Herpetofaunal Response To Urban Habitat Fragmentation With a Focus on Two Focal Salamander Species

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Urban-driven habitat fragmentation - the breaking of continuous habitats into smaller isolated patches - poses a significant threat to biodiversity. Amphibians, especially salamanders, are extremely sensitive to such environmental changes due to their limited dispersal ability and specific habitat requirements. Reptiles and amphibians both rely on external temperatures to maintain body temperature, causing them to be highly dependent on the environment around them. Following PRISMA guidelines, a systematic review was conducted using three databases (Web of Science, Scopus, Google Scholar) to evaluate how habitat fragmentation in urban and peri-urban landscapes affects general herpetofauna in North American forests and on two focal salamander species. A total of 97 studies were included after screening over 800 records, with a standardized quality assessment applied to weigh the evidence from each study. Additionally, analysis revealed a notable discrepancy between the amount of research on tropical and temperate forests, with a geographic bias with more studies in tropical forests. Trend analysis suggests publication rates in tropical systems have begun to plateau in the 2010s, whereas temperate research continues to increase. This difference may suggest research biases, such as an increased attention to specific biodiversity hotspots. Regarding ecological impacts, the study observed that fragmentation had a negative impact on herpetofaunal species. Though both the *A. macrodactylum* and *P. cinereus* displayed vulnerability to fragmentation, *A. macrodactylum* showed greater sensitivity, with salamanders being negatively affected in North American forests.

Keywords: Plethodon Cinerus, Ambystoma macrodactylum, salamanders, disturbance, amphibians, fragmentation, reptiles

Introduction

Habitat fragmentation - often a consequence of urban expansion, agriculture, and road development - is a leading cause of biodiversity decline[1]. Defined as the breaking apart of a natural habitat into smaller, isolated patches, habitat fragmentation is often accompanied with habitat loss, edge effects, and a general ecological disturbance[2]. It is critical to distinguish between these processes, as they all operate through different ecological mechanisms and should not be conflated. Habitat loss directly reduces population sizes, while fragmentation per se alters landscape configuration and can have additional effects on species movement and community structure. Urban habitat fragmentation specifically refers to any fragmentation caused by urban and suburban development that divides natural habitats into smaller green spaces. This form of fragmentation often produces high-contrast edges with the built environmental and intense human presence. It differs from rural fragmentation, which is any fragmentation caused by agriculture. Anthropogenic deforestation caused by agriculture and other activities significantly reduces species richness, alters community structure, and disrupts ecological interactions[3].

Despite global awareness of fragmentations effect, the response of species can vary widely. Some habitat generalists or edge-tolerant species may persist or even benefit in a fragmented landscape, while specialists often tend to be negatively affected. Tropical forest species are often considered more sensitive to fragmentation than temperate ones, as numerous tropical species often avoid crossing open areas and tropical fragments create larger microclimate contrasts. Temperate forest herpetofauna also face significant fragmentation from human activities, yet research in temperate regions have been comparatively underrepresented[4]. A literary review done by Tan et al. noted that herpetofauna fragmentation studies are heavily geographically biased (concentrated in a few regions) and taxonomically biased (fewer studies on amphibians and reptiles as compared to birds and mammals).

Comparative studies between tropical and temperate forest species are essential for identifying both general ecological patterns and species - specific responses to fragmentation, enabling more effective conservation strategies. The comparison between temperate forest and tropical forest species and their different responses to habitat fragmentation, allow us to identify common stressors faced by herpetofauna in different forest types. Comparing how herpetofauna in tropical versus temperate forests respond to habitat fragmentation can help identify shared stressors and guide targeted conservation planning[5].

Edge Effects and Fragmentation Mechanisms

A well-documented consequence of fragmentation is the creation of edge effects. Edge effects refer to the altered environmental conditions that occur at the boundary between habitat fragments and the surrounding matrix, including changes in temperature, light exposure, or desiccation[6]. These alterations in the habitat often impact species composition. Numerous studies have reported lower survival rates at fragment edges and corners compared to interior zones, with a positive correlation between survival and distance from the edge[7].

Amphibians and reptiles remain as one of the most affected groups by habitat fragmentation due to their sensitivity. For salamanders, which require cool, moist habitats, microclimatic shifts at edges can severely impact their species richness and abundance. With a limited dispersal ability, it makes them unable to live and adapt to a new area. Fragmentation limits its capacity to disperse or adapt to new habitats, exacerbating population declines[8].

Why Focus on Two Focal Salamander Species

In this study, I chose to highlight two salamander species that frequently appear in fragmentation studies, the Plethodon cinereus (*P. cinereus*, or the red-backed salamander) and the Ambystoma macrodactylum (*A. macrodactylum*, or the long-toed salamander). These two species were chosen due to their contrasting ecological traits, which provides a valuable comparative framework to measure the varying impacts of habitat fragmentation on amphibians with different life histories. While literature availability was a reason on why these two salamanders were chosen to be compared, their divergent strategies of habitat use and reproduction also was a reason, as it can help to shine light on the broader patterns in fragmentation sensitivity. The two species represent different ecological types and biogeographic contexts, allowing for a comparative perspective.

P. cinereus is a fully terrestrial, lungless salamander common in eastern North America (the Appalachian and Great Lakes region). It lacks an aquatic larval stage and mainly inhabits secondary forests, including urban woodlots and suburban parks. *P. cinereus* is known to be relatively tolerant of anthropogenic disturbance, however, its dependence on moist microhabitats and its limited dispersal make it vulnerable to desiccation and local extinction if the patches it occupies are too small or isolated[8]. In contrast, *A. macrodactylum* exists in parts of western North America and also parts of western Canada. It displays a biphasic life history, requiring aquatic environments during the larval stages and moist terrestrial habitats as an adult. As a result, fragmentation might not only mean a loss of forest habitat, but also a disruption of migratory pathways between uplands and breeding pools. Moreover, the two species inhabit different ecoregions (humid eastern deciduous forests vs. Pacific coniferous forests), allowing a comparison on whether fragmentation effects are consistent across temperate forest types or if they vary with regional climate.

According to the island biogeography theory, species like the *A. macrodactylum* would face higher extinction rates in fragmented islands and landscapes. Its dependence on both aquatic and terrestrial habitats makes it more sensitive to habitat disruptions and fragmentations. Species like the *P. cinereus*, on the other hand, with smaller habitat ranges and greater habitat flexibility may be more resilient in ecological islands, and fragmented landscapes. Their contrasting traits reflect the extinction risk, central to the island biogeography theory, which varies by species and landscapes.

Moreover, these comparisons can help display how fragmentation affects broader ecological systems and inform species - specific conservation interventions. Salamanders also act as biotic regulators and bioindicators, making them critical to evaluating habitat health[9]. Ecological balance is defined as the state of stability of how species in an ecosystem coexist with other species. Amphibians and reptiles play a key role in energy flow and nutrient cycling in both aquatic and terrestrial environments, helping to control pest populations and acting as pollinators[10]. Their presence and diversity are key indicators of ecosystem health, particularly in North American habitats.

The environmental conservation movement saw significant growth following the publication of *Silent Spring* by Racchel Carson in 1962 - 1963, which caused global awareness about anthropogenic environmental harm. While Carson primarily addressed the dangers of pesticide use, her work marked a pivotal moment that broadened environmental research, including studies on habitat fragmentation. Since then, research on environmental conservation - including habitat fragmentation - has grown significantly. Assessing the volume of research and its growth on habitat fragmentation and its effects on herpetofauna in different regions is crucial for several reasons. Understanding these trends is crucial for setting future research and conservation priorities[11].

Objectives

This review has two main goals. The first was to conduct a bibliometric assessment of habitat fragmentation research on herpetofauna across tropical and temperate forests from 1963 to 2022. The second was to synthesize ecological findings from peer - reviewed studies examining how habitat fragmentation affects the species abundance and richness of herpetofauna, focusing specifically on *P. cinereus* and *A. macrodactylum*. This combined perspective helps identify not only where ecological impacts are being studied, but also where research gaps exist. It is important however, to note that any bibliometric trends observed does not directly reflect any ecological processes. As such, each aim is addressed using a methodology appropriate to this scope. Moreover, my scope primarily covers only the forested habitats in North America, with urban habitat fragmentation considered broadly to include fragmentation caused by human land development. This human land development mainly applies to human activities that severely impact forests and habitats, such as suburban sprawl, residential or commercial expansion, and infrastructure such as highways or railroads. While some factors may not be exactly classified as urban, such as the development of rural roads and highways, they are included in this review as they are a major cause of fragmentation. Thus, the term urban habitat fragmentation and human land development does not strictly refer to any dense city development, but applies to a broader range of anthropogenic disturbances associated with human growth.

This systematic review seeks to address three main questions: 1) How has the volume of scientific research on habitat fragmentation and herpetofauna grown since 1963 and are there biases in the geographic or taxonomic focus (temperate vs. tropical forests, amphibians vs. reptiles)? 2) How have anthropogenic effects influenced the growth and development of the *Plethodon cinereus* in temperate North American forests compared to the *Ambystoma macrodactylum* in temperate North American forests? 3) What general effects does habitat fragmentation have on forest salamander populations and herpetofaunal diversity in North American forests?

Methodology

The two salamanders chosen differ in their habitat and diets, but are similar enough to make a significant comparison. The *P. cinereus* is much more terrestrial and less dependent on water as compared to the *A. macrodactylum*. Unlike *P. cinereus*, *A. macrodactylum* is unable to live on land completely, relying on aquatic environments to lay eggs, and to live during its larval stages. Both salamanders are mostly distributed in parts of America and Canada, with the *A. macrodactylum* in the Northwest, while the *P. cinereus* is in the Northeast. Overall, the red-backed salamander does have a larger distribution range, which could imply that they might be less affected by fragmentation than the long-toed salamander would be.

Literature Search

To address the research question, I followed the PRISMA guidelines to conduct a comprehensive literature search across multiple databases. Three primary databases were searched - Web of Science, Scopus, and Google Scholar - for any relevant studies. Exact methodologies for each question are varied, however, as each question requires different strings and different Boolean queries. Grey literature was also considered during the data collection process, however, only peer - reviewed studies were collected.

To address the first question, Google Scholar was the primary database used to track growth of scientific research over time. A total of 36 structured searches were conducted across combinations of taxa, forest types, and decades and Boolean operators and quotation markers were used to narrow results. Moreover, each search was time filtered to a specific decade, (e.g., 1963 - 1972, 1973 - 1982) to measure research growth. This process was repeated for each subsequent decade, ending with the year 2022.

Search Terms

- habitat fragmentation, amphibians, ”tropical forests,” effects
- habitat fragmentation, amphibians, ”temperate forests,” effects
- habitat fragmentation, effects, ”tropical forests,” reptiles,
- habitat fragmentation, effects, ”temperate forests,” reptiles,

Inclusion Criteria

1. Peer - reviewed journal articles
2. Primary research, meta - analyses/reviews, or secondary research
3. Studies published between 1963 and 2022
4. Focused on amphibians or reptiles
5. Must report data on habitat fragmentation and species richness and/or abundance.

Exclusion Criteria

1. Non peer - reviewed content
2. Focused solely on behavioral changes without demographic data
3. Non - English language papers
4. Studies without references to either tropical or temperate forests.

To address the second research question, Google Scholar, Web of Sciences, and Scopus were utilized. For question 2, the first 15 pages of results were screened from Google Scholar, and only the first 10 pages were screened from Web of Science and Scopus. Papers were chosen based on the exclusion and inclusion criteria listed below. Different sets of search terms were used for different databases.

Search Terms

1. **Google Scholar**
   - habitat fragmentation, effects, Plethodon cinereus, growth, body, development, North America
   - habitat fragmentation, effects, Ambystoma macrodactylum, growth, body, development, North America,
2. **Web of Sciences and Scopus**
   - TS=(”habitat fragmentation” OR ”fragmented habitat”) AND TS=Plethodon cinereus AND TS=(growth OR development OR abundance OR density)
   - TS=(”habitat fragmentation” OR ”fragmented habitat”) AND TS=Ambystoma macrodactylum AND TS=(growth OR development OR abundance OR density)

Inclusion Criteria

1. Empirical or review studies in temperate North American forests
2. Measures either species richness or abundance
3. Habitat fragmentation must be explicitly assessed
4. If both title and abstract had at least 3 key terms that matched the search terms.

Exclusion Criteria

1. Papers focused solely on habitat loss or climate changes
2. Studies conducted outside of North America

At the time of research, the *P. cinereus*, commonly known as the eastern red-backed salamander, displayed a stable population trend and was classified as least concerned by the IUCN Red List (Version 2024-1). The species primarily inhabited human - altered and terrestrial environments and was widely distributed throughout the Appalachian Mountains and northwestern United States. Specifically, they are found in the Canadian provinces of Ontario, Qubec, New Brunswick, Nova Scotia, as well as in the U.S states of Minnesota, New York, North Carolina, Massachusetts, Wisconsin, Delaware, Virginia, New Hampshire, Indiana, Pennsylvania, New Jersey, Vermont, Michigan, West Virginia, Ohio, Connecticut, Illinois, Tennessee, Maine, and the District of Columbia. *P. cinereus* exhibited no migration pattern and primarily fed on small invertebrates, such as arachnids, worms, and other insects.

Similarly, the *A. macrodactylum*, also known as the long-toed salamander,was also classified as least concern and exhibited a stable population trend. However, this species may reside in wetlands and freshwater ecosystems, combined with terrestrial areas. Specifically, they may be found near moist forest debris that is located near a permanent source of water. Generally preferring environments in humid forests or rocky shores of mountain lakes. *A. macrodactylum* depends on bodies of water during its breeding and larval stages, making them dependent on bodies of water, unlike the *P. cinereus*. Compared to the red-backed salamander, they have a higher elevation limit at 3050 meters, and mostly reside on the Northeastern side of the Americas and parts of the Rocky Mountains. The species was specifically found in the Canadian provinces of (British Columbia and Alberta, and in the U.S states of Oregon, Washington, Idaho, Alaska, California, and Montana.

To address the third research question, Google Scholar, Web of Sciences, and Scopus were utilized. For question 3, the first 15 pages of results were screened from Google Scholar, and only the first 10 pages were screened from Web of Science and Scopus. Papers were chosen and excluded based on the exclusion and inclusion criteria listed below. No specific time ranges were applied. Different sets of search terms were used for different databases.

Search Terms

1. **Google Scholar**
   - habitat fragmentation, effects, herpetofauna, North America, anthropogenic, species richness, species abundance
2. **Web of Sciences and Scopus**
   - TS= (”habitat fragmentation” AND herpetofauna AND ”North America” AND (anthropogenic OR human*) AND (richness OR abundance))

Inclusion Criteria

1. Species - specific empirical or review studies
2. Studies were done in North American forest ecosystems
3. Reports on abundance, richness, growth, or reproductive success

Exclusion Criteria

1. No fragmentation variable was measured
2. Studies conducted outside of North America
3. Studies concerning different salamander species than the one in the question

Screening Results

A total of 830 potential studies were identified, with 733 being excluded (most commonly for studies that were conducted in inappropriate settings, such as marine or purely aquatic habitats, or studies that were not about habitat fragmentation). From the initial 830 studies, duplicates were excluded and any papers that did not have key terms in the abstract or title that matched the search string were excluded. Then, each full text was examined for meeting inclusion criteria and for any extractable data. Figure 1 presents the PRISMA flow diagram of the literature selection process. The figure indicates the number of studies removed at each stage and the reasons for the full-text exclusions and inclusions. Ultimately, 97 studies were found that met all criteria and were included in the qualitative synthesis and analysis for questions 1 and 2. 21 articles were found that gave sufficient data for habitat fragmentation effect on general herpetofauna. 22 articles were found that gave sufficient data for habitat fragmentations effect on herpetofauna richness, and 18 articles were found on habitat fragmentations effect on herpetofauna abundance. 17 articles were found concerning habitat fragmentations effects on *A. macrodactylum* abundance, and 18 articles were found on habitat framgnetaions effects on *P. cinereus* abundance.

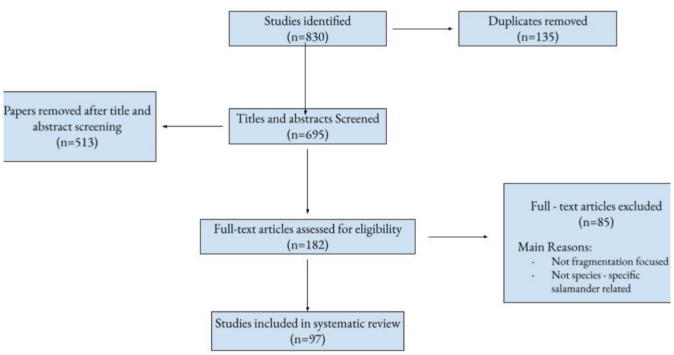


Fig. 1 Displays the screening process and PRISMA style method applied to the study. Figure was created using Google Docs, with n standing for the amount of papers either included or excluded at each step.

Data Extraction + Quality Assessment

For each study, specific data was extracted according to a predefined protocol. In the review, I recorded the study location, habitat type, focal species, and the key outcomes related to fragmentation. To standardize the synthesis of results, operational categories for fragmentation effects were defined. If a study reported a statistically significant decline in species abundance or richness due to fragmentation effects, the study was defined as reporting a negative effect. If a study reported a statistically significant increase in species abundance or richness that was attributable to fragmentation, then that study was defined as reporting a positive effect. If a study found no significant difference or mixed results overall, and was unable to form a definitive conclusion, then that study was defined as reporting no effect.

Moreover, I also conducted a quality appraisal for each study using a structured checklist that was adapted from established critical appraisal tools for ecological studies[12]. Each study was either given an overall quality rating of High, Moderate, or Low quality. Key criteria included: sample size, measurement of fragmentation (did the study account for confounding habitat loss vs. fragmentation), and duration. Studies that were qualified as high quality were robust experimental designs that included large sample sizes with reliable measurements. Moderate quality studies had some limitations, such as a smaller sample size, but still provided valuable data. Low-quality studies suffered from insufficient data or unreliable conclusions. Table 1 represents a summary quality assessment for a subset of representative studies that were chosen. It is to be noted that the table only serves to give clarity on what data was extracted and an example of the quality assessment.

Data Analysis

Both a bibliometric analysis and ecological synthesis were performed to address the distinctness in my research question. This was done to avoid conflating research trends with biological effects. For the research trend analysis, I compiled the number of publications on habitat fragmentation in herpetofauna over time, with Google Scholar being the primary database. I tallied the total number of studies by decade of publication from 1963 to 2022 based on tropical vs. temperate forests regions and amphibians vs. reptiles. This was also compared to the total number of studies by decade of publication of mammals and birds in temperate vs. tropical regions. A regression was applied to identify growth rates and any change-points; a simple change-point detection was also used to see if a significant slowdown in publication rate ever occurred. This bibliometric analysis is demonstrated graphically in Figure 2A.

Concerning the ecological synthesis, the proportion of studies reporting negative, positive, or neutral effects on salamander or herpetofaunal diversity was calculated. These proportions, given the small sample size, are descriptive and should be interpreted cautiously. Raw count was reported alongside the percentages in order to avoid false precision. Slope estimates and p-values for the publication increases were obtained with $\alpha = 0.05$.

By separating the analytical approaches for the research questions, mainly between publication trends and ecological outcomes, a clear methodological distinction is maintained.

Table 1 represents the data extraction and quality assessment of the studies in the review. All selected studies went through this process, however, the table only shows a small subset as an example. High-quality studies typically had empirical and experimental designs, whereas lower-quality ones may have lacked empirical data on fragmentation effects.

Study	Species/Group	Abundance Effect	Richness Effect	Habitat Type	Quality
Wilk et al. (2020)	*P. cinereus*	Negative	N/A	Terrestrial	High
Charity, B (2022)	*A. macrodactylum*	Negative	N/A	Terrestrial + Aquatic	Moderate
Loehle et al. (2005)	General Herpetofauna	Negative	Negative	Terrestrial + Aquatic	High
Jordan, M (2009)	*P. cinereus*	Negative	Negative	Terrestrial	High

Results

Over a 60-year period beginning in 1963, the number of published articles investigating amphibians and reptiles in tropical forests increased significantly with overall more research on reptiles (Fig.2A).

Since 1963, there has been an initial exponential growth in the number of papers in both amphibians and reptiles in tropical forests, with slightly more research on reptiles. However, the rate of increase is slowing down, and is changing to a more linear growth (Fig 2A). Research on amphibians and reptiles in temperate forest, while also experiencing a large increase in growth after the year 1963, had much less research as compared to tropical forests. Research in temperate forests contrasts with those in tropical forests, seeing a large growth between 1994 - 2013 (Fig 2B). However, there is a large observed disparity between the forest types.

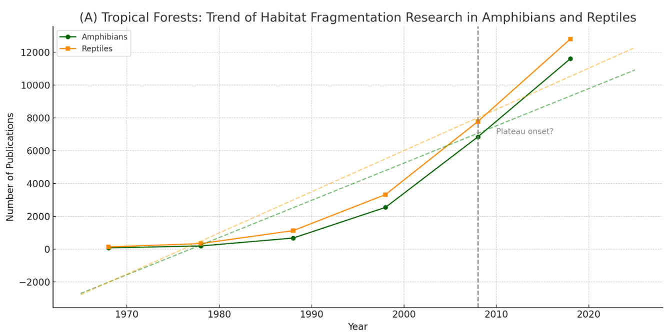


Fig. 2 (A) displays the publication output concerning habitat fragmentation in amphibians and reptiles from 1963-2022. Solid lines connect the observed data points, while dashed lines represent linear regression trends for each group. A dashed vertical line in 2008 represented a potential change-point, where the trend may begin to plateau. Slope estimates and p-values for the publication increases were obtained with $\alpha = 0.05$. Calculations were performed using Google Sheets. Amphibian research growth had a slope of 227.1 with a p-value of 0.011. Both lower and upper 95% confidence intervals were also calculated, with [127.5, 326.7]. Reptile research growth had a slope of 251.2 with a p-value of 0.008. Lower and upper 95% confidence intervals were [151.3, 351.0].

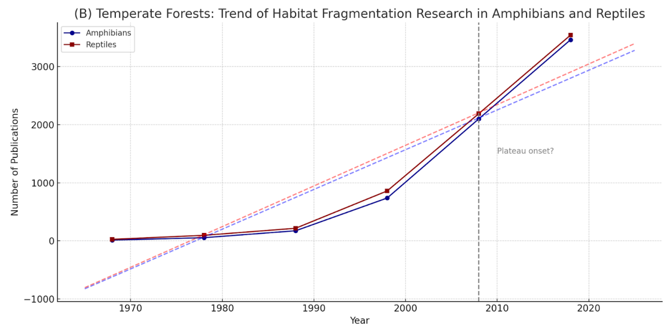


Fig.2 (B) illustrates the publication trends concerning habitat fragmentation research in amphibians and reptiles in temperate forests from 1963 - 2022. Dashed lines reflect best-fit linear regressions; slopes for both taxa indicated strong publication increases across the decades. A dashed vertical line in 2008 represented a potential change-point, where the trend may begin to plateau. Slope estimates and p-values for the publication increases were obtained with $\alpha = 0.05$. Calculations were performed using Google Sheets. A slope of 68.39 with a p-value of 0.011 was found for amphibians. 95% upper and lower confidence intervals were [38.3, 98.5]. A slope of 69.99 with a p-value of 0.009 was found for reptiles, both proving significant. 95% upper and lower confidence intervals were [40.8,99.2].

Figures C and D display the growth of mammals and birds in tropical and temperate forest respectively. Both observed large exponential growths, with signs of slowing down for tropical forests (Fig 1C). Mammal and bird research growth in temperate forests follow a more exponential growth, with no signs of plateauing yet, while growth in tropical forests, with an initial exponential growth, is seemingly slowing down (Fig 2C and D).

The bibliometric analysis suggests two main points: 1) research interest in habitat fragmentation effects on herpetofauna have grown dramatically since 1963. 2) There still remains biases and gaps, as from the graphs, it suggests a historical focus on tropical forests over temperate ones.

Figure (a) to Figure (e) consists of the 97 studies that were included in my systematic review. Across all five figures, negative effects were the dominant findings. These results suggest that habitat fragmentation does significantly reduce the viability of

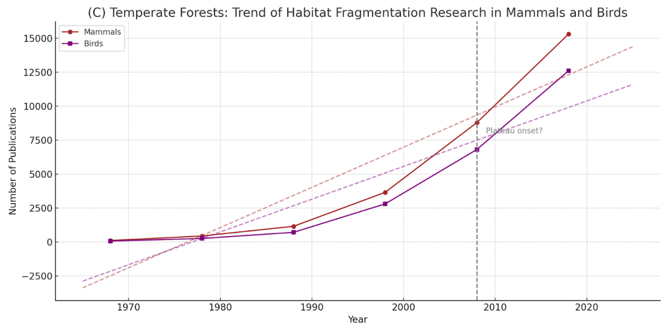


Fig.2 (C) illustrates the publication trends concerning habitat fragmentation research in mammals and birds in tropical forests from 1963 - 2022. Dashed lines reflect best-fit linear regressions; slopes for both taxa indicated strong publication increases across the decades. A dashed vertical line in 2008 represented a potential change-point, where the trend may begin to plateau. Slope estimates and p-values for the publication increases were obtained with = 0.05. Calculations were performed using Google Sheets. Mammal research growth had a slope of 295.65 with a p value of p = 0.0099. 95% upper and lower confidence intervals were [170.3, 421.0].]. Bird research growth had a slope of 241.10 with a p value of p = 0.0123. 95% upper and lower confidence intervals were [132.1, 350.1].

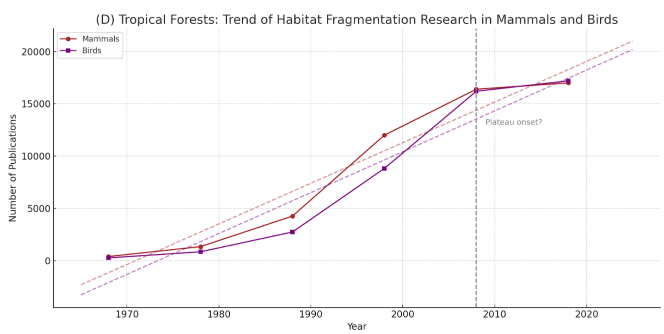


Fig.2 (D) illustrates the publication trends concerning habitat fragmentation research in mammals and birds in tropical forests from 1963 - 2022. Dashed lines reflect best-fit linear regressions; slopes for both taxa indicated strong publication increases across the decades. A dashed vertical line in 2008 represented a potential change-point, where the trend may begin to plateau. Slope estimates and p-values for the publication increases were obtained with $\alpha = 0.05$. Calculations were performed using Google Sheets. Mammal research growth had a slope of 388.41 with a p value of p = 0.0015. 95% upper and lower confidence intervals were [289.6, 487.3]. Bird research growth had a slope of 390.91 with a p value of p = 0.0025. 95% upper and lower confidence intervals were [278.1, 503.7].

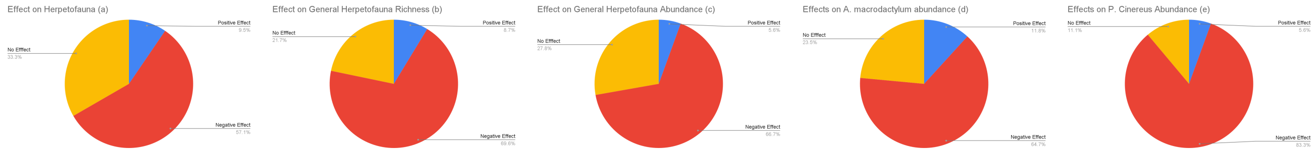
herpetofauna populations.

From 97 total papers I gathered for all three questions from Google Scholar, 57.1% of the papers showed a negative effect toward herpetofauna, 33.3% reported no effect, and 9.5% displayed a positive effect on species richness. Species abundance varied minimally from richness, with 66.7% of the papers reporting a negative effect on abundance, and 27.8% reporting no effect. This indicates an overall loss of biodiversity due to habitat fragmentation. One review paper observed that habitat fragmentation reduces biodiversity by 13 to 75%[13]. This aligns with my review and previous findings, which has shown a consistent trend of declining species abundance and genetic variability as habitat fragments become smaller[13]. Out of the 18 papers I gathered for the *P. cinereus*, more than half of the papers showed that habitat fragmentation had an overall negative impact on their species abundance. These results correspond with the papers also gathered on the *A. macrodactylum*, with the majority of the papers displaying a negative effect. Similar studies show similar results, with one seeing a history of species bottleneck at sites that suffered from a history of fragmentation and isolation[14].

As seen from the results, research in amphibians and reptiles and mammals and birds can be seen slowing down in recent decades. While this may be due to my data collection method, it may also be an indication that research priorities are shifting away from habitat fragmentation and onto more current environmental events. More pressing matters, such as current climate change and mass microplastic pollution, may cause researchers to focus less on fragmentation. From the data gathered, there is a significant association between the research in tropical and temperate forests. I can reject the null hypothesis and assume that the focus of herpetofauna research is significantly related to the type of forest being studied as well. This is what is meant by significant association. Although the results indicated a higher frequency of research on tropical forests, it is generally recognized that temperate forests have historically received more research attention. This discrepancy may be attributed to sampling or publication biases.

Discussion

This review sought to address three overarching questions in no particular order:(1) how habitat fragmentation influences herpetofauna abundance and richness in tropical and temperate North American forests, (2) how two salamander species - the Plethodon cinereus and Ambystoma macrodactylum - are affected by fragmentation between, and (3) how research trends have evolved since 1963. This systematic review highly suggests that habitat fragmentation, particularly in urbanizing landscapes, acts as a significant driver of decline for salamander and herpetofauna populations. Moreover, the bibliometric analysis conducted observed an overall growth in this research field. This trend is similar to other papers, with an overall pattern that the number of studies in both taxonomic groups have increased[15].



(a) (b) (c) (d) (e)

Fig. 3 **(a)**, with a sample size of n=21, found that 57.1% of studies reported negative effects of habitat fragmentation, while 33.3% observed no effect and 9.5% found positive effects. **Figure 3(b)**, with a sample size of n =22, found that 69.6% of studies reported a negative effect in richness due to fragmentation, 21.7% reported no effect, and 8.7% found positive effects. **Figure 3(c)**, with a sample size of n=18, found that 66.7% of studies reported reduced abundance under fragmentation, 27.8% indicated no effect, and 5.6% found positive effects. **Figure 3(d)**, with a sample size of n=17, reports that 64.7% of the studies showed negative impacts, 23.5% observed no effect, and 11.8% reported positive effects. **Figure 3(e)**, with a sample size of n=18, displays that 83.3% of studies reported declines in abundance, 11.1% oversed no effect, and only 5.6% found positive impacts.

Understanding these trends can allow conservationists to recognize understudied and unrepresented areas in scientific studies. The review indicates that more research has been conducted on tropical forests comparatively to temperate forests. While this may suggest more focus on temperate forests, like discussed before, this may be due to my data gathering method. Additionally, trends in research can provide essential data that can be used to inform environmental policies and strategies. Research that can show decline in herpetofauna abundance in certain environment types may cause policies to be implemented to protect these habitats. Though, it is surprising to note that studies of reptiles have been, while minimal, more abundant than those of reptiles.

By examining the volume of research since 1963, it is clear in my review that tropical forests dominated the scientific discussion on habitat fragmentation compared to research in temperate forests. However, it should be considered important to review the nuanced difference between how habitat fragmentation impacts herpetofauna differently in tropical versus temperate forests. A shift towards a more balanced research focus reflects a broader understanding that conservation must be more interconnected. Future research should aim to balance this disparity, ensuring that both forests remain studied, further enhancing global conservation strategies[16]. While research in herpetofauna is ample, research in mammals and birds still continues to garner more attention.

The growth of research - especially in tropical systems - suggested heightened global awareness of habitat fragmentation while also showing a geographic imbalance. Though temperate forests harbor rich herpetofaunal biodiversity, they remain underrepresented in the literature. This may be a reflection of publication and funding biases, rather than difference in ecological impact. Therefore, conservation practices and efforts may be skewed toward tropical forests, neglecting numerous endangered temperate taxa. Working to address this imbalance is critical to promoting a more inclusive conservation plan.

Moreover, fragmentation appears to be a significant driver of population bottlenecks, particularly in a low - mobility species like the salamanders. Habitat loss, isolation, and altered microclimates can severely disrupt the gene flow and reduce the salamanders population sizes. Habitat loss refers to the outright reduction in the total area of a habitat. It is considered the most direct threat to biodiversity, as it decreases the carrying capacity of landscapes and can often lead to extinctions. These long - term evolutionary impacts are difficult to quantify through short - term metrics like species abundance and richness. One report found that *P. cinereus* populations exhibited reduced genetic diversity in fragmentation, strengthening the idea that fragmentation and its effects extend beyond demographics[14].

Theoretical Context

The contrasts that were found between *P. cinereus* and *A. macrodactylum* displays how life-history traits can significantly affect fragmentation sensitivity. This aligns with the island biogeography theory and metapopulation dynamics. Island biogeography is the study of patterns in the distribution of species on islands as influenced by ecological and evolutionary processes related to island characteristics such as isolation and area[17]. *A. macrodactylums* dependence on aquatic habitats and terrestrial habitats causes it to be highly dependent on not just a habitat, but a network of habitat patches. Fragmentation can break this network, leading to local extinctions. *P. cinereus*, who solely depend on terrestrial habitats, is more resilient to defragmentation, being able to survive in tiny territories. This aligns with the idea of the species-area relationship, in which the *A. macrodactylum* likely has a larger area requirement to thrive and grow in. Due to *P. cinereus* resilience, it will likely have a smaller area requirement and can achieve high populations in small areas, so the species - area curve would be flatter. However, this does not mean that the *P. cinereus* can live forever in small, isolated patches, as island biogeography expectations will occur. The theory of island biogeography states that as the number of species on an island increases, extinction rates will also increase[17].

While the review found a majority of studies that reported negative effects of habitat fragmentation of herpetofauna, these findings do not establish causal relationships. I highly caution against the idea of conflating correlation with caution in my results. A majority of the studies reviewed and screened were observational, not empirical. Thus, while those studies did show association and statistical significance that fragmentation may have caused a decline in species diversity, it does not prove that fragmentation caused the decline. Confounding factors may also have affected the results; urban fragments might be subject to harmful effects, such as pollution or the introduction of invasive species. As such, it is hard to determine the direct effect of fragmentation from confounding variables, as declines in amphibian populations may also be attributed to other factors, such as pesticide exposure or pollution.

Therefore, while results may suggest a consistent trend of negative effects, strong causal claims can not be made. These findings should be interpreted as exploratory and as a preliminary synthesis that highlights areas of concern and knowledge gaps, not definitive evidence of fragmentation impacts.

Limitations

Though certain trends may have been observed as a result of the review, there are a number of limitations and biases that must be acknowledged. While the results heavily indicate that habitat fragmentation is a negative force upon herpetofauna, it must be considered that the selection of the papers may have only been papers that specifically showed a negative effect. Publication bias is also a factor, as studies showing strong effects may be more likely to be published. The papers were chosen through a word criteria, which can result in papers being excluded. Google Scholar will list out every paper that has at least one mention of any of the words that you entered. Moreover, Google Scholar lists papers in order of the papers impact/citations (i.e. studies that find an effect of fragmentation) will get more citations and be listed earlier than papers that do not find any effect.

Efforts were made to use specific and multi - term search strings, though this still likely excluded many relevant studies. Selection bias and human error may have also influenced study inclusion. Though an objective inclusion and exclusion criteria was implemented, the subjective nature of reviewing and limited reviewer capacity may have resulted in the unintentional exclusion and inclusion of some studies. Moreover, without evidence fathered from empirical fieldwork or experimental research, this review cannot make any definitive conclusions and claims.

This review provides insight into the impacts on herpetofauna, but it is crucial to recognize the limitations my review was subjected to. This review indicates a negative trend regarding the impacts on amphibians and reptiles, but the absence of empirical field data limits the ability to draw definitive conclusions.

Additionally, a post - hoc power analysis indicates that the sample size of n = 21 was insufficient to detect medium effect sizes. A minimum of approximately 108 studies would need to be gathered to reliably detect a medium effect size at approximately 80% power. This calculation was done by an online calculator called Stats Kingdom[18]. This limitation restricts the generalizability of the findings. Though a total of 97 studies were gathered, it was a compilation of studies used for both questions 2 and 3.

Future works should prioritize database triangulation and further screening to lessen bias and improve reproducibility. As such, the findings of this review should be interpreted as exploratory, rather than definitive. The review in itself should be seen as a preliminary synthesis of existing literature Implications This systematic review carries several important implications for conservation management and urban planning.

Conservation Planning

Urban and suburban development plans should integrate the preservation of connected green spaces. From the review, I found that urban plans which simply set aside small habitat patches within developments is not a sufficient habitat. Planners and local governments should use tools such as urban-growth boundaries to ensure that the networks and connectivity between habitats are protected, rather than small, disconnected islands. Maintaining a chain of forest parks through a city by installing a habitat corridor could allow herpetofauna and other wildlife to disperse, reducing the detrimental impacts of urbanization.

Forest Management Policies

Future forestry and land-use policies should consider fragmentation alongside total habitat loss. Policies should take into account not just how much acreage of forest was lost, but how the remaining acres of forest was fragmented. Environmental impact assessments (EIAs) can incorporate metrics of fragmentation to predict effects on specific species. Policies should give incentives for the clustering of development, and should aim to keep habitats from losing forest cover.

The negative effects of urban habitat fragmentation on salamanders highlight the urgency of integrating increased connectivity and configuration in habitat conservation actions. My synthesis proves that habitat amount and arrangement both matter in urban land planning. These implications can work towards landscapes in which both human and herpetofaunal communities are allowed to coexist.

Conclusion

This review sought to examine both the research trends and ecological impacts of habitat fragmentation on herpetofauna, with a specific focus on the *P. cinereus* and the *A. macrodactylum*. The bibliometric analysis may suggest a geographic imbalance in publication frequency, with tropical forests receiving disproportionately more attention than temperate ones. This disparity may influence conservation priorities and underrepresented temperate - region species in policy and research funding.

Ecological findings showed that habitat fragmentation negatively affects species richness and abundance in herpetofauna, particularly for amphibians with aquatic life stages, such as the *A. macrodactylum*. Although the *P. cinereus* displayed somewhat greater resilience, both species experienced declines linked to effects of habitat fragmentation, such as isolation, edge effects, and genetic bottlenecks.

These findings from the review underscore the urgent need for improvement in conservation strategies. Conservation strategies should work not only to mitigate habitat loss, but also mitigate how habitats are managed. Empirical studies should be expanded in underrepresented regions to allow for a more comprehensive understanding of fragmentation effects across ecosystems.

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