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Forty-five years of puma research in Chile: trends, knowledge gaps, and conservation implications

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Research on the puma (*Puma concolor*) in Chile has progressively developed over the past 45 years; however, no comprehensive synthesis had previously evaluated its spatial, thematic, and temporal development. We conducted a systematic review of peer-reviewed studies published between 1980 and 2025, identifying 34 articles addressing ecological, behavioral, genetic, sanitary, and socio-environmental aspects of the species. Research effort was spatially uneven across the country. Although central Chile currently accounts for the largest proportion of studies, early research was historically concentrated in the Magallanes Region, while northern ecosystems remain comparatively underrepresented. Trophic ecology dominated the initial decades of research, whereas studies on behavior, distribution and density, health, genetics, and human–puma interactions increased markedly after 2010. Temporal analyses and Correspondence Analysis revealed clear shifts in research priorities, with the most recent period (2016–2025) characterized by greater thematic diversification and the incorporation of molecular and socio-ecological approaches. Despite these advances, important gaps persist, particularly in long-term monitoring, telemetry-based studies, disease ecology, and research in arid or highly fragmented landscapes. Socio-ecological research remains limited relative to the growing challenges of human–puma coexistence in human-dominated environments. By providing the first integrated assessment of four and a half decades of puma research in Chile, this review establishes a baseline to guide future interdisciplinary and geographically representative conservation efforts.

Keywords: apex predator; carnivore conservation; ecological connectivity; human–wildlife conflict; large carnivores.

La investigación sobre el puma (*Puma concolor*) en Chile ha aumentado progresivamente durante los últimos 45 años; sin embargo, no existía previamente una síntesis integral que evaluara su desarrollo espacial, temático y temporal. En este estudio realizamos una revisión sistemática de publicaciones científicas indexadas publicadas entre 1980 y 2025, identificando 34 artículos que abordan aspectos ecológicos, conductuales, genéticos, sanitarios y socioambientales de la especie. El esfuerzo de investigación se distribuye de manera desigual a lo largo del país. Aunque la zona central concentra actualmente la mayor proporción de estudios, las primeras décadas estuvieron históricamente enfocadas en la Región de Magallanes, mientras que los ecosistemas del norte permanecen comparativamente subrepresentados. La ecología trófica dominó las etapas iniciales de investigación, mientras que los estudios sobre comportamiento, distribución y densidad, salud, genética e interacción humano–puma aumentaron de forma marcada después de 2010. Los análisis temporales y el análisis de correspondencias evidenciaron cambios claros en las prioridades de investigación, destacándose que el período más reciente (2016–2025) presentó mayor diversificación temática e incorporación de enfoques moleculares y socio-ecológicos. A pesar de estos avances, persisten vacíos relevantes, particularmente en monitoreo de largo plazo, estudios basados en telemetría, ecología de enfermedades e investigaciones en paisajes áridos o altamente fragmentados. Las investigaciones socio-ecológicas siguen siendo limitadas en relación con los crecientes desafíos de coexistencia humano–puma en entornos dominados por actividades antropogénicas. Al proporcionar la primera evaluación integrada de cuatro décadas y media de investigación sobre el puma en Chile, esta revisión establece una base para orientar futuros esfuerzos de conservación interdisciplinarios y con mayor representatividad geográfica.

Palabras clave: conflicto humano–fauna; conectividad ecológica; conservación de carnívoros; depredador tope; grandes carnívoros.

The puma, *Puma concolor* (Linnaeus, 1771), is one of the most widely distributed terrestrial predators in the world, occupying a latitudinal range of over 100 degrees from northern Canada to the southern tip of Chile and Argentina (Iriarte and Jaksic 1986; Iriarte *et al.* 1990; Nielsen *et al.* 2025; IUCN 2025). It is a large, solitary felid characterized by a predominantly uniform tawny coat, a long cylindrical tail typically measuring approximately one third of its total body length, rounded ears without prominent tufts, and the absence of rosettes or stripes in adults. These features distinguish it from other felids present in Chile, such as *Leopardus guigna* and *Leopardus colocolo*, as well as from medium-sized canids like *Lycalopex culpaeus*, which differ in cranial morphology, non-retractile claws, and overall body conformation (Iriarte and Jaksic 2012). Across this vast distribution, the species fulfils a key ecological role as an apex predator, influencing herbivore populations and shaping community dynamics through top-down processes (Franklin *et al.* 1999; Bank *et al.* 2002).

Beyond its contemporary ecological relevance, *P. concolor* has been a component of southern South American ecosystems since at least the Late Pleistocene. Fossil remains attributed to the species have been documented in southern Chile, including deposits from Cueva de los Chingues in Pali Aike National Park, Magallanes (San Román *et al.* 2000). Paleoecological analyses of the Late Pleistocene carnivore guild in southern South America further support the role of large felids, including pumas, as established predators within these ecosystems prior to the Holocene (Prevosti and Vizcaíno 2006). Although paleontological studies fall outside the primary ecological scope of the present review, acknowledging this deep temporal record situates the puma as a longstanding structural component of Chilean ecosystems.

In Chile, *P. concolor* occurs along a remarkable environmental gradient—from the xeric highlands of the northern Andes to Mediterranean shrublands, temperate forests, and the Patagonian steppe (Wilson 1984; Muñoz-Pedreros *et al.* 1995; Guzmán-Marín *et al.* 2023; Ministerio del Medio Ambiente 2024). This ecological plasticity has enabled the species to persist in landscapes under varying degrees of human transformation, including agricultural basins, forestry-dominated areas, and peri-urban environments (Rodríguez *et al.* 2019; Ramírez-Álvarez *et al.* 2021).

Despite its broad presence, scientific knowledge of pumas in Chile has historically been fragmented and geographically uneven. Early research, concentrated primarily in the southern regions, focused on predator–prey dynamics with native ungulates, especially guanacos (*Lama guanicoe*) (Wilson 1984; Iriarte *et al.* 1991; Rau *et al.* 1991; Bank *et al.* 2002). Although foundational, these studies provided limited insights into the ecological variability of pumas across the country. As a result, extensive biogeographic areas—including the central Andes, Mediterranean ecosystems, and the northern highlands—remained largely absent from the scientific record for decades (Zúñiga *et al.* 2009; Guarda *et al.* 2017; Dumont *et al.* 2022).

In the 2000s, methodological innovations began to reshape carnivore ecology globally, including camera trapping, genetic barcoding, stable isotope analysis, and spatially explicit capture–recapture models. These tools gradually permeated Chilean research efforts, enabling new insights into behavior, movement patterns, population density, and genetic structure (Elbroch and Wittmer 2013a; Elbroch *et al.* 2024). More recently, studies have begun to integrate socio-ecological dimensions, reflecting the growing importance of human–puma interactions in landscapes increasingly shaped by agriculture, livestock production, and urban expansion (Rodríguez *et al.* 2019; Ramírez-Álvarez *et al.* 2021; Iranzo *et al.* 2025). These conflicts—including livestock depredation and sightings near rural or peri-urban homes—have broadened conservation concerns beyond ecological patterns alone.

Although individual studies have yielded important contributions, national knowledge remains dispersed across decades, regions, and thematic domains (Hidalgo *et al.* 2013; Landaeta-Aqueveque *et al.* 2015). No comprehensive synthesis has evaluated how research on *P. concolor* in Chile has evolved over time, which themes have dominated or emerged, how regional biases have shaped the available evidence, or what methodological transitions have influenced scientific perspectives. This gap limits the ability to identify knowledge deficits, prioritize conservation needs, and align Chilean research with global directions in carnivore ecology (Pullin and Stewart 2006; Grant and Booth 2009; Haddaway *et al.* 2015; Snyder 2019).

This review addresses this gap by conducting the first systematic synthesis of peer-reviewed studies on *P. concolor* in Chile spanning 45 years (1980–2025). Specifically, we examine (1) the spatial distribution of research effort across administrative regions, (2) thematic patterns and their temporal evolution, (3) changes in publication frequency over time, (4) statistical associations between research topics and historical periods, and (5) major methodological and conceptual transitions. By integrating these dimensions, we provide a comprehensive assessment of the intellectual development of puma research in Chile and propose future directions to strengthen national capacity for conservation and human–puma coexistence.

Material and methods

We conducted a systematic review of peer-reviewed scientific literature on *P. concolor* in Chile published between 1980 and 2025. This period encompasses the earliest contemporary ecological research on the species within the country and captures 45 years of scientific development, including major methodological and conceptual advances in carnivore ecology.

Although several studies and published accounts referring to *P. concolor* in Chile predate 1980, these earlier contributions were predominantly descriptive, embedded within broader natural history syntheses, or lacking a specific ecological focus on the species. Peer-reviewed research explicitly addressing ecological questions—such as diet, spatial ecology, population dynamics, or human–wildlife interactions—began to consolidate more consistently from the early 1980s onward. In addition, pre-1980 publications are often inconsistently indexed in major scientific databases, limiting traceability and reproducibility under standardized search protocols. Establishing 1980 as the starting point therefore acknowledges the existence of earlier contributions while defining a temporal boundary aligned with the emergence of contemporary ecological research and standardized scientific publishing in Chile.

Literature search and eligibility criteria. Searches were performed in Scopus, Web of Science, SciELO, Google Scholar, and institutional repositories using combinations of English and Spanish keywords, including *Puma concolor*, puma, león de montaña, mountain lion, Chile, ecology, diet, behavior, genetics, conflict, coexistence, and conservation. Additional studies were identified through backward and forward citation tracking.

To ensure methodological consistency, we applied strict inclusion criteria. Studies were included if they (1) were published in peer-reviewed journals; (2) focused wholly or partially on pumas within Chile; (3) presented empirical, descriptive, or synthetic contributions related to ecology, behavior, genetics, distribution, health, or human–puma interactions; and (4) provided sufficient information to allow thematic classification. Theses, unpublished reports, government documents, conference abstracts, and other sources of grey literature were excluded because they do not correspond to peer-reviewed scientific literature (Donthu *et al.* 2021; Moher *et al.* 2009).

Data extraction and thematic classification. For each publication, we extracted the year of publication, administrative region(s) of study, main research theme, methodology, sample type, analytical approaches, and principal findings. Publications were classified into the following thematic categories: trophic ecology; distribution and density; behavior; health; genetics; human–puma interaction; and historical conservation. A synthesis of all reviewed studies is presented in Table 1.

Temporal and thematic analyses. To evaluate long-term patterns in scientific output, we analyzed (1) annual publication counts, (2) the frequency of research themes, and (3) the temporal distribution of thematic categories across the study period. To examine changes in research focus, studies were grouped into three publication periods reflecting major methodological transitions: 1980–2000, 2001–2015, and 2016–2025. The second categorical variable corresponded to research theme, classified into seven mutually exclusive categories: trophic ecology; distribution and density; behavior; health; genetics; human–puma interaction; and historical conservation. Although some categories had relatively low frequencies, thematic classifications were retained separately to preserve conceptual resolution and accurately reflect the diversification of research topics over time.

To assess whether thematic composition varied across publication periods, we constructed a 3 × 7 contingency table crossing publication period (three levels) with research theme (seven levels). We then applied a chi-square test of independence to evaluate whether thematic distribution

Table 1. Peer-reviewed studies on *Puma concolor* conducted in Chile between 1984 and 2025. For each study, we summarize the primary research topic, methodological approach, the specific knowledge gap addressed regarding puma ecology, population dynamics, health, genetics, behavior, or human interaction, and the principal findings directly related to the species. The column "Knowledge gap addressed by the study" refers explicitly to the research question or informational deficiency concerning *Puma concolor* that motivated the study at the time of publication, rather than to general limitations in wildlife research or other taxa. "Main findings" summarize the key results as they pertain specifically to puma biology, conservation, or management within the Chilean context. This structure allows direct correspondence between the research gap identified and the contribution made by each study to advancing knowledge of the species.

ID	Year	Authors	Region	Main topic	Methodology	Knowledge gap addressed by the study	Main findings
1	1984	Wilson	Austral	Community ecology	Telemetry	Lack of quantitative data on puma predation patterns and seasonal effects on guanaco populations	Puma predation increased winter mortality of female guanacos
2	1986	Iriarte and Jaksic	National	Historical conservation	Secondary data	Lack of historical assessment of human exploitation affecting puma populations	Fur trade records revealed strong historical hunting pressure on pumas
3	1987	Jaksic and Simonetti	Southern Cone	Community ecology	Literature review	Lack of synthesis of predator–prey interactions involving pumas in southern South America	Puma research primarily focused on mammalian prey; taxonomic bias identified
4	1990	Iriarte *et al.*	Americas	Community ecology	Comparative analysis	Lack of standardized dietary comparisons across regions for pumas	Significant regional variation in puma diet
5	1991	Rau *et al.*	South	Community ecology	Fecal analysis	Limited dietary data for pumas in southern Chile	Diet dominated by guanacos and European hares
6	1991	Iriarte *et al.*	Austral	Community ecology	Fecal analysis	Lack of interannual dietary studies for pumas	Hare (50%) and guanaco (32%) dominated diet
7	1995	Muñoz-Pedreros *et al.*	South	Distribution and density	Camera trapping	Lack of puma occurrence data in temperate forest habitats	Low densities detected in forested areas
8	1999	Franklin *et al.*	Austral	Community ecology	Telemetry	Lack of demographic and density estimates for Neotropical puma populations	Estimated density: 1 puma per 17 km²
9	2002	Rau and Jiménez	South	Community ecology	Fecal analysis	Lack of temporal dietary comparisons between ranges	Dietary differences observed across study areas
10	2002	Bank *et al.*	Austral	Community ecology	Carcass analysis	Limited understanding of puma predation impact under extreme climatic conditions	74% of guanaco deaths attributed to pumas
11	2005	Borrero *et al.*	Austral	Behavioral ecology	Carcass analysis	Lack of understanding of carcass use and abandonment patterns	Pumas partially abandoned carcasses, influencing scavenger dynamics
12	2009	Zúñiga *et al.*	South	Behavior	Camera trapping	Limited knowledge of puma response to habitat fragmentation	Forest plantations used as habitat
13	2009	Elbroch *et al.*	Austral	Behavior	Telemetry	Lack of dispersal and long-distance movement data	Movements exceeding 100 km documented
14	2012	Skewes *et al.*	South	Community ecology	Fecal analysis	Lack of information on invasive prey incorporation into puma diet	First record of wild boar in diet

15	2013b	Elbroch and Wittmer	Austral	Distribution and density	Telemetry	Lack of density estimates in open Patagonian habitats	Density estimated at 3.4 ind / 100 km²
16	2013	Hidalgo *et al.*	National	Health	Fecal analysis	Lack of sanitary data for Chilean pumas	First record of *Trichinella* infection
17	2014	Zúñiga and Muñoz-Pedreros	South	Community ecology	Fecal analysis	Limited data on dietary adaptation to altered habitats	Diet included pudú, rabbit, coypu
18	2015	Landaeta-Aqueveque *et al.*	National	Health	Comparative study	Limited understanding of zoonotic parasite transmission involving pumas	Domestic mammals identified as potential transmission vectors
19	2016	Leichtle *et al.*	National	Genetics	Morphogenetic review	Lack of taxonomic clarity within Chilean puma populations	Proposed north–south subspecific differentiation
20	2016	Guarda *et al.*	Central	Distribution and density	Camera trapping	Lack of density data in central Chile	Density estimated at 0.74–0.83 ind / 100 km²
21	2019	Rodríguez *et al.*	National	Human–puma interaction	Literature review	Lack of spatial evaluation of conflict distribution	91% of conflicts concentrated in 18 municipalities
22	2020	Osorio *et al.*	Central	Community ecology	Comparative study	Limited understanding of interspecific interactions in altered ecosystems	Puma–culpeo coexistence documented
23	2021	Echeverry *et al.*	National	Health	DNA analysis	Lack of updated zoonotic parasite confirmation in pumas	Confirmed *T. spiralis* in poached puma
24	2021	Ramírez-Álvarez *et al.*	Central	Human–puma interaction	Telemetry	Lack of data on puma movement near urban settlements	Low densities recorded near human settlements
25	2022	Dumont *et al.*	Central	Distribution and density	Camera trapping	Lack of coastal occurrence records	First documented record in Putaendo
26	2023	Guzmán-Marín *et al.*	Central	Distribution and density	Camera trapping	Limited understanding of connectivity under fragmentation	Range extension of 170 km documented
27	2023	Rodríguez-Arancibia and Escobar	Central	Distribution and density	Camera trapping	Lack of coastal-edge occurrence data	First record at coastal edge
28	2024	Elbroch *et al.*	Austral	Genetics	DNA analysis	Lack of genetic monitoring in southern populations	Low evidence of inbreeding detected
29	2024	Mac Allister *et al.*	Austral	Genetics	DNA analysis	Limited knowledge of population structure in southern extreme	Unique genetic diversification documented
30	2025a	Leichtle and Bonacic	Northern	Population ecology	Camera trapping; modeling	Lack of ecological data for northern Andean pumas	Lowest densities; nocturnal activity; preference for high-Andean shrublands
31	2025b	Leichtle and Bonacic	Northern	Trophic ecology	Fecal analysis	Lack of trophic studies for northern Andes	Diet dominated by wild artiodactyls; conflict linked to pastoral change
32	2025	Guzmán-Aguayo *et al.*	Austral	Behavior	Camera trapping	Limited data on behavioral responses to tourism	Temporal avoidance of high-use trails
33	2025	Iranzo *et al.*	Austral	Human–puma interaction	Interviews; modeling	Lack of integration between ecological data and human perception	Fear persisted despite stable ecological indicators
34	2025	Calvo and Skewes	South-central	Community ecology	Camera trapping	Scarce data in Araucaria forest ecosystems	Puma detected at low frequency

was statistically associated with historical period. Expected frequencies were calculated under the null hypothesis that research theme and publication period were independent. Prior to interpretation, we verified that the assumptions of the chi-square test were satisfied. Given the relatively small sample size (n = 34), results were interpreted cautiously and complemented with Correspondence Analysis (CA), which provides a multivariate visualization of associations among categorical variables. To characterize longitudinal thematic trajectories, we also generated temporal trend plots showing annual changes in study themes.

Spatial analysis: Spatial patterns of research effort were assessed by linking each publication to the administrative region(s) addressed in the study. Regional boundaries were obtained from the Natural Earth dataset (level-1 subdivisions), and publication counts were mapped to illustrate the geographic distribution of research effort and identify spatial biases in study representation across Chile. No standardization by regional area, habitat extent, or puma distribution range was applied, as the objective was to describe relative research effort rather than infer proportional sampling intensity.

Statistical environment and reproducibility: All analyses were conducted in R 4.3.1 (R Core Team 2024), using the packages ggplot2 (Wickham 2016), igraph (Csardi and Nepusz 2006), and the tidyverse collection (Wickham *et al.* 2019). Scripts for data processing, visualization, and statistical analysis are available upon request to ensure full reproducibility (Aria and Cuccurullo 2017).

Limitations and scope of literature inclusion: Because this review aimed to provide a standardized and reproducible synthesis of scientific knowledge, only peer-reviewed publications were included. Grey literature—such as theses, technical reports, environmental impact assessments, governmental documents, monitoring program reports, and non-indexed institutional publications—was deliberately

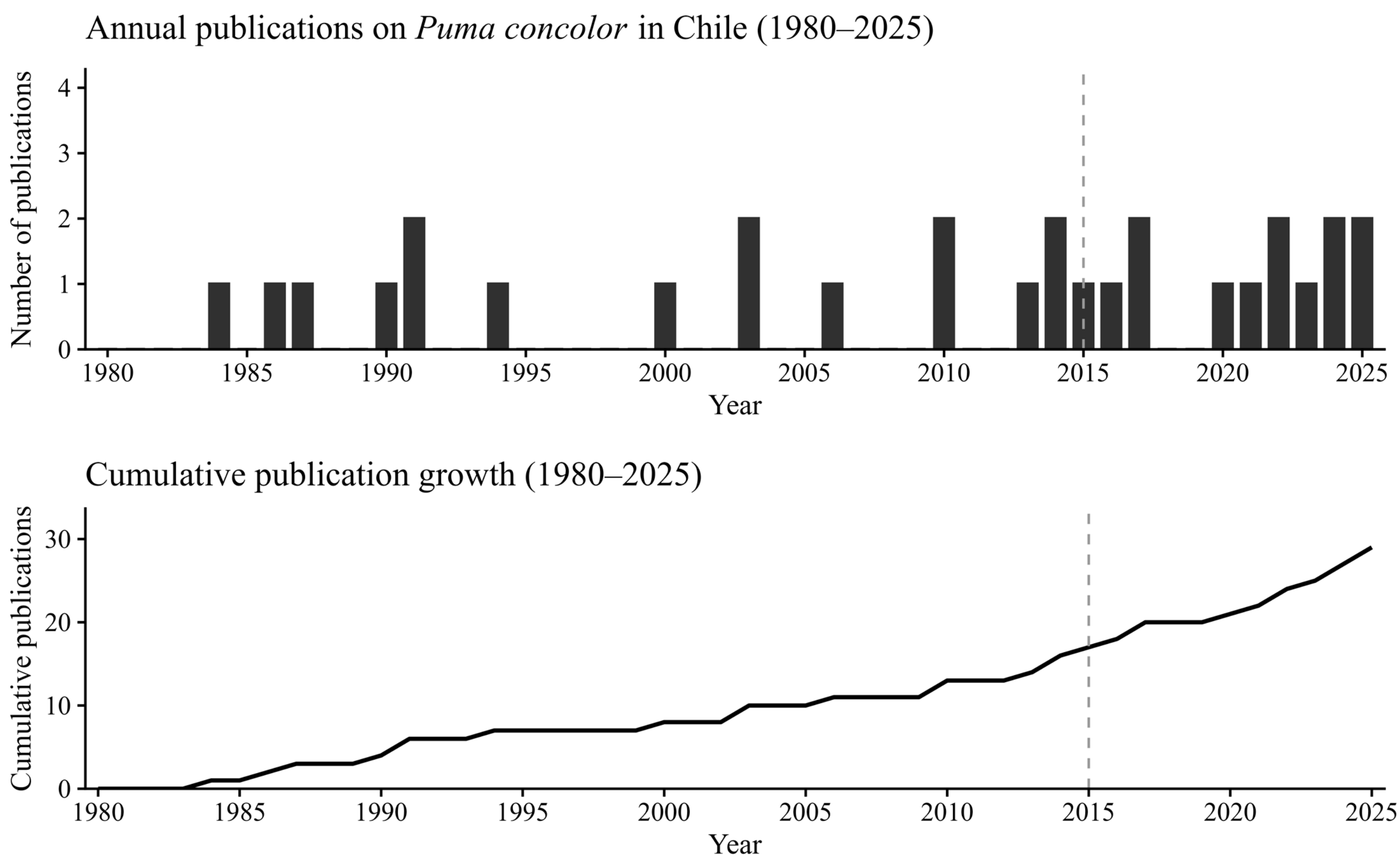

Figure 1. (A) Annual number of peer-reviewed publications on *Puma concolor* in Chile (1980–2025). (B) Cumulative publication growth over the same period. The dashed vertical line marks 2015, corresponding to the beginning of a more consistent publication frequency and a noticeable change in the slope of cumulative growth, indicating progressive consolidation of national research output during the most recent decade.

excluded. Although these sources may contain valuable ecological information, their methodological heterogeneity, variable accessibility, and lack of standardized peer-review processes can limit comparability across studies.

Restricting the analysis to peer-reviewed literature ensured consistency in quality control, traceability of sources, bibliographic verification, and analytical standardization. This decision also enhances reproducibility, allowing future researchers to replicate search strategies, update the dataset, and reassess temporal trends under equivalent criteria. Consequently, the knowledge gaps identified in this review reflect gaps within the indexed scientific literature rather than the totality of information that may exist in technical or unpublished formats.

Results

We identified 34 peer-reviewed publications addressing pumas in Chile between 1980 and 2025. The resulting synthesis reveals substantial spatial concentration, thematic evolution, and temporal shifts in research priorities.

Spatial distribution: Research effort was unevenly distributed across Chile. The highest proportion of studies was conducted in central Chile (38%), particularly during the last decade, followed by the Magallanes Region (32%). Studies conducted at a national scale represented 20%, whereas northern ecosystems accounted for only 10% of publications. Despite this recent increase in central Chile, extensive areas of northern and south-central regions remain poorly documented.

Temporal patterns: Publication output remained relatively low and stable during the first two decades (1980–2000), typically averaging one article per year or less. From the mid-2000s onward, publication frequency became more consistent, generally fluctuating between one and two articles annually. Although no abrupt surge is observed, the cumulative growth curve indicates a gradual acceleration in scientific production after 2010, culminating in the highest annual output recorded in 2025 (Figure 1). This pattern reflects progressive consolidation rather than a sudden expansion of research activity.

Thematic patterns: Trophic ecology dominated the literature (13 publications), reflecting Chilean ecology's early focus on predator–prey interactions. Distribution and density (6), behavior (5), genetics (3), health (3), and human–puma interaction (3) constituted the remaining themes (Figure 2). These patterns show that, while feeding ecology played a foundational role in national puma research, more diverse and multidisciplinary approaches have emerged in the last decade.

Temporal structure of themes: The temporal distribution of thematic categories showed that trophic ecology remains the only theme consistently represented across all decades.

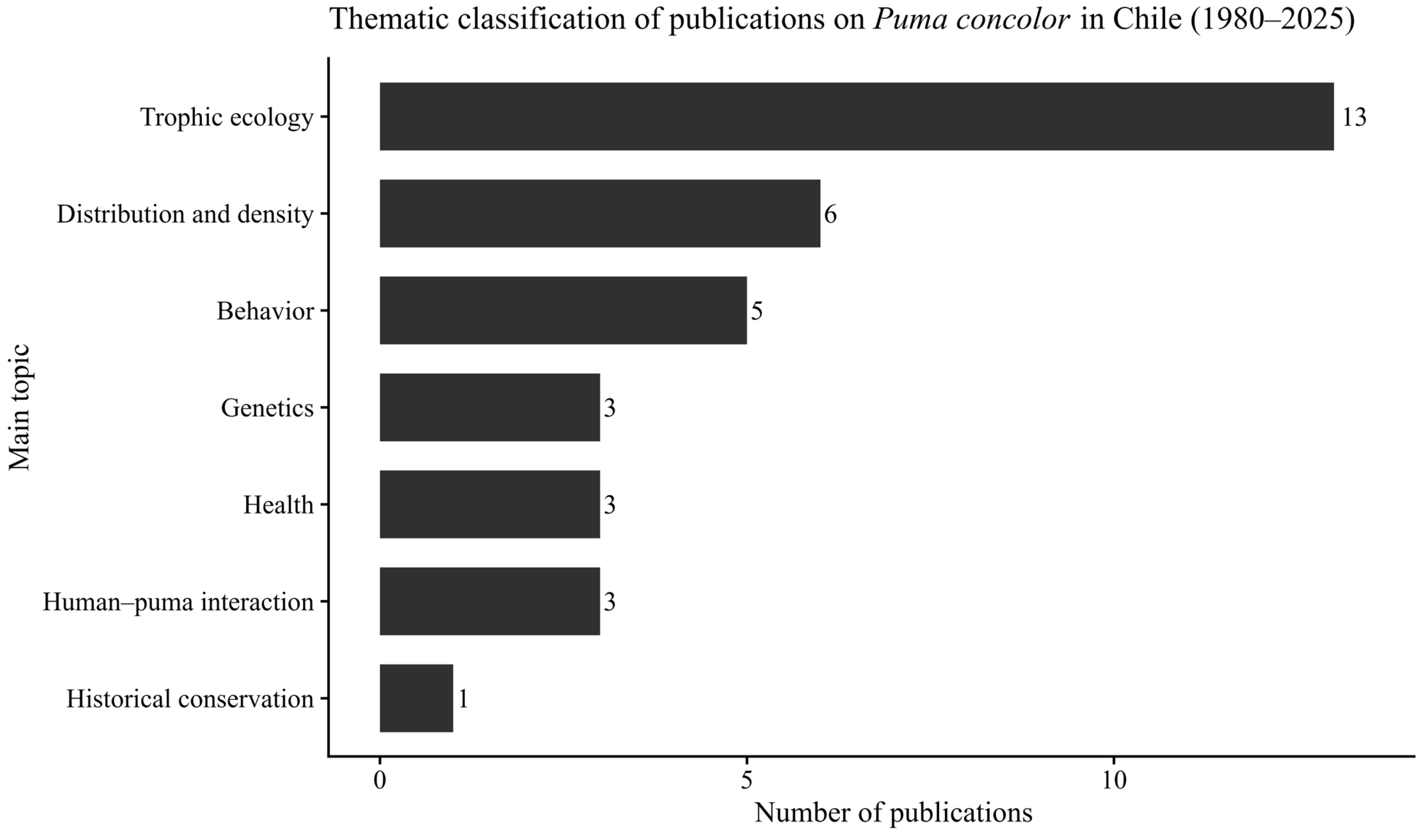

Figure 2. Thematic classification of peer-reviewed publications on *Puma concolor* in Chile (1980–2025) based on the main topic assigned to each study.

Distribution and density studies first appeared in 1995 but remained sporadic during the following decade and became more frequent and methodologically consolidated after 2010. Behavior studies intensified after 2005 and again after 2020, whereas genetics and human–puma interaction emerged almost exclusively in the last decade. Trend analyses further indicated a marked decline in the relative dominance of trophic ecology and a progressive increase in behavioral, spatial, and socio-ecological research (Figure 3).

Period comparison: To evaluate whether the distribution of research themes differed among historical periods, we applied a chi-square test of independence using a 3 × 7 contingency table crossing publication period (1980–2000, 2001–2015, 2016–2025) and research theme (trophic ecology; distribution and density; behavior; health; genetics; human–puma interaction; historical conservation). The test did not detect a statistically significant association between period and research theme ($\chi^2 = 20.43$, df = 12, $p = 0.059$). Although the association did not reach the conventional threshold for statistical significance, descriptive patterns indicated temporal clustering in thematic composition. Early studies (1980–2000) were predominantly focused on trophic ecology; the 2001–2015 period incorporated behavioral and health-related perspectives; and the most recent period (2016–2025) showed greater representation of genetics and socio-ecological research themes.

Correspondence Analysis: The Correspondence Analysis revealed clear temporal structuring in thematic composition. The first dimension explained 84.3% of the total inertia, indicating that most variation in research themes across periods is captured along a single dominant axis. The second dimension accounted for 15.7% of the inertia.

The earliest period (1980–2000) was positioned toward the side of the ordination space associated with trophic ecology and historical conservation. The intermediate period (2001–2015) was located closer to behavioral and health-related research themes, reflecting diversification beyond purely ecological approaches. In contrast, the most recent period (2016–2025) was situated near genetics, human–puma interaction, and distribution and density, indicating a shift toward socio-ecological and population-oriented research perspectives.

Overall, the ordination supports a progressive temporal reorganization of research themes, with early ecological emphasis transitioning toward greater thematic diversity and increasing incorporation of human dimensions in recent years (Figure 4).

Discussion

This review reveals a structured and progressive evolution of puma research in Chile over the past four decades, reflecting broader global patterns in large carnivore science. Worldwide, research on apex predators has transitioned from descriptive ecological studies toward increasingly integrative frameworks incorporating spatial modelling, genetics, disease ecology, and human dimensions (Treves

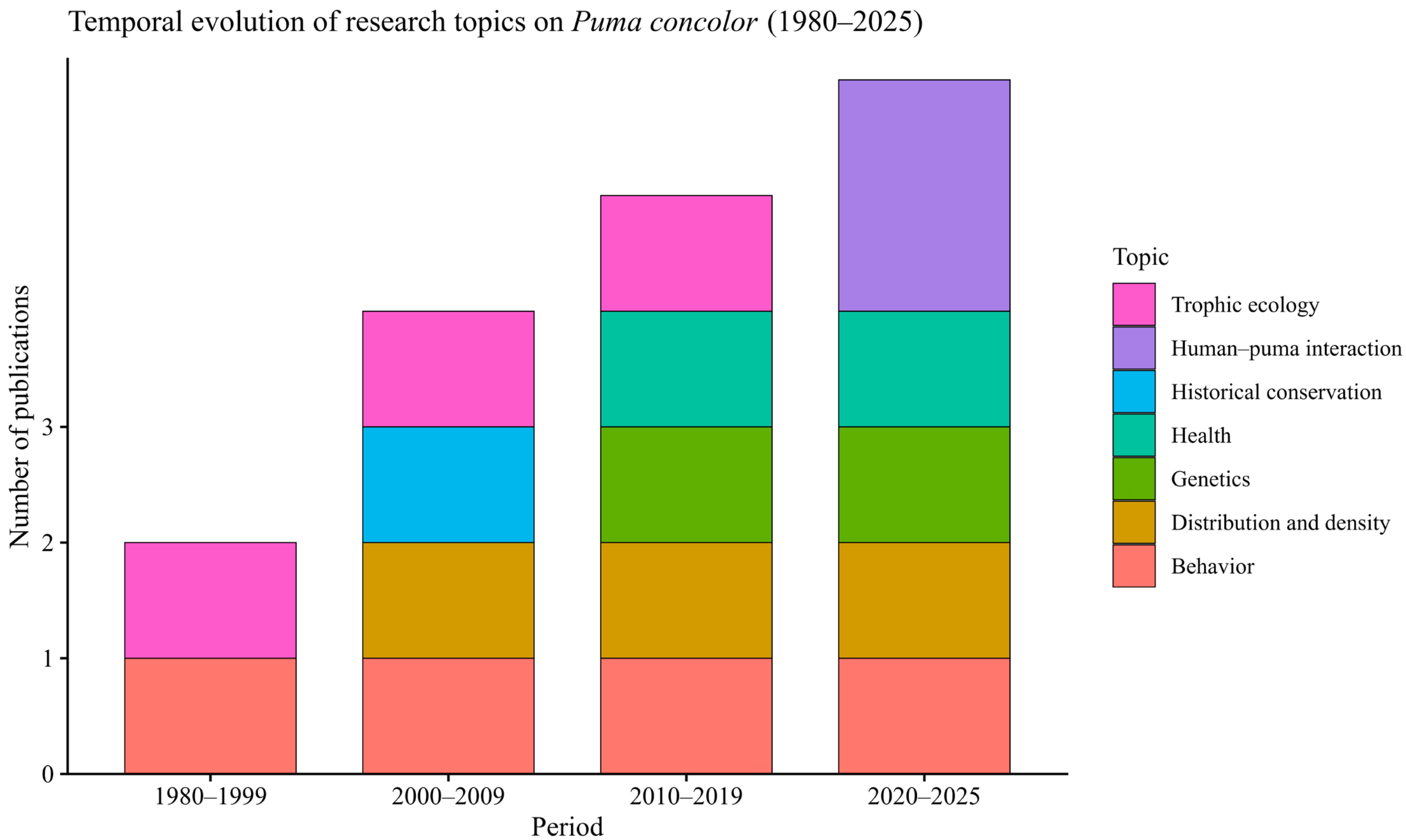

Figure 3. Temporal trends in research topics on Puma concolor in Chile (1980–2025). The figure illustrates the emergence, persistence, and occasional disappearance of thematic categories over time. Trophic ecology predominated during the early decades, whereas research on behavior, distribution and density, genetics, health, and human–puma interaction increased notably after 2010, reflecting a progressive diversification of the field.

and Karanth 2003; Ripple *et al.* 2014). A similar trajectory is evident in Chile. Although annual publication rates remained relatively modest throughout much of the study period, the thematic breadth of research expanded markedly after 2010, suggesting qualitative diversification rather than purely quantitative growth. This pattern aligns with global shifts in carnivore research, where methodological innovation and conservation urgency have reshaped research priorities (Crooks 2002; Chapron *et al.* 2014). In addition, increasing human expansion into formerly natural landscapes has intensified interactions between people and large carnivores, generating new research agendas focused on coexistence, conflict mitigation, and human dimensions of conservation (Randa and Yunger 2006; Bombieri *et al.* 2018).

In addition to broader global trends, the historical concentration of Chilean puma studies in southern regions likely reflects structural and institutional drivers. Ecological research effort commonly clusters around areas with long-term field programs, consolidated protected areas, and sustained logistical support, generating spatially uneven knowledge production (Haddaway *et al.* 2015; Gusenbauer and Haddaway 2020). In Chile, Patagonia has historically hosted internationally connected conservation initiatives and well-established research networks focused on large mammals, which may have facilitated repeated sampling and multi-year data continuity (Franklin *et al.* 1999; Bank *et al.* 2002; Elbroch *et al.* 2009). Thus, the regional concentration observed in early decades likely reflects research infrastructure and funding continuity rather than intrinsic ecological priority.

Shifts in thematic and methodological focus: The early predominance of trophic ecology in Chilean puma research reflects a combination of logistical feasibility, methodological accessibility, and regional research infrastructure rather than ecological exclusivity of any particular biome. During the 1980s and 1990s, many studies were conducted in southern Chile, particularly in Patagonian landscapes, where open habitats and abundant ungulate prey facilitated diet assessments through scat analysis and carcass inspection. Similar reliance on dietary studies characterized early phases of large carnivore research globally, as predator–prey interactions were more readily quantified than demographic, genetic, or movement parameters (Treves and Karanth 2003). These foundational studies generated important insights into prey selection, seasonal mortality, and predator–prey dynamics. However, their geographic concentration in southern ecosystems inherently constrained the ability to extrapolate findings across Chile's highly heterogeneous environmental gradient, which includes Mediterranean shrublands, temperate forests, high-Andean plateaus, and arid northern systems.

Importantly, the historical prominence of Patagonian

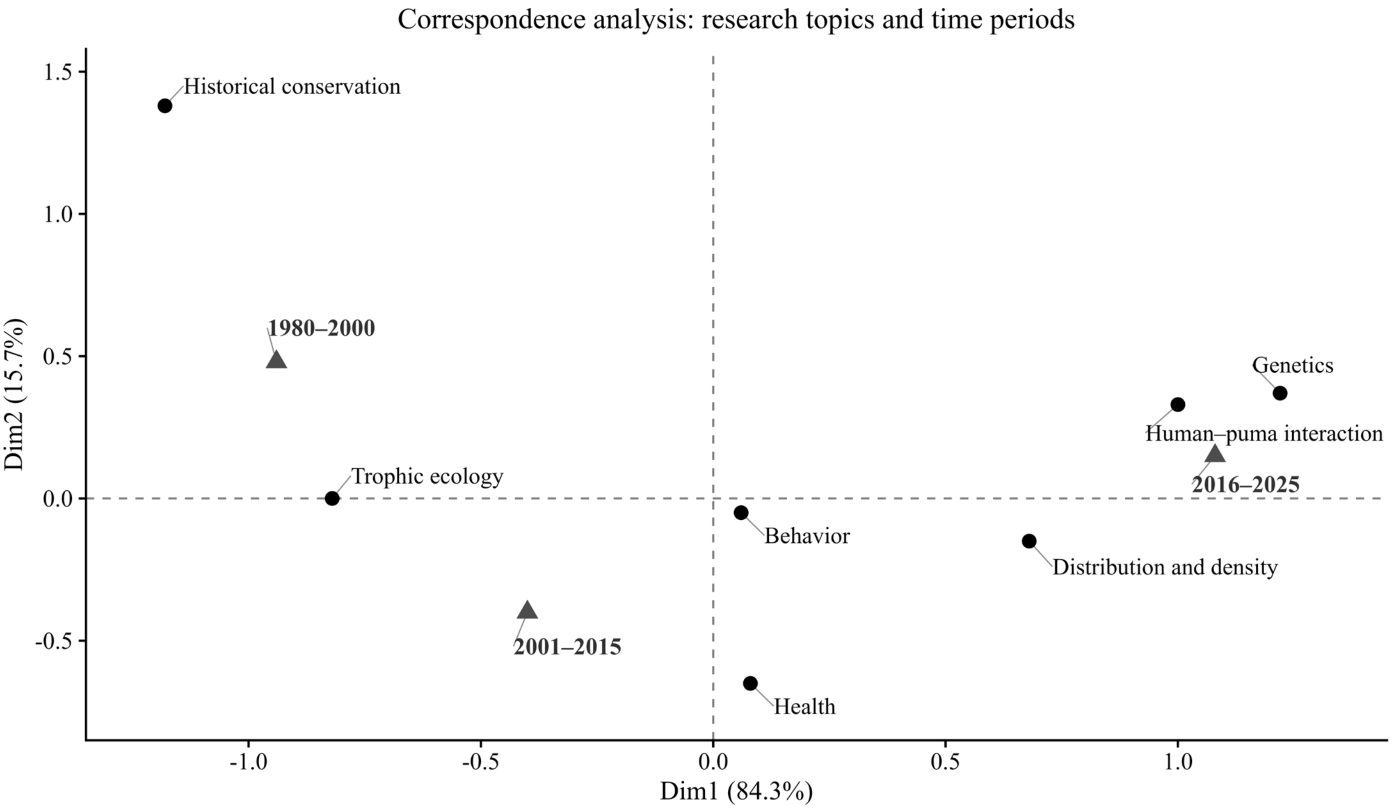

Figure 4. Correspondence Analysis (CA) ordination of research themes and publication periods for *Puma concolor* studies in Chile (1980–2025). Points represent thematic categories (blue) and historical periods (red). The first two dimensions explain 84.3% and 15.7% of the total inertia, respectively. The ordination illustrates temporal structuring in thematic focus, with early studies (1980–2000) associated primarily with trophic ecology and historical conservation, the intermediate period (2001–2015) linked to behavioral and health-related research, and the most recent period (2016–2025) positioned closer to genetics, distribution and density, and human–puma interaction themes.

systems in the literature should not be interpreted as ecological centrality of these landscapes for *P. concolor* in Chile. Most studies relied on indirect methodologies—including camera trapping, scat analysis, carcass inspection, and genetic sampling—rather than direct visual observation. In open southern environments, ecological evidence such as kills, tracks, and scats may have been more detectable, facilitating early research implementation. This pattern reflects detectability and logistical continuity of long-term field programs rather than greater biological importance of southern populations. Given the pronounced biogeographic diversity of Chile, extrapolating ecological patterns derived primarily from Patagonian systems may obscure region-specific dynamics operating in central and northern ecosystems, including variation in prey assemblages, habitat use, population density, movement ecology, and the intensity and form of human–puma interactions.

Beginning in the 2000s, Chilean puma research underwent a methodological transition consistent with broader developments in carnivore ecology. The incorporation of camera trapping, telemetry, and spatially explicit analytical frameworks expanded the scope of inquiry beyond diet-based studies. Advances in spatial capture–recapture models and individual tracking transformed large carnivore monitoring worldwide, enabling robust density estimation and movement analyses (Kelly *et al.* 2012; Royle *et al.* 2014). In Chile, these approaches produced the first standardized density estimates for both central and southern regions and documented dispersal movements and spatial behavior under varying degrees of anthropogenic influence. More recently, genetic analyses have begun to clarify patterns of population structure and connectivity, aligning with global recognition that molecular tools are essential for evaluating fragmentation and long-term demographic viability (Crooks 2002; Frankham 2005).

The emergence of health-related and socio-ecological studies during the last decade further reflects a shift toward interdisciplinary conservation science. As pumas increasingly overlap with livestock systems, forestry landscapes, and peri-urban environments, research attention has expanded to include pathogen transmission, livestock depredation, human perception, and coexistence dynamics (Treves *et al.* 2006; Ripple *et al.* 2014). In Chile, documented cases of zoonotic parasites and spatial concentration of conflicts illustrate this diversification of thematic focus. Nevertheless, despite increasing breadth, several methodological and geographic gaps persist.

Telemetry remains comparatively limited relative to its demonstrated value for understanding movement ecology, habitat selection, survival, and behavioral responses to anthropogenic disturbance (Logan and Sweanor 2001; Elbroch and Wittmer 2013b). The scarcity of long-term monitoring frameworks similarly constrains robust demographic inference. Globally, sustained multi-year telemetry programs have been central to evaluating carnivore recovery, dispersal dynamics, survival rates, and population viability (Chapron *et al.* 2014). In Chile, however, comparable longitudinal datasets remain rare, limiting the ability to assess population trajectories, climate-related responses, and functional connectivity across heterogeneous landscapes—an approach that has proven critical for understanding large carnivore population dynamics elsewhere (Chapron *et al.* 2014).

Long-term telemetry has been extensively developed in North American puma populations, where multi-decadal collaring programs have generated comprehensive demographic and behavioral datasets (Logan and Sweanor 2001). These programs have provided foundational insights into survival, dispersal, habitat selection, and landscape-scale ecological processes.

The limited implementation of telemetry in Chile should therefore be interpreted within a broader continental context rather than as an isolated national shortcoming. Across much of Latin America, capture-based monitoring of large carnivores remains comparatively limited and often project-dependent. Telemetry requires specialized capture teams, veterinary supervision, long-term permits, and sustained financial support—conditions that are frequently difficult to maintain in South American research systems. As a result, non-invasive approaches such as camera trapping and genetic sampling have become more accessible and scalable alternatives (Kelly *et al.* 2012; Royle *et al.* 2014). Consequently, the relatively low representation of telemetry-based studies in Chile reflects broader structural constraints in regional research capacity. Expanding long-term telemetry programs would nonetheless substantially strengthen national capacity to evaluate demographic trends, ecological connectivity, and adaptive responses to ongoing landscape transformation.

Spatial bias and its implications: Research effort on P. concolor in Chile remains unevenly distributed across regions. Although central Chile currently accounts for the largest proportion of peer-reviewed studies, the Austral region—particularly Patagonia—historically concentrated research activity during the early decades. Geographic bias is not unique to Chile; systematic reviews in ecology consistently reveal clustering of research in accessible or institutionally supported regions (Haddaway *et al.* 2015; Gusenbauer and Haddaway 2020). In the Chilean context, long-standing research programs within protected Patagonian landscapes, together with sustained international collaborations, likely facilitated multi-year field continuity and repeated sampling.

Importantly, this historical concentration should not be interpreted as reflecting greater biological centrality or direct visibility of pumas in southern ecosystems. Most Chilean studies have relied on indirect methodologies—including scat analysis for dietary reconstruction, genetic identification from fecal samples (barcoding), carcass inspection, and camera trapping for detection and density estimation—rather than direct visual encounters. In open southern landscapes, early research feasibility was likely enhanced by greater detectability of ecological evidence (e.g., prey remains, tracks, and scats) and improved camera-trap performance in structurally simple habitats. Thus, the spatial pattern observed reflects detectability and institutional continuity rather than intrinsic ecological priority.

Northern Chile, by contrast, remains comparatively underrepresented despite its distinctive high-Andean and arid ecological conditions. Differences in prey assemblages, pastoral systems, climatic variability, and habitat structure suggest that puma ecology in these environments may differ substantially from patterns described in southern systems. However, the limited research effort in northern regions cannot be attributed solely to ecological variation. High-Andean and desert landscapes impose substantial logistical constraints, including seasonal inaccessibility, extreme environmental conditions, elevated field costs, and low infrastructure density, all of which can restrict sustained monitoring. Furthermore, pastoralist land-use systems and dispersed property regimes may complicate research access relative to regions characterized by large, consolidated protected areas.

Such structural conditions likely contributed to the delayed emergence of systematic research in northern ecosystems. Spatially biased research coverage can obscure national-scale patterns of connectivity, demographic resilience, and adaptive responses, particularly for wide-ranging carnivores whose conservation depends on landscape-level processes (Crooks 2002; Ripple *et al.* 2014). Extrapolating ecological patterns derived primarily from southern populations may therefore mask important regional dynamics. Future comparative analyses explicitly evaluating research effort relative to accessibility, institutional presence, or estimated regional densities would help disentangle ecological from structural drivers of spatial research bias and strengthen geographically representative conservation planning.

Knowledge gaps and future directions: The synthesis identifies several priority areas for future research. First, expanded geographic sampling is necessary to address uneven coverage and to evaluate ecological variation across Chile's diverse biomes. Second, greater integration of telemetry and spatial modelling would strengthen understanding of dispersal, habitat connectivity, and behavioral plasticity under fragmentation pressures (Logan and Sweanor 2001; Royle *et al.* 2014). Third, broader genetic monitoring is required to assess population structure and potential isolation, particularly in regions experiencing rapid land-use change (Frankham 2005).

Disease ecology represents another critical frontier. Increasing interaction between domestic animals and wildlife elevates opportunities for cross-species pathogen transmission, a phenomenon widely documented in carnivore systems worldwide (Bevins *et al.* 2012; Foley et al. 2013; Escobar et al. 2022). In Chile, confirmed records of *Trichinella* infection highlight the relevance of integrating epidemiological surveillance into carnivore research. Beyond these cases, evidence from other regions demonstrates exposure of pumas to pathogens commonly associated with domestic carnivores, including feline retroviruses such as Feline Leukemia Virus and Feline Immunodeficiency Virus (Biek *et al.* 2006; Brown *et al.* 2008), as well as associations between domestic animal proximity and pathogen exposure risk (Foley *et al.* 2013). Multi-host parasites such as *Toxoplasma gondii* represent additional ecological and public health concerns in felid systems (Hatam-Nahavandi *et al.* 2021), and emerging panzootics such as sarcoptic mange further illustrate the permeability of wildlife–domestic interfaces (Escobar *et al.* 2022). Although systematic epidemiological monitoring of Chilean puma populations remains limited, increasing overlap among wildlife, livestock, and free-ranging domestic carnivores underscores the need to integrate disease ecology into national research agendas under a One Health framework.

Finally, socio-ecological research must continue to expand. Perception-driven conflict can persist independently of ecological indicators, as demonstrated in multiple carnivore systems (Treves *et al.* 2006). Understanding how fear, economic vulnerability, and cultural narratives shape coexistence outcomes is essential for designing effective management interventions.

Broader conservation implications: Taken together, these findings indicate that Chile's puma populations exhibit ecological adaptability across diverse habitats yet remain insufficiently studied to support a fully integrated and spatially representative national conservation strategy. Apex predators exert disproportionate influences on ecosystem structure and trophic regulation (Ripple *et al.* 2014), and incomplete understanding of their spatial ecology, demographic processes, and landscape connectivity may limit effective long-term management. Although the diversification of research themes since 2010 reflects substantial scientific progress, persistent gaps remain in long-term monitoring, northern geographic representation, telemetry-based studies, and interdisciplinary integration.

At the same time, four decades of research have generated a substantial foundation of knowledge. Chilean studies have elucidated key aspects of trophic ecology, produced regional density estimates, documented movement patterns and dispersal events, identified emerging health risks, and increasingly incorporated socio-ecological dimensions of human–puma interactions. This cumulative body of work demonstrates a clear maturation of puma research in Chile, evolving from predominantly localized ecological descriptions toward more integrative, conservation-oriented and multidisciplinary frameworks.

Strengthening national conservation capacity will require coordinated efforts that link ecological monitoring, genetic surveillance, epidemiology, and social science within a coherent long-term strategy. As Chile continues to experience rapid land-use transformation, infrastructure expansion, and intensifying human–wildlife interfaces, maintaining functional connectivity across heterogeneous landscapes will become progressively more critical (Crooks 2002). By synthesizing four and a half decades of research, this review provides both a retrospective evaluation of scientific development and a forward-looking framework to guide future research and management. Consolidating methodological advances while addressing remaining spatial and thematic gaps will be essential for advancing robust, evidence-based conservation of P. concolor in Chile.

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Declaration of artificial intelligence use

This manuscript used artificial intelligence tools (ChatGPT) exclusively to assist with linguistic editing, text refinement, and verification of internal coherence. All ideas, study design, analyses, interpretations, and conclusions are solely the responsibility of the authors. The authors thoroughly reviewed and corrected all content generated or suggested by AI to prevent errors, biases, or inaccuracies. No data, results, or scientific evidence were created using AI, in full compliance with the ethical standards of *Therya*.

Author contributions

Jorge Leichtle conceived the study, designed the review protocol, compiled and classified the literature, conducted the statistical analyses, generated the figures, and led the writing of the manuscript. Cristián Larraguibel-González contributed to study design, validated thematic classifications, supported interpretation of temporal and spatial patterns, and performed critical revisions that substantially improved the structure and clarity of the manuscript. Both authors approved the final submitted version and agree to be accountable for all aspects of the work.

Data availability

All data matrices and R scripts used to perform classification, statistical analyses, and figure generation are available from the corresponding author upon reasonable request. The dataset includes study metadata, thematic categories, regional assignments, temporal classifications, and analysis scripts (R 4.3.1).

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