Assessing the History of Reptile and Amphibian Specimen Collecting on California's Channel Islands

Final Report

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INTRODUCTION

California's Channel Islands are home to at least 14 non-marine reptile and 5 amphibian species (Table Reptilia-1, Amphibia-1). The main islands vary from having a single species on Santa Barbara Island to at least 13 species on Catalina Island. The Channel Islands' reptile and amphibian fauna includes a number of ecologically and/or evolutionarily interesting taxa including lineages that are endemic to one or several islands, that show dramatic island dwarfism or gigantism, and/or that are of conservation concern. The best studied island endemic is the Island Night Lizard (*Xantusia riversiana*) which is found only on the southern islands of San Clemente, Santa Barbara, and San Nicolas. The Northern Channel Islands are also home to several endemic lineages including the Channel Islands Slender Salamander (*Batrachoseps pacificus*) which is found across all the main northern islands. The Island Fence Lizard (*Sceloporus occidental becki*), which occurs on San Miguel, Santa Rosa, and Santa Cruz Islands, is also an endemic taxon; it is variously treated as a subspecies of the Western Fence Lizard, or as a distinct species. The final island endemic is the Santa Cruz Island Gophersnake (*Pituophis catenifer pumilus*), which is found on Santa Rosa and Santa Cruz Islands.

The Channel Islands herpetofauna is also remarkable for several known or hypothesized examples of island dwarfism and gigantism. The Santa Cruz Island Gophersnake (*P. c. pumilus*) as well as the Western Yellow-bellied Racer (*Coluber constrictor mormon*) show dramatic size reductions on the Northern Channel Islands relative to their mainland relatives (Sparkman et al., 2018). Gophersnakes on Catalina Island are considered the same subspecies as their adjacent mainland conspecifics (*P. c. annectens*), but the island snakes show reduced body size, although not nearly as dramatically as in *P. c. pumilus* (Pauly, unpubl. data). Island Night Lizards (*Xantusia riversiana*) are much larger than their mainland congeners although whether these are true island giants or inherited large size from their ancestor remains unresolved (see Noonan et al., 2013). Similarly, the Channel Islands Slender Salamander is larger than its mainland relatives, as is the Island Fence Lizard and the Side-blotched Lizard (*Uta stansburiana;* Mahoney et al., 2003; Pauly, unpubl. data).

Despite the occurrence of these endemic lineages and examples (or possible examples) of island dwarfism and island gigantism, the evolution, ecology, and natural history of most of the island populations have been little studied. Notable exceptions include ecological studies on the Island Night Lizard, *X. riversiana* (Goldberg and Bezy, 1974; Fellers and Drost, 1991; Mautz, 1993; Fellers et al., 2008) and recent work on *P. c. pumilus, C. constrictor,* and *E. multicarinata* (Sparkman et al., 2018). *Xantusia riversiana* was on the Federal List of Endangered and Threatened Wildlife from 1977 until 2014 (USFWS, 2014), and much of the work on this species was driven by conservation interest. Nevertheless, for most of the Channel Island reptiles and amphibians, little has been published about the ways in which island populations are similar or different from their mainland relatives (e.g., in diet, in reproductive ecology, morphologically, or genetically). Similarly, although the islands have experienced dramatic changes in habitat with the introduction and subsequent removal of non-native mammals, including rats, feral cats, and various ungulate species, no studies have explicitly examined the ecological impacts of these habitat changes on island reptiles and amphibians. So far, only a few genetic studies have examined demographic impacts of historical landscape management practices by testing for genetic bottlenecks (Holmes et al., 2016; O'Donnell et al., 2018; Trumbo et al, 2021).

There is a need for more studies that examine the level of differentiation within islands, between island and mainland populations, and among populations inhabiting different islands. This work is critical for identifying the colonization history of island species and in determining which island lineages should be a focus for conservation and management. For example, Adams et al. (2018) examined 172 *X. riversiana*

museum specimens collected between 1911 and 2014 to assess divergence among the three main island populations. This work highlighted the distinctiveness of the San Nicolas Island population arguing that they should be recognized as a distinct lineage (*X. r. riversiana).* Because night lizards occur at far lower densities on San Nicolas Island than on San Clemente or Santa Barbara Islands, these authors advocated that this lineage should receive greater conservation attention. As another example, Trumbo et al. (2021) examined genetic variation in Island Fence Lizards on Santa Cruz Island. This study was possible because of recent collecting activity to generate both museum specimens and tissue samples. These authors found that the effective population size was on par with island species that are currently of far greater conservation concern, indicating the need for increased conservation attention directed towards this lizard.

The opportunity to conduct future studies and assessments on the ecology, evolution, and conservation of Channel Islands reptiles and amphibians depends upon the availability of specimens and tissue samples. Here, we conduct an analysis of temporal, spatial, and taxonomic gaps in herpetofaunal specimens across the Channel Islands (not including marine reptiles, e.g., sea turtles). Our goal is to identify any gaps in collecting activity that could be targeted with additional fieldwork to ensure that the conservation biologists and landscape managers of the future have the specimens and knowledge to make informed management decisions (see also Boser et al., 2018). One of the most common uses of museum specimens is for the locality data linked to the specimen collecting event. In recent years, digital community science platforms like iNaturalist aggregate photo-vouchered observations that also provide similar data documenting where and when species were observed. Although these photo vouchers do not have the same utility as museum specimens, which can also be used for genetic studies and studies of diet, parasites, body condition, and reproductive condition, the photo-vouchers still provide management-relevant information. Thus, we also include iNaturalist photo-vouchered observations in this analysis.

METHODS

Two 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. 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 two data sources were used for these analyses are: 1) natural history museum specimen records available through the Global Biodiversity Information Facility (GBIF: gbif.org), and 2) iNaturalist observation data. 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 only "research grade" iNaturalist observations (www.iNaturalist.org). To be research grade, an observation must have a photographic voucher, a community-supported identification, and date and locality data. All iNaturalist observations are from prior to July 5, 2021.

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 (5,214 reptile records and 4,037 amphibian records), an Island Name field was generated from a combination of place names where given, and coordinates (using scripts in ArcGIS) where not. All “obscured” iNaturalist observations could still be correctly assigned to each island for our analyses. 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. One of us (GBP) provided current taxonomy, which was synonymized in the database by inserting acceptedFamily, acceptedGenus, and acceptedName fields.

Initial specimen data were scrutinized for possible errors, such as incorrect collection dates and incorrect localities. Simple errors such as duplications or specimens incorrectly attributed to the Channel Islands were corrected (e.g., specimens listed as being from Santa Catalina Island, California that were actually collected on Isla Santa Catalina, Baja California Sur). When possible, we also tried to resolve more complicated errors, such as specimens with unknown or incorrect collection dates. Although correcting these errors is beyond the project scope of work, as collections-focused scientists, we felt it was important to try and correct these errors. Thus, one of us (GBP) contacted curators and collections managers at relevant institutions to obtain collection catalogs, field notes, or other information needed to resolve questionable records. These efforts allowed us to determine that some specimens listed as being from the Channel Islands were actually from mainland locations. An especially common error results from a bug in how data are shared between Arctos collection databases and GBIF. When collection dates are unknown, Arctos allows specifying the earliest and latest possible collection dates. Earliest dates are often considered the earliest known specimen in a given collection (usually early- to mid-1800s), and latest dates are treated as the date a collection was entered into Arctos (usually in the 2010s). Unfortunately, in transferring data to GBIF, the earliest collection date is then treated as the actual collection date, resulting in specimens incorrectly listed as being some of the earliest collected from the Channel Islands. These entries were re-classified as having unknown collection dates for our analyses.

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 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 A** to facilitate improvement of the original museum data.

RESULTS

Overview —GBIF records included 4,347 reptile and 3,896 amphibian specimens (Table Reptilia-2; Table Amphibia-2); these were collected between 1861 and 2015 (Fig. Reptilia-1; Fig. Amphibia-1). It is likely that additional specimens have been collected more recently than 2015, but these have not yet been uploaded to GBIF. An additional 864 reptile and 141 amphibian observations were available through iNaturalist. The iNaturalist platform was created in 2008, and nearly all of the iNaturalist observations are from 2008 to the present (Fig. Reptilia-1; Fig. Amphibia-1). However, some users have also uploaded older photos; as a result, iNaturalist observations from the Channel Islands extend back to 1985.

Seventeen species of reptiles (not including sea turtles) have been documented on the Channel Islands in recent times (Table Reptilia-1, 2). Fourteen species are represented by museum specimens, and 11 species are represented by iNaturalist observations. Four rarely-observed species are only represented by museum specimens, and the non-native Red-eared Slider (*Trachemys scripta elegans*) is the only species for which there are photo vouchers on iNaturalist but no museum specimens (Table Reptilia-1, 2).

Eight species of amphibians have been documented on the Channel Islands in recent times (Table Amphibia-1, 2). Museum specimens have been collected for seven of these eight species, and iNaturalist observations have been made for all five amphibian species that are extant on the Channel Islands.

Temporal Patterns —From the late 1800s to World War II, reptile and amphibian specimens were infrequently collected from the Channel Islands except during dedicated survey efforts (Fig. Reptilia-1; Fig. Amphibia-1). Large numbers of museum specimens were collected by the California Academy of Sciences 1911–1919 and during the Channel Islands Biological Survey, which was run by the Natural History Museum of Los Angeles County (LACM; 1939–1941). Following World War II, specimens were deposited into museums on a more regular basis through the 1970s. Efforts by David Wake and students at the Museum of Vertebrate Zoology, University of California Berkeley studying *Batrachoseps* salamanders on Santa Cruz led to 1036 amphibians collected in 1974, resulting in 26.6% of all amphibian specimens collected from the Channel Islands. The peak collecting year for reptiles was in 1972, largely due to efforts by Bob Bezy and Steve Goldberg at the LACM collecting *X. riversiana.* Starting in the late 1970s, there was a dramatic drop in specimen collecting that continued for three decades. Specimen collecting then increased again in the 2010s primarily due to work by one of us (GBP) at the LACM in collaboration with W. Christopher Funk at Colorado State University and Jeanne M. Robertson at California State University, Northridge. These efforts were motivated by the need for recent specimens that could provide tissue samples as well as specimens that could be compared to existing, older museum specimens.

The growth of iNaturalist in recent years has resulted in the rapid increase in photo vouchers of Channel Island reptile and amphibian species (Fig. Reptilia-1; Fig. Amphibia-1). This is especially pronounced for the reptiles, with 293 iNaturalist observations made in 2019, the most recent year before the COVID-19 pandemic.

For the reptiles, most specimen and photo observations have been made during the spring and summer months when these species are most active, although records occur for nearly every month on each island (Fig. Reptilia-2). For the amphibians, seasonal coverage is spottier with few records from late summer and fall. This pattern is expected because amphibians are less active on the surface during the driest periods of the year (Fig. Amphibia-2).

Spatial Patterns —Museum specimens and iNaturalist observations have been collected from all of the Channel Islands (Table Reptilia-1, 3, Table Amphibia-1, 3; Fig. Reptilia-3, 4, 5; Fig. Amphibia-3, 4, 5). The largest number of specimens have been collected from San Clemente Island, where 1680 Island Night Lizards and 660 Side-blotched Lizards have been collected (avg. 1170 specimens/species; Table Reptilia-1; Fig. Reptilia-3a). When considering the number of observations relative to island size, Catalina, Santa Cruz, San Miguel, and Santa Rosa are the least sampled for reptiles (Table Reptilia-3; Fig. Reptilia-3b). For amphibians, Santa Rosa Island is also the least sampled relative to island size (Table Amphibia-3; Fig. Amphibia-3b).

Collecting efforts have also been uneven across each island. When overlaying each island in 1-km grid squares, all have at least 50% of grid squares without a single specimen (i.e., collecting event; Table Reptilia-3; Table Amphibia-3). Further, except for Anacapa, all islands lack reptile specimens for 73.3–86.3% of grid squares (Table Reptilia-3) and lack amphibian specimens for 84.7–90.5% of grid squares

(Table Amphibia-3). In some cases, these sampling biases likely reflect underlying distributions and available habitat; for example, the sparsely vegetated, windswept, western portion of San Miguel Island is likely poor habitat for Island Fence Lizards and Channel Island Slender Salamanders. However, in many other cases, these biases likely reflect a lack of collecting effort, especially in areas that are further from roads and trails. For example, on Santa Cruz Island, most sampling sites have been along or adjacent to the roads, especially from Prisoner's Harbor to the Stanton Ranch area and UC Field Station, and west along the Central Valley; very few collections have been made on the slopes of the two mountain ranges framing the Central Valley (Fig. Reptilia-5; Fig Amphibia-5). Similarly, sampling sites on San Miguel Island are largely on the eastern end of the island near the primary structures, such as Rancho Rambouillet, the ranger station, Cuyler Harbor, and the airfield (Fig. Reptilia-5; Fig Amphibia-5). Many of the sampling sites further west on San Miguel Island were from recent intentional efforts by GBP to sample the western end of the island. Collecting activity also decreases towards the south on San Clemente Island and towards the west on San Nicolas Island, again consistent with declining collecting activity further from the main buildings and centers of activity (Figure Reptilia-5).

Not surprisingly, iNaturalist observations are most common on those islands with the most public access (e.g., Santa Cruz, and Santa Catalina, as well as Anacapa Island when controlling for area), but people visiting the Navy islands (San Clemente and San Nicolas) are also posting observations to iNaturalist (Table Reptilia-1, Table Amphibia-1; Fig. Reptilia-3, 4; Fig. Amphibia-3, 4). San Miguel Island, with the most challenging access, has only six iNaturalist observations (Table Reptilia-1, Table Amphibia-1). Santa Barbara Island also has very few iNaturalist observations (n = 6). This is understandable because the only reptile or amphibian there is the Island Night Lizard; this species is rarely observable on the surface and few visitors have permission on this National Park Service (NPS) island to disturb rocks or other items in search of this species.

Taxonomic Patterns —Amphibian specimens are collected more than reptile specimens (on a per species basis), but the reverse is true for iNaturalist observations for which reptiles are photographed more often (Table Reptilia-1, 2; Table Amphibia-1, 2). For each of the five islands on which amphibians occur, between 182 and 743.3 museum specimens have been collected for each established amphibian species (Table Amphibia-1). In contrast, seven of the eight islands on which reptiles occur have lower per-species collection rates. Only San Clemente Island, from which many Side-blotched Lizards and Island Night Lizards have been collected, has more specimens per species (avg = 1170 specimens/species) than for the amphibians (Table Reptilia-1).

Channel Island reptiles are documented via iNaturalist much more frequently than are the amphibians (864 vs 141 observations). Most amphibian observations are of the Pacific Treefrog, which can be located visually or acoustically and also can be found congregating at edges of ponds and reservoirs. Slender salamanders are usually found under cover objects, and few iNaturalist users visiting the islands, especially the NPS islands, are likely to be checking under rocks and other debris. The reptiles, however, are more likely to be active during the day, including basking in conspicuous locations where they can be photographed.

Specimen Preparations —Reptile and amphibian specimens can be prepared as standard fluid-preserved specimens, as a skeleton (including partial skeletons such as only the skull), or as a study skin. Anuran tadpoles may also be preserved. For some preparations, a single individual can yield multiple preparations such as a skin and skeleton. Tissue samples may also be taken separately (e.g., tail snips and toe clips) with the animal then released or may be taken prior to a specimen being fluid-preserved.

Assessments of preparation type should be interpreted cautiously. Individual museums may categorize preparations differently, especially when documenting multiple preparations from a single specimen. For

example, for most Channel Islands specimens collected in the last two decades, tissue samples were also taken, but GBIF data do not always indicate that a tissue and a specimen exist for the same individual. Further, many museums maintain separate tissue collections that include tissues for which no specimen was collected (e.g., tail clips or toe clips with the animal then released, or salvaged specimens for which a tissue was collected but the body was not worth preserving). These tissue collections may be maintained in an independent database that is not shared with data aggregators like GBIF. Thus, the number or tissue samples and multiple preparations reported here are underestimates of the true numbers.

Despite the likelihood that tissues are underestimated in our tallies, the overall patterns are quite clear—the vast majority of collections are due to whole-body specimens (Table Reptilia-4; Table Amphibia-4). Tissue samples are much less common. These results are to be expected because maintaining separate tissue samples only started in the late 1960s with the development of allozyme methods and only became commonplace with the popularization of Sanger sequencing in the late 1990s. As demonstrated in Fig. Reptilia-1 and Amphibia-1, very few specimens were collected from the Channel Islands between the mid-1970s and about 2011. Thus, it is only in the past decade that new specimens have been added to collections and more extensive tissue collections have been developed.

Table Reptilia-1. The number of occurrence records for each reptile species by island. Occurrences are given as number of museum specimens (Cal-IBIS) / number of Research Grade iNaturalist observations. Shaded cells indicate that this species is established on this island. Bolded values indicate species that are known to be recent introductions. Notes below the table are indicated by N and the note number.

Scientific name	Common name	Catalina	Clemente	Nicolas	Barbara	Miguel	Rosa	Cruz	Anacapa
Emys marmorata	Western Pond Turtle					1/0		1/0 (N1)	
Trachemys scripta	Red-eared Slider	**0/1**						0/1 (N7)	
Elgaria multicarinata	Southern Alligator Lizard	112/39	N2	**10/9**		57/3	77/13	164/41	54/1
Sceloporus occidentalis becki	Island Fence Lizard					29/3	66/27	136/69	
Uta stansburiana	Side-blotched Lizard	427/138	660/70	**19/9**			N8	290/203	52/24
Plestiodon skiltonianus	Western Skink	8/9							
Xantusia vigilis	Desert Night Lizard	**1/0 (N3)**							
Xantusia riversiana	Island Night Lizard		1680/66	262/17	72/6				
Coluber constrictor mormon	Western Yellow-bellied Racer							30/2	
Diadophis punctatus	Ring-necked Snake	12/8							
Hypsiglena ochrorhyncha	Coast Nightsnake							**1/0**	
Lampropeltis getula californiae	California Kingsnake	12/15							
Lampropeltis multifasciata	Coast Mountain Kingsnake	Note4							
Pituophis catenifer	Gophersnake	11/27	**0/1 (N5)**				22/1	39/31	
Thamnophis elegans	West. Terrestrial Gartersnake						1/0		
Thamnophis hammondii	Two-striped Gartersnake	3/0							
Crotalus oreganus helleri	Southern Pacific Rattlesnake	38/30	N6						
	Total No. of occurrences	624/267	2340/137	291/35	72/6	87/6	166/41	660/346	106/25
	Avg. No of specimens per established species	62.4	1170	97	72	43.5	41.5	131.8	53

Notes

0. A single deceased *Emys marmorata* was found washed up on the southwest side of Santa Cruz Island; it has been catalogued into the SBMNH collection, but those data were not added to GBIF or VertNet in time for inclusion in this analysis (P. Collins, pers. comm.).
1. SDNHM 18544 is reported as being collected by Chapman Grant in 1948 from San Clemente Island. Presumably this is an introduction or an error. Investigations into the history of this specimen are continuing.
2. A single *Xantusia vigilis* (SDNHM 20121) was collected from Catalina Island May 26, 1933 and is presumed to be introduced (Savage, 1952).
3. *Lampropeltis multifasciata* was first reported from Catalina in 1910, subsequently photographed in 1999 and videoed in 2015 (Backlin et al., 2004; Hansen et al., 2015).
4. Theodore Reddick (Channel Islands Biological Survey, Progress Report, 4/1/39–4/8/39 [p. 19]) reported that on April 4, 1939 Marines killed an 18-inch long snake in the hills behind Pyramid Cove. Based on verbal descriptions, he believed the snake was a *P. catenifer* but the carcass could not be found on April 5 after he learned of the observation. He presumed it was introduced with military shipments from the mainland. A *P. catenifer* was also documented on San Clemente on May 11, 2006 (iNaturalist 41257885). It was believed to have been a stowaway, transported to the island via a barge on May 10 or 11, 2006.
5. A single *C. o. helleri* (MVZ 43716) is listed as being collected on San Clemente Island. This is presumably an error, but there is little supporting collections information to determine the source of this error. Investigations into the history of this specimen are continuing.
6. A single shell of a *Trachemys scripta* was photographed on Santa Cruz Island (iNaturalist 56583599). The shell was found by island visitors on the beach at Chinese Harbor and taken to the ranger cabin. Although the Red-eared Slider, *T. s. elegans,* is widespread on the mainland and is the likely subspecific identification for this shell, we only identified it to species level due to lack of diagnostic characters on the available remains.

7. There is one iNaturalist observation of *Uta stansburiana* that plots to Santa Rosa Island, where this species is not known to occur. iNaturalist 14316853 appears to be plotted to the generic locality “Channel Islands National Park” which just happens to plot to Santa Rosa Island. This lizard was likely observed on Santa Cruz and is a locality error. Attempts to contact the observer have not succeeded. This observation was originally “research grade,” but has since been downgraded following a careful review by GBP.

Table Reptilia-2. The number of occurrence records for each island reptile species or subspecies by data source shows the relative proportion of specimens (Cal-IBIS) and observations (Research Grade iNaturalist).

Order	Family	Species	Cal-IBIS	iNaturalist	Sum
Testudines	Emydidae	*Emys marmorata*	1	0	1[1]
		Trachemys scripta	0	2	2
Squamata	Anguidae	*Elgaria multicarinata*	475	106	581
	Colubridae	*Coluber constrictor mormon*	30	2	32
		Diadophis punctatus modestus	12	8	20
		Hypsiglena ochrorhyncha klauberi	1	0	1
		Lampropeltis getula californiae	12	15	27
		Pituophis catenifer[2]	0	1	1
		Pituophis catenifer annectens[2]	11	27	38
		Pituophis catenifer pumilus[2]	61	32	93
		Thamnophis elegans	1	0	1
		Thamnophis hammondii	3	0	3
	Phrynosomatidae	*Sceloporus occidentalis becki*	231	99	330
		Uta stansburiana	1448	444	1894
	Scincidae	*Plestiodon skiltonianus*	8	9	17
	Viperidae	*Crotalus oreganus helleri*	39	30	69
	Xantusiidae	*Xantusia riversiana reticulata*	1752	72	1824
		Xantusia riversiana riversiana	262	17	279
All Reptilia			**4347**	**864**	**5213**
Species Diversity			**14**	**11**	**15**

[1]A second *Emys marmorata* was documented on the southwest side of Santa Cruz Island. It was catalogued into the SBMNH collection, but those data were not added to GBIF or VertNet in time for inclusion in this analysis.
[2]*Pituophis catenifer* are listed to subspecies, with *P. c. annectens* on Santa Catalina and *P. c. pumilus* on Santa Cruz and Santa Rosa Islands. The single iNaturalist observation is of a snake observed on San Clemente Island that was considered an introduced animal; this individual has not been confidently identified to subspecies.

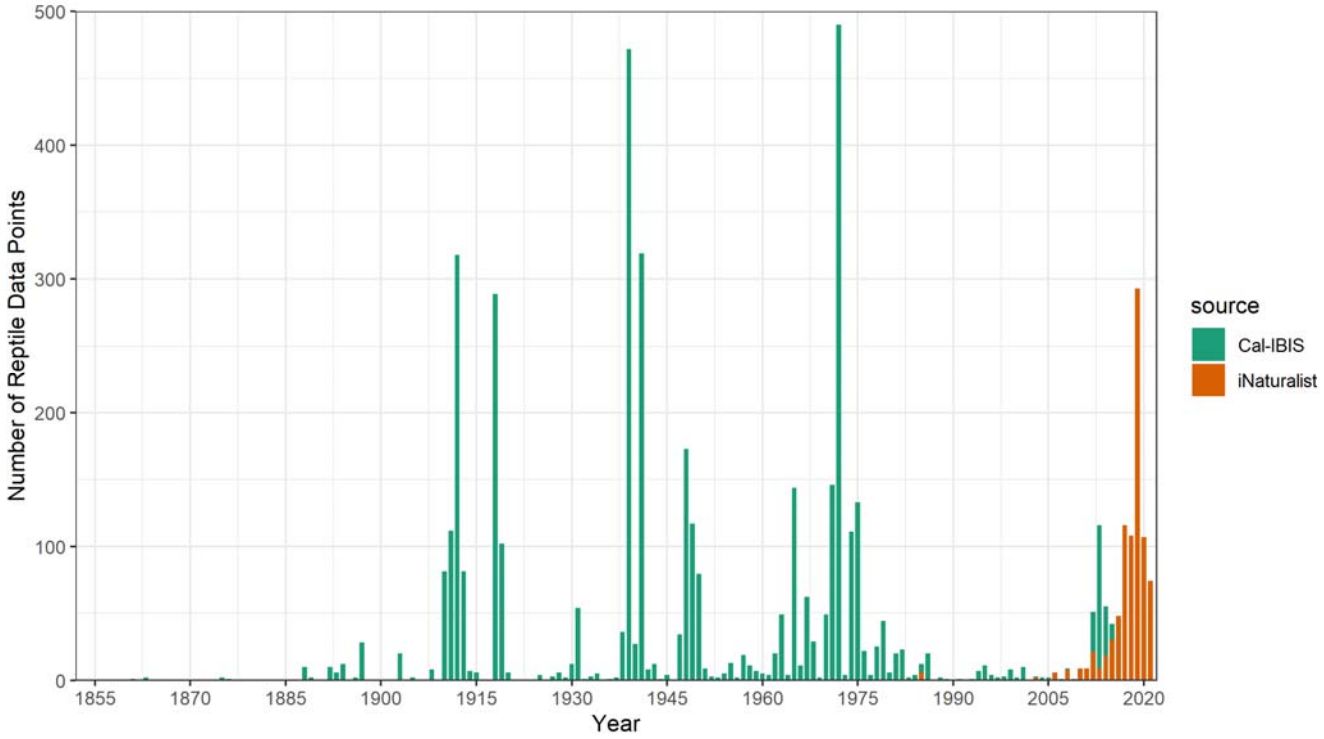


Figure Reptilia-1. The number of island reptile occurrence records by year and data source reveals temporal gaps in the data.

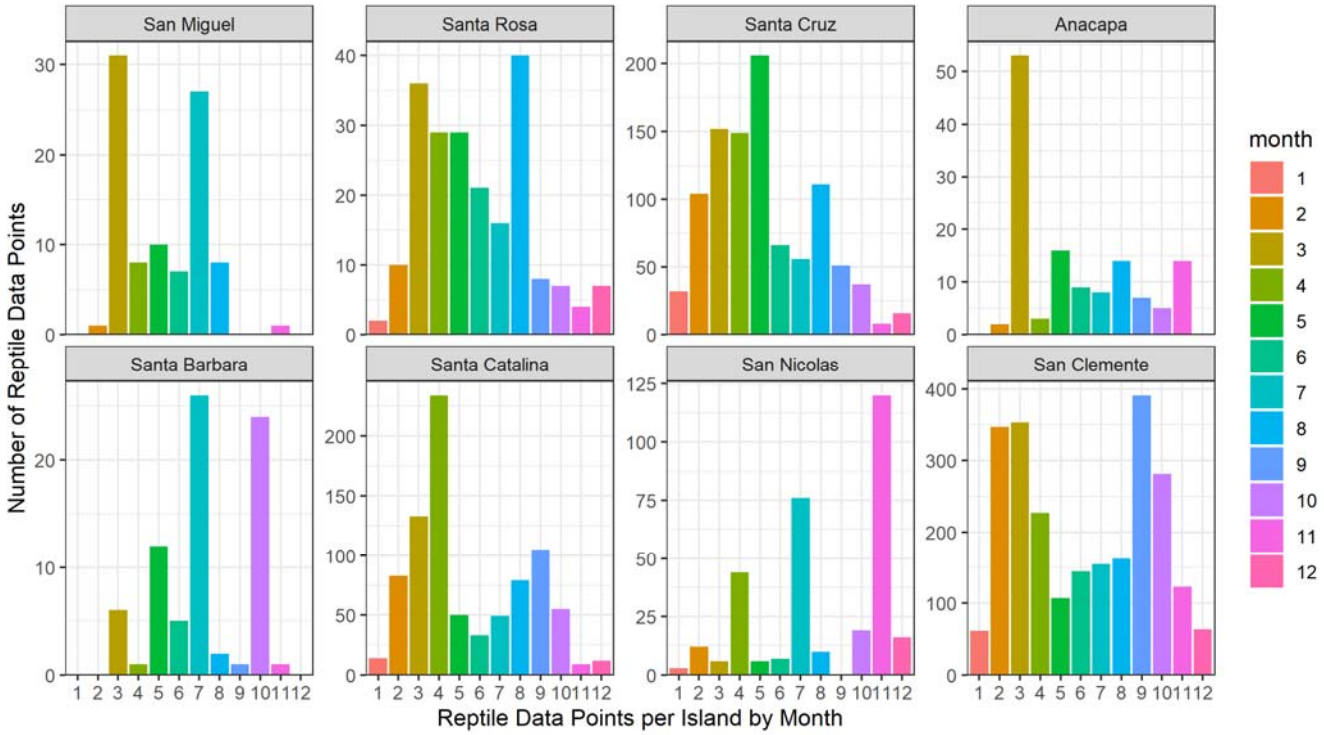
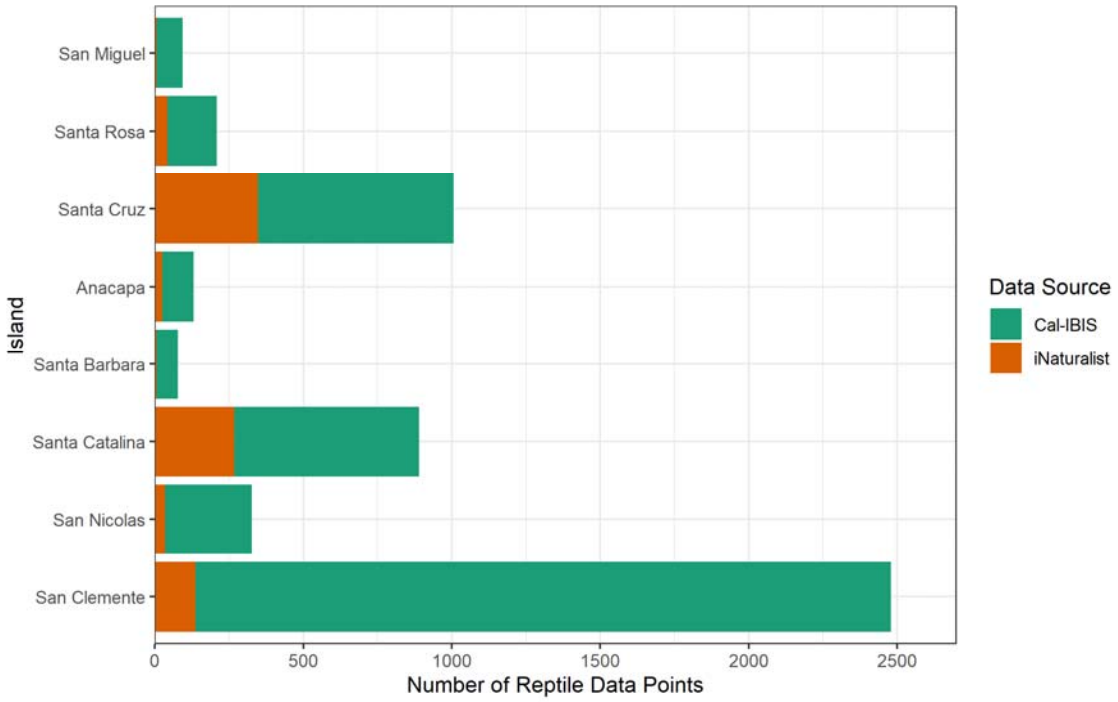


Figure Reptilia-2. The number of island reptile occurrence records by month, by island, reveals seasonal gaps in the data.

(a)



(b)

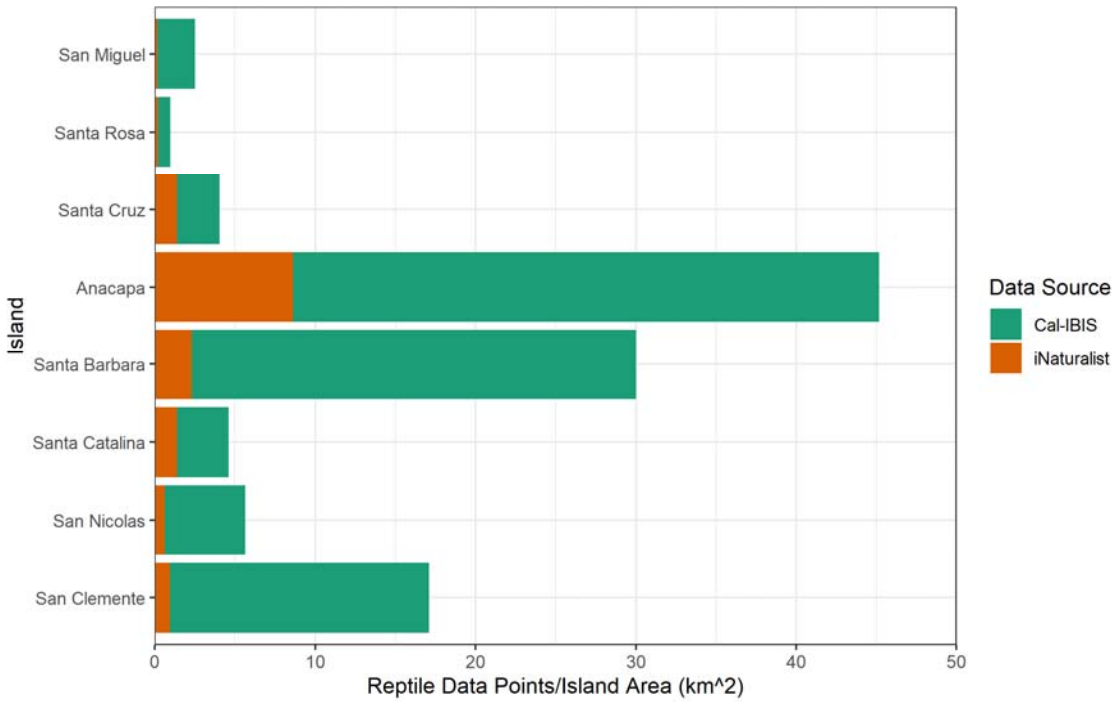
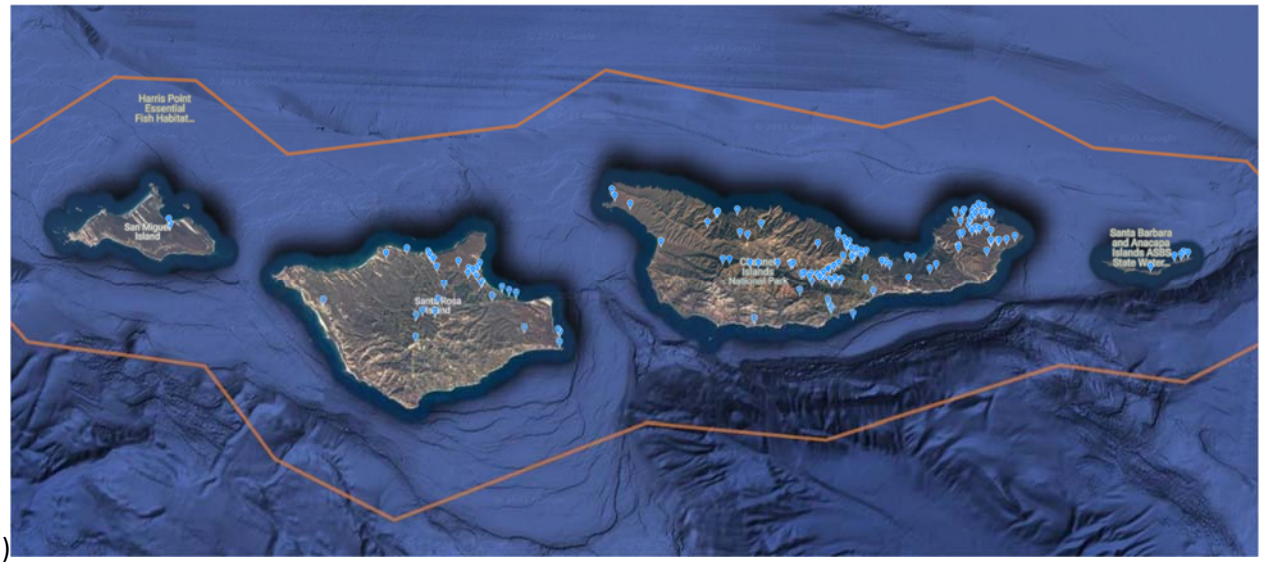


Figure Reptilia-3. The (a) absolute number and (b) proportional number/island size of reptile occurrence records on each island by data source reveals spatial gaps in the data.

(a)



(b)

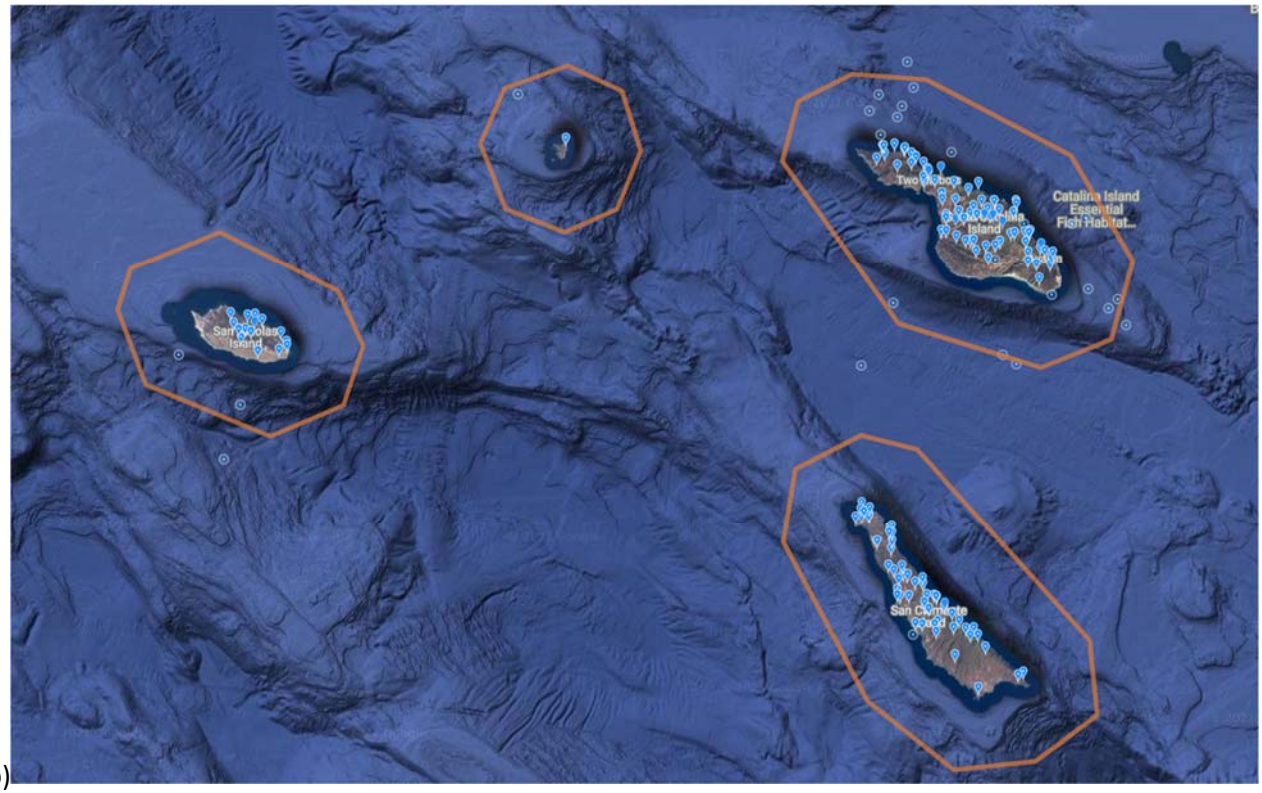


Figure Reptilia-4. Distribution of iNaturalist reptile observations on (a) the Northern Islands and (b) the Southern Islands. Drops represent “open” observations for which the plotted location is the actual observation location; circles are “obscured” observations for which the plotted location is offset from the actual observation location.

Table Reptilia-3 & **Figure Reptilia-5**. Spatial specimen collecting effort based on 1 km grid cells overlaid onto each of the eight California Channel Islands. A total of 2,888 records were included (4,356 records had coordinates, but some were removed because locality information did not match the coordinates or they were obvious centroids). Note that the color scale varies for each island.

Island	Island Collections	1 km^2 cells	Empty 1 km^2 cells	% empty cells	Mean records/cell
Anacapa	106	14	7	50.0%	15.1
Santa Cruz	660	313	264	84.3%	13.5
Santa Rosa	166	263	227	86.3%	4.6
San Miguel	85	61	48	78.7%	6.5
Santa Catalina	639	250	202	80.8%	13.3
San Clemente	2323	198	155	78.3%	54.0
San Nicolas	291	81	66	81.5%	19.4
Santa Barbara	72	11	8	72.7%	24.0

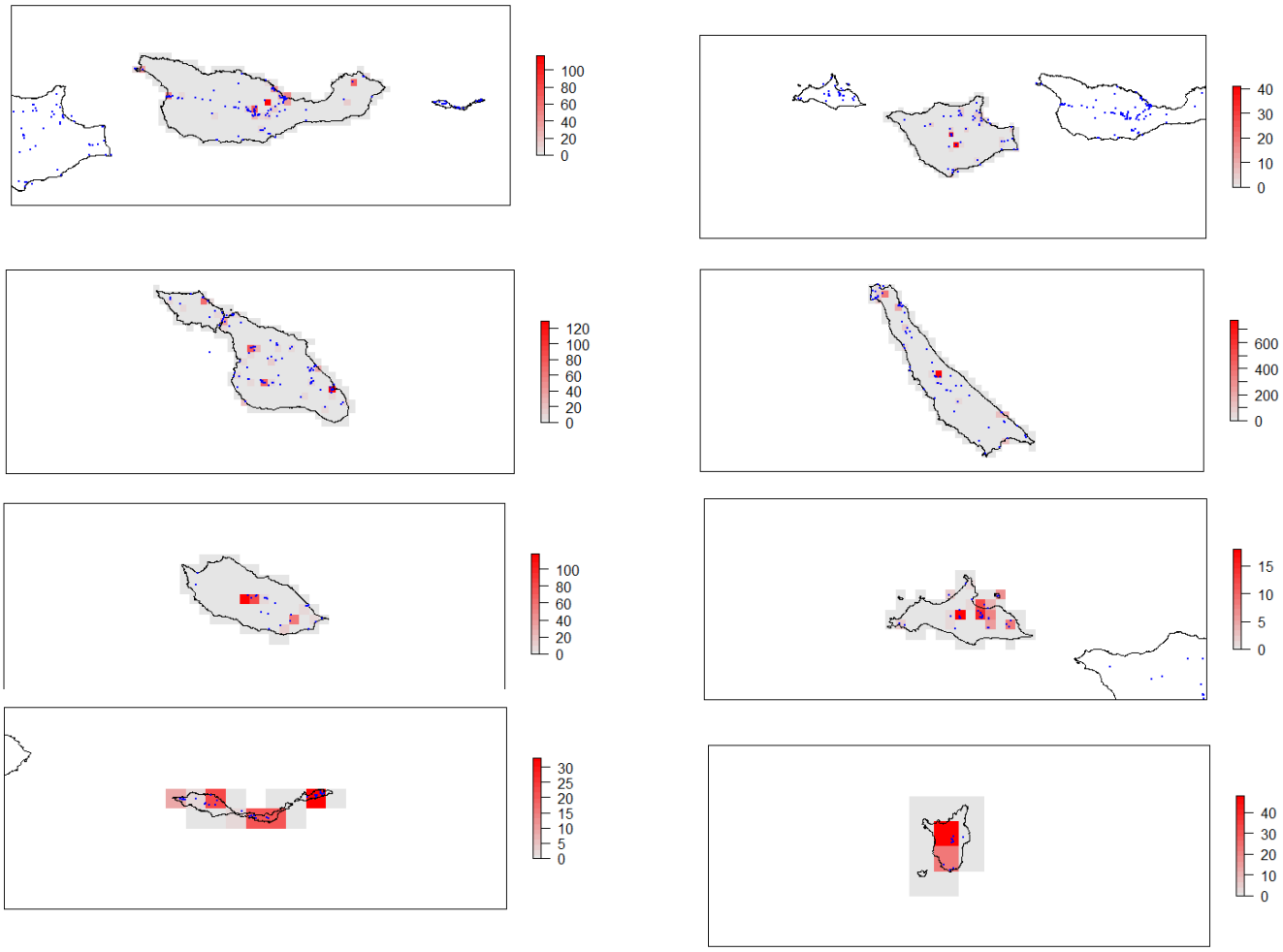


Table Reptilia-4. The number of island reptile specimens by collection type within the Cal-IBIS (specimen) data set. There are two skin collections (not enough to show a colored bar).

Reptile Collection Type (Cal-IBIS records only)	n
Skeleton/skull	15
Skeleton | Tissue	27
Skin | Skeleton	1
Specimen	3562
Tissue	188

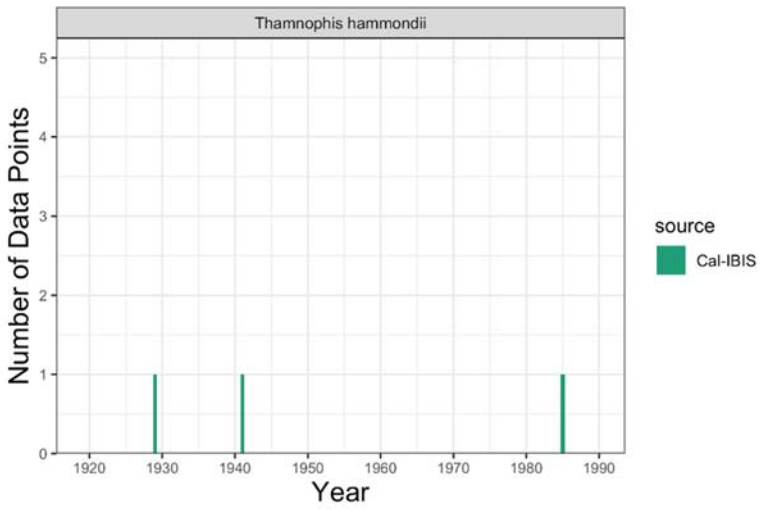


Figure Reptilia-6. The number of rare Two-striped Gartersnake museum specimens by year reveals temporal trends for this taxon. Cal-IBIS data represent specimens.

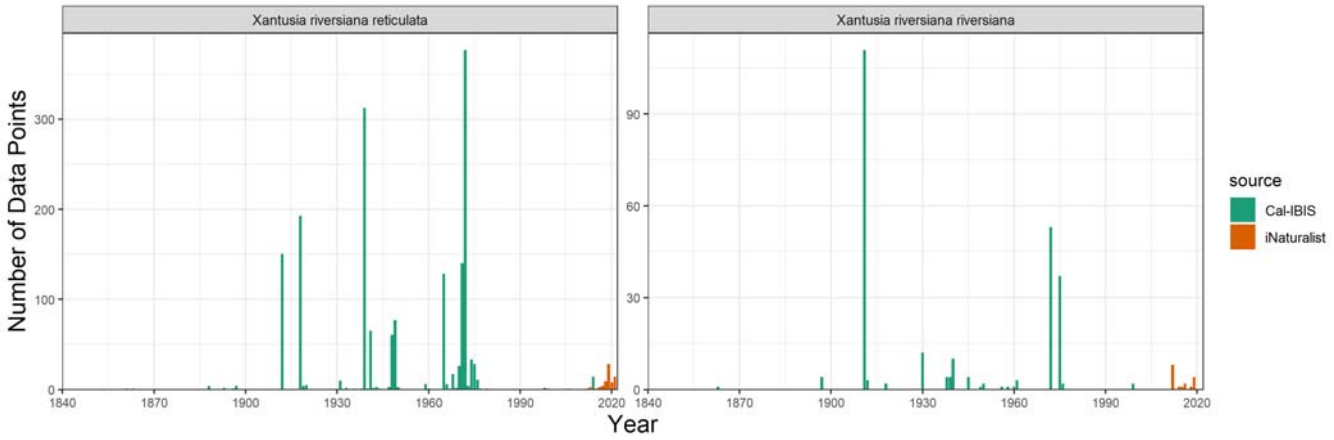


Figure Reptilia-7. The number of endemic Island Night Lizard occurrence records by year reveals temporal trends for this taxon. Cal-IBIS data represent specimens, and Research Grade iNaturalist data indicate observations.

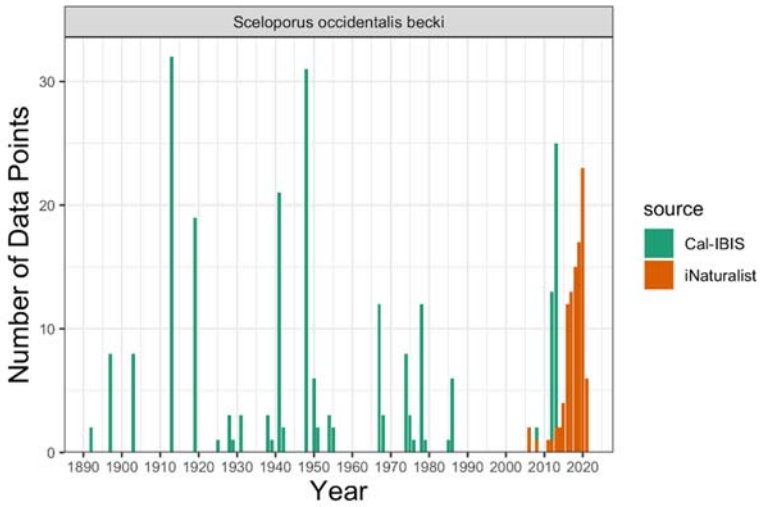


Figure Reptilia-8. The number of endemic Island Fence Lizard occurrence records by year reveals temporal trends for this taxon. Cal-IBIS data represent specimens, and Research Grade iNaturalist data indicate observations.

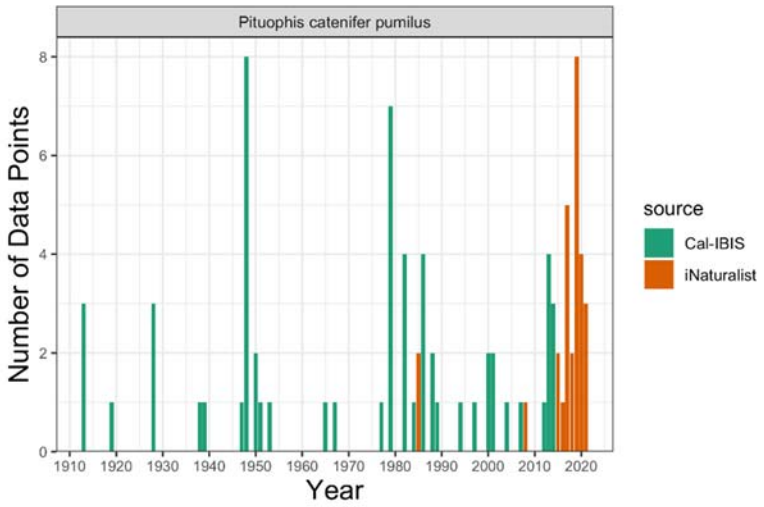


Figure Reptilia-9. The number of endemic Santa Cruz Island Gophersnake occurrence records by year reveals temporal trends for this taxon. Cal-IBIS data represent specimens, and Research Grade iNaturalist data indicate observations.

Table Amphibia-1. The number of occurrence records for each amphibian species by island. Occurrences are given as number of museum specimens (Cal-IBIS) / number of Research Grade iNaturalist observations. Shaded cells indicate the species is established on that island. Bolded values indicate species that are known to be recent introductions.

Scientific name	Common name	Catalina	Clemente	Nicolas	Barbara	Miguel	Rosa	Cruz	Anacapa
Pseudacris regilla	Pacific Treefrog	273/35					168/27	395/34	
Rana catesbeiana	American Bullfrog	**9/8**							
Rana draytonii	California Red-legged Frog							**3/0**	
Rana (unidentified)	N/A	**Note1**							
Aneides lugubris	Arboreal Salamander	1/0 Note2							
Batrachoseps major	Garden Slender Salamander	328/18							
Batrachoseps nigriventris	Black-bellied Slender Salamander							798/16	
Batrachoseps pacificus	Channel Islands Slender Salamander					422/0	276/1	1037/2	182/0
	Total No. of occurrences	611/61				422/0	444/28	2233/52	182/0
	Avg. No of specimens per established species	203.3				422	222	743.3	182

Notes

1. A single ranid frog, possibly a leopard frog, was collected at Summit Reservoir, Catalina Island, but the specimen has not been deposited in a museum collection, nor has it been identified to species.
2. A single Arboreal Salamander (LACM 61952, formerly LACM 13600) was collected at Middle Ranch, Catalina Island March 5, 1941 during the Channel Islands Biological Survey (Hilton, 1945). Subsequent surveys failed to detect additional individuals, but further surveys of oak woodland habitats especially during or after rainstorms are needed to determine if this species occurs on Catalina (Backlin et al., 2004). Alternatively, this individual

Table Amphibia-2. The number of occurrence records for each island amphibian species by data source shows the relative proportion of specimens (Cal-IBIS) and observations (Research Grade iNaturalist).[1]

Order	Family	Species	Cal-IBIS	iNaturalist	Sum
Anura (Frog)	Hylidae	*Pseudacris regilla*	836	96	932
	Ranidae	*Rana catesbeiana*	9	8	17
		Rana draytonii	3	0	3
Urodela (Salamander)	Plethodontidae	*Aneides lugubris*	1	0	1
		Batrachoseps major	328	18	346
		Batrachoseps nigriventris	798	16	814
		Batrachoseps pacificus	1917	3	1920
		Batrachoseps sp.	4	0	4
All Amphibia			**3896**	**141**	**4037**
Species Diversity			**7**	**5**	**7**

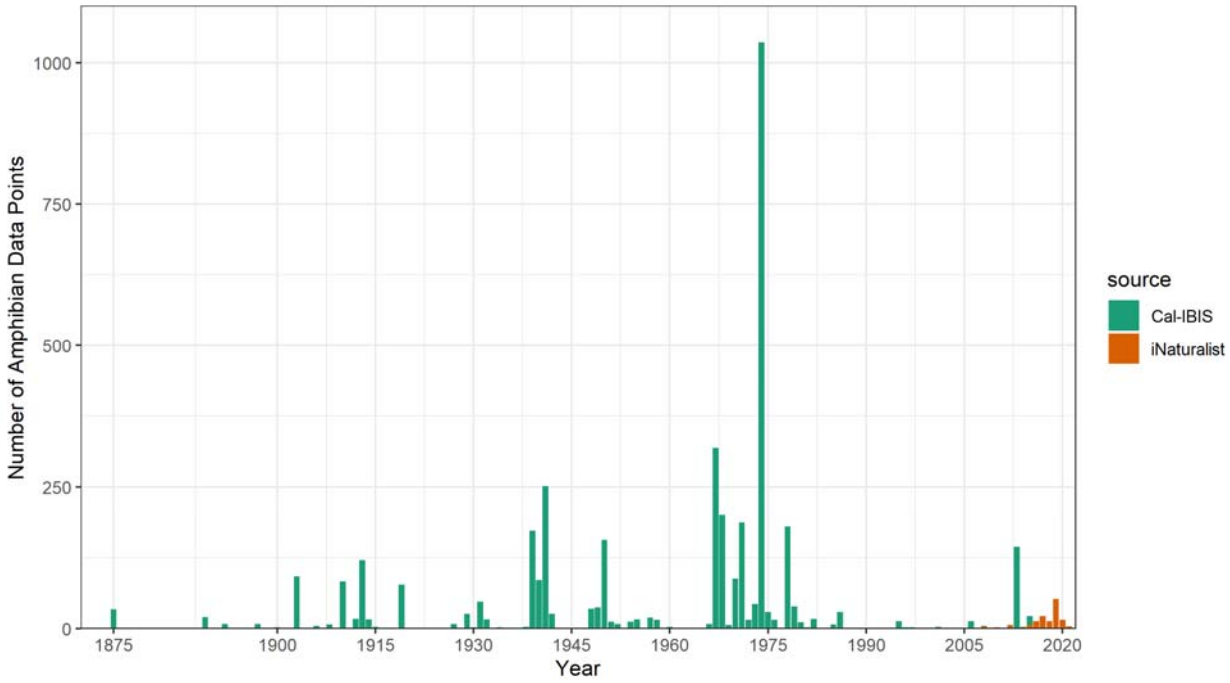


Figure Amphibia-1. The number of island amphibian occurrence records by year and data source (Cal-IBIS for specimens and Research Grade iNaturalist for observations) reveals temporal gaps in the data.

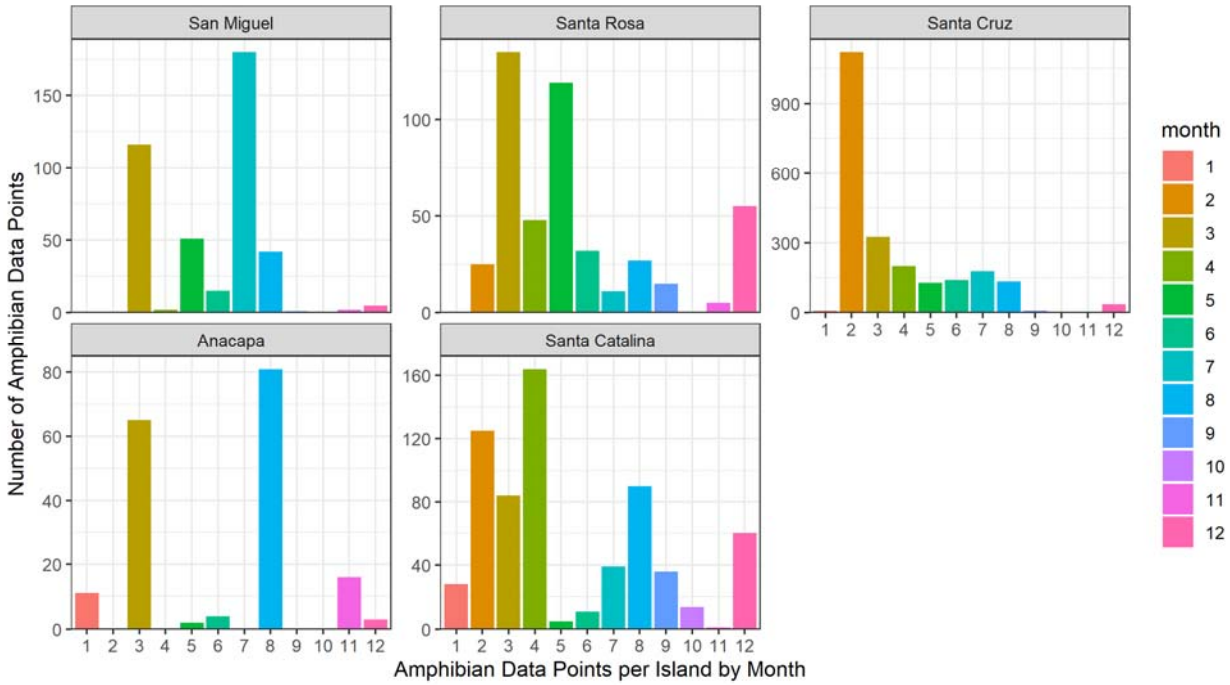
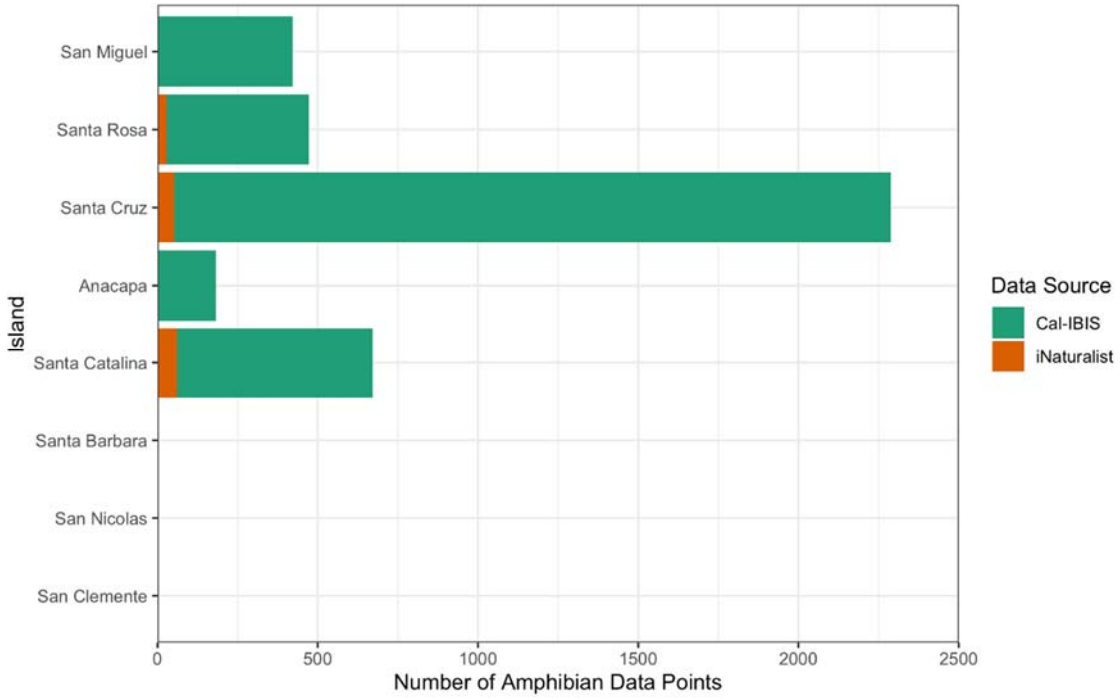


Figure Amphibia-2. The number of island amphibian occurrence records by month, by island, reveals seasonal gaps in the data. Specimen (Cal-IBIS) and observation (Research Grade iNaturalist) data have been combined.

(a)



(b)

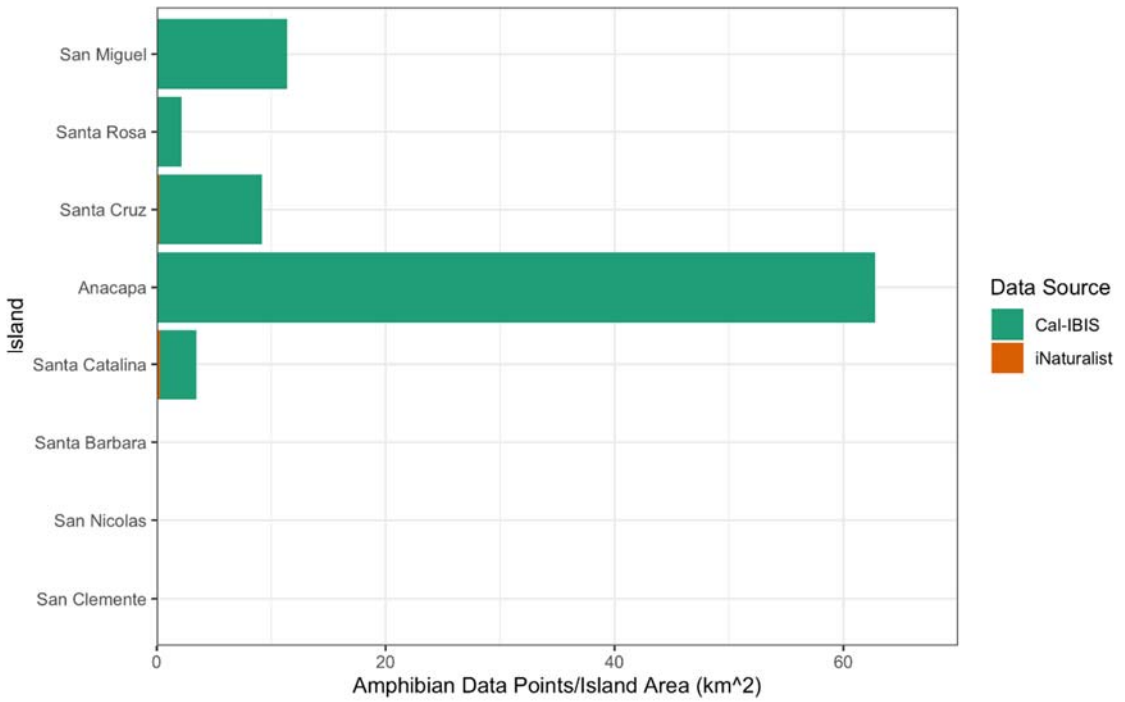


Figure Amphibia-3. The (a) absolute number and (b) proportional number/island size of amphibian occurrence records on each island by data source (Cal-IBIS for specimens and Research Grade iNaturalist for observations) reveals spatial gaps in the data.

(a)

(b)

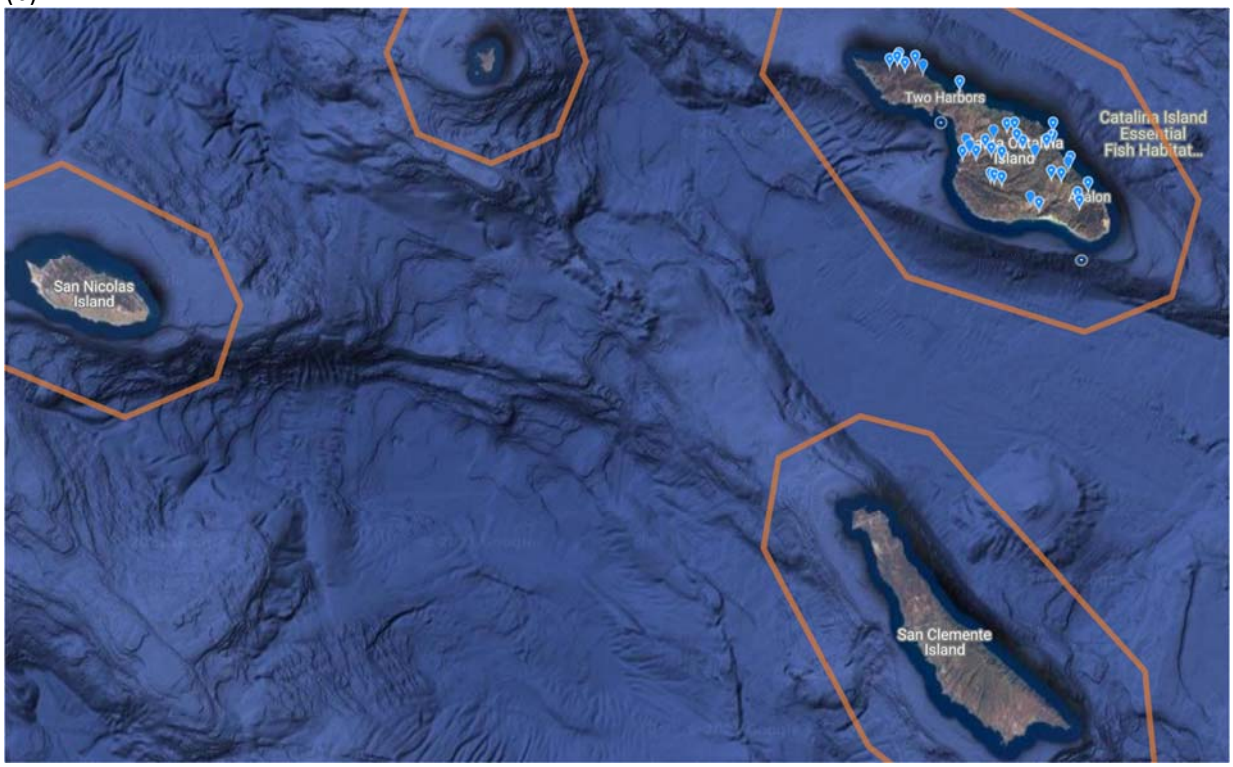
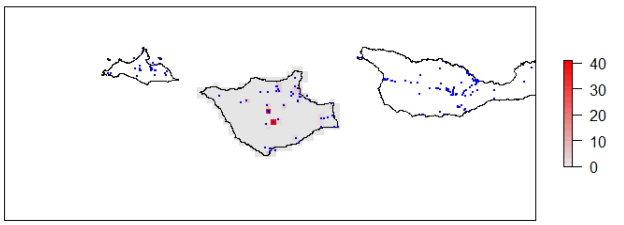
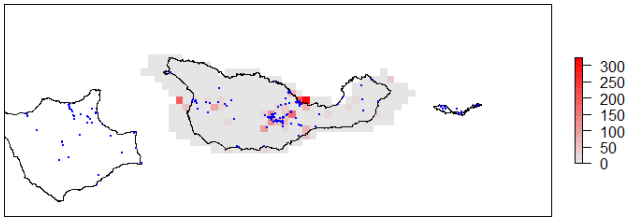


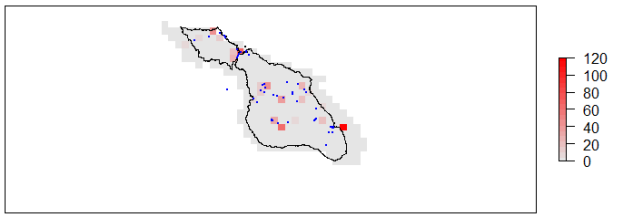
Figure Amphibia-4. The distribution of iNaturalist amphibian observations on (a) the Northern Islands and (b) the Southern Islands reveals spatial gaps in these data. Drops represent “open” observations for which the plotted location is the actual observation location; circles are “obscured” observations for which the plotted location is offset from the actual observation location.

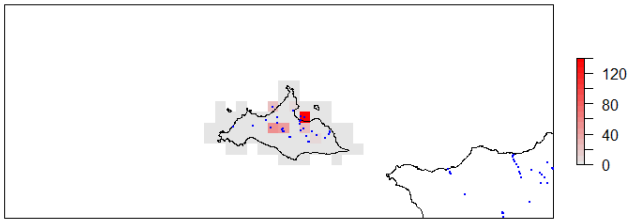
Amphibian-Table 3 & **Amphibian Figure 5**. Spatial specimen collecting effort based on 1 km grid cells overlaid onto each of the eight California Channel Islands. A total of 3,454 records were included (3,896 records had coordinates, but some were removed because locality information did not match the coordinates or they were obvious centroids). Only five of the islands had amphibian specimen records. Note that the color scale varies for each island.

Island	Island Collections	1 km^2 cells	Empty 1 km^2 cells	% empty cells	Mean records/cell
Anacapa	137	14	9	64.3%	27.4
Santa Cruz	2100	313	265	84.7%	43.8
Santa Rosa	299	263	238	90.5%	12.0
San Miguel	310	61	46	75.4%	20.7
Santa Catalina	595	250	220	88.0%	19.8









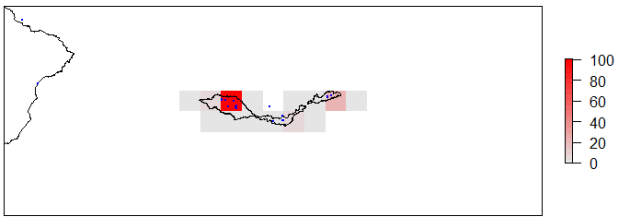


Table Amphibia-4. The number of amphibian specimens, by collection or preparation type, within the Cal-IBIS data set.

Amphibian Collection Type	n
Skeleton	1
Skeleton | Tissue	2
Specimen	3457
Specimen | tadpole	35
Specimen | Tissue	214
Tissue	182

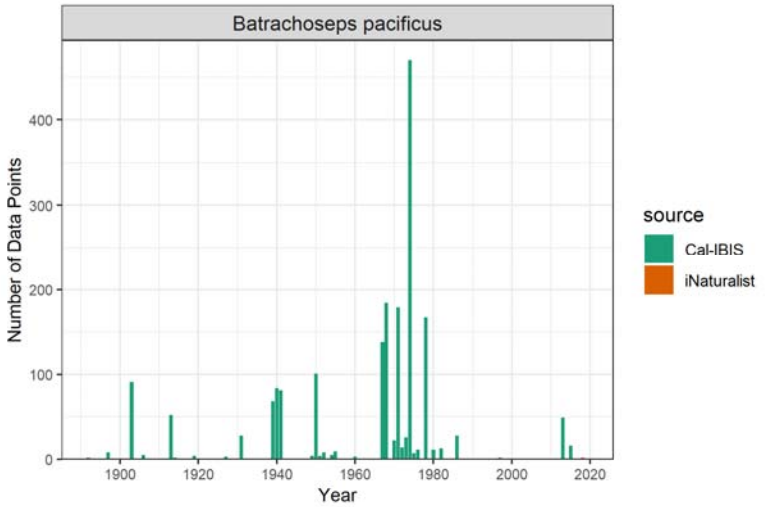


Figure Amphibia-6. The number of endemic Channel Islands Slender Salamander (*Batrachoseps pacificus*) occurrence records by year reveals temporal trends for this taxon. Cal-IBIS data represent specimens, and Research Grade iNaturalist data indicate observations.

DISCUSSION

Reptiles and Amphibians of the Channel Islands —The list of reptile and amphibian species inhabiting each of California's Channel Islands has been largely understood for multiple decades. The few exceptions to this include the recent verification of Coast Mountain Kingsnakes (*L. multifasciata*) on Catalina Island (Hansen et al., 2015), the discovery of Western Terrestrial Gartersnakes (*T. elegans*) in one or possibly two drainages on Santa Rosa Island (Charles Drost, pers. comm.), and ongoing efforts to document introduced Red-eared Slider Turtles on Catalina Island (G. Pauly, unpubl. data). Field studies are needed for these three species to better understand their distribution and natural history on the islands. Additionally, further surveys are needed to determine whether the Arboreal Salamander, *Aneides lugubris,* exists on Catalina Island (Table Amphibia-1). The Two-striped Gartersnake (*Thamnophis hammondii*) is also rarely observed on Catalina, and additional surveys are needed to understand its current distribution and abundance as well as potential impacts from non-native Bullfrogs, which could be consuming these rarely-observed snakes. The current drought conditions present a unique opportunity to attempt American Bullfrog and Red-eared Slider eradications on Catalina because individuals are likely to be confined to the few available areas of surface water.

Of the 17 reptile species documented on the Channel Islands, 12 are believed to be native, and the Red-eared Slider (*Trachemys scripta elegans*) is introduced to Catalina (Table Reptilia-1, 2). The remaining four species have more nuanced histories. The occasional waif Western Pond Turtle (*Emys marmorata*) has been infrequently documented on the Northern Channel Islands (note that the shell of a non-native Common Slider, *Trachemys scripta,* was also documented on Santa Cruz Island in 2020). Single individuals were found on San Miguel and Santa Cruz Islands and deposited at the Santa Barbara Museum of Natural History (SBMNH). The specimen from Santa Cruz was catalogued so recently that the data have not yet been uploaded to GBIF. Thus, this individual was not included in the gap analysis. This species is found in aquatic habitats on the California mainland, and individuals found on the islands likely washed out during storm events. A single Desert Night Lizard (*Xantusia vigilis*) was documented on Catalina Island in 1933 and is presumed to be introduced (Savage, 1952). Three Coast Nightsnakes (*Hypsiglena ochrorhyncha*) were documented in 1939 during the LACM's Channel Islands Biological Survey, with one preserved specimen still available. All were found in close proximity to each other at Prisoner's Harbor, Santa Cruz Island. Because this is a main point of goods and people entering the island, it is possible that these nightsnakes were introduced. The Prisoner's Harbor area is one of the more heavily visited and surveyed regions of the island (including by visitors who might post observations to iNaturalist), but no other individuals have been documented. Lastly, in the past 20 years, at least four Western Terrestrial Gartersnakes (*Thamnophis elegans*) have been documented on eastern Santa Rosa Island (Charles Drost, pers. comm.), with one specimen in a museum collection. The origins of this population are unknown.

The eight species of amphibians that have been documented to occur on the Channel Islands include three native species, three introduced frogs (*Rana catesbeiana, Rana draytonii,* and an unidentified ranid frog), one salamander of questioned origin (*Batrachoseps major*), and one salamander of unknown origin (*Aneides lugubris;* Table Amphibia-1, 2). The three native amphibians are the Pacific Treefrog (*Pseudacris regilla*) and two species of slender salamanders: *Batrachoseps pacificus* across the Northern Channel Islands; and *B. nigriventris* on Santa Cruz Island. The Garden Slender Salamander (*Batrachoseps major*) has typically been considered native to Catalina Island, but recent work questions this (Jockusch et al. 2020). *Rana catesbeiana* is a widespread non-native species throughout much of the western U.S., and it continues to be found on Catalina Island today typically in association with man-made ponds and reservoirs. *Rana draytonii* is a federally endangered species found from northern Baja California, Mexico through Northern California. It is believed to have been introduced to Santa Cruz, San Miguel, and Santa Barbara Islands (Sweet and Leviton 1983; Jennings 1988), although appropriate habitat is not available on the latter two islands. Specimens were only ever collected from Santa Cruz Island and only shortly after the introduction event (Jennings, 1988). Another ranid frog, possibly a leopard frog, was also documented at Summit Reservoir, Catalina Island (Rorabaugh et al. 2002), although subsequent surveys failed to detect any evidence that this non-native species remained at this location (Backlin et al. 2004). Contrary to the information provided in Rorabaugh et al. (2002) only a single individual, not a population, was ever documented (Charles Drost, pers. comm.). The single specimen was transferred from the Catalina Island Conservancy to the United States Geological Survey. It was in poor shape and has never been deposited into a museum (Charles Drost, pers. comm.). The Arboreal Salamander (*Aneides lugubris*) is known from only a single specimen collected during the Channel Islands Biological Survey; further surveys are needed to determine if this individual was introduced or if this species is established on the island (Hilton 1945; Backlin et al. 2004).

Taxonomic and Spatial Gaps —The amphibian species are better represented in museum collections than the reptile species. For amphibians, four of the five established species are relatively common on the islands on which they occur and are represented by a low of 168 Pacific Treefrog specimens from Santa Rosa Island to 1037 Channel Islands Slender Salamander specimens from Santa Cruz (Table Amphibia-1).

As discussed below, the non-native American Bullfrog is the only amphibian that is noticeably underrepresented in museum collections. Each island inhabited by amphibians has between 182 (Anacapa; with one species) and 743.3 (Santa Cruz; average of three species) amphibian specimens per species catalogued into museum collections. In contrast, for reptiles, seven of the eight main islands have lower per-species collection rates (ranging from 41.5 on Santa Rosa to 131.8 on Santa Cruz Island; (Table Reptilia-1). Only on San Clemente Island has reptile collecting activity surpassed the amphibian collecting activity seen on other islands.

Within the reptiles, the snake species are especially underrepresented with relatively few specimens per island. On Catalina Island, the six snake species that occur there are represented by 0 to 38 museum specimens, with no specimens of the Coast Mountain Kingsnake and only three specimens of the Two-striped Gartersnake, the last being found in 1985 (Table Reptilia-1; Fig. 7). A similar situation exists on the NPS islands of Santa Cruz and Santa Rosa where only a single specimen of the Western Terrestrial Gartersnake has been documented and between 22 and 39 specimens have been deposited in museums for the Western Yellow-bellied Racer and Santa Cruz Island Gophersnake, both of which are widespread and relatively common at present. Increasing representation of these snake species in museum collections is an important step to allowing further research into the ecology, evolution, and natural history of these rarely collected species.

All islands have major spatial sampling biases, with collecting efforts occurring primarily along roads and near buildings and areas of human activity. This is most pronounced for the reptile specimens from Santa Cruz Island, but obvious geographic trends are found on all of the larger islands (Fig. Reptilia-5; Fig Amphibia-5). The correlation between sampling sites and roads or access points is common for museum specimen data, but it may be even more pronounced on the Channel Islands where researchers may be especially time-limited during a visit and not have the opportunity to wander overland far from roads and trails. Thus, if there are areas or habitats of research or conservation interest far from roads, extra time and funds may be needed to ensure that representative voucher specimens can be gathered to document biodiversity in the target area.

We have one caveat to note. Throughout this analysis Anacapa Island was treated as a single island, when it is actually made up of three larger islands and multiple smaller islets. For the past several decades, the public and biologists have ready access to Eastern Anacapa, while there is no public access to terrestrial sites on Middle and Western Anacapa. Not surprisingly, 24 of the 25 “Anacapa” iNaturalist observations are from Eastern Anacapa; the one Middle Anacapa observation was made during an LACM collecting trip (by Tom Wake, for GBP). There are also biases in recently collected museum specimens with more coming from Eastern than Middle or Western Anacapa.

Temporal Gaps —The most obvious gap in the reptile and amphibian specimen record for the Channel Islands results from the rapid decline of specimens being deposited in museums since the mid-1970s (Figs. Reptilia-1; Amphibia-1). This pattern is also seen across some of the more charismatic Channel Islands species, such as the island endemics, that we might expect *a priori* to be the focus of increased research interest (Figs. Reptilia-7, Amphibia-6). More broadly, this pattern is found across museum holdings for U.S. amphibians and reptiles (Fig. 3a, 3b; Shultz et al., 2021).

On the Channel Islands, this is an especially significant loss because the islands experienced dramatic change during this period. For nearly 200 years, island habitats were drastically altered by the introduction of non-native ungulates (Schoenherr et al., 1999). The native reptiles and amphibians also faced direct predation from introduced rats and feral cats (Schoenherr et al., 1999). Many of these non-native species were removed in recent decades (Howald et al., 2009; Parkes et al., 2010; Faulkner and Kessler, 2011),

and vegetation communities have changed rapidly as a result. For example, on Santa Cruz Island, vegetative cover prior to sheep removal was estimated to be 74.3% grassland and bare ground and 25.7% woody vegetation; 20 years after sheep removal, following passive recovery of the vegetation, these values more than flipped with 77.2% of the island covered in woody vegetation (Beltran et al., 2014). The lack of specimens collected through this transition limit the opportunity to assess how reptiles and amphibians have responded to invasive species removal and subsequent dramatic changes to the vegetation. The increased sampling in the 2010s, and continued sampling while these habitat changes continue will be critical for creating the specimen resources that can inform how the reptile and amphibian species are responding to these significant conservation interventions.

Moreover, the lack of specimens across recent decades also prevents conducting studies examining how species are responding to drought, decreased fog formation, and other shifts related to ongoing climate change. Conducting regular sampling, especially of the more abundant species, will provide critical specimen resources to the future island ecologists, evolutionary biologists, and conservation biologists.

Tissue samples **—**Because so few specimens were deposited into museum collections after the mid-1970s, there are also relatively few tissue samples available for genetic and genomic studies. Although people started collecting tissue samples for allozyme studies in the 1960s, relatively few researchers were doing this. Thus, there are a very limited number of tissue samples available from the more intense collecting activities of the late 1960s and early1970s. With the increasing ease of Sanger sequencing through the late 1990s, more researchers were collecting tissue samples, but specimen collection on the Channel Islands remained limited. Thus, it wasn't until the 2010s that tissue collections from the Channel Islands started increasing rapidly. Some researchers were also collecting tissue samples without having to sacrifice specimens (e.g., tail and toe clips), but tracking these collections is challenging because they often remain in the freezers of the original researcher instead of getting transferred to a museum or other recognized repository where they can be made available to the broader scientific community and be curated by dedicated collections staff after the original collector moves to other projects or retires.

Salvage programs **—**As discussed above, reptile species are underrepresented in collections relative to amphibians. Within reptiles, snakes are particularly poorly represented in museum collections. A straightforward approach to increasing the number of museum specimens, and especially snake specimens, is to establish salvage programs in which personnel working on the islands are encouraged to salvage any roadkilled or otherwise deceased animals. Vehicles can be stocked with small salvage kits that include gloves, plastic bags, and notecards on which the date, location, and collector's name can be written. Salvaged specimens can then be placed in a temporary storage freezer before being deposited at a museum. Note that collections of the Channel Islands Gophersnake did not show as dramatic of a decline after the mid-1970s as the other reptiles and amphibians did, and this is due in part to salvage efforts (Fig. Reptilia-10).

Introduced Species —For the introduced species that occur on the Channel Islands, surprisingly few specimens have been deposited into museum collections. For example, Southern Alligator Lizards and Side-blotched Lizards are introduced to San Nicolas Island, but specimens from only 10 of the former and 19 of the latter have been placed into museum collections even though these species are relatively numerous on the island and have each been there for over 50 years (Table Reptilia-1). Similarly, only nine American Bullfrog specimens from Catalina Island have been placed into collections (Table Amphibia-1). This lack of specimens limits opportunities to examine basic natural history of these introduced species such as assessing their diet and reproductive activity on the islands. This information is critical to assessing potential impacts on native species and to informing potential management and conservation efforts.

Smaller Islands and Islets —The herpetofauna of the smaller islands and islets across the Channel Islands is very poorly understood. For example, Southern Alligator Lizards are known from Prince's Island off the coast of San Miguel, but only from a single specimen collected in 1919 and another six in 1938. No tissues are available nor any documentation that the species is still there more than 80 years after the most recent occurrence record. San Miguel Island is also home to the Island Fence Lizard and the Channel Islands Slender Salamander, but it is not clear if surveyors have looked for these species on Prince's Island. Similarly, Castle Rock off the west end of San Miguel Island seems large enough to potentially be inhabited by reptiles or amphibians, but there are no published reports of surveys of this outcrop. Bezy et al. (1980; from a personal communication with R. Wilson) report that Island Night Lizards were observed on Sutil Islet off Santa Barbara Island, but no photo vouchers, specimens, or tissues exist. Modern surveys of these small islands are critical for finally documenting the presence/absence of reptiles and amphibians and would provide much needed voucher specimens and tissue samples to assess divergence from populations on the larger islands.

The Utility of iNaturalist Observations —For the reptiles, iNaturalist users are generating large numbers of observations from many of the islands (Figs. Reptilia-1, 3). In 2019, the last year prior to the COVID pandemic, iNaturalist observations represented the fifth largest number of reptile occurrence records ever generated in a single year, with higher numbers only generated by dedicated studies such as the 1972 *X. riversiana* collecting effort (Goldberg and Bezy, 1974) or the 1939 Channel Islands Biological Survey collections efforts. For the amphibians, iNaturalist observations are made at much lower rates that are not substantially filling the information gap caused by the lack of specimen collecting.

iNaturalist users are making important observations of reptiles that are helping to increase knowledge of the distribution of these species on the islands, especially on Catalina and Santa Cruz Islands (Table Reptilia-1). For example, on Catalina, despite iNaturalist being a relatively new platform, there are more iNaturalist observations of the Western Skink (9 vs 8), California Kingsnake (15 vs 12), and Gophersnake (27 vs 11) than there are of museum specimens, and iNaturalist observations are on pace to soon surpass museum specimen records of the Ring-necked Snake (8 vs 12) and Southern Pacific Rattlesnake (30 vs 38). Similarly, on Santa Cruz Island there are now nearly as many iNaturalist observations of Gophersnakes as there are museum records (31 vs 39), and iNaturalist observations of basking lizards (*U. stansburiana* and *S. o. becki*) are rapidly increasing as well relative to museum specimens. These results indicate that future specimen collecting on the islands should target these poorly sampled species and that the use of iNaturalist should be encouraged to increase knowledge of the distribution of rarely observed species on the islands.

Targeted efforts could also be promoted to increase the chance of detecting certain rarely-observed species. For example, if Arboreal Salamanders do occur on Catalina Island, then they are most likely to be observed during or immediately after rain storms and are therefore more likely to be observed by biologists or iNaturalist users who are regularly on the island as opposed to mainland biologists who may not be able to get onto Catalina when appropriate weather conditions materialize. These salamanders can be found on damp nights on oak tree trunks especially in or around cracks and holes and therefore can be observed with minimal disturbance to individuals or habitats. Although beyond the taxonomic scope of this study, photo vouchers of sea turtles or their tracks should similarly be encouraged to document these species using the Channel Islands.

iNaturalist use should also be encouraged as an important tool for the possible early detection of introduced species, especially on Catalina and Santa Cruz where there are larger numbers of potential visitors. More visitors results in a higher risk of introductions but also a higher number of potential iNaturalist users. The use of iNaturalist should also be encouraged on the Navy Islands because the

increased movements of goods and people to/from those islands has led to previous introductions (e.g., *E. multicarinata* and *U. stansburiana* which are now established on San Nicolas Island, and multiple single introductions of *P. catenifer* to San Clemente; Table Reptilia-1). Encouraging iNaturalist use could also help in detecting occurrences of American Bullfrogs and Red-eared Sliders on Catalina Island that could inform eradication efforts.

Availability of Microfossils —Phylogenetic analyses of reptiles and amphibians of the Channel Islands have resulted in cases where species cannot be confidently identified as being native or possibly introduced to one or more islands by Native Americans or more recently by western colonists (e.g., Mahoney et al., 2003; Jockusch et al., 2020). One approach to resolving these questions is through the use of fossil data. Fossil material can be used to determine if the species was present on an island prior to the arrival of Native Americans and/or prior to the past two centuries during which large shipments of goods and increased transport of people could have possibly introduced species from the mainland. Unfortunately, studies of herpetofaunal remains on the Channel Islands are limited to only a few of the islands. For example, Guthrie (1993) and Allen (2013) have reported on herpetofaunal remains from San Miguel Island, and Collins et al (2018) have examined *X. riversiana* fossil material over the last 1,500 years on Santa Barbara Island. Although other studies have identified herpetofaunal remains for a given species (e.g., Mead et al, 2004, 2018), it is only the above-mentioned studies that provide more detailed chronologies. Unfortunately, such information does not exist for the islands with higher herpetofaunal diversity (i.e., Catalina, Santa Cruz, and Santa Rosa Islands). Increased efforts to discover and analyze Channel Island reptile and amphibian fossils will contribute to our understanding of the colonization history of the islands and therefore inform ongoing conservation and management of these species.

Integrating biodiversity data across multiple organizations —The Channel Islands are owned and/or managed by a number of different organizations including the National Park Service, The Nature Conservancy, the Catalina Island Conservancy, and the U.S. Navy. The University of California and California State University systems also have field stations on the Northern Channel Islands. These organizations are all involved in the collection of biodiversity data, and most of them maintain records about biological surveys and observations. Sharing information across relevant organizations and with the many researchers studying the Channel Islands will increase the impact of research and better inform management and conservation. The California Islands Biodiversity Information System (Cal-IBIS; www.cal-ibis.org) was specifically created to improve the sharing of biodiversity data across island stakeholders, and we strongly recommend that organizations with relevant datasets contribute those to this portal as a way of both sharing information and providing for its long-term storage and preservation.

RECOMMENDATIONS

Below, we provide recommendations to strategically improve specimen and tissue holdings and iNaturalist observations. These recommendations are based upon the gap analysis and/or based upon best practices. For most recommendations, the relevant results of the gap analysis and more information is provided above in the Results and Discussion sections. Our two primary considerations in making these recommendations are 1) to create the biodiversity resources needed to address *current* research, conservation, and landscape management needs; and 2) to ensure that *future* researchers, conservationists, and landscape managers have the specimens, tissue samples, occurrence records, and existing and historical knowledge needed to make informed conservation and landscape management decisions.

- *Taxon-specific surveys* —Surveys for snakes and non-native reptiles and amphibians should be prioritized to build better specimen and tissue holdings. For the native (or possibly native) snakes, some island populations may be so small that specimen collection is not in the best conservation

interest of that population (e.g., *Thamnophis hammondii* on Catalina); in these cases, collecting photo vouchers and tissue collections and developing salvage programs (see below) should be prioritized.

- *Regular sampling* —Resample island populations consistently over time to build a temporal series of specimens and tissue samples that can be used to study ecological and evolutionary change as populations respond to changing vegetation regimes, changing climate, and other longer-term processes.
- *Smaller islands and islets* —Basic biodiversity surveys of the smaller islands and islets are needed to determine whether any are currently inhabited by reptiles and amphibians and to generate much needed tissue samples and specimens.
- *Salvage programs* —Relevant organizations on each island should develop salvage programs so that deceased animals and relevant data can be easily and safely collected and then contributed to appropriate repositories to grow specimen and tissue holdings.
- *iNaturalist* —The use of iNaturalist to photo-document occurrences should be encouraged on all islands. Targeted efforts should be promoted to encourage documentation of non-native and rarely observed species, especially on Catalina and the Navy-owned islands, where risks of non-native species introductions are higher.
- *Microfossil sorting* —Researchers and funding organizations should pursue microfossil sorting studies. These analyses can be critical to understanding the colonization history of island lineages, in addition to informing island archaeology and paleontology.
- *Requiring specimen deposition* —Permitting agencies should require that all biological samples or specimens collected under scientific collecting permits and not destroyed in the original research are deposited in an appropriate repository (i.e., a natural history museum with dedicated curatorial staff and collections information easily accessible to the broader research and conservation communities; see also Schultz et al., 2021).
- *Sharing occurrence data* —Similar to the above recommendation, agencies and organizations collecting biological occurrence records should share those data with other island stakeholders by depositing datasets in the California Islands Biodiversity Information System (Cal-IBIS; www.cal-ibis.org). Agencies and organizations permitting the collection of such data should require that resulting datasets be deposited in Cal-IBIS or similar platforms as part of the permitting language.

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