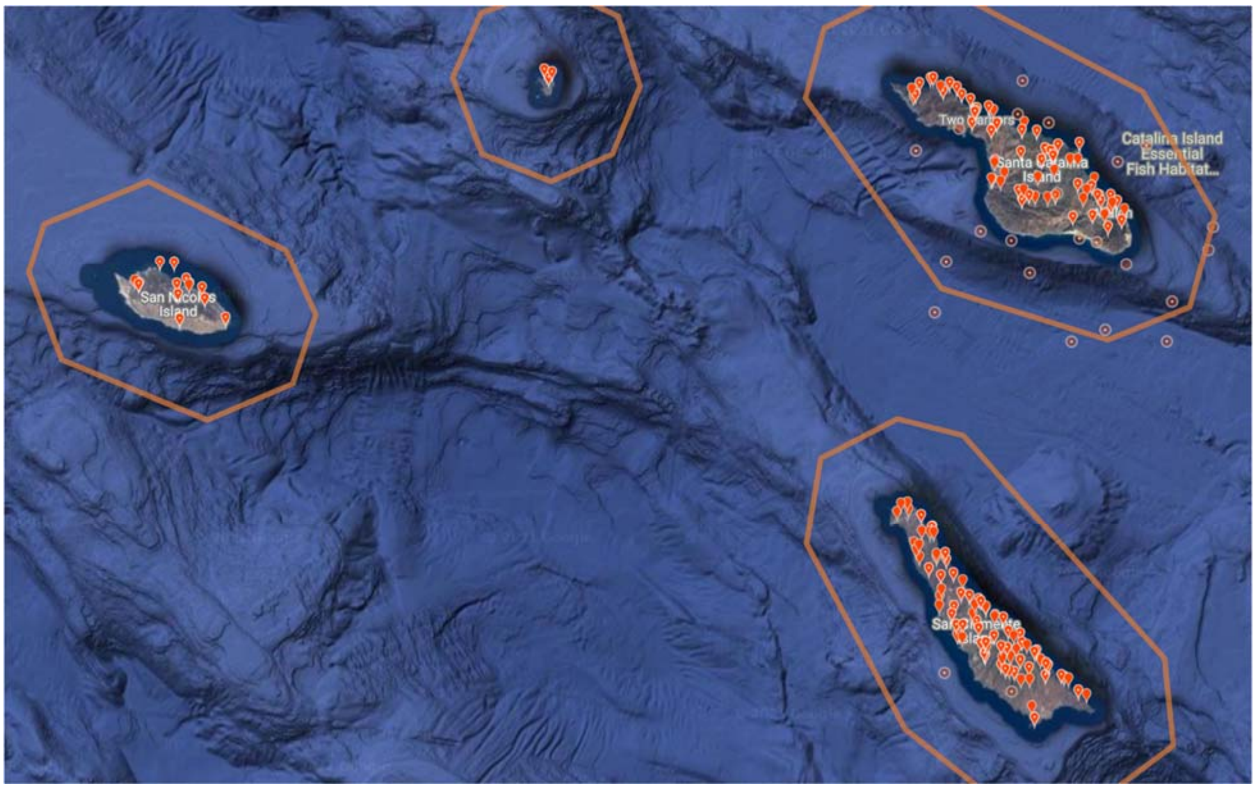


Figure Lepidoptera-4. Distribution of iNaturalist butterfly and moth observations on (a) the Northern Islands and (b) the Southern Islands.

Mollusca

Table Mollusca-1 shows the families represented in the Mollusca occurrence records. Collected specimens (Cal-IBIS) make up 39% of the Mollusca data points and observations (iNaturalist) make up 61%. In total, 28 families are represented, with iNaturalist capturing 18 of them. The Helicidae are strongly represented in the occurrence data; all but 2 of those records were iNaturalist observations. LACM has an iNaturalist project dedicated to documenting Mollusca in Southern California called SLIME (Snails and Slugs Living in Metropolitan Environments), and 416 of the island records were in this project.

Table Mollusca-2 shows that the taxonomic resolution for Mollusca data points is high, as 98.1% are identified to family, 94.4% are identified to genus and 77.1% are identified to species. A little less than three quarters (74%) of the research grade iNaturalist observations are identified to species.

Table Mollusca-3 shows that there is a gap between known Mollusca taxa found on the Channel Islands from the literature and taxa represented in digitized collections and naturalist observations. There are 6 families, 11 genera, and 19 species known to occur on the Channel Islands based on the literature that were not represented in the occurrence data. Thirty-two percent of the known species are not represented by a digitized specimen. **Appendix C Table 9** contains a complete list of taxa found in the occurrence data and literature.

Figures Mollusca-1a and 1b show the absolute number and proportional number/island size of Mollusca occurrences on each island. San Clemente Island has by far the most data points (nearly 750), largely due to iNaturalist observations; biologists on San Clemente are very active on this platform. Santa Catalina has nearly 300 data points, followed by Santa Barbara and San Nicolas islands, with closer to 150 each. The graph that has been normalized by island size shows that Santa Barbara Island has been relatively well sampled for its size.

Figure Mollusca-2 shows the number of specimens by year over time. The first collections recorded (at the Chicago Academy of Sciences, or CHAS) are reportedly from 1800, however this number was likely entered as a placeholder for an unknown date. There were small pulses of Mollusca collections made in the 1940s, 1960s, and the late 1980s. The 1940s collections are predominantly from the Channel Islands Biological Survey. The 1960s specimens were made by W.O. Gregg and W.B. Miller (housed at LACM) and Munroe Walton (housed at the Denver Museum of Natural History, or DMNH). The late 1980s collections were made by F.G. Hochberg, C.C. Coney, D.R. Muhs, G.L. Kennedy, T.K. Rockwell, H.G. Kuck, and E.G. Veal, and are housed at LACM. There are many collections without date and collector information, including those at Academy of Natural Sciences of Drexel University in Philadelphia (ANSP), DMNH, Museum of Comparative Zoology at Harvard (MCZ), University of Florida (UF), and University of Michigan Museum of Zoology (UMMZ). All of those collections include specimens from Henry Hemphill, who published in 1905 (Hochberg et al. 1987). The vast majority of the data points, all collected in the past 10 years, are iNaturalist observations, with a huge peak in observations in 2020. These observations are led by a handful of iNaturalist enthusiasts on San Clemente Island, and has been a friendly competition between "shrike2" (Nicole Desnoyers), "serpophaga" (Adam Searcy), "pileated" (Casey Richart), and "cedric_lee" (Cedric Lee).

Figure Mollusca-3 shows the data by month and island. There are too few observations made on most islands to identify any seasonal patterns except for perhaps on San Clemente Island, which has over 700 observations. Most of the data points on San Clemente were recorded during the winter and spring, which makes sense given the behavior of mollusks.

Figure Mollusca-4 shows the spatial distribution of Mollusca points on iNaturalist. Many of these point locations have been obscured because they are of rare taxa. The southern islands have been much better covered on this platform than the northern islands, likely due to a combination of accessibility (Santa Catalina) and biologists active on this platform (San Clemente).

Table Mollusca-1. The number of occurrences for each island terrestrial mollusk family by data sou rce shows the relative proportion of specimens (Cal-IBIS) and observations (iNaturalist).

Family	Cal-IBIS	iNaturalist	n	%
Achatinidae	0	20	20	1.31%
Agriolimacidae	0	7	7	0.46%
Ampullariidae	0	1	1	0.07%
Ariolimacidae	0	17	17	1.11%
Assimineidae	3	0	3	0.20%
Binneyidae	8	2	10	0.65%
Camaenidae	1	0	1	0.07%
Ellobiidae	5	0	5	0.33%
Gastrodontidae	5	7	12	0.79%
Haplotrematidae	13	5	18	1.18%
Helicidae	2	144	146	9.55%
Helicinidae	1	1	2	0.13%
Limacidae	0	37	37	2.42%
Liotiidae	10	0	10	0.65%
Megomphicidae	1	0	1	0.07%
Milacidae	0	4	4	0.26%
Oreohelicidae	0	2	2	0.13%
Oxychilidae	0	6	6	0.39%
Physidae	5	10	15	0.98%
Planorbidae	0	1	1	0.07%
Pristilomatidae	4	0	4	0.26%
Raphitomidae	2	0	2	0.13%
Rissoinidae	13	0	13	0.85%
Succineidae	2	76	78	5.10%
Trinchesiidae	1	0	1	0.07%
Valloniidae	4	0	4	0.26%
Vertiginidae	118	37	155	10.14%
Xanthonychidae	395	529	924	60.47%
undetermined family	0	7	7	0.46%
all Mollusks	593	913	1528	
family diversity	19	18	28	

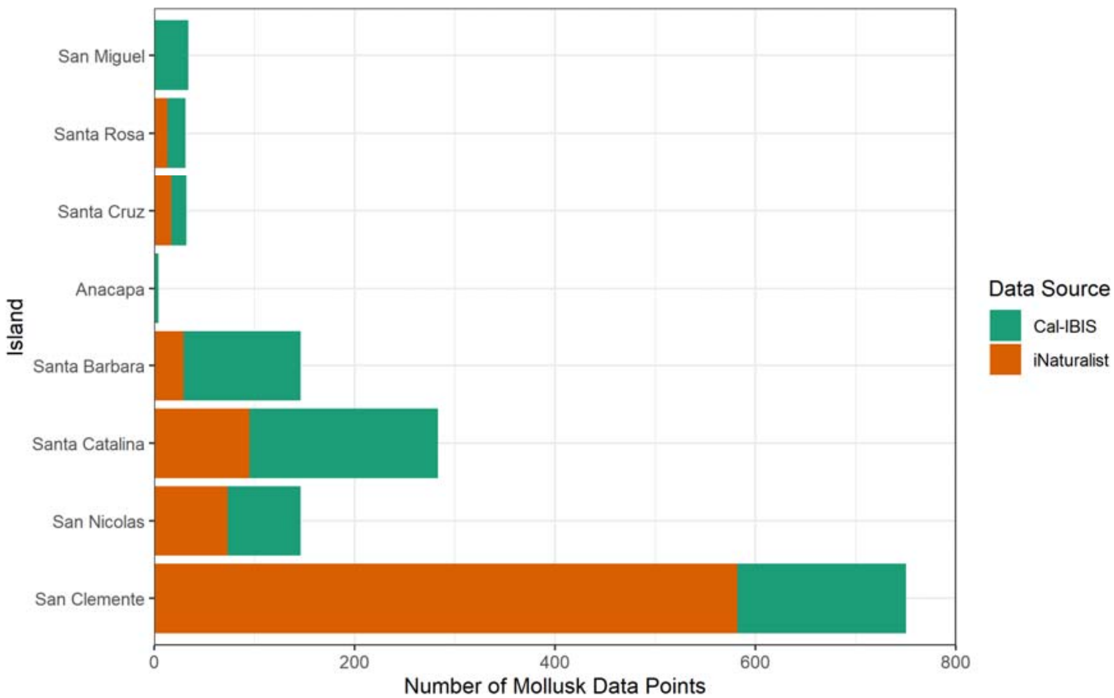
Table Mollusca-2. Taxonomic resolution of island terrestrial mollusk occurrence records by source. Note that only 747 of the iNaturalist records are Research Grade.

Rank	**Cal-IBIS**	**iNaturalist**	**iNaturalist(RG)**	**totals**
Order	593	913		1528
Family	593 (100%)	906 (99.23%)	680 (74.48%)	1499 (98.10%)
Genus	588 (99.16%)	855 (93.65%)	680 (74.48%)	1443 (94.44%)
Species	426 (71.84%)	752 (82.37%)	677 (74.15%)	1178 (77.09%)

Table Mollusca-3. Island terrestrial mollusk taxa added by a literature search as compared to those represented in digitized specimen and observation data, revealing the digitization gap.

	# of Families	# of Genera	# of Species
Occurrence Data	28	39	41
Taxa added by Literature	6	11	19
Total Mollusca	34	50	60

(a)



(b)

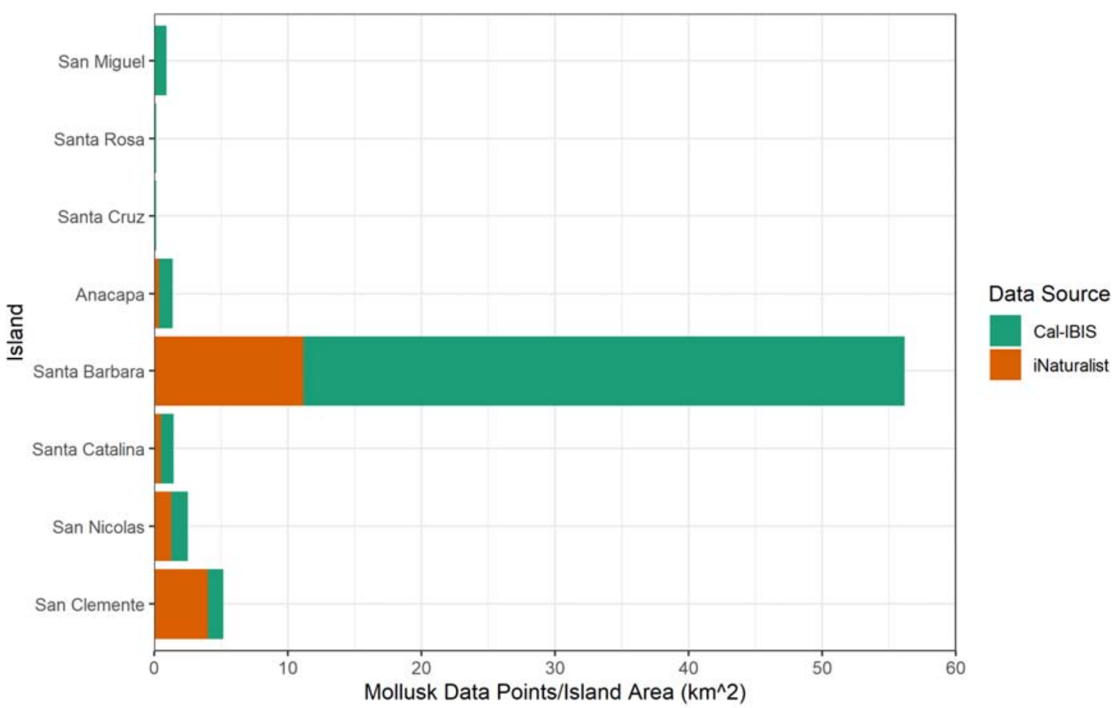


Figure Mollusca-1. The (a) absolute number and (b) proportional number/island size of terrestrial mollusk occurrences on each island by data source reveals spatial gaps in the data.

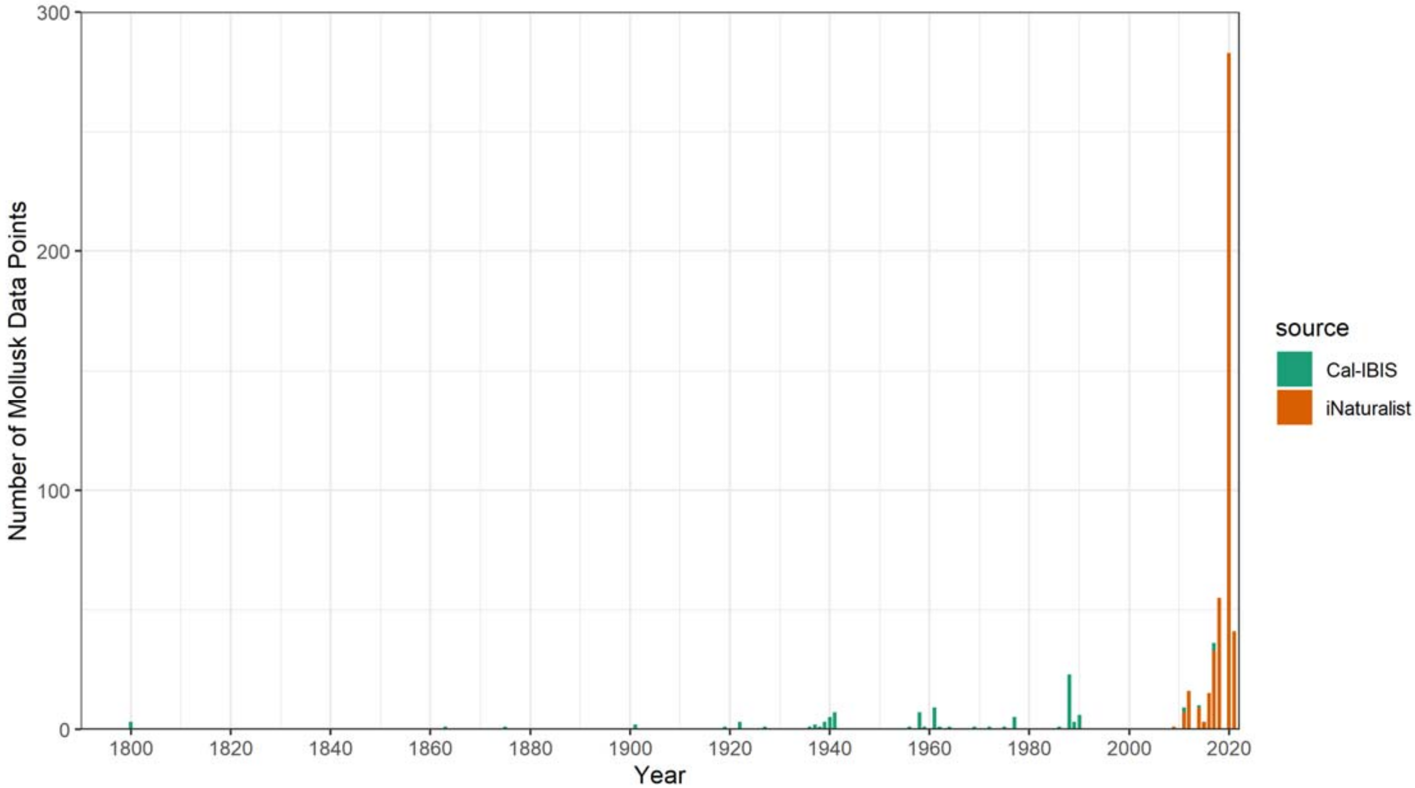


Figure Mollusca-2. The number of island terrestrial mollusk occurrences by year and data source reveals temporal gaps in the data. Cal-IBIS represents publicly available specimen data and iNaturalist represents observation data.

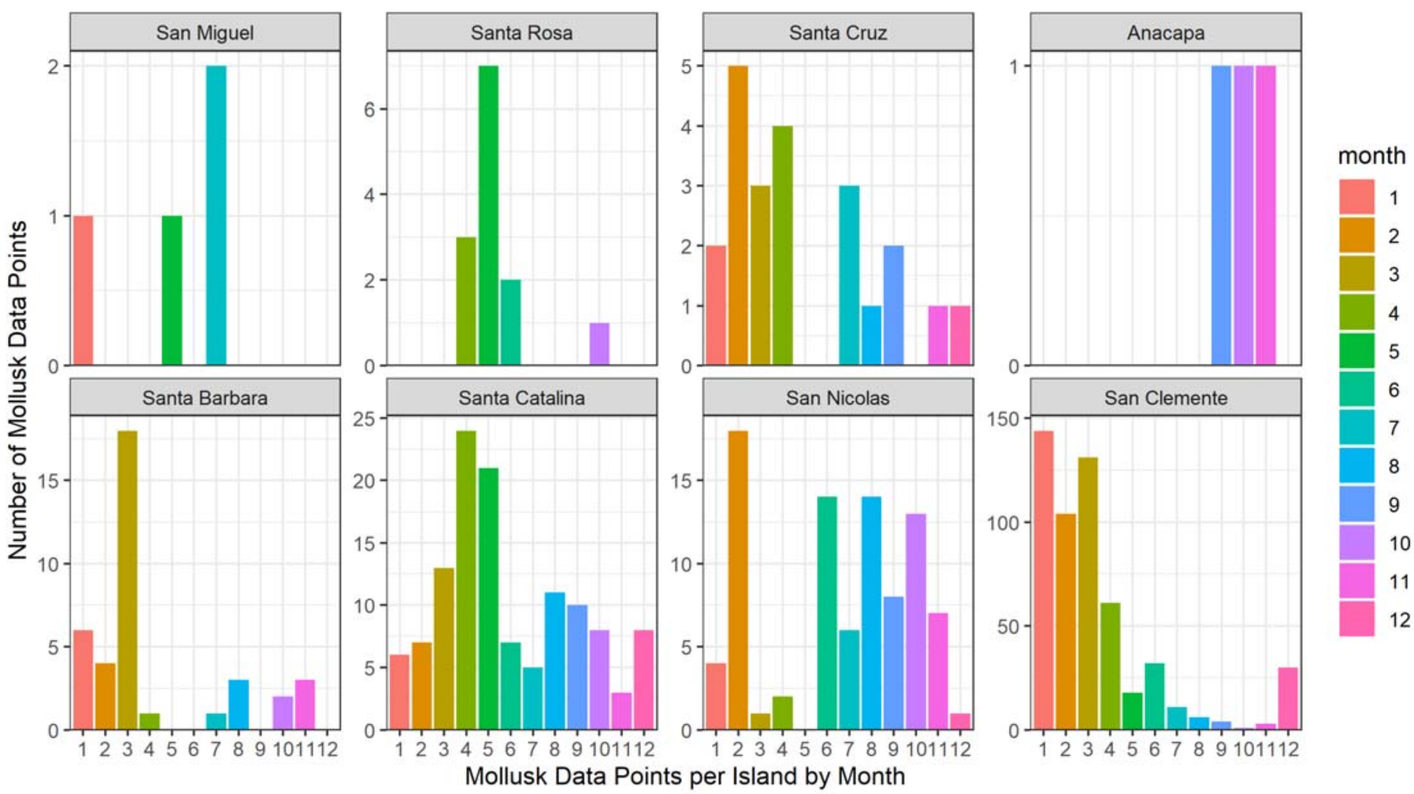


Figure Mollusca-3. The number of terrestrial mollusk occurrences by month, by island, reveals seasonal gaps in the data.

(a) 

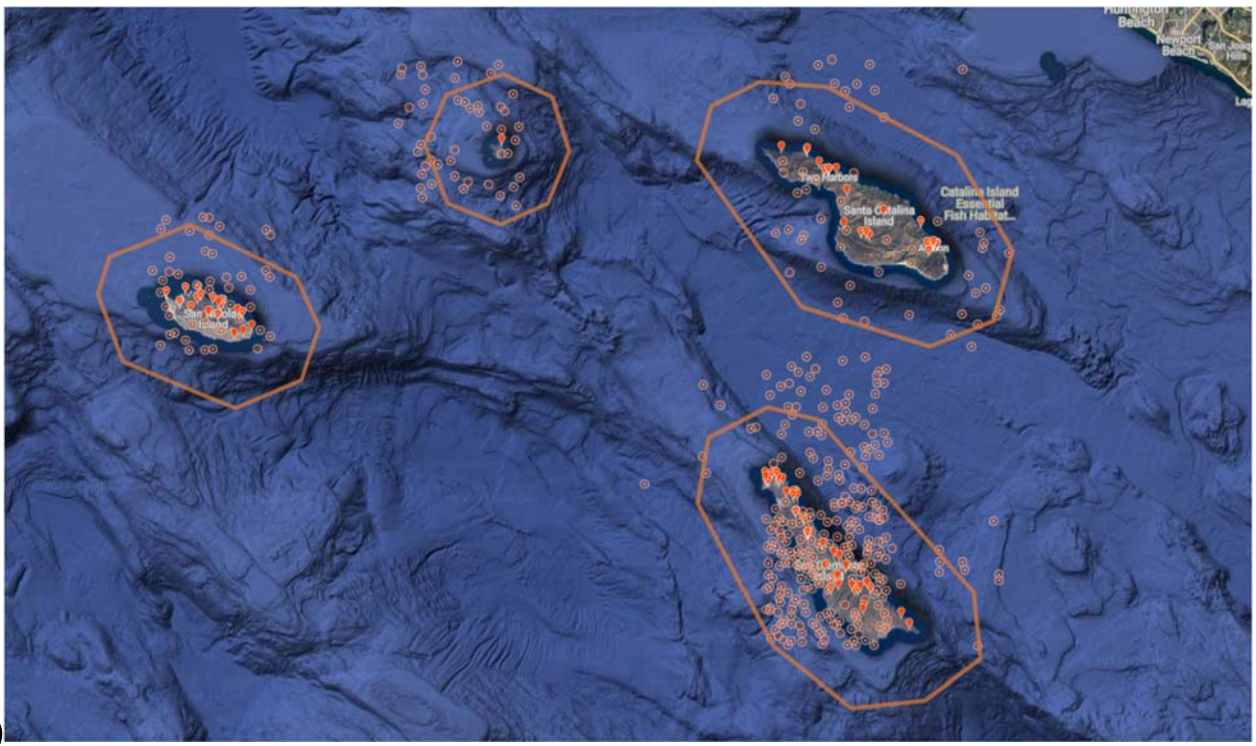
(b) 

Figure Mollusca-4. Distribution of iNaturalist terrestrial mollusk observations on (a) the Northern Islands and (b) the Southern Islands. Note: the bullseye style point locations have been obscured because they are of rare taxa.

Odonata

Tables Odonata-1 & Odonata-3 show the four Odonata families represented in the occurrence records. Collected specimens (Cal-IBIS) make up 30% of the Odonata data points, and iNaturalist observations make up 70%. This makes sense given the popularity of dragonflies and damselflies. Twenty species were identified in the data points. *Argia vivida*, which is a common, bright blue damselfly, was documented the most (43/211 records).

Table Odonata-2 shows that the taxonomic resolution for Odonata data points is relatively high: 92% are identified to family, 89% are identified to genus and 81% are identified to species. More than half (61%) of the iNaturalist observations are identified to species and research grade.

Table Odonata-4 shows that there is a small gap between known Odonata taxa found on the Channel Islands from the literature and taxa represented in digitized collections and naturalist observations. Only one family is known to occur on the Channel Islands based on the literature that is not represented in the occurrence data (out of five total known families). **Appendix B Table 10** has a complete list of taxa found in the occurrence data and literature.

Figures Odonata-1a and 1b show the absolute number and proportional number/island size of Odonata occurrences on each island. iNaturalist observations are the majority of the data points on all of the islands except for Santa Cruz, which has a relatively high number of both specimens and observations. San Clemente Island again has a relatively high number of iNaturalist observations. The graph that has been normalized by island size show that Anacapa Island has been relatively better sampled for its size. It makes sense that the drier islands would have fewer Odonata observations, since their larvae are aquatic.

Figure Odonata-2 shows the number of specimens by year over time. The first collections recorded are from 1915 (by C.H. Kennedy and housed at UMMZ). There were small Odonata collections made in the 1930s (by M. Willows and T.D.A. Cockerell and housed at CAS) and late 1960s to late 1970s (by D. Weissman, housed at CAS, and A. Menke, D. Miller, and R. Rust, housed at the U.S. National Museum [USNM]). There was also a spike of collections in 2012, made by Joan Ball (housed at EMEC). The majority of the data points have been made in the past 10 years, and are iNaturalist observations. **Figure Odonta-3** shows the data by month and island. There are too few data points on the islands to identify any seasonal patterns. **Figure Odonata-4** shows the spatial distribution of iNaturalist observations on the islands, which are generally sparsely scattered.

Table Odonata-1. The number of island dragonfly and damselfly occurrences recorded in each data source by family shows the relative number of observations (iNaturalist) and specimens (Cal-IBIS).

	Family	Cal-IBIS	iNaturalist	n
Infraorder Anisoptera (Dragonflies)	Aeshnidae	13	30	43
	Libellulidae	29	62	91
Suborder Zygoptera (Damselflies)	Coenagrionidae	36	71	107
	Lestidae	1	0	1
	undetermined family	0	20	20
	all Odonata	79	183	262
	family diversity	4	3	4

Table Odonata-2. Taxonomic resolution of island dragonfly and damselfly records by source. Note that only 112 of the iNaturalist records are Research Grade.

Rank	Cal-IBIS	iNaturalist (All)	iNaturalist (Research Grade)	totals
Order	79	183		262
Family	79 (100%)	163 (89.07%)	112 (61.20%)	242 (92.37%)
Genus	79 (100%)	154 (84.15%)	112 (61.20%)	233 (88.93%)
Species	78 (98.73%)	133 (72.68%)	112 (61.20%)	211 (80.53%)

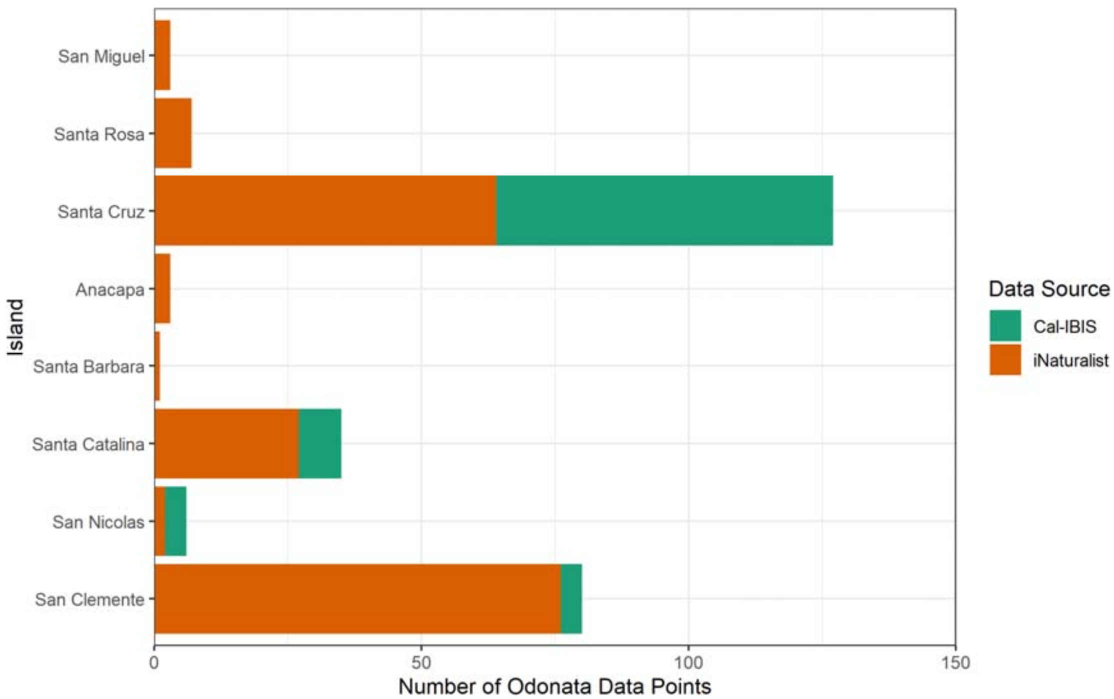
Table Odonata-3. List of island dragonfly and damselfly species in the occurrence data.

	Family	Species	# of Occurrences
Infraorder Anisoptera (Dragonflies)	Aeshnidae	*Aeshna walkeri*	8
		Anax junius	10
		Anax walsinghami	2
	Libelluidae	*Libellula saturata*	15
		Paltothemis lineatipes	15
		Pantala flavescens	6
		Pantala hymenaea	3
		Rhionaeschna multicolor	17
		Sympetrum corruptum	38
		Sympetrum illotum	12
		Tramea lacerata	2
Suborder Zygoptera (Damselflies)	Coenagrionidae	*Argia agrioides*	6
		Argia vivida	43
		Enallagma annexum	7
		Enallagma carunculatum	3
		Enallagma civile	19
		Ischnura cervula	1
		Ischnura denticollis	2
		Ischnura ramburii	1
	Lestidae	*Archilestes californica*	1

Table Odonata-4. Island dragonfly and damselfly taxa added by a literature search as compared to those represented in digitized specimen and observation data. (only one family added, Calopterygidae)

	# of Families	# of Genera	# of Species
Occurrence Data	4	13	20
Taxa added by Literature	1	0	0
Total Hemiptera	5	13	20

(a)



(b)

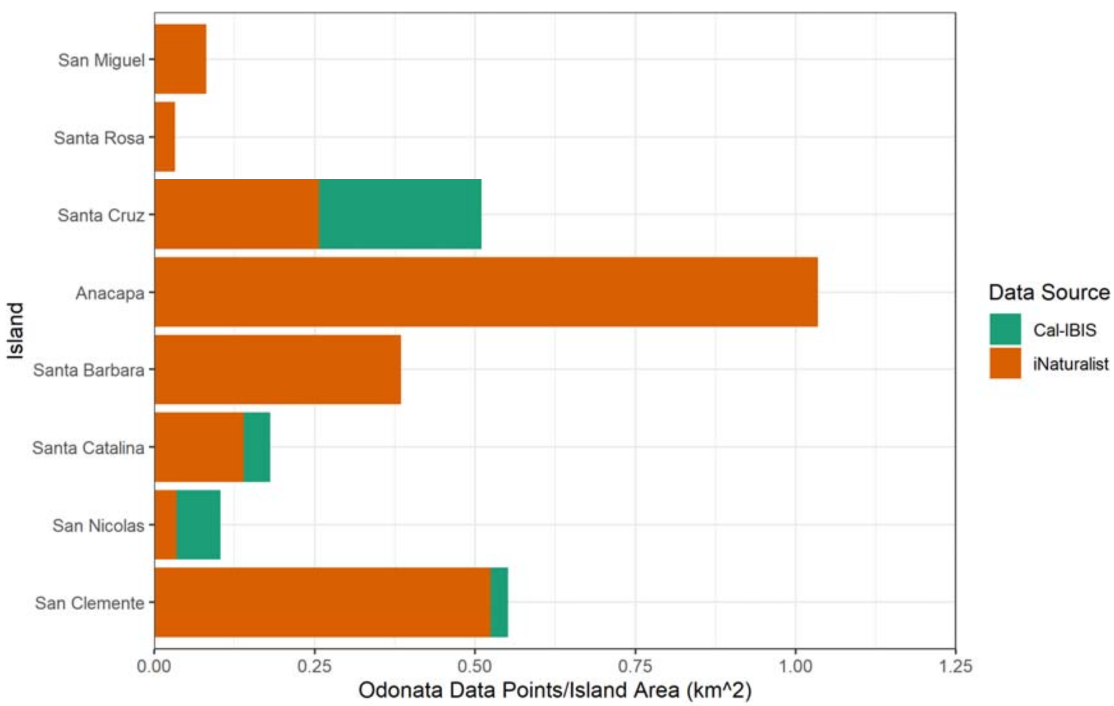


Figure Odonata-1. The (a) absolute number and (b) proportional number/island size of dragonfly and damselfly occurrences on each island by data source reveal spatial gaps in the data.

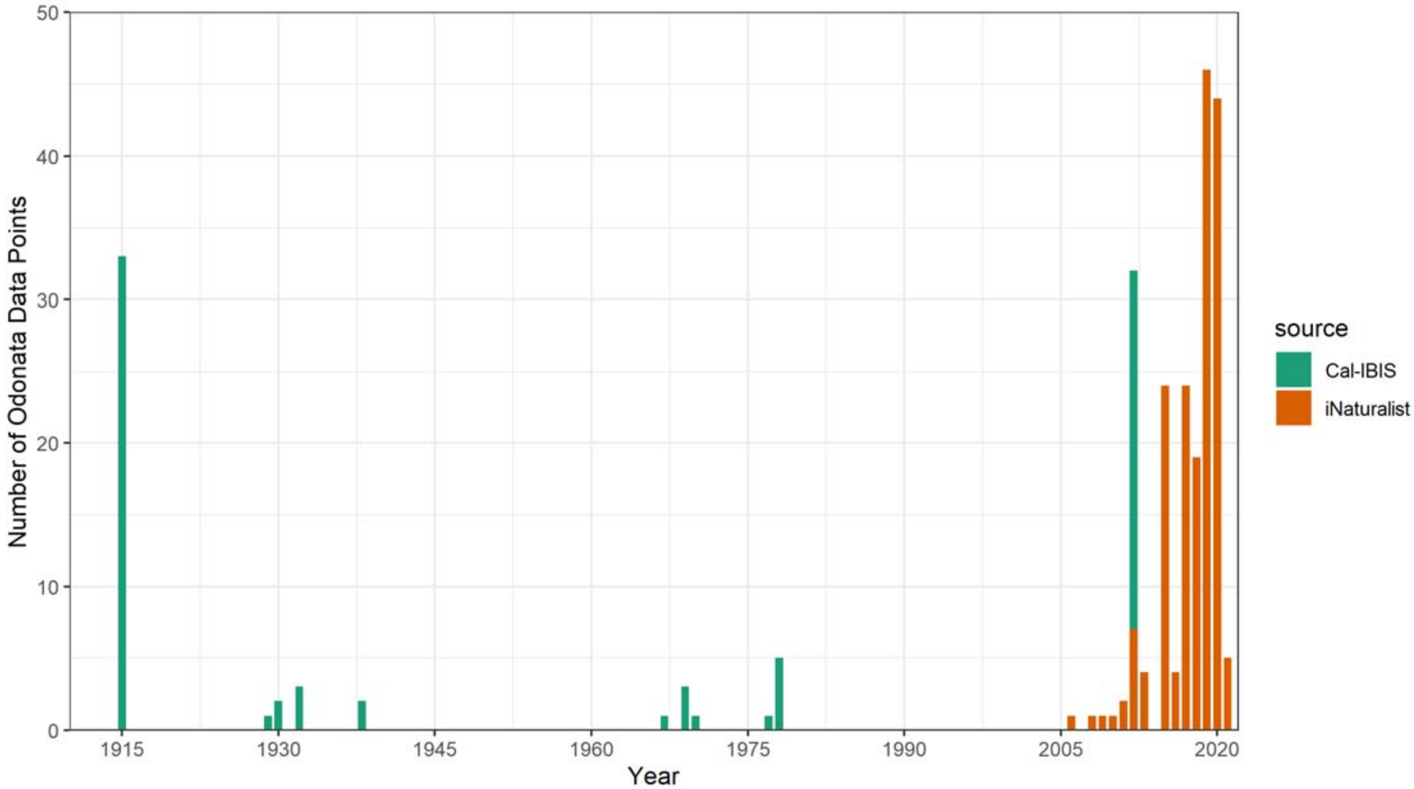


Figure Odonata-2. The number of island dragonfly and damselfly occurrences by year and data source reveals temporal gaps in the data. Cal-IBIS represents publicly available specimen data and iNaturalist represents observation data.

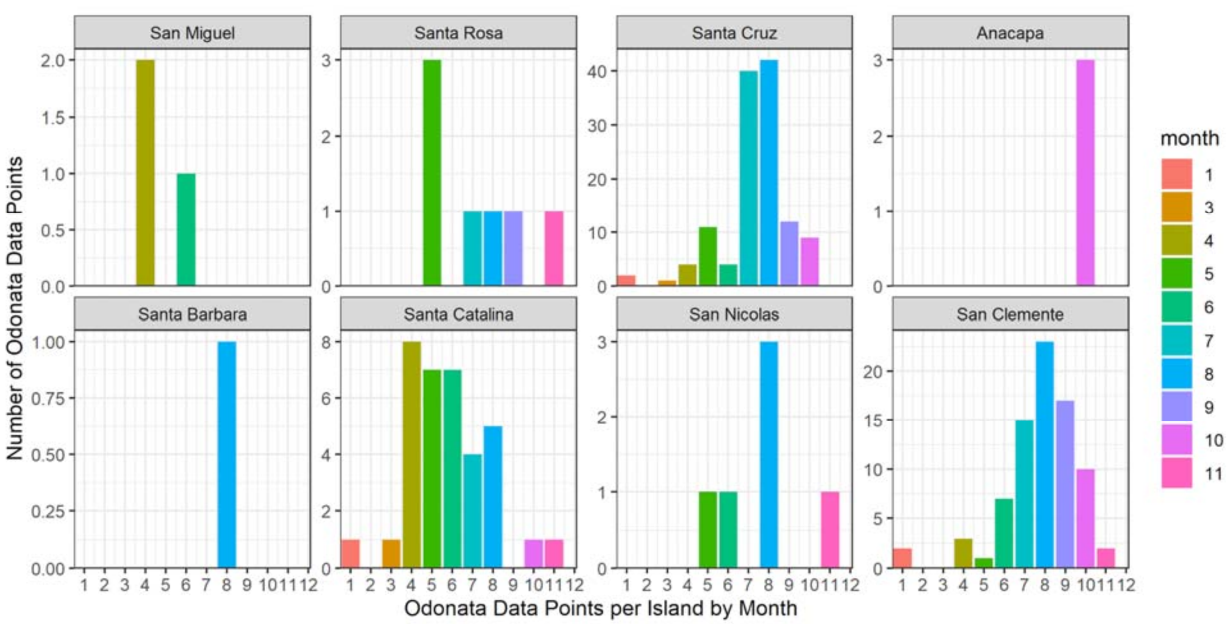


Figure Odonata-3. The number of dragonfly and damselfly occurrences by month, by island, reveals seasonal gaps in the data.

(a)

(b)

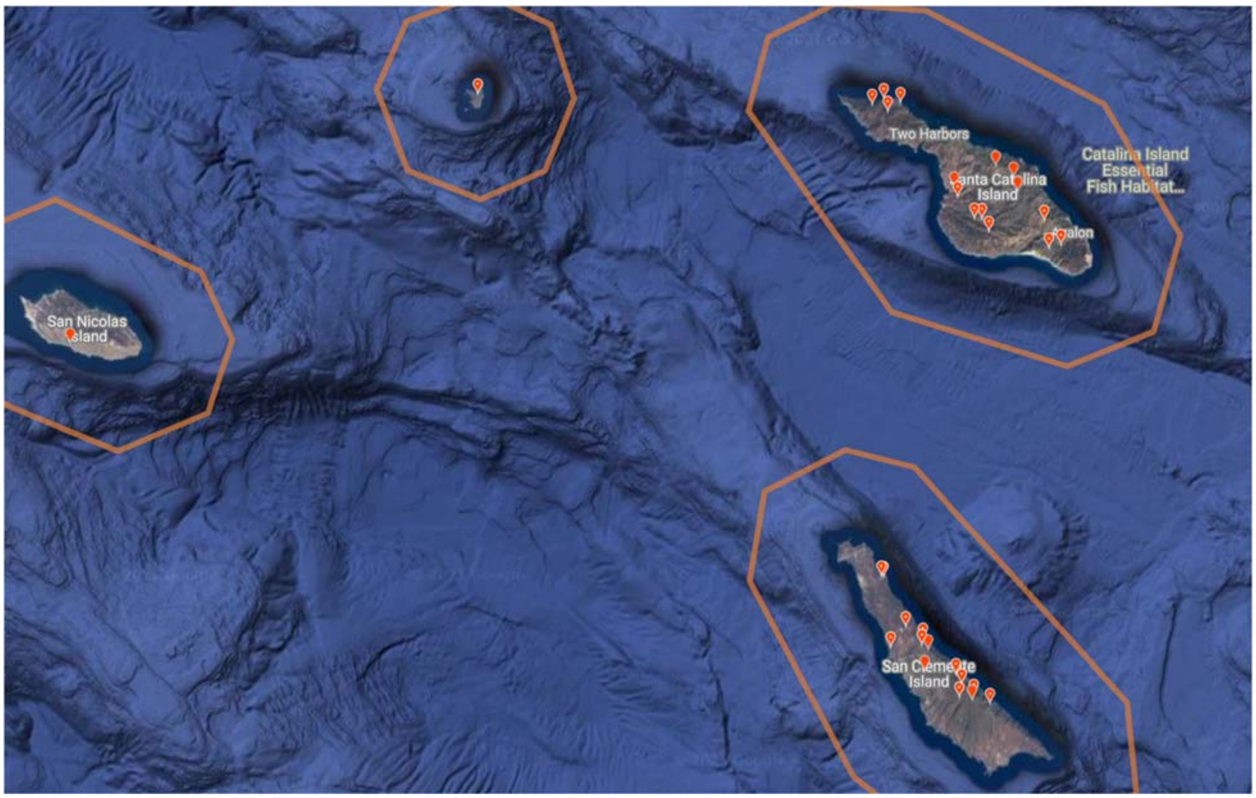


Figure Odonata-4. Distribution of iNaturalist damselfly and dragonfly observations on (a) the Northern Islands and (b) the Southern Islands.

Orthoptera

Table Orthoptera-1 shows that there are 11 Orthoptera families represented in the occurrence records. Collected specimens (Cal-IBIS and LACM) make up 59% of the Orthoptera data points and observations (iNaturalist) make up 41%. There are fewer specimens (363) than would be expected given the extensive research that has been done on this order (Rentz and Weissman 1982). The best represented families are Acrididae and Gryllidae, which are larger-bodied and more obvious.

Table Orthoptera-2 shows that the taxonomic resolution for Orthoptera data points is decently high overall: 90.86% are identified to family, 83.03% are identified to genus and 67.70% are identified to species. Less than half (39.76%) of the iNaturalist observations are research grade, however.

Table Orthoptera-3 shows the relatively large gap between known Orthoptera taxa found on the Channel Islands from the literature and taxa represented in digitized collections and naturalist observations. There are 1 family, 2 genera and 19 species known to occur on the Channel Islands based on the literature that were not represented in the occurrence data. Thirty three percent of the known species are not represented by specimens. **Appendix B Table 11** has a complete list of taxa found in the occurrence data and literature.

Table Orthoptera-4 shows that seven island taxa have expanded range data via the iNaturalist platform.

Figures Orthoptera-1a and 1b show the absolute number and proportional number/island size of Orthoptera occurrences on each island. Santa Cruz and Santa Catalina Islands have been relatively well sampled. These two islands plus San Clemente also have a relatively high number of iNaturalist observations, likely due to a combination of accessibility and biologists active on this platform. The graphs that have been normalized by island size show that Anacapa and Santa Barbara islands have been disproportionately well-sampled. It is interesting that there is a relatively high number of LACM specimens from San Miguel Island.

Figure Orthoptera-2 shows the number of specimens by year over time. The first collections recorded are from 1907 (from Santa Catalina, collector unknown, housed at ANSP and UMMZ). There are visible peaks in collections during the 1940s (associated with the Channel Islands Biological Survey) and from 1970 to ~1987. The latter were predominantly collected by J.P. Donahue, C. Henne, C.L. Hogue, J.N. Hogue, S. Bennett, C.D. Nagano, and S. Miller, and are housed at LACM. There is a significant amount of unattributed material at UCSB. Clearly the important collections of Rentz and Weissman at CAS have not yet been digitized. The majority of the data points in the past 10 years have been iNaturalist observations, primarily in the larger and more obvious families such as Acrididae (grasshoppers), Gryllidae (crickets), Stenopelmatidae (large crickets including Jerusalem crickets), and Tettigoniidae (katydids or bush crickets).

Figure Orthoptera-3 shows the data by month and island. There are too few data points on most of the islands to identify any seasonal patterns.

Figure Orthoptera-4 shows the spatial distribution of iNaturalist Orthoptera observations on the islands. It shows relatively good coverage on the southern islands, scattered coverage on Santa Cruz, and poor coverage on Santa Rosa and San Miguel Islands, which are relatively inaccessible.

Table Orthoptera-1. Number of Orthoptera data points recorded in each data source by family, showing the relative number of observations (iNaturalist) and specimens (Cal-IBIS and LACM).

Family	Cal-IBIS	LACM	iNaturalist	total	%
Acrididae	37	175	131	343	55.95%
Anostostomatidae	0	5	5	10	1.63%
Eumastacidae	0	0	1	1	0.16%
Gryllidae	9	36	28	73	11.91%
Mogoplistidae	0	0	4	4	0.65%
Myrmecophilidae	0	0	1	1	0.16%
Rhaphidophoridae	0	7	10	17	2.77%
Stenopelmatidae	2	6	32	40	6.53%
Tetrigidae	0	31	0	31	5.06%
Tettigoniidae	1	4	30	35	5.71%
Trigonidiidae	0	1	0	1	0.16%
undetermined family	0	49	7	56	9.14%
all Orthoptera	49	314	249	612	
family diversity	4	9	9	11	

Table Orthopetra-2. Taxonomic resolution of island Orthoptera records by source.

Rank	Cal-IBIS	LACM	iNaturalist (All)	iNaturalist (RG)	Totals
Order	49	314	249	102 (40.96%)	612
Family	49 (100%)	265 (84.39%)	242 (97.19%)	102 (40.92%)	557 (90.86%)
Genus	16 (32.65%)	265 (84.39%)	227 (91.16%)	102 (40.92%)	509 (83.03%)
Species	10 (20.41%)	265 (84.39%)	139 (55.82%)	99 (39.76%)	415 (67.70%)

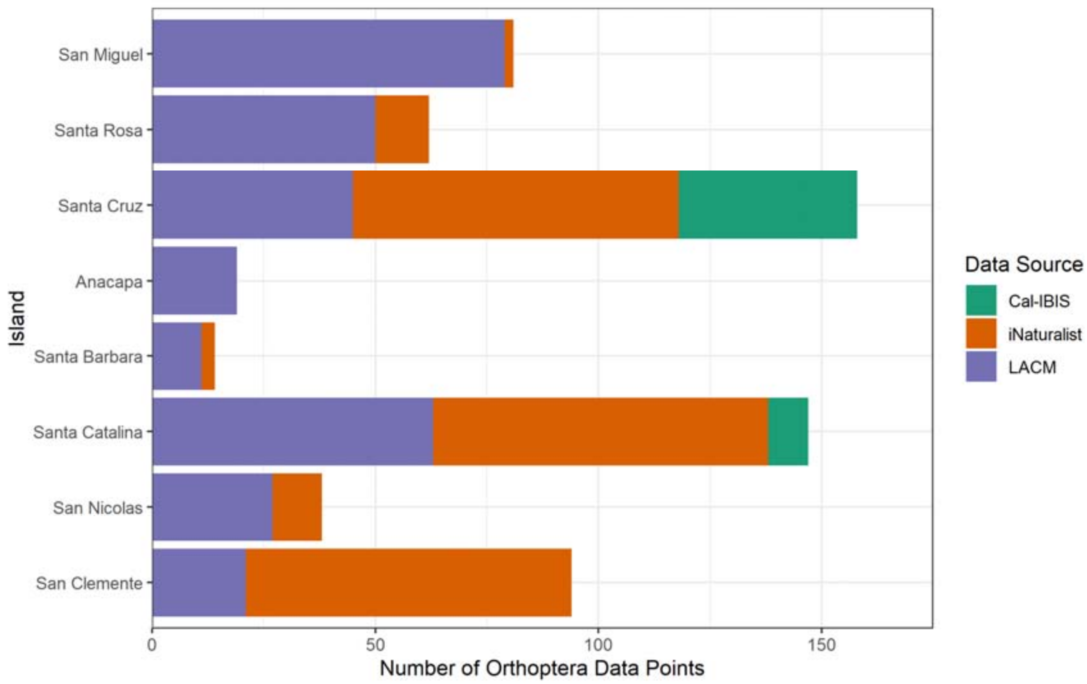
Table Orthoptera-3. Channel Islands Orthoptera taxa added by a literature search as compared to those represented in digitized specimen and observation data, revealing the digitization gap.

	# of Families	# of Genera	# of Species
Occurrence Data	11	31	38
Taxa added by Literature	1	2	19
Total Orthoptera	12	33	57

Table Orthoptera-4. New Channel Island taxa in the Orthoptera occurrence data.

Rank	Taxon	New To	Source
Family Genus and species	Tettigoniidae *Scudderia mexicana*	San Clemente Island	https://www.inaturalist.org/observations/54082660
Family Genus	Stenopelmatidae *Ammopelmatus*	San Nicolas Island	https://www.inaturalist.org/observations/61091202
Family Genus	Rhaphidophoridae *Pristoceuthophilus*	Santa Barbara Island	https://www.inaturalist.org/observations/37420372
Genus	*Paropomala*	Channel Islands Santa Cruz Island	http://www.cal-ibis.org/collections/individual/index.php?occid=1574994
Genus and Species	*Chloealtis gracilis*	Channel Islands Santa Cruz Island	https://www.inaturalist.org/observations/6374905
Genus and Species	*Schistocerca nitens*	Santa Cruz Island	https://www.inaturalist.org/observations/6464905
Species	*Oedaleonotus phryneicus*	Channel Islands Santa Rosa Island Santa Cruz Island	https://www.inaturalist.org/observations/15025372 https://www.inaturalist.org/observations/25358078

(a)



(b)

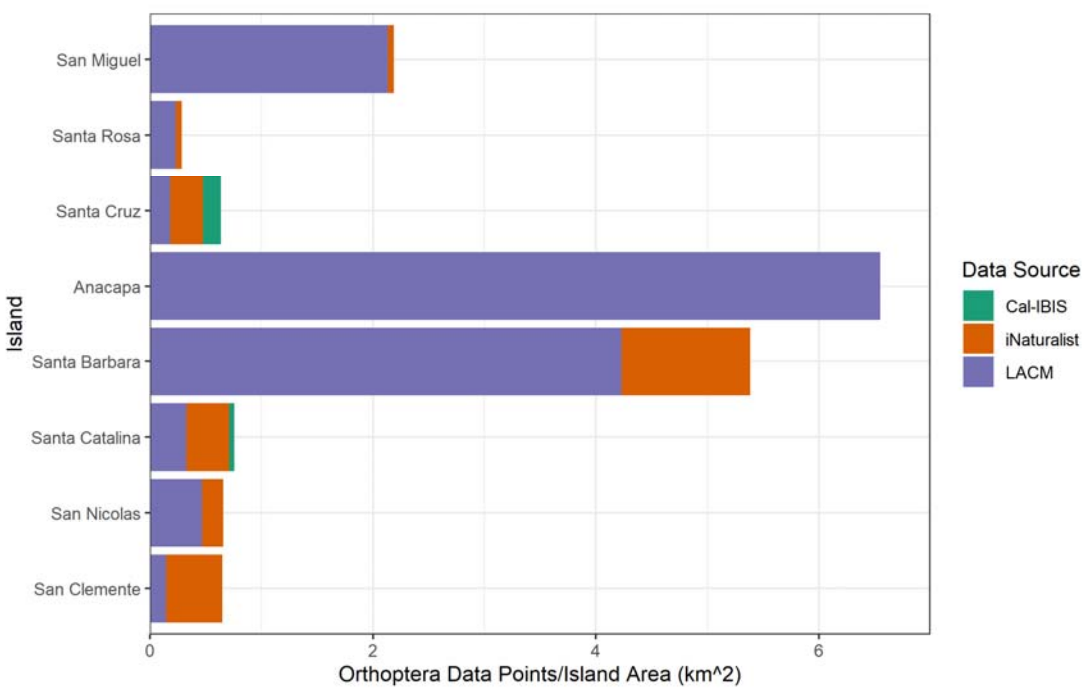


Figure Orthoptera-1. The (a) absolute number and (b) proportional number/island size of Orthoptera data points on each island by data source reveals spatial gaps in the data. Cal-IBIS represents publicly available specimen data, LACM represents private Los Angeles County Museum data, and iNaturalist represents observation data.

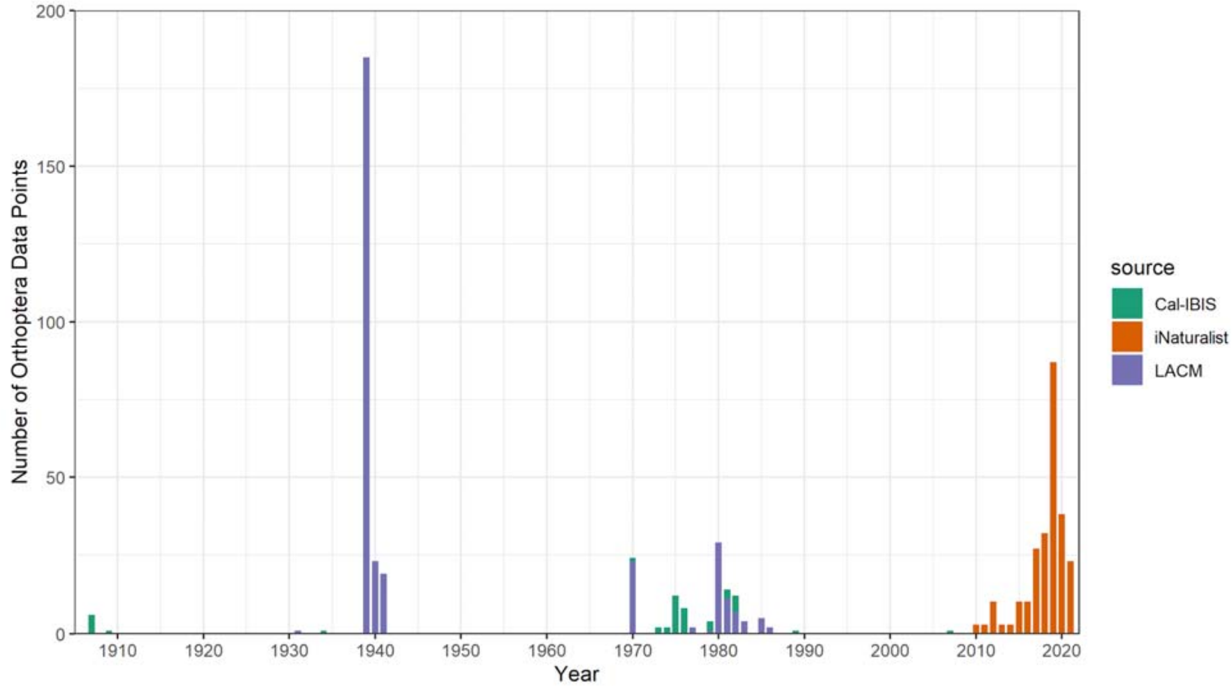


Figure Orthoptera-2. The number of island Orthoptera data points by year and data source reveals temporal gaps in the data. Cal-IBIS represents publicly available specimen data, LACM represents private Los Angeles County Museum data, and iNaturalist represents observation data.

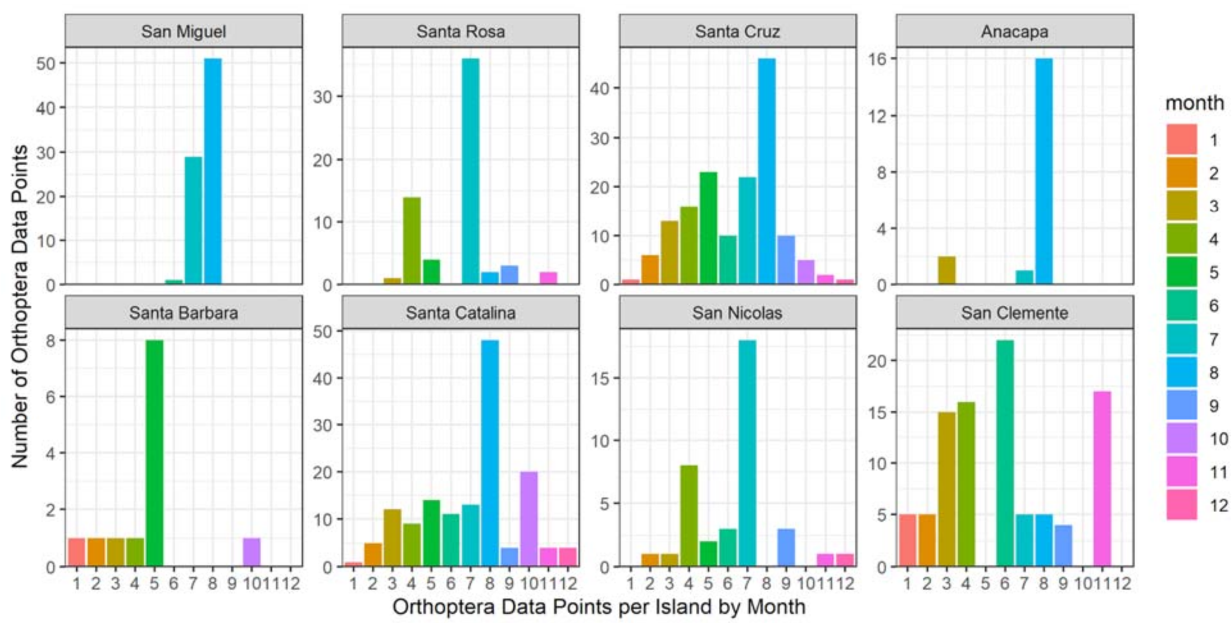


Figure Orthoptera-3. The number of Orthoptera data points by month, by island, reveals seasonal gaps in the data, which were combined for this analysis.

(a) 

(b)

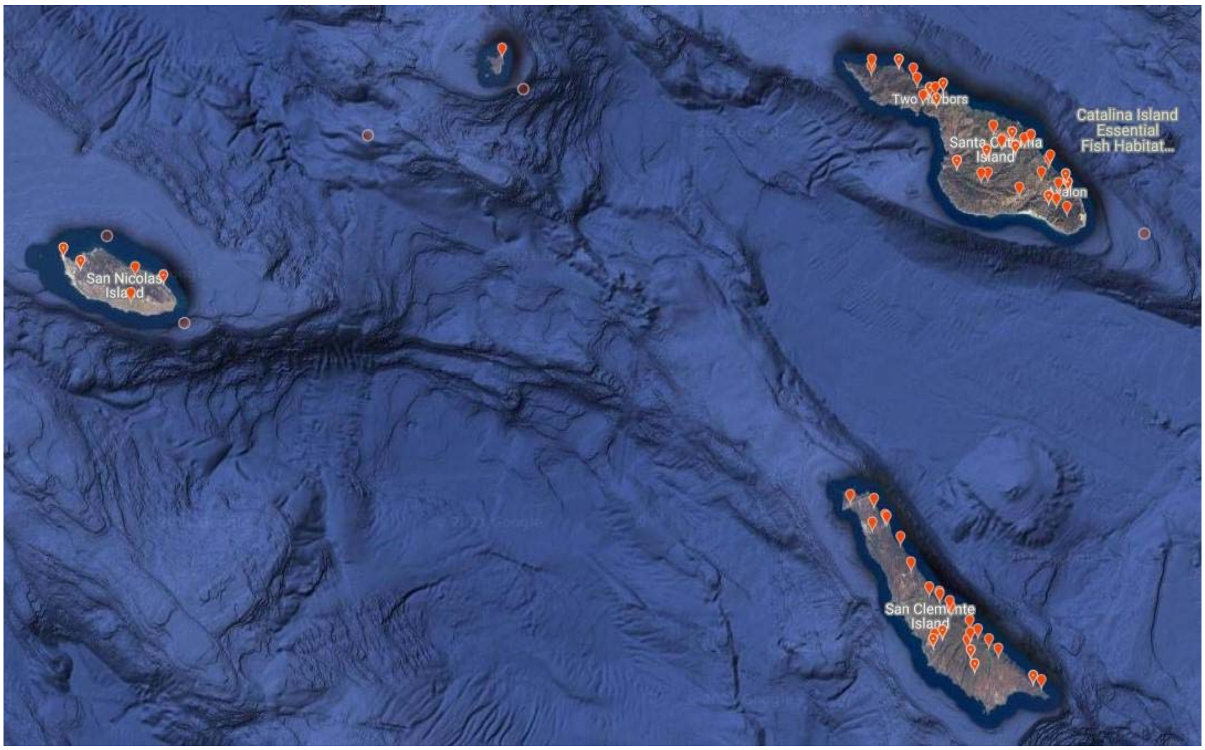


Figure Orthoptera-4. Distribution of iNaturalist Orthoptera observations on (a) the Northern Islands and (b) the Southern Islands.

Phasmida

Table Phasmida-1 shows all seven island Phasmida data points. Cal-IBIS only contains one collected specimen, and iNaturalist has 6 observations of Phasmida. Three species were identified: *Pseudosermyle catalinae, Pseudosermyle straminea **and** Parabacillus Hesperus.*

Figures Phasmida-1a and 1b show the absolute number and proportional number/island size of Phasmida occurrences on each island. The only island with Phasmida data points is Santa Catalina. Walking sticks are fairly common on the central coast, therefore we would expect to see them on all of the islands. There may be LACM specimens that have not yet been digitized.

Figure Phasmida-2 shows the number of specimens by year over time. The first collections recorded are from 1932 (housed at CAS, no collector recorded). The other six data points are all on the iNaturalist platform, between 2010-2021. All of these occurrences are on Santa Catalina Island, the only island where Phasmids have been recorded.

Figure Phasmida-3 shows the data by month and island. There are too few data points on Santa Catalina to identify any seasonal patterns.

Figure Phasmida-4 shows the iNaturalist points on Catalina Island, which are generally clustered on the eastern end, with one point on the west end.

Table Phasmida-1. All occurrence records of island walkingsticks captured in our data sets. Note: there were no walkingsticks in our compiled literature.

Source	Year	Family	Genus	Species
iNaturalist	2016	Diapheromeridae	*Pseudosermyle*	*Pseudosermyle catalinae*
iNaturalist	2018	Diapheromeridae	*Pseudosermyle*	*Pseudosermyle catalinae*
Cal-IBIS	1932	Diapheromeridae	*Pseudosermyle*	*Pseudosermyle straminea*
iNaturalist	2010	Diapheromeridae	*Pseudosermyle*	sp.
iNaturalist	2021	Diapheromeridae	*Pseudosermyle*	sp.
iNaturalist	2019	Heteronemiidae	*Parabacillus*	*Parabacillus hesperus*
iNaturalist	2010	Heteronemiidae	*Parabacillus*	sp.

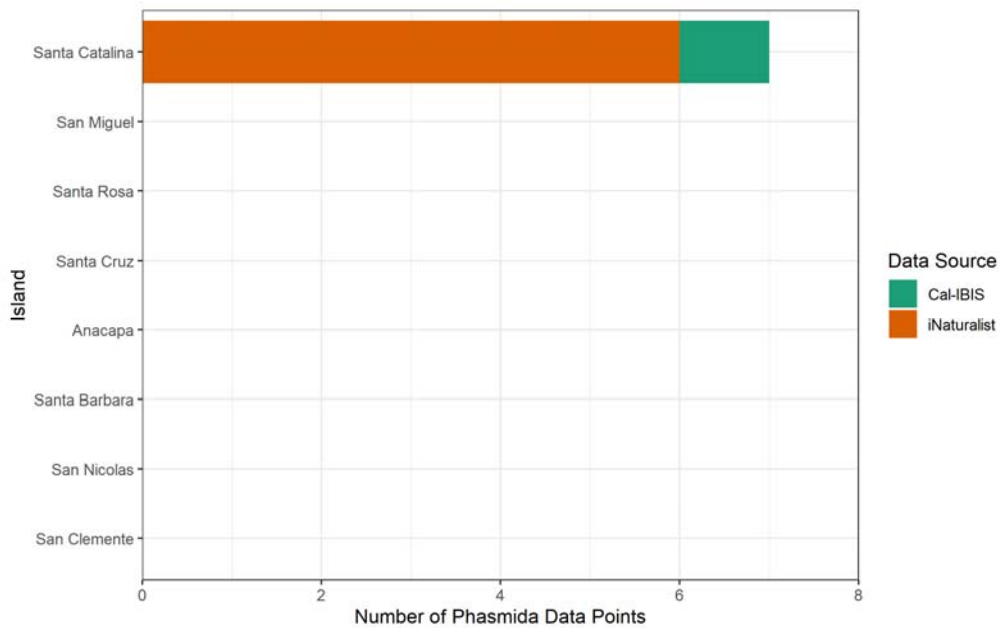


Figure Phasmida-1. The number of walkingstick occurrences on each island by data source reveals spatial gaps in the data.

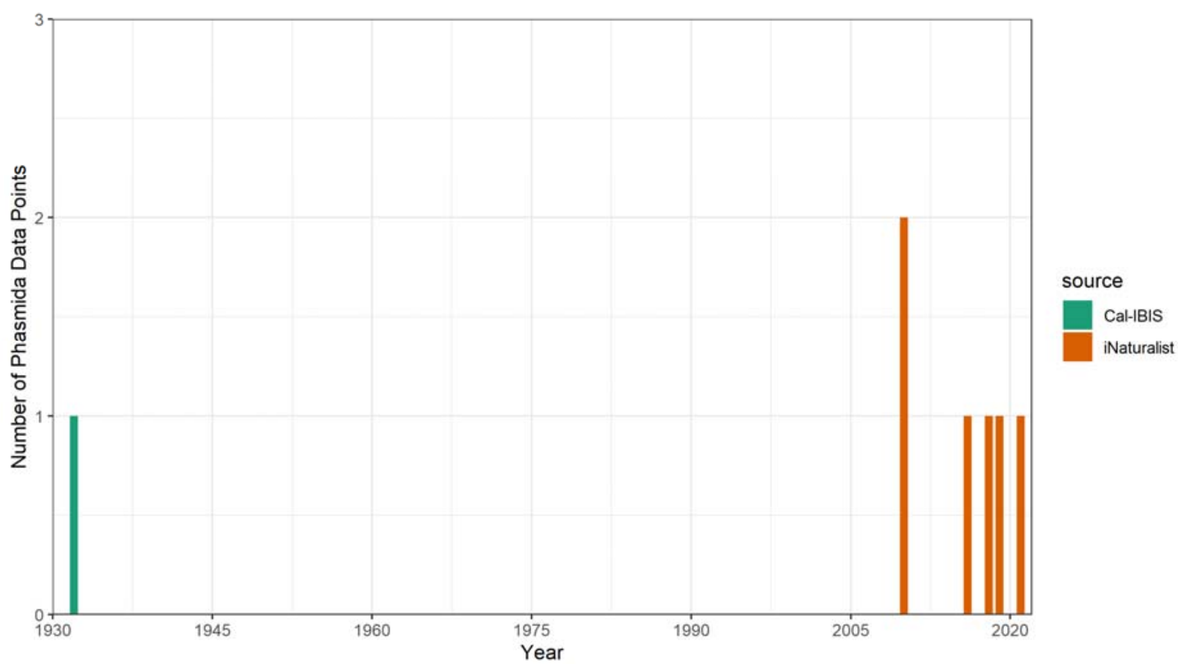


Figure Phasmida-2. The number of island walkingstick occurrences by year and data source reveals temporal gaps in the data. Cal-IBIS represents publicly available specimen data and iNaturalist represents observation data.

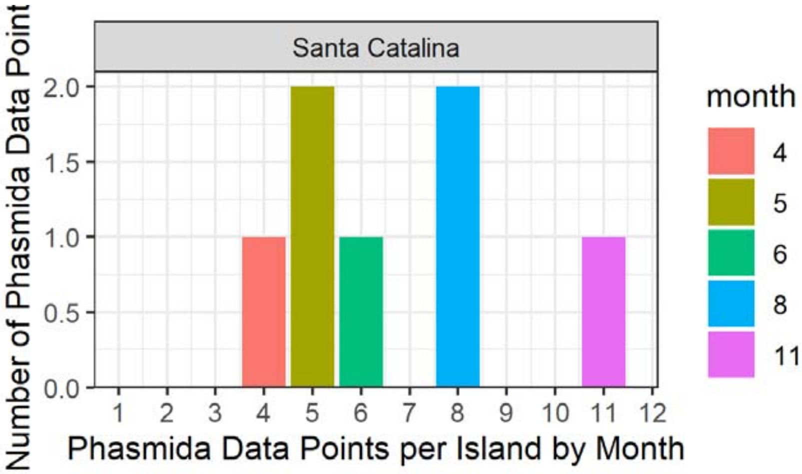


Figure Phasmida-3. The number of walkingstick occurrences by month, by island, reveals seasonal gaps in the data. Note that only Santa Catalina Island has available walkingstick data.

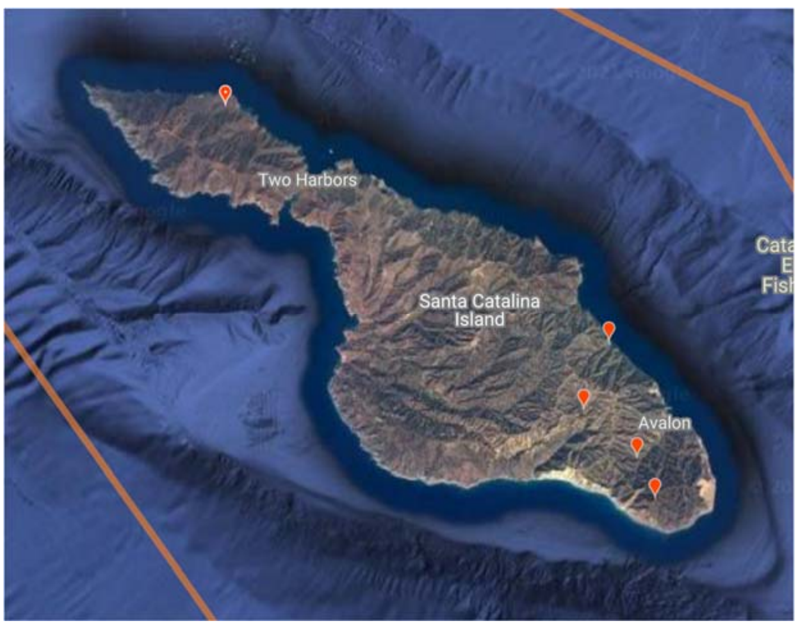


Figure Phasmida-4. Distribution of iNaturalist walkingstick observations on Santa Catalina Island.

Table Endemics-1 presents a list of all known rare and endemic Channel Island invertebrate taxa (129 insects and 22 mollusks) with the islands on which they have been collected and last year recorded. It shows that a large proportion (46%) of these taxa, which are known from the literature, are not yet represented by digitized specimens. This further demonstrates the large digitization gap for island invertebrates. Many of the taxa that have occurrences in our data have been documented via iNaturalist. The majority (55.6%) of the rare and endemic invertebrates are only known from one island. The percentage of rare and endemic island invertebrates declines steadily as the number of islands increases, with 17.9% found on two, 9.9% found on three, 7.3% found on four, 5.3% found on five, 1.3% found on six, 2.0% found on seven, and only one taxon (<1%) found on all eight islands. This could be due to either the poorly sampled nature of island invertebrates (where, with more sampling we will find that these taxa are found on more of the islands), the generally limited dispersal abilities of these invertebrates (leading to their distinct evolution in-place), or both.

Table Taxonomic Diversity-1 and **Figure Taxonomic Diversity-1** summarize the taxonomic diversity of the island invertebrates within the occurrence data. They show that 1,955 unique taxa are present, with 1,764 of those taxa in the Class Insecta. For comparison, Hogue (1993) estimated between 3,000-4,000 insect taxa in the Los Angeles Basin, although this number requires upward revision. The Coleoptera have the most diversity in our data with 510 taxa, followed by Lepidoptera (492) and Hymenoptera (383). Forbes et al. (2018) argue that the Hymenoptera, and not the Coleoptera, is the most species-rich animal order, and that the huge diversity within the Hymenoptera is due to parasitic wasps. However, more Coleoptera taxa than Hymenoptera are represented in our occurrence data, likely because only 20% of the taxonomic diversity of Hymenoptera is from parasitic wasp taxa.

Table Taxonomic Diversity-1. Taxonomic richnes for each of the groups in the occurrence data

Phylum	Class	Order	Taxonomic Richness
Arthropoda	Arachnida		116
Arthropoda	Insecta	Blattodea	5
Arthropoda	Chilopoda		13
Arthropoda	Insecta	Coleoptera	510
Arthropoda	Insecta	Dermaptera	2
Arthropoda	Diplopoda		6
Arthropoda	Insecta	Diptera	148
Arthropoda	Insecta	Hemiptera	160
Arthropoda	Insecta	Hymenoptera	383
Arthropoda	Insecta	Lepidoptera	492
Mollusca			56
Arthropoda	Insecta	Odonata	20
Arthropoda	Insecta	Orthoptera	41
Arthropoda	Insecta	Phasmida	3
All Invertebrate Groups evaluated in the Gap Analysis			1955

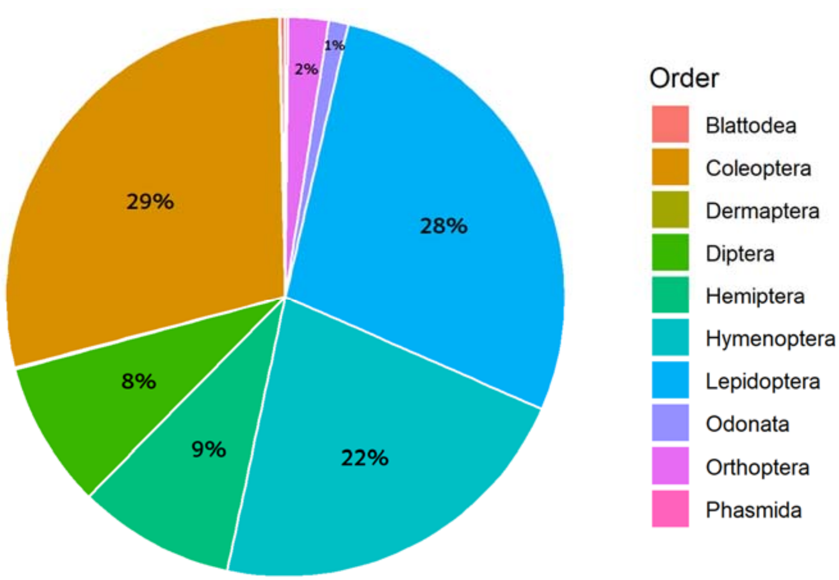


Figure Taxonomic Diversity-1. Insect taxonomic diversity of the occurnce data by order. 1764 unique insect taxa were in the occurrence data.

Table Endemics-1. Channel Islands invertebrate endemic taxa, with island occurrences and last year recorded via either specimens or observations. Red zeroes (o) indicate that taxon is known from that island, but there are no digitized specimens or online observations available; x! indicate taxa that were not previously recorded on that island, but have digitized specimens or online observations available. # is = # of islands. Endemics data were sourced from Miller 1985, the Miller database, Powell 1994, the Catalina Island Conservancy (catalinaconservancy.org), McCoshum et al 2012, and Drost et al. 2018, then synonymized. Rare codes: V=Vulnerable, CE= Critically Endangered, CI=Critically Imperiled.

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Arachnida: Acari														
Ixodidae	Ixodes peromysci	Channel Islands Deer Mouse Tick					o	o			o	3	na	na
Laelapidae	Laelaps pilosula	Santa Rosa Island Parasite Mite			o							1	na	na
Microtrombidiidae	Microtrombidium augustipes	Santa Rosa Island Micro Velvet Mite			o							1	na	na
Arachnida: Araneae														
Agelenidae	Rualena alleni	San Nicolas Island Funnel-weaver Spider							o			1	na	na
Agelenidae	Rualena cockerelli	San Miguel Island Funnel Weaver Spider		o								1	na	na
Agelenidae	Rualena cruzana	Santa Cruz Island Funnel Weaver Spider				o						1	na	na
Gnaphosidae	Drassyllus barbus	Santa Barbara Island Ground Spider						o				1	na	na
Gnaphosidae	Zelotes cruz	Channel Islands Ground Spider				o	o	o				3	na	na
Segestriidae	Citharoceps cruzana	Santa Cruz Island Tube-dwelling Spider				o						1	na	na

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Zodariidae	Lutica clementea	San Clemente Island Dune Spider									o	1	na	na
Zodariidae	Lutica nicolasia	San Nicolas Island Dune Spider							x			1	5	2019; iNaturalist
Opiliones														
Protolophidae	Protolophus cockerelli	San Clemente Island Harvestman									x	1	13	2019; iNaturalist
Scorpiones														
Vaejovidae	Catalinia thompsoni	Northern Channel Islands Scorpion			x	x	x					3	46	2021; iNaturalist
Chilopoda														
Geophilidae	Geophilus nicolanus	San Nicolas Island Centipede							o			1	na	na
Schendylidae	Pectiniunguis catalinensis	Catalina Island Centipede								o		1	na	na
Lithobiidae	Nothembius insulae	Santa Cruz Island Garden Centipede				o						1	na	na
Diplopoda														
Parajulidae	Bollmaniulus catalinae	Catalina Island Parajulid Millipede								o		1	na	na

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Cambalidae	Nannolene catalina	Catalina Island Cambalid Millipede								x		1	1	1927; Cal-IBIS
Cambalidae	Tigolene clementinus	San Clemente Island Millipede									x	1	5	2020; iNaturalist
Mollusca: Gastropoda														
Binneyidae	Binneya notabilis	Slug Snail						o				1	na	na
Haplotrematidae	Haplotrema catalinense	Catalina Lancetooth	CI							x		1	5	1961; Cal-IBIS
Haplotrematidae	Haplotrema duranti duranti	Ribbed Lancetooth	CI	o	o	o		o	x			5	2	2021; iNaturalist
Helminthoglyptidae	Xerarionta intercisa	Plain Cactussnail	V, CI								x	1	70	2021; iNaturalist
Helminthoglyptidae	Xerarionta kellettii	Catalina Cactussnail	CI						x!	x	x!	3	69	2021; iNaturalist
Helminthoglyptidae	Xerarionta redimita	Wreathed Cactussnail	V, CI								x	1	40	2020; iNaturalist
Helminthoglyptidae	Xerarionta tryoni	Bicolor Cactussnail	V, CI					x	x			2	51	2021; iNaturalist
Oreohelicidae	Radiocentrum avalonense	Catalina Mountainsnail	CE, CI							x		1	2	2019; iNaturalist
Polygyridae	Trilobopsis sp.	Santa Cruz Island Chaparral Snail				o						1	na	na

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Pristilomatidae	Pristiloma shepardae	Island Tightcoil	CI		o	o	o			o		4	na	na
Vertiginidae	Vertigo californica longa	Elongate Ribbed Vertigo						o	o		o	3	na	na
Vertiginidae	Vertigo catalinaria	Catalina Ribbed Vertigo			o		o	o		o	o	5	na	na
Vertiginidae	Vertigo clementina	Insular Birddrop Snail						o	x	x!	x	4	31	2019; iNaturalist
Vertiginidae	Vertigo pimuensis	Pimu Island Vertigo								o		1	na	na
Xanthonychidae	Helminthoglypta ayresiana	San Miguel Shoulderband	CI	x	x	x!	x!	x!				5	50	1986; Cal-IBIS
Xanthonychidae	Micrarionta beatula	Avalon Islandsnail	CI							x		1	5	2020; iNaturalist
Xanthonychidae	Micrarionta facta	Santa Barbara Islandsnail	CI					x		x!	x!	3	39	2021; iNaturalist
Xanthonychidae	Micrarionta feralis	San Nicolas Islandsnail	CE, CI						x		x!	2	7	2019; iNaturalist
Xanthonychidae	Micrarionta gabbi	San Clemente Islandsnail	V, CI								o	1	113	2021; iNaturalist
Xanthonychidae	Micrarionta maxima	Maximal Islandsnail									o	1	na	na
Xanthonychidae	Micrarionta opuntia	Prickly Pear Islandsnail	V, CI						x			1	3	1989; Cal-IBIS

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Xanthonychidae	Micrarionta rufocincta	Santa Catalina Islandsnail	CI					x!		x	x!	3	39	2015; iNaturalist
Coleoptera														
Anobiidae	Euvrilletta catalinae	Catalina Island Death Watch Beetle								o		1	na	na
Anobiidae	Xarifa insularis	Southern Island Death Watch Beetle								o	o	2	na	na
Cantharidae	Cantharis hatchi dorothyae	Catalina Island Soldier Beetle								o		1	na	na
Carabidae	Amara insularis	Channel Islands Sun Beetle		x!	x!			x!	x!		x	5	214	1941; LACM
Carabidae	Pterostichus gliscans	Channel Islands Ground Beetle		x							x	2	30	2019; iNaturalist
Chrysomelidae	Colaspidea subvittata	Channel Islands Leaf Beetle								o	o	2	na	na
Coccinelidae	Scymnus falli	Channel Islands Dusky Ladybug			o	o		o				3	na	na
Curculionidae	Sciopithes insularis	San Clemente Island Broad-nosed Weevil									o	1	na	na
Curculionidae	Trigonoscuta catalina	Catalina Island Broad-Nosed Weevil								x		1	24	1980; LACM
Latridiidae	Melanophthalma insularis	San Clemente Island Fungus Beetle									o	1	na	na

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Malachiidae	Collops crusoe	Channel Islands Red Cross Beetle		x!	x	x			x			4	71	2020; iNaturalist
Melolonthidae	Phobetus ciliatus	Catalina Island Rain Scarab				x!				x		2	17	1988; LACM
Melolonthidae	Phobetus testaceus	Santa Cruz Island Rain Scarab				x			x!			2	13	2009; Cal-IBIS
Melolonthidae	Serica catalina	Catalina Island Gleaming Scarab								o		1	na	na
Melolonthidae	Serica cruzi	Santa Cruz Island Gleaming Scarab				x						1	8	1979; LACM
Melyridae	Amecocerus anacapensis	Anacapa Island Soft-winged Flower Beetle					o					1	na	na
Melyridae	Attalus transmarinus	San Clemente Island Soft-winged Flower Beetle									o	1	na	na
Melyridae	Dasytastes catalinae	Catalina Island Soft-winged Flower Beetle								o		1	na	na
Melyridae	Dasytastes insularis	Island Soft-winged Flower Beetle								o		1	na	na
Melyridae	Trichochrus calcaratus	Northern Channel Islands Soft-winged Flower Beetle			o	o	o					3	na	na
Melyridae	Trichochrus pedalus	Southern Channel Islands Soft-winged Flower Beetle								o	o	2	na	na
Scarabaeidae	Coenonycha clementina	San Clemente Island Junebug									x	1	21	2019; iNaturalist

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Scarabaeidae	Coenonycha clypeata	Catalina Island Junebug								x		1	3	1982; LACM
Scarabaeidae	Coenonycha fulva	Yellow Channel Islands Junebug					x!			x		2	48	1984; LACM
Staphylinidae	Acrotona sonomana	Anacapa Island Rove Beetle								o		1	na	na
Tenebrionidae	Apsena grossa	Channel Islands Textured Darkling Beetle			x!		x!	x	x	x	x	6	342	2020; iNaturalist
Tenebrionidae	Cibdelis bachei	Channel Islands Cluster Beetle				x		o		o		3	1	2018; iNaturalist
Tenebrionidae	Coelus pacificus	Channel Islands Dune Beetle		x	x	x	o	x!	x	x	x	8	758	2019; iNaturalist
Tenebrionidae	Coniontis lata	Channel Islands Oval Darkling Beetle		x	o	x	x	x	o		x	7	95	1957; LACM
Tenebrionidae	Coniontis santarosae	Northern Channel Islands Oval Darkling Beetle		o	o							2	na	na
Tenebrionidae	Eleodes inculta	Channel Islands Stink Beetle		x	x	o	o	x	x!		x!	7	174	2017; iNaturalist
Tenebrionidae	Eleodes laticollis apprima	First Channel Islands Stink Beetle		o	o	o	o	o	o		o	7	na	na
Tenebrionidae	Eleodes subvestita	San Nicolas Island Stink Beetle							o			1	na	na
Tenebrionidae	Eusattus politus politus	Northern Islands Globose Darkling Beetle		o	o							2	na	na

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Tenebrionidae	Eusattus robustus	Southern Islands Globose Darkling Beetle		x!	x!			x!	x		x	5	69	2021; iNaturalist
Tenebrionidae	Metoponium insulare	Catalina Island Narrow Darkling Beetle								o		1	na	na
Diptera														
Agromyzidae	Amauromyza insularis	Blotched Leaf Miner								o		1	na	na
Asilidae	Cophura hennei	Henne's Robber Fly							x			1	19	1980; LACM
Asilidae	Efferia anacapai	Anacapa Island Robber Fly			x!		x	o				3	3	1987; Cal-IBIS
Asilidae	Efferia clementei	San Clemente Island Robber Fly									x	1	14	1981; Cal-IBIS
Asilidae	Stenopogon neojubatus	Island Robber Fly		o	x	x	o	x				5	17	1979; LACM
Tipulidae	Tipula hastingsae diperona	Santa Cruz Island Cranefly				o						1	na	na
Tipulidae	Tipula sanctaecruzae	Santa Cruz Island Cranefly				x						1	1	2019; iNaturalist
Hemiptera														
Cicadellidae	Tiaja cruzensis	Santa Cruz Island Leafhopper				o						1	na	na

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Cicadellidae	Tiaja insula	Santa Barbara Island Leafhopper						o				1	na	na
Cicadidae	Okanagana catalina	Catalina Island Cicada								x		1	9	2020; iNaturalist
Cicadidae	Okanagana hirsuta	Channel Islands Cicada			o	x	o					3	1	2015; iNaturalist
Lygaeidae	Melanopleurus fuscosus	Santa Cruz Island Seed Bug				x						1	24	2021; iNaturalist
Miridae	Insulaphylus meridianus	Catalina Island Plant Bug								o		1	na	na
Pseudococcidae	Heliococcus clemente	San Clemente Island Mealybug									o	1	na	na
Hymenoptera														
Apidae	Anthophora urbana clementina	San Clemente Island Digger Bee							x!		x	2	94	2020; iNaturalist
Apidae	Anthophora urbana nicolai	San Nicolas Island Digger Bee							x			1	5	1977; Bohart
Apidae	Anthophorula cockerelli	Catalina Island Long-horned Bee								o		1	na	na
Apidae	Melissodes scotti	Catalina Island Long-horned Bee								o		1	na	na
Apidae	Nomada avalonica	Avalon Cuckoo Bee								x		1	1	1938; Cal-IBIS

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Crabronidae	Bembix americana dugi	San Clemente Island Sand Wasp									o	1	1	1978; Cal-IBIS
Crabronidae	Bembix americana hamata	Northern Island Sand Wasp		x	o	x						3	3	2019; iNaturalist
Crabronidae	Bembix americana nicolai	San Nicolas Island Sand Wasp							x			1	2	2019; iNaturalist
Formicidae	Aphaenogaster patruelis	Channel Islands Funnel Ant						x	x	x	x	4	99	2020; iNaturalist
Formicidae	Camponotus bakeri	Channel Islands Carpenter Ant			o			x		x	x	4	42	2021; iNaturalist
Halictidae	Lasioglossum avalonense	Avalon Sweat Bee			x	x				o	o	4	222	2012; Cal-IBIS
Halictidae	Lasioglossum cabrilli	Cabrillo's Sweat Bee		o	x	x						3	6	2012; Cal-IBIS
Halictidae	Lasioglossum megastictus	Large Spotted Sweat Bee		x						x!		2	33	2012; Cal-IBIS
Halictidae	Lasioglossum punctiferellum	Tiny Spotted Sweat Bee		o								1	na	na
Halictidae	Sphecodes nigricans miguelensis	San Miguel Island Blood Bee		o								1	na	na
Sphecidae	Ammophila azteca clemente	San Clemente Island Sand Wasp									o	1	na	na
Sphecidae	Palmodes insularis	Island Thread-Waisted Wasp		x	o	x	x				o	5	12	1986; Cal-IBIS

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Lepidoptera														
(Gelechioidea)	Vladimiria? n. sp.					o					o	2	na	na
Blastobasidae	Holcocera phenacocci	Scavenger Moth								o		1	na	na
Crambidae	Evergestis angustalis catalinae	Cambrid Snout Moth								x		1	3	1981; LACM
Erebidae	Arachnis picta insularis	Island Painted Tiger Moth			x!	x!	x			x!		4	56	1983; LACM
Erebidae	Arachnis picta meadowsi	Meadows' Painted Tiger Moth								x		1	44	1980; LACM
Erebidae	Lophocampa indistincta	Indistinct Tiger Moth			x	x	o			x		4	8	2020; iNaturalist
Gelechiidae	Chionodes n. sp.					o	o	o		o		4	na	na
Gelechiidae	Coleotechnites n. sp.					o					o	2	na	na
Gelechiidae	Scrobipalpula n. sp.					o						1	na	na
Gelechiidae	Scrobipalpula n. sp.										o	1	na	na
Gelechiidae	Tuta n. sp. nr. chiquitella										o	1	na	na

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Geometridae	Pero catalina	Catalina Island Geometer Moth								x		1	8	2019; iNaturalist
Geometridae	Pero n. sp. nr. gigantea										o	1	na	na
Geometridae	Pterotaea crinigera	San Clemente Island Geometer Moth								x!	o	2	2	1932; Cal-IBIS
Gracillariidae	Acrocercops insulariella	Island Leaf Miner Moth				o						1	na	na
Hesperiidae	Ochlodes sylvanoides santacruza	Channel Islands Woodland Skipper			o	x						2	26	2020; iNaturalist
Lycaenidae	Strymon avalona	Avalon Hairstreak Butterfly								x		1	429	2020; iNaturalist
Nepticulidae	Stigmella n. sp.					o					o	2	na	na
Noctuidae	Feralia meadowsi	Meadows' Owlet Moth				o				x		2	7	2019; iNaturalist
Noctuidae	Zosteropoda clementei	Channel Islands Owlet Moth			o	x				x!	x	4	94	2019; iNaturalist
Nymphalidae	Euphydryas editha insularis	Edith's Island Checkerspot			x							1	20	2019; iNaturalist
Oecophoridae	Agonopterix toega	San Clemente Island Flat-Bodied Moth									x	1	28	1981; LACM
Pieridae	Anthocharis cethura catalina	Catalina Island Orangetip Butterfly								x		1	6	2019; iNaturalist

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Pyralidae	Acrobasis comptella	Santa Cruz Island Snout Moth				o				x		2	4	2015; iNaturalist
Pyralidae	Sosipatra proximanthophila	Channel Islands Snout Moth				o				o		2	na	na
Pyralidae	Vitula insula	Channel Islands Driedfruit Moth				x				x		2	7	2018; iNaturalist
Tortricidae	Argyrotaenia franciscana insulana	Channel Islands Tortrix Moth		x	x	o	x		x		x	6	69	2020; iNaturalist
Tortricidae	Argyrotaenia isolatissima	Santa Barbara Island Tortrix Moth				x!		x				2	35	2015; iNaturalist
Tortricidae	Eucosma avalona	Avalon Tortrix Moth				o				o		2	na	na
Ypsolophidae	Ypsolopha lyonothamnae	Island Ironwood Moth				o					o	2	na	na
Orthoptera														
Acrididae	Conozoa clementina	San Clemente Island Grasshopper									o	1	na	na
Acrididae	Conozoa nicola	San Nicolas Island Short-horned Grasshopper							x			1	7	2020; iNaturalist
Acrididae	Trimerotropis santabarbara	Santa Barbara Island Band-winged Grasshopper						x				1	8	2017; iNaturalist
Anostostomatidae	Cnemotettix caudulus	Santa Rosae Silk-spinning Cricket		x	x	x						3	4	2012; iNaturalist

Family	Scientific Name	Common Name	Rare	SM	SR	SCR	A	SB	SN	SCA	SCL	# is	n	Last time recorded
Anostostomatidae	Cnemotettix pulvillifer	San Clemente Island Silk-spinning Cricket									x	1	1	2019; iNaturalist
Anostostomatidae	Cnemotettix spinulus	Channel Islands Silk-spinning Cricket			x	o	o		x			4	2	1940; LACM
Eumasticidae	Morsea catalinae	Catalina Island Monkey Grasshopper								o		1	na	na
Eumasticidae	Morsea islandica	Island Monkey Grasshopper			o	x						2	1	2017; iNaturalist
Stenopelmatidae	Stenopelmatus n. spp. (Catalina)	Catalina Island Jerusalem Cricket								o		1	na	na
Tettigoniidae	Aglaothorax morsei islandica	Channel Islands Shield-back Cricket			o		o					2	na	na
Tettigoniidae	Aglaothorax morsei santacruzae	Santa Cruz Island Shield-back Cricket				x						1	7	2020; iNaturalist
Tettigoniidae	Neduba propsti	Propst's Shield-back Cricket								x!		1	2	2013; iNaturalist
Phasmida														
Diapheromeridae	Pseudosermyle catalinae	Catalina Island Walkingstick								x		1	2	2018; iNaturalist

CONCLUSION AND RECOMMENDATIONS

General Observations

This work has revealed that island invertebrate collections are highly idiosyncratic and skewed towards larger, more popular groups of insects. Tiny insects such as parasitoid wasps and mites in particular are significantly under sampled. Invertebrates are "the little things that run the world", which perform many important jobs and with perhaps seven times the number of species of all vertebrates combined (Wilson 1987). A total of 151 taxa are found nowhere else on earth, many of which have evolved after dispersing to the islands, and we have only scratched the surface – focused survey work regularly adds 50% more species to our lists. Therefore, we feel that an important aspect of conservation is being missed on the California Channel Islands. While invertebrates are challenging to study for a whole host of reasons, we can harness modern technology, the help of volunteers and community scientists, and strategic priorities to accomplish our goals, as discussed in our recommendations below.

Many specimens have not been identified to the species level. This is not surprising, given how few entomological experts there are for how diverse the groups are, and how much there is to learn about their taxonomy. This gap is also revealed by the fact that most island endemics are not recorded in the digitized specimens. It is also possible that these species have been collected, but not identified to the species level.

The iNaturalist platform has not only engaged many people in learning about and documenting biodiversity, but it has contributed greatly to our island invertebrate knowledge. The platform is limited by two main factors, however: 1) it is most useful for the larger, more obvious and charismatic groups, such as true spiders, snails, bees and butterflies, and 2) it is only useful on the more accessible islands and portions of islands. Enthusiasts and experts for particular groups have made outsized contributions on this platform.

Our work revealed a large digitization gap, as evidenced by the typically large number of species added from the literature. As stated in the introduction, entomological collections containing island specimens are only about 1–3% digitized. Discussions with Entomology Curators yielded the following information regarding the status of significant island invertebrate collections:

- The **Bohart** Museum collection at UC Davis, of 8 million specimens, is 1% databased. Their island bees were recently databased under contract to The Nature Conservancy and those data were provided by curator Lynn Kimsey.
- A **CAS** island invertebrates search by curator Chris Grinter in 2020 yielded 1,000 specimens, whereas Chris' guess is that tens of thousands of island specimens reside in their collection. Cal Academy has about 17 million specimens overall.
- An **EMEC** search by curator Peter Oboyski yielded 569 island specimens.
- **LACM** has many of their Channel Island specimens sequestered in a separate collection of about 100 drawers. About one-half of these (22,000 specimens) have been digitized. There are also an unknown number of other specimens mixed in through the remainder of the collection.
- The **MCZ** has quite a few Channel Islands ants
- At **SBMNH,** Island specimens are sometimes mixed into the collection, sometimes clustered. Many of the museum's beetles have been databased.
- At the **USNM**, all of the Channel Islands material is mixed into the general collection of 35 million specimens.
- **UCR** has >500,000 specimens out of ca. 4 million databased (12.5%). A search by Doug Yanega yielded 112 specimens from the Channel Islands (primarily flower visitors and Miridae).

Challenges Encountered

Through this work we have revealed many challenges to the use of online biodiversity data. Before even working with the data, several improvements to Symbiota and Cal-IBIS were needed, including fixing errors in the taxonomic thesaurus, standardizing the data pulled from other portals, and eliminating the many duplicates that result from their appearance in multiple databases. This will make Cal-IBIS a better "one-stop shop" for island biodiversity data. This work has necessitated both consulting contracts with Benjamin Brandt (Green Theory Studios), one of the original developers of Symbiota, and internal work by Josie Lesage, SBBG's Applied Ecologist, who has been updating and adding to the code that TNC contractors at Northern Arizona University (NAU) wrote to bring data into the portal. This has been an involved process, as one issue leads to another. Some improvements that have been accomplished (or are nearly there) include:

- Adding Ecdysis, which is now used by SBMNH for their invertebrate specimens, to the list of portals that are snapshotted into Cal-IBIS;
- Refining and standardizing the search polygons used to bring data in from all other portals. We aimed to set a standardized distance from the terrestrial island boundary that included all of the associated islets as well as marine taxa that should be associated with the islands. Denise Knapp consulted with David Kushner, Marine Biologist for Channel Islands National Park (CINP) on reasonable criteria that would include such marine taxa, and we explored the idea of using bathymetric data with Rockne Rudolph, GIS specialist for CINP. Rockne (Rocky) ultimately produced polygons using a 10 km ocean buffer, which encompasses the ideal bathymetry for all of the islands as well as all of the associated islets. The new search polygons have the side benefit that they also include points for terrestrial taxa that have landed in the ocean due to slight georeferencing errors. We also troubleshot the buffers that overlapped with the mainland;
- Assessing the best way to remove duplicates. Symbiota is already well set-up to remove these duplicates, as long as we upload all of the records in one batch (rather than as snapshots portal-by-portal). This requires running the searches and uploading all of the snapshots at one time, which Dr. Lesage wrote code to do;
- We worked with SBBG IT staff, NAU, and Benjamin Brandt to fix some technical glitches in the Cal-IBIS website;
- To ensure that no duplicate data remained, Benjamin wiped the original data uploads from Cal-IBIS before uploading all of the new data.

The lack of one central source for the best taxonomic standardization was a challenge in this project. To overcome this, as outlined in the methods section, we consulted with experts on the best resources to use for this information. Even so, these sources work differently and are in different states of currency, and we often needed to consult several sources to find the taxa we were seeking. This combined with the many taxa and records (63,306) we were working with made the synonymy work very time-consuming.

We had proposed to census priority collections at SBMNH and planned to include specimens from general arthropod/invertebrate surveys for several islands (including San Nicolas and Santa Cruz Islands), as well as bees, earwigs, and sphecid wasps. The Covid-19 pandemic curtailed this plan, as even Museum staff have not been allowed to be fully on-site for the majority of the time since March of 2020. Several developments will help to mitigate this shortcoming, however: 1) The SBMNH Hymenoptera from the Channel Islands are now fully databased, and many specimens have been imaged, taking care of both bees and sphecid wasps; 2) Curator of Entomology Dr. Matthew Gimmel and Dr. Andrew Johnston (at Arizona State University) have been committed some funds to produce a literature- and museum-record-based, island-by-species/genus checklist of California Channel Islands beetles, and will be producing deliverables by the end of 2021. This project involves assessing material at selected other museums, as well as databasing the remaining SBMNH mounted island beetles, which will provide a list with updated classification and nomenclature; 3) Databasing of the pinned specimens from Ken Osborne's San Nicolas Island collection is nearly complete. Unfortunately, a major problem with that project, Dr. Gimmel reports, is that Mr. Osborne did not include determination labels, so identifications will be determined gradually (starting with beetles).

Background to our Suggested Future Work

The Global Taxonomy Initiative Forum (Convention on Biological Diversity 2021) lists six emerging technologies that provide opportunities for generating and sharing biodiversity knowledge. They are: 1) harnessing the immense knowledge base accumulated in natural history collections through digitization and sharing of data (check!), 2) technological improvements in genetic sequencing of organisms, 3) providing digital access to taxonomic literature and associated archives, 4) the engagement of citizens, indigenous peoples, and local communities in observation and documentation, 5) enabling conservation of all branches of the Tree of Life by recognizing the evolutionary framework underlying taxonomy by incorporating phylogenetic and systematics information with spatial data, and 6) enabling improved management, assessment, and surveillance to prevent negative impacts on biodiversity and human well-being. We kept these opportunities in mind as we generated the suggested future work in the section below.

As noted in the introduction, for invertebrates we are in both the era of exploration and the era of restoration (ecology). Ideally, we should design our surveys to inform both at the same time. Yet it is notoriously difficult to isolate the determinants of change in arthropod assemblages. Flower visitors, for example, vary significantly between and even within a population, depending on weather conditions, sun exposure, plant composition and density, and the suite of active insects (e.g. Herrera 1995, Schurr et al. 2019). Variability is "the norm rather than the exception", making it difficult to separate the signal of an effect from the noise of this variability (Gaston & Lawton 1988, Didham et al. 2020). Solutions include using a relatively large number of samples that are repeated multiple times per year, monitoring across a gradient of disturbance, pairing plots, and measuring multiple covariates (such as climate data) that can be included in the analysis and help to separate the signal from the noise (Williams et al. 2001, Winfree et al. 2011, Andrew et al. 2013, Didham et al. 2020). Still, many years of data may be required to detect an effect (White 2019). Focusing analyses on functional groups, which combine multiple taxa, rather than species may increase our ability to detect change (Williams et al. 2001).

A combination of significant gaps in our taxonomic knowledge and a shortage of trained taxonomists to fill this need together form what has been called the "taxonomic impediment" (de Carvallo et al. 2007; Scotland et al. 2003). For future work, invertebrate groups which have active taxonomists in California should be prioritized, to ensure that specimens are properly identified and curated. The availability of experts will be important not just for groups to study in the future, but also for utliizing existing island collections. Taxonomic specialists that are the authors' active island collaborators include experts in the Coleoptera (especially Melyridae, Scarabaeidae, and Carabidae), Diptera (especially Tipulidae, Mycetophilidae, Phoridae, Bombyliidae, and Syrphidae), Lepidoptera, Orthoptera, Hymenoptera (including Formicidae, Apoidea, Sphecodea, and various parasitic families), Arachnida (especially Salticidae, Opiliones), Hemiptera (including Aphidoidea, Auchenorrhyncha, and Heteroptera), and Psocodea.

Suggested Future Work

Digitize high-priority, well identified collections, like the Orthoptera (Rentz and Weissman 1982) and Lepidoptera (Powell 1994). Include host plant information where available, including Dr. Powell's large paper files of island data. These data should be georeferenced. In addition, island centroids should be recitified to actual locations where possible (records and institutions summarized in **Appendix A**).

Inventory and identify selected high-quality historic collections**.** Because the quality of identifications in island invertebrate collections is often suboptimal, digitization of these collections without taxonomic assessment would only propagate such errors. As Scott Miller recently stated, "I trust very little now at the species level without a DNA barcode or a genitalic dissection." Focal groups should be chosen that are either already grouped together as Island specimens or readily drawn out of a more general collection. Examples would be the LACM Channel Islands Biological Survey specimens, or Island collections at the SBMNH (such as general arthropod/invertebrate surveys for several islands, bees, earwigs, and Sphecid wasps). For some groups in particular, like the Dermaptera, genetic work can help to clarify taxonomic mysteries. For some taxa with specific curation needs, historic data will not be as useful as new data – for example, Brian Brown would prefer fresh material for his focal group, the Phoridae. While other potential sources of already-collected island invertebrate material exist (including eagle, fox, and warbler diet studies, NPS coverboard surveys, USGS pitfall arrays), these may not be curated to the standards of entomological specialists.

Initiate new surveys. We recommend a three-pronged approach to future survey work if resources allow:

1. Repeat historic surveys for selected taxonomic groups that are well-known, contain a high proportion of endemic taxa, represent different ecosystem functions, and for which the work is logistically feasible. Comparisons of abundance and specific distributions will not be possible given the resolution of the data that are generally available, but by mirroring the level of effort and sampling locations, species lists could be compared. Ants (Formicidae), ground beetles (Carabidae), Orthoptera, selected indicator/endemic Lepidoptera, bees (Apoidea), sphecid wasps (Sphecidae), and robber flies (Asilidae) would be good candidates. Careful design of these surveys will enable comparison of past to present, and future conditions. Employing a large number of multi-year samples, with simple, quantifiable, and repeatable monitoring protocols will give the best chance of discerning changes with future conditions.
2. Conduct Malaise trapping surveys to increase our knowledge of important groups exhibiting gaps in coverage, such as the parasitic Hymenoptera and virtually any of the families of smaller Diptera (Cecidomyiidae, Ceratopogonidae, Phoridae, Sciaridae, Sphaeroceridae, etc.). Identify and barcode these taxa to the best of our ability to build a genetic library, then monitor more easily in the future via mass processing and DNA barcoding technology. Incorporate measurement of volume/biomass in this monitoring protocol as a measure of ecosystem health.
3. Initiate focused work for a selected group(s) of poorly known yet ecologically important and tractable taxa. We suggest the bee flies (Bombyliidae) and flower flies (Syrphidae). They are important (often generalist) pollinators in dryland regions (Kastinger and Weber 2001), with different ecosystem functions at different life stages (Bombyliidae larvae are parasitoids of other insects, while Syrphidae larvae are typically predators or saprotrophs). Generalist pollinators are important for maintaining network structure and function, as they are more likely to persist in time and space (Resasco et al. 2021). Flower flies are also often used as environmental indicators (e.g. Schweiger et al. 2007). These two fly families are also charismatic, making them good candidates for iNaturalist challenges, which would be a good way to monitor bee and butterfly taxa as well.

Make this work go farther by gaining ecological information such as ecosystem health assessment or interactions with plants, birds, or other organisms. Rick et al. (2014) argue convincingly that long-term, interdisciplinary research can inform conservation decisions such as rare species conservation and building resilience to global change. The above surveys could be performed in paired locations to assess the impacts of invasive species and/or benefits of habitat restoration and management actions, as was done in Knapp et al. (2018). This would be a good way to show changes with recovery following non-native animal removal, especially as biogeographic surveys in the 1970s/1980s were conducted during what was arguably the peak period of impact. Surveys can also be designed to gather plant and other associations at the same time, as with surveys recently performed on San Clemente Island. Invertebrate trends could be tied to those of other taxonomic groups such as island endemic birds, lizards, mice, skunks, and foxes utilizing metabarcoding of scat or linked study designs. For example, insect declines in Denmark were related to both the abundance of barn swallows and the rate at which they fed their nestlings (Moller 2019).

Pollinator network approaches are a good way to increase our understanding of key invertebrates and priority plants at the same time, and allow for conservation research to extend beyond single pairs of interacting species to look at community-level cascading effects of environmental disturbance and species loss on interactions. The structure of such networks determines the nature of coextinction cascades (Bascompte and Stouffer 2009, Kaiser-Bunbury and Bluethgen 2015). This approach would cover key groups already mentioned, like bees, butterflies and moths, and bee flies and flower flies, as well as soft-wing flower beetles (Melyridae), which are a focus of the current SBMNH Entomology Curator. We have good reason to believe that pollinator populations are more abundant on the islands than on the mainland, which would be an interesting comparison.

Another unique opportunity on the islands is to study the interactions of insects with the large colonies of marine birds and mammals. The large accumulation of dead bodies and dung provides a little-studied influx of nutrients from the ocean to the terrestrial realm (Hentati-Sundberg et al. 2020). These resources are further distributed by the many scavenging flies and beetles that help to break them down. The ecology and fauna of these interactions are not commonly studied, due to the protected status of most such colonies and the unglamorous nature of the work, but we expect that their study would yield interesting results (e.g. Smith 1981), especially since most carrion and dung studies are based on experiments done with domestic animals in low density situations.

The California Channel Islands are an outstanding natural resource for the study of natural processes. They require basic inventory work for many invertebrate groups, but with what is already known, there are opportunities for interesting in-depth studies and comparisons with past studies as well. Such studies will undoubtedly reveal a plethora of new taxa, many of them endemic and new to science. Comparisons with the better-known mainland will allow better understanding of the historical processes that have shaped the fauna, in addition to the effects of their continuing isolation. As the islands recover from decades of overgrazing, they should also be a laboratory for conservation biology. There is still a lot to be done.

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