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EVALUATING KNOWLEDGE GAPS IN REPTILE RECORDS IN NAYARIT, NORTHWESTERN MEXICO

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Abstract. Mexico hosts a great diversity of reptile species; yet, many reptiles are either threatened or endangered. Complete and updated information is required to implement appropriate management and conservation actions; however, species inventories can include taxonomic, geographic, and temporal gaps. Therefore, this study aimed to evaluate the magnitude of these gaps in digitally accessible information on reptiles from the state of Nayarit, located in northwestern Mexico. A database was generated using information from the National Biodiversity Information System (SNIB) of the National Commission for the Knowledge and Use of Biodiversity (CONABIO). The growth rate of new species descriptions was calculated, and the completeness of the inventory was evaluated in 10-km grid cells across various time periods, considering biogeographic and physiographic regions. The species description growth rate was low. In addition, approximately 40% of the surface of Nayarit exhibited information gaps among reptile records, particularly in mountainous and hard-to-reach areas. Notably, the least amount of information was recorded between 1981 and 2000. Our results lay the groundwork for future research and the development of effective strategies to conserve and manage the natural resources of Nayarit.

Key words: taxonomic gap; spatial gap; temporal gap; geographic information systems; Nayarit state.

Introduction

The class Reptilia comprises a diverse group of vertebrates, including the orders Testudines (turtles), Rhynchocephalia (tuataras), Squamata (lizards and snakes), and Crocodylia (crocodiles and caimans) that collectively encompass 12,386 living species. Of these, approximately 97% belong to the order Squamata (Uetz et al., 2025).

In addition to their intrinsic value as biotic components of the ecosystems they inhabit, reptiles provide multiple ecosystem services (Millennium Ecosystem Assessment, MAE, 2005). Among other supporting and regulating services, reptiles participate in nutrient cycling, bioturbation, biological control, and seed dispersal (Valencia-Aguilar et al., 2013; Cortés-Gómez et al., 2015; de Miranda, 2017). Reptiles also contribute provisioning services by acting as sources of food, raw materials, and medicine. Finally, reptiles hold notable importance for various cultures and are reflected in numerous cultural and religious expressions (Valencia-Aguilar et al., 2013; Valdez-Rentería et al., 2023).

Despite their importance, reptile species worldwide face major threats, with habitat destruction and fragmentation among the most important (Cox et al., 2022; Farooq et al., 2024). Other major threats include defaunation (Nijman et al., 2012; Young et al., 2016; Marshall et al., 2020; Finn et al., 2023), the introduction of exotic or invasive species (Pyšek et al., 2020), and the spread of diseases, which can lead to local population declines (Okoh et al., 2021; Schilliger et al., 2023). Climate change is also a key threat that can directly or indirectly affect reptile development by altering temperature and precipitation patterns and water availability (Pieau, 1996; Booth, 2006; Newbold, 2018).

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From 1971 to 2000, the extinction rate of reptiles was ~0.03% per year; however, this rate is expected to increase to 2.93% over the next century (Alroy, 2015). Consequently, the International Union for Conservation of Nature (IUCN) has estimated that ~21.1% of reptile species are at risk of extinction (Cox et al., 2022). Notably, Mesoamerica has the highest number of threatened species identified to date (Alroy, 2015).

Given the multiple factors that threaten reptile diversity and conservation, it is crucial to understand how species are distributed across time and space. Indeed, accurate species identification and monitoring are essential for future decision-making, although obtaining this information can be costly in terms of time and resources. Understanding species distributions provides key insights for detecting, monitoring, measuring, and predicting variations in biological diversity and their effects on ecosystems (Wheeler et al., 2012).

Several authors have warned of an impending mass extinction or biodiversity crisis related to human activities that negatively impact habitats and promote the overexploitation of natural resources (Rull, 2022; Sandor et al., 2022). Notably, this biodiversity crisis is also partly due to a lack of public awareness of its existence (Dirzo et al., 2022). Thus, mapping the biosphere provides valuable information that can be used to generate potential solutions to the biodiversity crisis (Zhang et al., 2017). In this context, biodiversity information repositories, such as the Global Biodiversity Information Facility (GBIF), play a crucial role in compiling, storing, and safeguarding vast amounts of biological data. These resources, combined with various analyses, such as modeling species distributions and the effects of climate change, offer a means to better understand the ecology of individual species and large taxonomic groups (Luo et al., 2021; Lajeunesse & Fourcade, 2023). In particular, such tools are essential for addressing information gaps and improving sampling and monitoring strategies (Neves et al., 2019; Grattarola et al., 2020).

Despite the large volume of recorded data, the information stored in these repositories contains multiple gaps, with taxonomic, spatial, and temporal gaps being the most common (Hortal et al., 2015; Isaac & Pocock, 2015; Marshall et al., 2024). Taxonomic gaps refer to potential omissions or absences in the species composition of a given region (Hortal et al., 2015). These are typically evaluated through the annual species description rate, which serves as an indicator of new species discoveries (Marshall et al., 2024). Spatial gaps occur when distribution data is incomplete at the level of individual species, groups, or taxocenoses (Lobo et al., 2018; Nori et al., 2023). These gaps can be quantified by assessing inventory completeness, which measures the proportion of recorded species in a given area relative to the estimated total number of species present (Sousa-Baena et al., 2014; Escribano et al., 2019; Huang et al., 2020; Chesshire et al., 2023). Temporal gaps refer to inconsistencies in species inventories over time (Tessarolo et al., 2017; Escribano et al., 2019), which can be measured by analyzing the frequency of species records and inventory completeness (Shirey et al., 2021).

Geographic bias may be present in biodiversity data, meaning that species records have been disproportionately collected from certain regions, environments, or ecosystems (Loiselle et al., 2008; Hortal et al., 2015). Identifying and evaluating this bias can provide a more balanced understanding of the natural capital of a region, allowing researchers and conservationists to pinpoint areas with high potential for implementing future research efforts and management actions (Soberón et al., 2007; Asase & Peterson, 2016; Ganglo & Kakpo, 2016).

Mexico is one of the most biodiverse countries in the world. In addition, Mexico hosts over 8% of all reptile species (~1,023 recorded species), ranking second globally (Johnson et al., 2017; Uetz et al., 2024). Most of these species (~60.1%) are endemic and adapted to various habitats throughout the country (Johnson et al., 2017; Smith & Lemos-Espinal, 2022; Lemos-Espinal & Smith, 2023; Ramírez-Bautista et al., 2023; Suazo-Ortuño et al., 2023). Currently, ~15% of reptile species in Mexico are threatened or endangered (SEMARNAT, 2010; Smith & Lemos-Espinal, 2022; Lemos-Espinal & Smith, 2023; Suazo-Ortuño et al., 2023; IUCN, 2024), while the conservation status of ~13% remains uncertain (IUCN, 2024).

Previous studies have provided insights into species diversity across various regions and states in Mexico (Flores-Villela & Goyenechea, 2003; Flores-Villela & García-Vázquez, 2014; Aguilar-López et al., 2016; Lemos-Espinal & Smith, 2020; 2023), including Nayarit state, which is the focus of this study. According to Ramírez-Bautista et al. (2023), Nayarit exhibits an intermediate level of reptile richness (135 recorded species). Located in northwestern Mexico, Nayarit spans the Neotropical and Mexican Transition Zone biogeographic regions, where species from the Nearctic and Neotropical regions converge (Morrone, 2019). In addition diverse geoforms, land cover types, and geological processes, converge in Nayarit, creating a unique geographic identity

Although previous studies have examined the reptile composition of Nayarit (Luja et al., 2014; Woolrich-Piña et al., 2016; Ramírez-Bautista et al., 2023; Loc-Barragán et al., 2024), no assessment has been conducted to validate the sufficiency and quality of the available information.

Therefore, the objective of this study was to determine the magnitude of taxonomic, spatial, and temporal gaps in digitally accessible reptile data from Nayarit. This assessment aimed to validate existing inventories, and its results provide a foundation for designing future sampling and conservation plans.

Materials and Methods

Study Area

The state of Nayarit (23°05'04" to 20°36'12" N and 103°43'15" to 105°45'37" W) is located on the northwestern coast of Mexico (Fig. 1). The state borders the Pacific Ocean to the west and the states of Sinaloa, Durango, Zacatecas, and Jalisco to the north and east. Nayarit covers an approximate area of 28,000 km², representing 1.4% of the national territory, and has a coastline of 296 km. Its elevation ranges from 0 to 2,400 meters above sea level.

Physiographic provinces provide a means to divide the surface of the Earth into regions that share common geological and geomorphological characteristics. Nayarit hosts four physiographic provinces: Eje Neovolcánico, Llanura Costera del Pacífico (including the Tres Marías Islands subprovince), Sierra Madre del Sur, and Sierra Madre Occidental. The predominant climate in 60.6% of the territory is tropical savanna (Aw), while 22% has a humid subtropical climate (Cwa). The remaining areas exhibit subtropical highland climate (Cwb) and hot semi-arid climate (BSh) (Beck et al., 2018). The annual mean temperature ranges between 14 °C and 28 °C, while the average annual precipitation varies from 600 mm to 2,500 mm (INEGI, 2022). The main land cover types of Nayarit are tropical or sub-tropical broadleaf deciduous forest (27%), croplands (22%), and temperate or sub-polar broadleaf deciduous forest (18%) (CEC, 2023).

Presence Data

A comprehensive review of reptile records in Nayarit was conducted using the Biodiversity Information System of Mexico (SNIB[1]), managed by the National Commission for the Knowledge and Use of Biodiversity (CONABIO). SNIB-CONABIO serves as the official Global Biodiversity Information Facility (GBIF[2]) node for Mexico, providing national biodiversity data on a global scale. The SNIB-CONABIO database contains biological records from Mexico dating back from the mid-19th century up to 2023, data from scientific collections, information from citizen science initiatives (CONABIO, 2024), and data stored in VertNet[3]. The information in SNIB-CONABIO is curated, validated, updated periodically, and available for download in all versions. Therefore, this article focused on analyzing only this biodiversity information system. The present review was conducted using the advanced search system of SNIB-CONABIO with filters for taxonomic group (reptiles), country (Mexico), and state (Nayarit). The basic download included 49 selected fields.

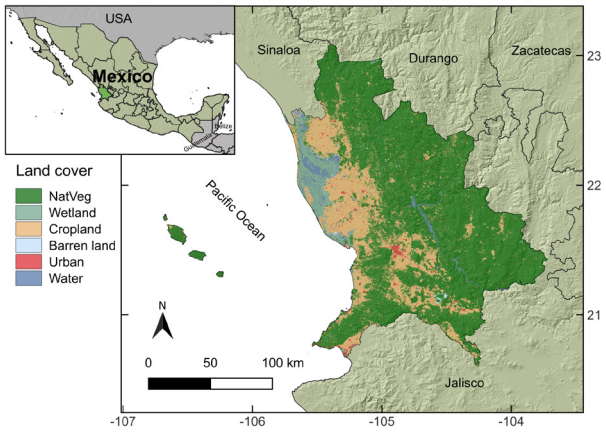

Figure 1. Study area: State of Nayarit, Mexico. Land use classification by the Commission for Environmental Cooperation (modified from CEC [2023]). NatVeg is natural vegetation.

Data Processing

Once the SNIB database was generated and downloaded, a thorough cleaning process was conducted to remove duplicate records, entries lacking a scientific name at the species level, and records without a registration date. Records containing errors or taxonomic synonyms (nomenclatural updates) were corrected whenever possible using validated names from The Reptile Database (Uetz et al., 2024). Additionally, records without geographic coordinates or those located outside the boundaries of Nayarit were excluded.

The SNIB database (v. 2024-02-26) contained 8,864 reptile records for Nayarit, with the oldest dating back to 1861 and the most recent pertaining to 2023. Of these, 34.4% lacked a registration date, and 3.0% were missing a species-level name. After the data-cleaning process, a total of 5,761 valid records were obtained for analysis. Additionally, 279 records from Tres Marías Islands, sourced from the SNIB database (v. 2021-05-28), were incorporated, resulting in a final dataset of 6,040 records. The processed records were integrated into comma-separated value (*.csv) spreadsheets for further analysis and processing in geographic information system (GIS) applications, specifically QGIS v. 3.34.6 (QGIS, 2025).

Taxonomic Gap Analysis

The taxonomic gap analysis was conducted by constructing a species accumulation curve based on the year

[1] https://www.snib.mx/ejemplares/descarga/
[2] https://www.gbif.org/
[3] http://www.vertnet.org/

of each description. The analysis was performed using Microsoft Excel (Microsoft Corporation, 2013), and the best-fit model was determined using Solver, a Microsoft Excel tool. The Gompertz model (Tjørve, 2003) provided the best fit and is described as follows:

$$N(t) = ae^{(-be^{(-ct)})},$$

Eq. (1)

where N(t) represents the recorded number of species over time *t*, *a* is the final population size, *b* is a constant related to the initial points, *c* is the growth constant, and *e* is the exponential function.

The goodness-of-fit for the Gompertz model was evaluated using deviance (Fox, 2015; Dobson & Barnett, 2018) calculated as:

$$D = 2\sum_i \left[y_i ln\left(\frac{y_i}{\hat{y}_i}\right) - (y_i - \hat{y}_i)\right],$$

Eq. (2)

where y_i represents the observed cumulative number of species, and $\hat{y}_i$ is the estimated cumulative number of species. To prevent convergence issues in logarithmic calculations, cases of $\hat{y}_i < 1$ were excluded.

Deviance (*D*) was used to evaluate the model fit (Fox, 2015). Under the null hypothesis (H_0), it was assumed that the model adequately described the observed data. The asymptotic distribution of *D* followed a chi-square (X^2) distribution with *n–r* degrees of freedom, where *n* is the number of data points and *r* is the number of estimated parameters (in this case, *r = 3*).

The annual rate of species accumulation was determined following the methodology proposed by Marshall et al. (2024). The average species accumulation rate from 1990 to the present was calculated as an approximation of the probability of discovering new species.

Spatial Gap Analysis

The spatial analysis of the data was conducted using QGIS v. 3.34.6 (QGIS, 2025). A 10-km resolution grid (100 km² per cell) was generated for the study area, following the methodologies previously applied in Nayarit and similarly sized regions (Baselga & Novoa, 2006; González et al., 2007; Arvizu & Ruiz-Luna, 2024).

From the generated grid, expected species richness (S_{exp}) per cell was estimated using the equation proposed by Chao (1984) and Colwell & Coddington (1994):

$$S_{exp} = S_{obs} + \left(\frac{a^2}{2b}\right),$$

Eq. (3)

where S_{obs} is observed species richness, *a* is the number of species recorded only once in a quadrat, and *b* is the number of species recorded only twice in the same quadrat during the study period.

The inventory completeness (*C*) index was calculated as follows:

$$C = \frac{S_{obs}}{S_{exp}}.$$

Eq. (4)

The *C* index ranges from 0 (lacking) to 1.0 (when observed and expected richness are equal). Following the methods of Peterson et al. (2016) and Troia & McManamay (2016), cells with *C* values ≥0.8 were considered well-surveyed. Using similar classification criteria as Arvizu & Ruiz-Luna (2024) for amphibians in Nayarit, the *C* values were categorized into three levels: complete ($C \geq 0.8$), partially complete ($0.5 \leq C < 0.8$), and incomplete ($0 < C < 0.5$). These classifications were visualized in maps generated using QGIS.

In addition to evaluating the proportion of well-inventoried areas for reptiles at the state level, the *C* index was analyzed across biogeographic regions (a geographic unit defined by the biotic and ecological characteristics shared by the species that inhabit it, shaped by evolutionary history) and physiographic provinces (a geographic area defined by its geological and geomorphological c haracteristics). Biogeographic regions are the largest ecozones that divide the Earth and are based on the distribution of terrestrial organisms, biogeographic subdivisions are called provinces, which are areas defined by endemism and by their ecological and physiographic identities (Morrone, 2019).

In Nayarit, the two biogeographic regions were the Neotropical Region, with one province (Pacific Lowlands), and the Mexican Transition Zone, with two provinces (Sierra Madre Occidental and the Transmexican Volcanic Belt). On the other hand, considering the Physiographic provinces, the Nayarit limits include four of them, named Eje Neovolcánico, Llanura Costera del Pacífico (including the Tres Marías Islands subprovince), Sierra Madre del Sur, and Sierra Madre Occidental. Given that each of these regions and provinces contains distinct vegetation types, soil conditions, climates, and elevations, each has the potential to harbor unique reptile communities. Both regionalization were used to generate comprehensive knowledge of the state of Nayarit, which can be used by decision-makers to develop management and conservation plans, and support policy for the study and conservation of biological diversity.

To assess geographic bias, the relationship between reptile records and the major roads and urban areas in Nayarit was analyzed. For this, we calculated the proportion of records located near roads, including roads sur-

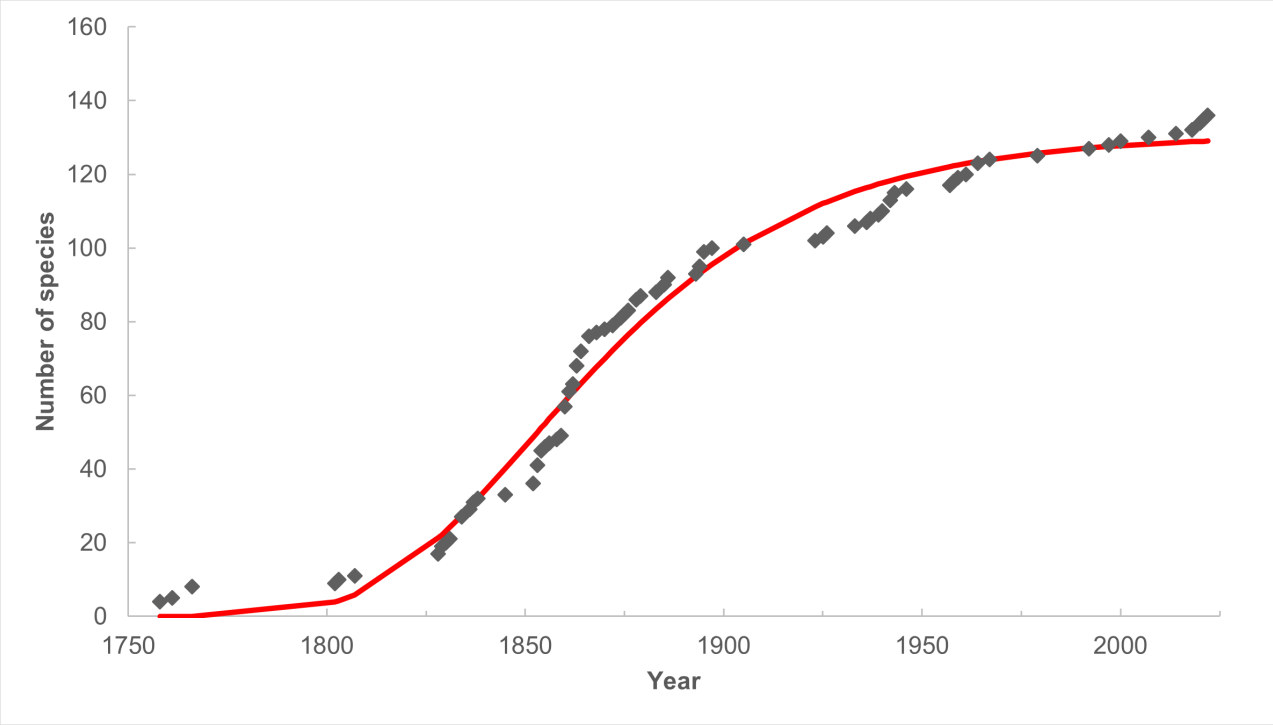

Figure 2. Species accumulation curve for reptiles in Nayarit by year of description. The black diamonds represent accumulated species, and the red line represents the Gompertz model.

rounding and within urban centers, using buffer zones of 100 m and 250 m perpendicular to both sides of the road network. These buffer zones were created using vector geometry tools in QGIS. In this study, the exclusive focus on distance to roads carries a sampling bias, which was due to a prior data analysis. Other potential geographic biases include proximity to urban centers, especially those with educational institutions, and protected areas.

Temporal Gap Analysis

To establish a timeline of species records, the *C* index was evaluated over time to identify trends in species documentation and the periods during which the most important contributions to reptile inventory completeness in Nayarit occurred. The dataset was divided into five specific periods (i.e., 1861–1960, 1961–1980, 1981–2000, 2001–2020, and 2021–2023), and the *C* index was calculated for each. Although the first period spans 100 years, the largest proportion of data (85%) came from the 20-year period of 1941–1960 (933 records). The remaining periods spanned 20 years, with the exception of the final period, which spanned 3 years. This final 3-year period (2021–2023), which ensured our analysis was as current as possible, included 26% of all records.

Results

Based on the SNIB records for Nayarit, a total of 136 reptile species were taxonomically validated for this study. These species were described in Nayarit between 1861 and 2023. The species accumulation curve followed a sigmoidal pattern, indicating a decline in the rate of new species records reported in recent years. A notable inflection point was observed in the third decade of the last century, with the curve approaching an asymptote of nearly 140 species (Fig. 2). The best fit for this curve was obtained using the Gompertz model with a growth constant estimated at 0.025:

$$N(t) = 130.7e^{(-10.8e^{(-0.025t)})}.$$

In the first three years of the analyzed period, the estimated accumulated species count ($\hat{y}_i$) was less than one, thus these observations were excluded from the goodness-of-fit test using deviance. Of the 71 years analyzed, the test was conducted with 68 years, resulting in 65 degrees of freedom. The fit of the data to the Gompertz model was significant ($D = 47.8$, $p = 0.945$), supporting the ability of the model to describe the accumulation of species records over the study period (Fig. 2). For the period of 1990–2022, the average species description growth rate, which was used as a proxy for the probability of the occurrence of a new species, was estimated to be 0.26 ± 0.46%.

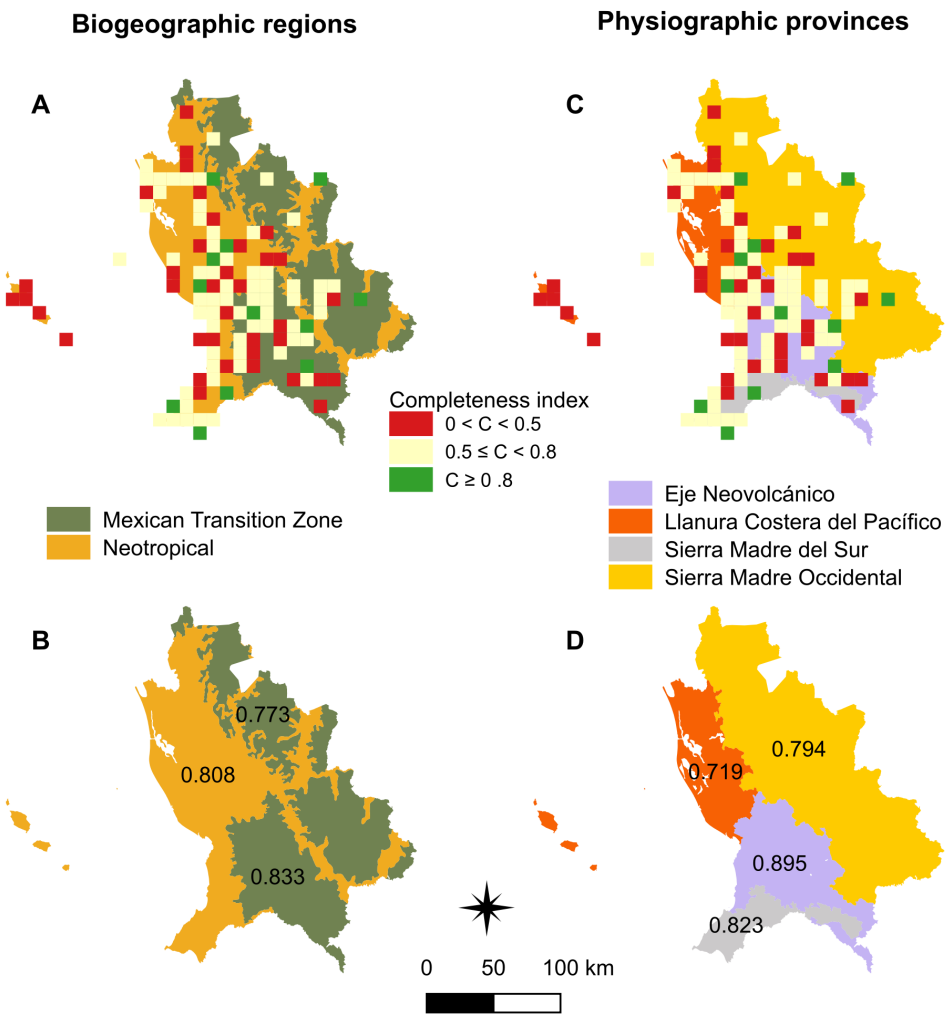

Figure 3. Inventory completeness in the biogeographic regions and physiographic provinces of Nayarit. A) Cells representing the completeness index categories in the biogeographic regions: incomplete ($0 < C < 0.5$; red), partially complete ($0.5 \leq C < 0.8$; yellow), and complete ($C \geq 0.8$; green). B) Inventory completeness values by biogeographic region: Neotropical (Pacific Lowlands province; orange) and Mexican Transition Zone (Sierra Madre Occidental and Trans-Mexican Volcanic Belt provinces; green). C) Cells representing the completeness index categories in the physiographic provinces: incomplete ($0 < C < 0.5$; red), partially complete ($0.5 \leq C < 0.8$; yellow), and complete ($C \geq 0.8$; green). D) Inventory completeness values by physiographic province: Llanura Costera del Pacífico (orange), Sierra Madre Occidental (yellow), Eje Neovolcánico (purple), and Sierra Madre del Sur (gray).

Approximately 60% of the 356 cells (10-km resolution) in the study area contained at least one reptile record within the analyzed period. However, due to methodological constraints, it was not possible to estimate the *C* index for all cells with species records. Among the cells where the *C* index could be estimated, only 3.4% exhibited *C* values ≥0.8, indicating that these cells were well-inventoried. Notably, these cells were heterogeneously distributed across the state. Additionally, 17.4% of the cells had *C* index values of 0.5–0.8, indicating that these cells contained partially complete inventories. These cells were more evenly distributed throughout the state (Fig. 3a). Overall, only a little more than 20% of Nayarit can be considered completely or partially inventoried in terms of reptile species.

Differences were found in inventory completeness between the two biogeographic regions of Nayarit, despite their similarities in territorial extent. The Neotropical Region included 183 grid cells, with 70% of them containing at least one record of a reptile species. In contrast, the Mexican Transition Zone included 173 grid cells, with reptile species records in only 50%. Of these, only 27% and 14% of the grid cells corresponded to the Neotropical Region (50) and Mexican Transition Zone (24), respectively, exhibiting *C* index values ≥0.5, with less than 5% of cases exhibiting *C* index values ≥0.8 (Table 1a). When each region and its respective provinces were evaluated globally, the *C* index values ranged between 0.77 to 0.83 (Fig. 3b), indicating the regions were partially to fully inventoried, with the highest species richness (110) observed in the Neotropical Region.

Table 1. Number of reptile species records (RSR), number of cells with records (CWR), and number of cells by inventory completeness index (*C*) category by (a) biogeographic region (BR) and (b) physiographic province (PhP). Biogeographic regions: Neotropical (NTP) and Mexican Transition Zone (MTZ). Physiographic provinces: Sierra Madre del Sur (SMS), Llanura Costera del Pacífico (LCP), Eje Neovolcánico (ENV), and Sierra Madre Occidental (SMO).

(a) BR	**Cells**	**RSR**	**CWR**	***C* index category**		
				$0 < C < 0.5$	$0.5 \leq C < 0.8$	$C \geq 0.8$
NTP	183	4616	128	27	42	8
MTZ	173	1424	87	10	20	4
(b) PhP						
SMS	31	1340	18	4	7	3
LCP	65	2287	55	12	15	2
ENV	70	1741	57	12	23	2
SMO	190	672	85	9	17	5

Table 2. Number of reptile species records (RSR), observed species richness (S_{obs}), number of species found once (*a*), number of species found twice (*b*), expected species richness (S_{exp}), and inventory completeness index (*C*) by biogeographic region, biogeographic province, and physiographic province of Nayarit.

Type	**Name**	**RSR**	S_{obs}		***a***	***b***	S_{exp}	***C***
			Bdc	Adc				
Biogeographic region and province*	Mexican Transition Zone (1)	210	63	55	22	15	71	0.773
	Mexican Transition Zone (2)	1214	102	85	21	13	101	0.833
	Neotropical (3)	4616	151	110	24	11	136	0.808
Physiographic provinces	Sierra Madre Occidental	672	105	88	27	16	111	0.794
	Llanura Costera del Pacífico	2287	106	80	25	10	111	0.719
	Eje Neovolcanico	1741	125	100	20	17	112	0.895
	Sierra Madre del Sur	1340	65	58	10	4	71	0.823

* (1) Sierra Madre Occidental, (2) Trans-Mexican Volcanic Belt, and (3) Pacific Lowlands biogeographic provinces (Morrone 2019). Bdc: species richness before data cleaning; Adc: species richness after data cleaning.

The analysis of the physiographic provinces indicated that more than 50% of grid cells (190) were located within the Sierra Madre Occidental province, which also covered the largest area of Nayarit (Fig. 3c). However, only 45% of these cells contained records of at least one reptile species, with 11.6% of the cells showing *C* index values ≥0.5. The highest level of inventory completeness was observed in the Eje Neovolcánico province, which spatially represented 20% of the total grid cells and had *C* index values ≥0.5 in 35.7% (Table 1b). For the Sierra Madre del Sur and Llanura Costera del Pacífico provinces, which together accounted for 27% of the total area, 28.1% of grid cells exhibited *C* index values ≥0.5. In general, the proportion of grid cells with *C* index values ≥0.8 ranged from 2.6% to 9.7% across these provinces.

When the territory of the physiographic provinces was considered globally, the *C* index values exceeded 0.72 in all cases. The Eje Neovolcánico and Sierra Madre del Sur provinces could be considered fully inventoried ($C \geq 0.8$), while the two remaining provinces exhibited *C* index values indicating that they were partially inventoried. In terms of completeness, these followed the order of Sierra Madre Occidental > Llanura Costera del Pacífico (Fig. 3d).

It is worth noting that while the Neotropical Region exhibited the highest number of reptile records and the greatest species richness, this pattern was not mirrored among the physiographic provinces. The Llanura Costera del Pacífico province had the highest number of reptile records, but the Eje Neovolcánico province exhibited the highest species richness (100 species; Table 2).

In relation to the above, a close association was observed between the grid cells with *C* index values and the locations of urban and rural settlements and road infrastructure. The proportion of records located near the main roads of Nayarit was estimated at perpendicular distances of 100 and 250 m, with 34% and 51% of the records, respectively, within these limits (Fig. 4). According to this distribution, approximately 72% of grid cells with *C* index values ≥0.5 (61% of the cells had *C* index values of 0.5–0.8, and 11% of those had *C* index values ≥0.8) were located near towns and roads.

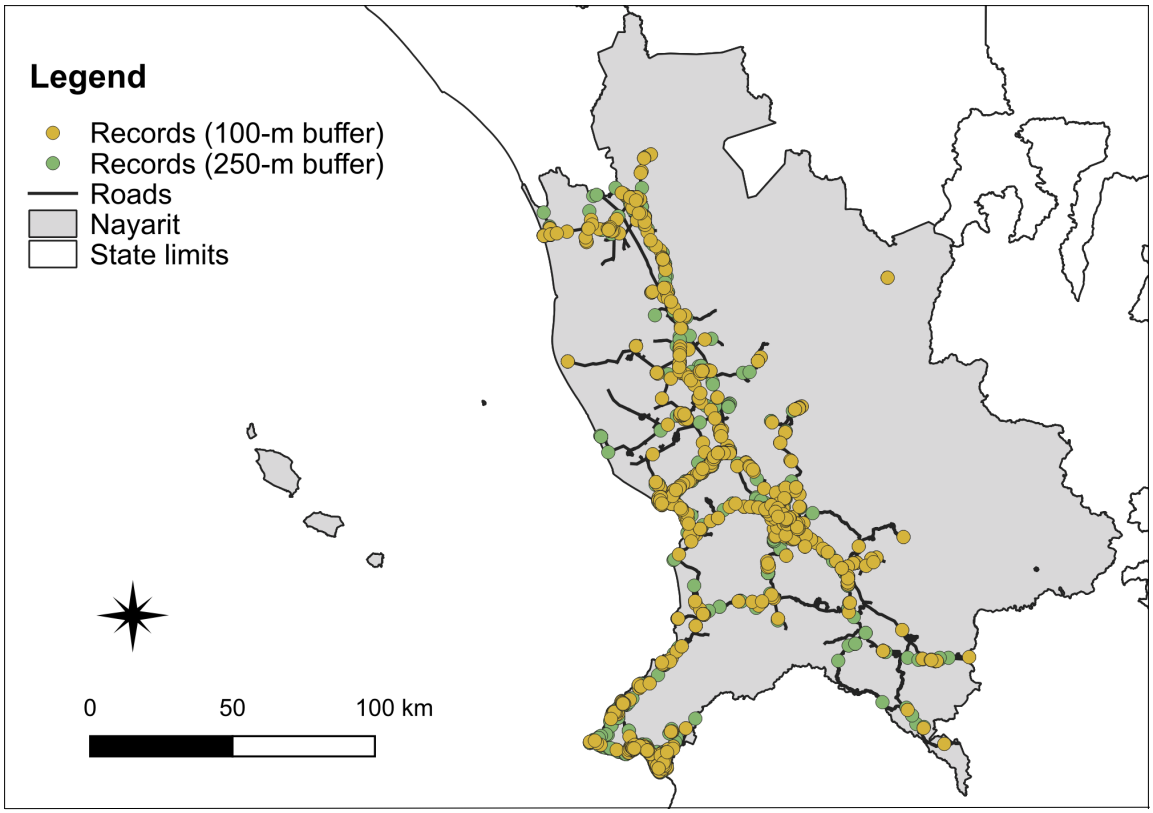

Figure 4. Records within the 100-m and 250-m buffers on both sides of the main roads in Nayarit.

Table 3. Number of reptile species records (RSR), number of cells with records (CWR), and number of cells by inventory completeness index (*C*) category by time period.

Period	RSR	CWR	*C* index category		
			$0 < C < 0.5$	$0.5 \leq C < 0.8$	$C \geq 0.8$
1861–1960	969	64	11	8	4
1961–1980	1155	81	8	13	1
1981–2000	310	61	3	5	8
2001–2020	2012	167	20	27	14
2021–2023	1594	116	9	19	13

The analysis of the species records per grid cell across different time periods indicated that only 18% of the 356 grid cells contained species records during the earliest period (1861–1960), with *C* index values ≥0.5 in ~3.3% of the territory (Table 3). During this period, most records originated from research that had been primarily conducted by international institutions, such as the Museum of Comparative Zoology at Harvard University, the Natural History Museum in London, the San Diego Natural History Museum, and the Biodiversity Institute and Natural History Museum at the University of Kansas, with smaller contributions from national institutions.

For the following period (1961–1980), the number of reptile records increased to include 22% of the grid cells, although those with *C* index values ≥0.5 represented only 3.9% of Nayarit, reflecting only a marginal increase from the previous period. During 1961–1980, most contributions came primarily from foreign institutions, such as the Natural History Museum of Los Angeles County, the Museum of Natural History at the University of Illinois, and the Museum of Vertebrate Zoology at the University of California, Berkeley, with limited participation from national institutions.

In the next period (1981–2000), the number of grid cells with records declined to the lowest proportion in the entire study (17%). This period was characterized by a greater presence of national institutions, such as *Museo de Zoología Alfonso L. Herrera* of the *Facultad de Ciencias* and *Instituto de Biología* of the *Universidad Nacional Autónoma de México* (UNAM), with a smaller contribution from international institutions.

In the two most recent periods (2001–2020 and 2021–2023), the number of records increased substantially

(46.9% and 32.6%, respectively), despite the most recent period covering only three years. This increase was mainly attributed to the participation of citizen science, particularly through the iNaturalistMX[4] platform, along with contributions from national and international academic institutions. An increase in inventory completeness was also evident, with *C* index values ≥0.5 in 11.5% (2001–2020) and 9.0% (2021–2023) of the grid cells, while the proportion of cells with *C* index values ≥0.8 decreased to just under 4% for both periods. When integrating the entire study period, 20.8% of grid cells exhibited *C* index values ≥0.5, with only 3.4% having *C* index values ≥0.8 (Fig. 5).

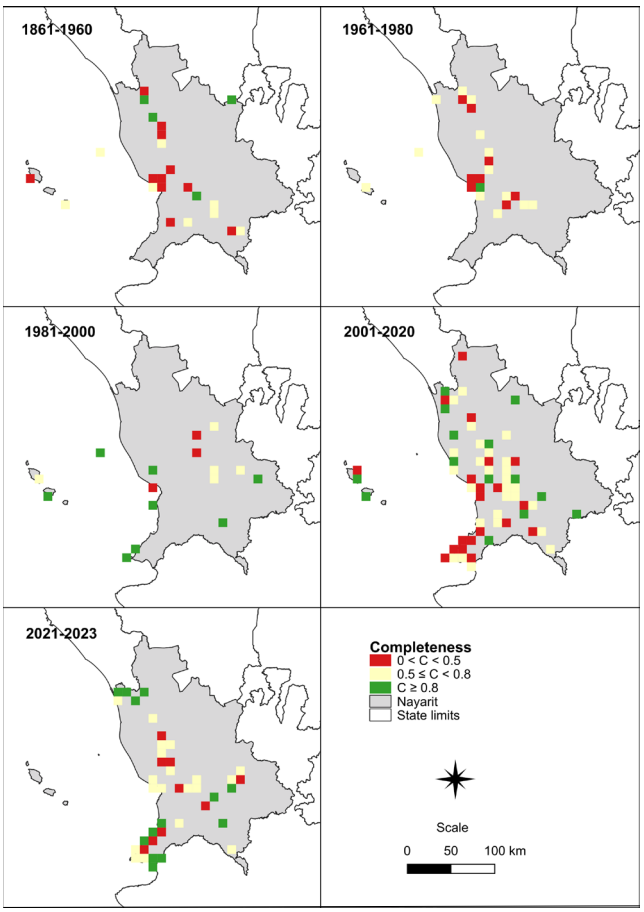

Figure 5. Inventory completeness of the reptiles in Nayarit for each time period. The gray area represents cells where the inventory completeness (*C*) index could not be measured or where no reptile records were present.

Discussion

Gaps in the taxonomic, spatial, and temporal knowledge of the reptile inventory in Nayarit were identified based on information stored in the SNIB database of CONABIO, which includes records from the mid-19th century to the present. The information generated in the present study is representative of the actual conditions in Nayarit and serves as a baseline for future research aimed at assessing reptile diversity in the state, which is crucial for developing adequate conservation measures and managing natural resources.

The gap in taxonomic knowledge represents a potential lack of information for all species; in this study, specifically the reptiles found in Nayarit. The data adjustment for newly incorporated reptile species showed a sigmoid trend with a reliable confidence level, indicating that the theoretical maximum number of species inhabiting the state has nearly been reached. However, the estimated growth rate of new species records for the past thirty years suggests that approximately one new species has been added to the list every four years. Despite these results, since 2000, eight new species (order Squamata) have been described that belong to the families Phrynosomatidae (*Sceloporus huichol* Flores-Villela, Smith, Campillo-García, Martínez-Méndez & Campbell, 2022), Phyllodactylidae (*Phyllodactylus cleofasensis* Ramírez-Reyes, Barraza-Soltero, Nolasco-Luna, Flores-Villela & Escobedo-Galván, 2021), Scincidae (*Marisora aquilonaria* McCranie, Matthews & Hedges, 2020), Colubridae (*Tantilla ceboruca* Canseco-Márquez, Smith, Ponce-Campos, Flores-Villela & Campbell, 2007), Natricidae (*Thamnophis rossmani* Conant, 2000), Viperidae (*Crotalus campbelli* Bryson Jr, Linkem, Dorcas, Lathrop, Jones, Alvarado-Díaz, Grünwald & Murphy, 2014), and Kinosternidae (*Kinosternon vogti* López-Luna, Cupul-Magaña, Escobedo-Galván, González-Hernández, Centenero-Alcalá, Rangel-Mendoza, Ramírez-Ramírez & Cazares-Hernández, 2018; *Kinosternon cora* Loc-Barragán, Reyes-Velasco, Woolrich-Piña, Grünwald, Venegas de Anaya, Rangel-Mendoza & López-Luna, 2020).

As of 2020, four of these new species were included in the herpetofauna of Nayarit due to morphological analyses and molecular techniques employed to distinguish cryptic species (Loc-Barragán et al., 2024). It was assumed that these species were previously captured and recorded for the state inventory but misidentified. Additionally, Loc-Barragán et al. (2024) compiled a list of 19 reptile species distributed in areas adjacent to Nayarit, namely in the states of Jalisco, Zacatecas, Durango, and Sinaloa, which may eventually be incorporated into the records of Nayarit. These cases were not considered in the methods used to estimate the taxonomic gap, as they only included formally accredited records; thus, future adjustments may be needed. Nonetheless, the taxonomic gap for the reptiles of Nayarit is close to being resolved.

The analysis of spatial gaps indicated that ~40% of the grid cells in Nayarit lacked reptile records, particular-

[4] https://mexico.inaturalist.org/

ly those in mountainous and difficult-to-access regions. These areas may serve as refuges that host high endemism due to their isolation and environmental conditions, even in tropical zones, which makes them more sensitive to environmental changes (Spehn, 2011; Silveira et al., 2019).

Additionally, a correlation was observed between the number of records and the proximity to roads and human settlements (roads within urban centers). This sampling bias has been documented by Kadmon et al. (2004), who noted that random surveys over large areas are rare, leading to species distribution models often being based on biased and incomplete data. Similarly, the areas with the highest *C* index values (≥0.8) were mainly located near urban areas (Tepic, Santiago Ixcuintla, Ruíz, Nuevo Vallarta, Sayulita, Santa María del Oro, and Guadalupe Victoria), a trend that has been observed in other regions in which well-surveyed grid cells have been geographically associated with cities, rivers, and major roads (Ballesteros-Mejía et al., 2013; Stropp et al., 2016; Arvizu & Ruiz-Luna, 2024).

It is likely that the greater inventory completeness associated with certain biogeographic regions or physiographic provinces, such as the Neotropical Region or Eje Neovolcánico, results more from their accessibility due to the presence of roads and urban areas than from the use of effective sampling strategies. This scenario has also been suggested by Ficetola et al. (2014) when evaluating reptile records on Mediterranean islands. Regardless of this bias, the Neotropical Region, which includes humid and semi-humid tropical areas, was identified as having a higher proportion of cells with species records and higher inventory completeness ($C \geq 0.8$) than the Mexican Transition Zone, where Nearctic and Neotropical biota overlap. Given its characteristics, the Mexican Transition Zone would be expected to have a higher level of endemism (Morrone, 2019).

The physiographic province of Sierra Madre Occidental, the largest and most rugged province located in eastern Nayarit, exhibited the greatest geographic gap. In contrast, Sierra Madre del Sur, the smallest province, exhibited the highest proportion of fully inventoried grid cells and, simultaneously, a higher *C* index value at the regional scale. The Eje Neovolcánico province exhibited a lower proportion of fully inventoried grid cells and, in contrast, exhibited the highest *C* index value at the regional level. Additionally, Eje Neovolcánico was identified as the province with the greatest reptile diversity in Nayarit (Loc-Barragán et al. 2024). At the regional scale, Sierra Madre Occidental also exhibited a high *C* index value despite having the largest geographic gap, suggesting that using this value at the regional scale to estimate completeness is not advisable, as conclusions may be highly biased.

Finally, the temporal gap analysis provided insights into how the contributions to the reptile inventory of Nayarit have evolved over time, as well as the main sources of data. Of the 6,040 verified reptile records for the continental and insular zones of Nayarit, ~60% were contributed during recent periods (2001–2020 and 2021–2023), which coincides with the increase in citizen science initiatives. With citizen science contributions, which are typically hosted through open-access online platforms, studies like the present one are able to compile a larger volume of data for analysis. Furthermore, given that citizen science initiatives are based on public participation, they inherently increase the number of opportunities to improve environmental education efforts focused on conserving biodiversity (Peter et al., 2019). However, there are potential risks or challenges associated with citizen science in biodiversity documentation that must be addressed, such as observer differences, reporting preferences, false positive errors, data validation, and detectability (Johnston et al., 2023).

During the period of 1981–2000, the lowest number of records were contributed to the reptile inventory of Nayarit; therefore, the fewest number of grid cells with *C* index values ≥0.8 were present. This result may be explained by the data sources of the period, which were mainly national institutions. During the first two periods (1861–1960 and 1961–1980), data were primarily sourced from a diverse range of international and national institutions. Thus, the trend observed during 1981–2000 suggests that a lower sampling effort was present during the period, which was possibly associated with the reduced participation of international institutions (Meyer et al., 2015) and, consequently, reduced financial support for biodiversity conservation. This trend has been observed in various countries across Africa, the Americas, Asia, Europe, and Oceania (Waldron et al., 2013). However, the efforts of researchers, educational institutions, and research centers in Mexico should be recognized for their contributions to biological inventories despite the challenges associated with securing funding for such studies when they are not prioritized in national policies or budgets.

Studies like the present one are important for identifying knowledge gaps in biological inventories, establishing a foundation for future research, and optimizing resources to fill notable gaps. Importantly, the results of the present study indicate that few reptile species remain to be described in the state of Nayarit. In addition, records of this terrestrial vertebrate group are influenced by accessibility

to sampling areas and proximity to urbanization. Thus, future sampling efforts should focus on remote, mountainous, and difficult-to-access areas. Lastly, the use of citizen science applications to increase the number of biodiversity records over the past two decades has notably contributed to the completeness of the reptile inventory in Nayarit.

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Competing Interests

The authors have declared that no competing interests exist.

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