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Research Article

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Posted Date: November 10th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11054454/v1

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Additional Declarations: No competing interests reported.

Representation Targets Shape the Spatial Requirements for Conserving *Apiomerus* and *Zelus* (Reduviidae) across the Americas

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Abstract

Systematic conservation planning translates biodiversity representation objectives into spatially explicit conservation networks. The spatial requirements associated with alternative representation targets may vary among species according to the geographic extent and spatial overlap of their documented distributions. This study evaluated the spatial representation requirements of 181 species of the assassin-bug genera *Apiomerus* and *Zelus* across the Americas using occurrence-based systematic conservation prioritization. A total of 11,329 georeferenced occurrence records were compiled from taxonomic literature and biodiversity databases, yielding 10,327 unique species-coordinate records after duplicate removal. Occurrences were assigned to 50 × 50 km planning units, and minimum-set optimization was performed for six representation targets: 10%, 20%, 30%, 50%, 75%, and 100% of each species' occupied planning units. Species occupied between one and 507 planning units; 16 species (8.84%) occupied a single planning unit, whereas 31 (17.13%) occupied no more than two. The number of selected planning units increased from 118 at the 10% target to 2,592 at 100%. All 181 species achieved their specified target in every scenario. Mean realized representation exceeded nominal targets at lower target levels, increasing from 29.45% at 10% to 100% at 100%. Species with few occupied planning units were more strongly affected by the discrete planning framework, whereas widespread species had more spatial

alternatives for representation. Increasing representation targets progressively expanded the minimum-set network, demonstrating how species distributional extent and complementarity jointly determine spatial conservation requirements.

Implications for insect conservation

Systematic conservation planning can quantify how alternative representation targets translate into spatial requirements for insect conservation. Considering target levels, species distributional extent, and complementarity can help identify spatially efficient networks while highlighting species for which few documented spatial alternatives are available.

Keywords: Apiomerini; biodiversity conservation; complementarity; Harpactorini; minimum-set prioritization; planning units; systematic conservation planning

Introduction

Biodiversity is distributed unevenly across geographic space, and the areas required to represent species diversity are consequently unlikely to coincide completely with areas of highest species richness. Habitat loss, land-use change, fragmentation, climate change, biological invasions, and other anthropogenic pressures affect species and ecosystems heterogeneously, creating a need for spatially explicit approaches to conservation planning. Systematic conservation planning provides such an approach by defining explicit representation objectives and identifying combinations of areas capable of meeting those objectives while minimizing the amount of land required (Margules and Pressey 2000; Pressey and Bottrill 2009; Kukkala and Moilanen 2013).

A central principle of systematic conservation planning is complementarity. The contribution of a particular area depends not only on the number of species occurring there but also on which species are represented elsewhere. An area containing many widespread species may contribute less additional representation than an area containing fewer species that occur nowhere else in the candidate network. Consequently, conservation networks based exclusively on species richness may fail to represent spatially restricted species or may require substantially more area to achieve equivalent species-level objectives (Rodrigues et al. 2004; Kukkala and Moilanen 2013).

Representation targets provide a mechanism for making these objectives explicit. A representation target specifies the proportion of the documented distribution of a conservation feature that should be included in a selected network. Different targets can therefore produce substantially different spatial solutions, allowing the consequences of alternative levels of conservation ambition to be evaluated quantitatively (Pressey et al. 1993; Pressey and Bottrill 2009). Lower targets may allow compact networks, whereas increasingly stringent targets generally require progressively larger networks because the opportunities for representing multiple species through the same locations become more limited (Pressey et al. 1997; Kukkala and Moilanen 2013).

This target–area relationship is particularly relevant for taxonomic groups in which species differ strongly in geographic extent. Widespread species may occupy many alternative locations, allowing their representation requirements to be satisfied through a range of spatial configurations. Species with highly restricted documented distributions, in contrast, may depend on a small number of specific areas. Such species can exert a disproportionate influence on the configuration of a minimum-set conservation network because the areas containing their occurrences may be difficult or impossible to replace (Pressey and Logan 1998; Kukkala and Moilanen 2013).

Insects provide an important context for examining these patterns. They represent a substantial proportion of terrestrial biodiversity and perform essential ecological functions, including predation, pollination, herbivory, decomposition, and nutrient cycling. Nevertheless, insect diversity remains comparatively underrepresented in broad-scale conservation planning, partly because many groups are poorly sampled and because species-level distributional information is incomplete or spatially biased (Samways 2007; Leather 2018). Explicit spatial assessments of insect assemblages can therefore contribute to identifying geographic gaps in representation while also testing the applicability of systematic conservation approaches to highly diverse taxonomic groups.

Assassin bugs (Hemiptera: Reduviidae) constitute a particularly diverse insect lineage with a predominantly predatory ecology. Species occur across a wide range of terrestrial environments, and the family includes numerous morphologically and ecologically diverse lineages. Despite their ecological importance and taxonomic diversity, broad-scale spatial conservation assessments focused specifically on reduviid assemblages remain limited. Occurrence-based prioritization can provide a first quantitative assessment of the spatial

requirements associated with representing species diversity in this group (Maldonado 1990; Weirauch et al. 2014).

The genera *Apiomerus* Hahn and *Zelus* Fabricius provide a useful system for evaluating these issues in the Americas. Both genera are species-rich lineages of Reduviidae with broad geographic distributions and substantial variation in the spatial extent of individual species (Berniker et al. 2011; Zhang et al. 2016). Their distributions encompass large portions of the New World, while individual species vary considerably in the number and geographic arrangement of documented localities. This variation creates an appropriate basis for examining how species-specific spatial distributions interact with alternative representation targets.

Zelus is a diverse genus of Harpactorini distributed throughout much of the Americas. The genus extends from southern Canada through Central America and South America, and species differ considerably in their geographic distributions and ecological associations (Zhang et al. 2016). Species of *Zelus* are predators of a broad range of arthropods and have been documented feeding on insects of ecological and agricultural importance (Ables 1978; Cohen and Tang 1997). The combination of broad geographic occurrence and heterogeneous species distributions makes *Zelus* suitable for examining differences in spatial flexibility among species.

Apiomerus is the most species-rich genus of Apiomerini, a New World lineage within Reduviidae (Berniker et al. 2011). Species of *Apiomerus* occur from the southern United States through Central and South America and display substantial variation in morphology, coloration, ecology, and geographic distribution. Many species are associated with the use of plant resins in prey capture, a distinctive behavioral characteristic of the genus (Berniker et al. 2011; Masonick and Weirauch 2022). Geographic variation among *Apiomerus* species provides an additional opportunity to examine how spatially restricted and widespread species contribute differently to conservation prioritization.

The geographic distributions of *Apiomerus* and *Zelus* include species represented by numerous localities as well as species known from relatively few documented locations. This heterogeneity is central to systematic prioritization because species with broad distributions generally provide more alternative planning units through which representation can be achieved, whereas species occupying only a small number of planning units can impose strong spatial constraints (Cabeza and Moilanen 2001; Ball et al. 2009).

Occurrence-based assessments require careful interpretation because documented distributions do not necessarily correspond to complete biological ranges. The number of occupied planning units reflects the available occurrence records and is therefore influenced by both biological distribution and sampling effort. It does not directly measure population abundance, occupancy probability, demographic viability, or habitat suitability (Gaston 1994, 2000). The same consideration applies to species occupying only one planning unit: such species are spatially restricted at the analytical resolution but cannot automatically be regarded as rare, endemic, or threatened.

Spatial grain also affects the interpretation of species distributions. Planning-unit size determines the degree of geographic aggregation and influences the number of decision units available for conservation prioritization. Coarse planning units can combine geographically distinct localities, whereas fine-resolution units may increase spatial detail but also increase the apparent complexity of distributions and potentially imply a level of precision unsupported by heterogeneous occurrence data (Shriner et al. 2006; Kukkala and Moilanen 2013). A 50 × 50 km planning-unit framework provides a broad-scale decision-making grain appropriate for continental comparison while avoiding interpretation as a fine-scale habitat map.

The present analysis examines the spatial representation requirements of 181 species of *Apiomerus* and *Zelus* across the Americas using a systematic conservation-prioritization framework. Occurrence records were converted into species-by-planning-unit distributions, and minimum-set networks were generated for six representation targets: 10%, 20%, 30%, 50%, 75%, and 100% of the occupied planning units of each species. The analysis focuses on four complementary aspects of spatial representation: variation in species occupancy, spatial patterns of species richness, the number of planning units required to satisfy alternative representation targets, and the distribution of realized representation among species.

The analysis was designed to test whether increasing representation targets would produce progressively larger conservation networks and whether species with restricted and widespread distributions would respond differently to the same representation objectives. Particular attention was given to the distinction between nominal targets and realized representation because discrete planning units can cause selected networks to exceed the specified target, especially for species occupying few units. The resulting framework provides a quantitative assessment of the spatial consequences of alternative representation objectives for a diverse group of New World assassin bugs.

Materials and Methods

Species occurrence data

Occurrence records for *Apiomerus* and *Zelus* were compiled from published taxonomic and distributional sources, including Berniker et al. (2011), Berniker and Weirauch (2012), Forero et al. (2013), Zhang et al. (2016), and Masonick and Weirauch (2022). Additional records were obtained from Discover Life (https://www.discoverlife.org). These sources were combined to maximize the available geographic information for the focal species and to provide a common occurrence dataset for spatial analysis (Gaston and García-Viñas 2011; Zizka et al. 2019).

Records were examined for geographic plausibility, coordinate errors, duplicates, and spatial inconsistencies. Records without species identification or geographic coordinates were excluded. Duplicate records representing the same species at identical coordinates were removed to prevent repeated observations from disproportionately influencing the spatial representation of species (Gaston and García-Viñas 2011; Zizka et al. 2019).

The resulting initial dataset contained 11,329 georeferenced occurrence records representing 181 focal species. After removal of duplicate species-coordinate combinations, 10,327 unique occurrence records remained. These records formed the basis for subsequent spatial analyses.

Geographic coordinates were projected to WGS 84 / NSIDC EASE-Grid 2.0 Global (EPSG:6933), an equal-area coordinate reference system suitable for continental-scale spatial analysis. The study extent encompassed the geographic distribution of the retained occurrence records across the Americas.

Each occurrence was assigned to a 50 × 50 km planning unit. A binary species-by-planning-unit matrix was subsequently generated, with presence recorded when at least one occurrence of a species was located within a planning unit. This procedure transformed point-based occurrence information into spatially explicit conservation features suitable for systematic prioritization (Pressey et al. 1993; Margules and Pressey 2000).

For each species, the number of occupied planning units was calculated as a measure of documented spatial occupancy. This measure represents the geographic extent of available occurrence information at the analytical resolution rather than a direct estimate of the species'

complete biological range, population size, abundance, or demographic viability (Gaston 1994, 2000).

Spatial planning units

The spatial framework consisted of regular 50 × 50 km planning units, corresponding to approximately 2,500 km^2 per unit. The selected grain was intended for continental-scale comparison of spatial representation requirements rather than fine-scale habitat assessment or delineation of individual protected areas (Margules and Pressey 2000; Kukkala and Moilanen 2013).

Planning-unit size can influence systematic conservation prioritization by affecting the number of decision units, the apparent spatial extent of species distributions, and the degree of complementarity among areas (Shriner et al. 2006). A relatively coarse grid can reduce excessive fragmentation of the planning framework and is appropriate when occurrence data originate from heterogeneous sources with variable spatial precision. The 50 × 50 km grid was therefore treated as the decision-making grain appropriate to the objectives and data structure of the analysis.

The same planning-unit framework was maintained across all representation-target scenarios. Candidate planning units were defined as units containing at least one occurrence record of any focal species. Candidate units therefore represented the union of the documented occupied distributions of the 181 species.

Planning units were treated as indivisible decision units. As a consequence, realized representation could exceed the nominal target, particularly for species occupying small numbers of units. The inclusion of one additional planning unit can produce a large proportional increase in representation when the total number of occupied units is small, whereas the same addition has a much smaller proportional effect for widespread species (Pressey et al. 1997; Kukkala and Moilanen 2013).

Species richness

Species richness was calculated for each planning unit as the number of the 181 focal *Apiomerus* and *Zelus* species recorded within that unit. The resulting richness distribution was used to characterize broad-scale spatial variation in the concentration of the focal assemblage.

Species richness was treated as a descriptive variable rather than as the optimization criterion. High-richness planning units can simultaneously contribute to the representation of multiple species, but richness alone does not account for the geographic uniqueness of individual species. A planning unit containing relatively few species can be indispensable if those species have few or no alternative occupied units elsewhere (Rodrigues et al. 2004; Kukkala and Moilanen 2013).

Conservation representation targets

Six representation targets were evaluated: 10%, 20%, 30%, 50%, 75%, and 100% of the occupied planning units of each species. The target represented the minimum proportion of each species' documented occupied planning units required to occur within the selected network.

The targets were applied independently to all 181 focal species. The 10%, 20%, 30%, 50%, and 75% scenarios represented progressively higher levels of partial spatial representation. The 100% scenario represented complete inclusion of all documented occupied planning units and served as the complete-representation reference.

Because planning units were discrete, exact realization of a target was not always possible. A species could therefore receive a greater proportion of its occupied units than required, particularly when it occupied only a small number of planning units (Pressey et al. 1997).

Spatial conservation prioritization

Spatial prioritization was formulated as a minimum-set representation problem. The objective was to identify the smallest possible set of candidate planning units capable of satisfying the specified representation target for every focal species.

For each species, the optimization required a proportion of its occupied planning units equal to or greater than the selected representation target to be included in the priority network. Planning units containing occurrences of multiple species could contribute simultaneously to the representation requirements of all those species. This complementarity allowed spatially overlapping distributions to be represented through shared planning units (Cabeza and Moilanen 2001; Ball et al. 2009).

All planning units were assigned equal cost. Consequently, the optimization minimized the total number of selected planning units rather than incorporating differences in land

acquisition, management, opportunity, restoration, or socioeconomic costs. Six independent optimization scenarios were generated, corresponding to the six representation targets.

The minimum-set formulation is widely used in systematic conservation planning because it identifies spatially efficient solutions while maintaining explicit representation constraints for all conservation features (Pressey et al. 1993; Margules and Pressey 2000).

Evaluation of species representation

Realized representation was calculated for each species as the proportion of its occupied planning units included in the selected network. The resulting value was expressed as a percentage.

A species was considered to have achieved the specified representation target when its realized representation was equal to or greater than the nominal target. The number of occupied planning units and the number selected in the priority network were recorded for each species and scenario.

The distinction between nominal and realized representation was retained throughout the analysis because discrete planning units can produce substantial deviations from the specified target, especially for species with few occupied units (Pressey et al. 1997; Kukkala and Moilanen 2013).

Mean and minimum representation

Mean realized representation was calculated across the 181 focal species for each target scenario. This metric summarizes the overall level of documented spatial coverage obtained by the network.

Minimum realized representation was defined by the least-represented species in each scenario. Comparison between minimum representation and the nominal target provided a direct assessment of whether the optimization satisfied the representation requirement for every species.

Mean representation can exceed the nominal target because some species receive additional planning units as a consequence of complementarity and the discrete nature of the planning framework. Minimum representation is therefore particularly informative for evaluating the performance of the optimization with respect to the least-represented conservation feature.

Spatially restricted species

Species occupying only one planning unit were classified as spatially restricted at the analytical resolution. This classification refers exclusively to their documented occurrence within the 50 × 50 km planning framework.

Spatial restriction at the analytical resolution was not interpreted as evidence of biological rarity, endemism, small population size, or conservation threat. Instead, it identifies species for which the available occurrence records were concentrated within a single planning unit.

Planning units containing multiple spatially restricted species were considered potentially efficient because selection of one unit could simultaneously satisfy the representation requirements of several species. Such overlap contributes to complementarity and can reduce the number of planning units required by a minimum-set solution (Cabeza and Moilanen 2001; Kukkala and Moilanen 2013).

Comparison of scenarios

The six representation-target scenarios were compared using four principal measures: the number of selected planning units, mean realized representation, minimum realized representation, and the distribution of species-level realized representation.

The number of selected planning units represented the spatial extent of each network because all candidate units had equal cost. Mean representation summarized the average level of documented occupancy represented across the focal assemblage, while minimum representation identified the species receiving the lowest level of coverage.

The distribution of species-level representation was examined to determine how strongly realized representation departed from the nominal target and whether these departures were associated with differences in the number of occupied planning units.

The 100% scenario was treated as the complete-representation reference. At this target, all documented occupied planning units were required to be represented, providing the maximum spatial extent against which lower-target solutions could be compared.

Software and computational analysis

All spatial data processing, planning-unit construction, occurrence assignment, species-by-planning-unit matrix generation, prioritization, representation calculations, and graphical analyses were conducted in R version 4.5.3 (R Core Team 2025).

Spatial vector processing was performed with *sf* version 1.0-22, raster and spatial-data processing with *terra* version 1.8-42, and data manipulation with *dplyr* version 1.1.4 and *tidyr* version 1.3.1 (Pebesma 2018; Hijmans 2025).

Systematic conservation prioritization was conducted with *prioritizr* version 8.1.1 using a minimum-set objective, relative representation targets, and binary planning-unit decisions. Optimization was performed using the HiGHS solver through *highs* version 1.12.0 (Hanson et al. 2020; Hanson et al. 2025).

The analytical workflow consisted of occurrence-data preparation, duplicate removal, spatial projection, planning-unit assignment, construction of the binary species-by-planning-unit matrix, calculation of species occupancy and richness, generation of conservation-prioritization scenarios, and evaluation of selected planning units and species-level representation. Data and analytical outputs were archived in Zenodo (10.5281/zenodo.22781859) to support reproducibility.

Results

Occurrence records and spatial occupancy

The compiled dataset contained 11,329 georeferenced occurrence records representing 181 focal species of *Apiomerus* and *Zelus*. No retained records lacked species identification or geographic coordinates. After removal of duplicate species-coordinate combinations, 10,327 unique occurrence records remained, corresponding to 1,002 duplicate records.

The retained records extended across the documented geographic distributions of the focal species in the Americas (Fig. 1). When assigned to the 50 × 50 km planning framework, the species occupied between one and 507 planning units (Fig. 2).

Sixteen species (8.84%) occupied a single planning unit, while 15 species occupied two planning units. Consequently, 31 species (17.13%) occupied no more than two planning units. The distribution of species occupancy was highly uneven, with a large difference between the most spatially restricted species and the most widespread species.

Several species occupied hundreds of planning units. *Zelus tetracanthus* Stål occupied 507 planning units, followed by *Z. renardii* Kolenati with 348, *Apiomerus spissipes* (Say) with 332, *Z. cervicalis* Stål with 320, *Z. longipes* (Linnaeus) with 314, and *Z. luridus* Stål with 291.

Overall, the number of occupied planning units varied by more than two orders of magnitude among species. The resulting distribution encompassed species with highly restricted documented occupancy at the analytical resolution and species distributed across extensive portions of the Americas.

Species richness

Species richness varied substantially among the 50 × 50 km planning units (Fig. 3). The focal species were therefore not distributed uniformly across the study area, and several planning units contained multiple species simultaneously.

High-richness planning units provided opportunities for efficient representation because selection of a single unit could contribute to the representation requirements of several species. However, the richness pattern did not directly determine the prioritization solutions because the optimization incorporated species-specific representation requirements.

Planning units containing relatively few species could nevertheless be selected when they contributed essential representation for spatially restricted species or provided complementary coverage for species not adequately represented elsewhere.

Effects of representation targets on network size

Six representation targets were evaluated: 10%, 20%, 30%, 50%, 75%, and 100%. All 181 species achieved the specified target under every scenario.

The number of selected planning units increased progressively with the representation target (Table 1; Figs. 4 and 5). The 10% scenario selected 118 planning units. The network increased to 250 planning units at 20% and 377 at 30%. At 50%, 729 planning units were selected, increasing to 1,432 at 75%. Complete representation at 100% required 2,592 planning units.

The increase in network size became progressively greater at higher representation targets. The transition from 10% to 20% required 132 additional planning units, whereas the transition from 20% to 30% required 127 additional units. Increasing the target from 30% to 50% required 352 additional units. The increase from 50% to 75% required 703 additional units, while the increase from 75% to 100% required 1,160 additional planning units.

The 100% scenario therefore encompassed the complete set of candidate planning units containing documented occurrences of the focal species. It represented the maximum spatial extent of the occurrence-based conservation framework.

Realized species representation

Realized species-level representation exceeded the nominal target for many species, particularly at lower target levels (Table 1; Figs. 6–8).

At the 10% target, minimum representation was 10%, whereas mean representation was 29.45% and median representation was 18.18%. At the 20% target, minimum representation was 20%, with mean and median values of 40.44% and 33.33%, respectively.

At 30%, minimum representation was 30%, while mean representation reached 48.73% and median representation reached 40.00%. At 50%, minimum representation was 50%, with mean representation of 64.93% and median representation of 57.14%.

At 75%, minimum representation was 75%, while mean and median representation reached 86.49% and 83.33%, respectively. At 100%, minimum, mean, and median representation were all 100%.

The difference between nominal and mean realized representation was greatest at the lowest target. At 10%, mean representation exceeded the nominal target by 19.45 percentage points. At 75%, the difference was reduced to 11.49 percentage points. At 100%, nominal and realized representation were identical.

The distribution of species-level representation shifted progressively toward higher values as the representation target increased. This pattern reflected both the larger number of selected planning units and the discrete structure of the planning framework.

Spatially restricted species

Sixteen species were represented by only one occupied planning unit: *Apiomerus carbonarius* Costa Lima, Seabra & Hathaway, *A. carvalhoi* Costa Lima, Seabra & Hathaway, *A. discopterus* Stål, *A. mayi* Costa Lima, Seabra & Hathaway, *A. mendesi* Costa Lima, Seabra & Hathaway, *A. osorioi* Costa Lima, Seabra & Hathaway, *A. rosenbergi* Costa Lima, Seabra & Hathaway, *A. tejerai* Costa Lima, Seabra & Hathaway, *Zelus audax* Stål, *Z. bahiaensis* Zhang & Hart, *Z. casii* Zhang & Hart, *Z. filicauda* Bergroth, *Z. grandoculus* Zhang & Hart, *Z. rosulentus* Zhang & Hart, *Z. spatulosus* Zhang & Hart, and *Z. zayasi* Zhang & Hart.

For species occupying one planning unit, selection of the occupied unit resulted in 100% realized representation. Consequently, these species necessarily exceeded lower representation targets whenever their occupied unit was included in the network.

Species occupying two or a few planning units also exhibited relatively large deviations between nominal and realized representation. The proportional contribution of a single planning unit was substantially greater for these species than for species distributed across hundreds of planning units.

Representation of widespread species

Widespread species generally approached their nominal targets more closely than spatially restricted species.

At the 30% target, *Apiomerus* was represented in 101 of 332 occupied planning units, corresponding to 30.42%. *A. pictipes* Herrich-Schaeffer was represented in 72 of 235 units (30.64%), and *A. crassipes* (Fabricius) in 75 of 244 units (30.74%). Among *Zelus*, *Z. cervicalis* was represented in 98 of 320 units (30.63%), *Z. renardii* in 107 of 348 units (30.75%), and *Z. tetracanthus* in 157 of 507 units (30.97%).

At 50%, *A. spissipes* and *A. crassipes* each reached exactly 50.00% representation. *A. pictipes* reached 51.49%, *A. flaviventris* Herrich-Schaeffer 51.15%, *Z. cervicalis* 50.31%, *Z. longipes* 50.32%, *Z. luridus* 50.17%, *Z. renardii* 50.29%, and *Z. tetracanthus* 50.30%.

At 75%, *A. spissipes*, *A. crassipes*, *A. lanipes* (Fabricius), and *Z. cervicalis* Stål each reached 75.00%. *A. pictipes* reached 75.32%, *A. montanus* Burmeister 75.76%, *Z. longipes* 75.16%, *Z. luridus* 75.26%, *Z. renardii* 75.00%, and *Z. tetracanthus* 75.15%.

These values demonstrate the progressively closer correspondence between nominal and realized representation associated with species occupying large numbers of planning units.

Complete representation

The 100% target resulted in complete representation of the documented occupied planning units of all 181 species. A total of 2,592 planning units were selected.

Minimum, mean, and median representation were all 100%. Every occupied planning unit represented in the candidate dataset was included in the resulting network.

For widespread species, complete representation required the inclusion of all occupied planning units. This included 507 units for *Zelus tetracanthus*, 348 for *Z. renardii*, 332 for *Apiomerus spissipes*, 320 for *Z. cervicalis*, and 244 for *A. crassipes*.

The 100% scenario consequently represented the maximum documented spatial extent of the focal assemblage within the 50 × 50 km analytical framework.

Discussion

Representation targets and spatial requirements

The principal finding is the strong increase in network extent associated with increasing representation targets. The minimum-set network expanded from 118 planning units at 10% to 250 at 20%, 377 at 30%, 729 at 50%, 1,432 at 75%, and 2,592 at 100%. Thus, the spatial requirements for representing the documented distributions of *Apiomerus* and *Zelus* depend strongly on the level of representation considered acceptable. This pattern is consistent with a fundamental principle of systematic conservation planning: higher representation targets generally require larger networks because progressively more of the geographic distribution of each conservation feature must be included (Margules and Pressey 2000; Pressey and Bottrill 2009).

The increase in network size was progressively greater at higher targets. Only 132 additional planning units were required between 10% and 20%, compared with 127 between 20% and 30%, 352 between 30% and 50%, 703 between 50% and 75%, and 1,160 between 75% and 100%. This pattern reflects the decreasing availability of alternative locations capable of contributing to higher levels of representation. At lower targets, planning units shared by several species can satisfy multiple requirements simultaneously, whereas higher targets increasingly require inclusion of additional portions of individual species distributions (Pressey et al. 1993; Kukkala and Moilanen 2013).

The results therefore illustrate the importance of evaluating multiple targets rather than adopting a single arbitrary threshold. A compact 10% network may be useful where conservation resources are highly constrained, whereas 50% or 75% targets provide substantially greater spatial representation at a considerably higher spatial requirement. No target is universally optimal because the appropriate level depends on conservation objectives, implementation capacity, uncertainty, and the consequences of incomplete representation (Game et al. 2013; Pressey et al. 2015). The value of the target scenarios is consequently not that one represents the correct solution, but that they quantify the spatial consequences of progressively more ambitious representation objectives.

The 100% scenario is particularly informative as a benchmark. It required 2,592 planning units and represented all documented occupied planning units of the 181 focal species. This scenario should be interpreted as complete representation of documented occupancy at the

selected analytical resolution, rather than as a requirement that every occupied location must be conserved to guarantee population persistence. Spatial representation is only one component of conservation effectiveness; persistence additionally depends on habitat quality, population size, demographic processes, connectivity, environmental conditions, and future threats (Pressey and Bottrill 2009; Kukkala and Moilanen 2013).

An additional feature of the results was the difference between nominal and realized representation. Mean realized representation was 29.45%, 40.44%, 48.73%, 64.93%, and 86.49% under the 10%, 20%, 30%, 50%, and 75% targets, respectively, while all species achieved at least their specified target. The excess representation results primarily from the discrete nature of planning units and their simultaneous contribution to multiple species. Thus, target attainment should be evaluated using species-level realized representation rather than assuming that every species will receive exactly the nominal percentage (Pressey et al. 1997; Kukkala and Moilanen 2013).

Spatially restricted and widespread species

The 16 species occupying a single planning unit and the 31 species occupying no more than two planning units demonstrate the importance of spatial restriction in determining network configuration. Planning units containing these species can become indispensable because few or no alternative locations are available to satisfy their representation requirements. Consequently, a relatively species-poor planning unit may be more important to the minimum-set network than a richer unit containing species that are already represented elsewhere (Rodrigues et al. 2004; Kukkala and Moilanen 2013).

The discrete structure of the planning framework also explains why spatially restricted species frequently receive substantially more representation than the nominal target. A species occupying a single planning unit cannot receive 10%, 20%, or 30% representation independently; the unit must either be selected or excluded. If selected, 100% of the documented occupancy is represented. Similar effects occur for species occupying two or a few planning units. This is an expected consequence of indivisible planning units rather than an inefficiency of the optimization procedure (Pressey et al. 1997).

The interpretation of these species as “spatially restricted” is explicitly dependent on the 50 × 50 km analytical grain. A finer planning framework could distribute their records among several units, whereas a coarser framework could combine occurrences currently assigned to separate units. Accordingly, occurrence in a single planning unit should not be interpreted as

evidence of biological rarity, endemism, restricted habitat requirements, or extinction risk (Gaston 1994, 2000). The result instead indicates that, given the available data and analytical resolution, there are few documented spatial alternatives for representing those species.

Widespread species showed the opposite pattern. *Zelus tetracanthus*, *Z. renardii*, *Z. cervicalis*, and *Apiomerus spissipes*, among others, occupied hundreds of planning units and therefore offered many alternative combinations through which representation targets could be achieved. At 30%, 50%, and 75%, realized representation for several widespread species was close to the nominal target. This greater flexibility is expected because selection of individual planning units has a smaller proportional effect when a species occupies many units (Cabeza and Moilanen 2001; Ball et al. 2009).

The contrast between restricted and widespread species does not imply that widespread species have lower conservation importance. Rather, distributional extent affects the degree to which a species constrains the spatial configuration of a minimum-set network. Widespread species can often be represented incidentally through units selected for other species, whereas spatially restricted species are more likely to determine which particular units must be included. This distinction between conservation importance and spatial constraint is central to complementarity-based planning (Rodrigues et al. 2000; Kukkala and Moilanen 2013).

Species richness, complementarity, and network configuration

Species richness provides useful information about the geographic concentration of the focal assemblage, and planning units containing many species can contribute efficiently to conservation because a single selected unit can satisfy portions of several species' representation requirements. However, richness alone cannot identify the complete set of areas required to meet species-specific targets. A high-richness planning unit may contain species that are widely represented elsewhere, whereas a low-richness unit may contain a spatially restricted species for which no alternative is documented (Rodrigues et al. 2004; Pressey et al. 2007).

This distinction illustrates the difference between richness and complementarity. Richness describes how many focal species occur in a location, whereas complementarity concerns the additional contribution of that location to a network relative to areas already selected. Minimum-set optimization incorporates this distinction by identifying combinations of planning units that collectively satisfy the representation requirements of all species while

minimizing network extent. Consequently, an area does not need to be species-rich to be important within a systematic conservation network (Margules and Pressey 2000; Kukkala and Moilanen 2013).

The results are therefore consistent with previous evidence that conservation priorities based exclusively on richness can overlook geographically distinctive assemblages. This issue is particularly relevant for insects because species distributions can be highly heterogeneous, and areas containing relatively few species may still contribute disproportionately to the representation of taxa with restricted distributions. Richness maps are consequently most useful as descriptive products that provide geographic context, whereas complementarity-based prioritization identifies the combinations of areas required to achieve explicit conservation objectives (Rodrigues et al. 2004; Game et al. 2013).

The same principle explains why the selected networks should not be interpreted simply as maps of biodiversity hotspots. A minimum-set solution is determined by the interaction among species distributions, representation targets, and planning-unit structure. The geographic configuration of the network therefore reflects the collective representation requirements of the 181 species rather than the concentration of species richness alone. This distinction is particularly important when comparing conservation networks across alternative targets.

Comparison with previous insect conservation-prioritization studies

The patterns identified for *Apiomerus* and *Zelus* are broadly consistent with systematic conservation planning studies conducted for other insect groups, although direct comparisons are limited by differences in geographic extent, spatial grain, taxonomic composition, data quality, and target definitions. Studies of butterflies, beetles, and other insects have repeatedly shown that conservation networks depend strongly on complementarity, spatial distribution, and representation targets rather than on richness alone (Cabeza and Moilanen 2001; Kukkala and Moilanen 2013).

Butterflies provide one of the most developed bodies of comparative evidence. Systematic conservation planning for Turkish butterflies, for example, identified priority areas through complementarity-based approaches and demonstrated that areas important for overall representation were not necessarily those with the highest species richness. This result closely parallels the present analysis, in which low-richness planning units can become necessary when they contain species with highly restricted documented distributions (Zeydanlı et al.

2012). Similarly, conservation planning for Finnish butterflies has shown that spatial scale and the type of distributional information available can substantially influence the resulting priorities, emphasizing the importance of matching planning methods to the spatial scale of the conservation problem (Cabeza et al. 2004).

Studies of beetles provide another useful comparison. Conservation planning for saproxylic beetles in Italy demonstrated the importance of identifying geographically distinctive combinations of species rather than relying solely on richness-based criteria. Such results are consistent with the present finding that complementary planning units can provide greater collective representation than a set of sites selected only because they contain many species (D'Amen et al. 2013). More recent insect prioritization studies have additionally incorporated habitat suitability and future environmental change, illustrating how occurrence-based networks can be expanded by integrating ecological and environmental predictors.

The target–area relationship observed here also corresponds to the broader conservation-planning literature. Increasing targets generally require progressively larger networks because the number of alternative locations capable of contributing to representation decreases as the required proportion of each species' distribution increases (Pressey et al. 1993; Kukkala and Moilanen 2013). The increase from 118 planning units at 10% to 2,592 at 100% therefore represents an expected feature of minimum-set planning rather than a pattern specific to Reduviidae.

The present analysis nevertheless extends this literature in two important respects. First, relatively few systematic spatial prioritization studies have focused specifically on predatory Reduviidae. Second, the analysis evaluates six representation levels across 181 species of *Apiomerus* and *Zelus* distributed across the Americas, allowing the spatial consequences of target selection to be examined explicitly. The results therefore provide a taxon-specific baseline that complements the more extensive conservation-planning literature on butterflies, beetles, and other insect groups.

At the same time, the comparison emphasizes that the present network should not be interpreted as a surrogate for insect biodiversity as a whole. Different taxonomic groups can exhibit different spatial distributions and conservation requirements, and multi-taxon studies have demonstrated that priority areas identified for one group do not necessarily represent all components of biodiversity. The resulting network should therefore be regarded specifically as a representation framework for *Apiomerus* and *Zelus*, with potential for integration into

broader Reduviidae or multi-taxon assessments (Rodrigues and Brooks 2007; Game et al. 2013).

Data limitations, spatial grain, and implications for conservation planning

The principal limitation is that the analysis is based on documented occurrence records. The number of occupied planning units therefore reflects both biological distribution and the structure of available sampling. Unequal collecting effort, geographic accessibility, historical sampling, taxonomic interest, and database coverage can cause species to appear more widespread or more spatially restricted than their actual distributions (Boakes et al. 2010; Meyer et al. 2016). Removing duplicate species-coordinate records reduces the influence of repeated observations but does not correct broader sampling biases.

This limitation is especially relevant for species occupying one or a few planning units. Such patterns may represent genuine geographic restriction, incomplete sampling, or a combination of both. The classification of these species as spatially restricted should therefore be interpreted as a property of the documented occurrence dataset at the selected analytical resolution. Incorporating additional occurrence sources, sampling-effort correction, expert-validated range maps, or species-distribution models would allow the sensitivity of the prioritization results to distributional uncertainty to be assessed (Zizka et al. 2019).

Spatial grain represents a second important limitation. The 50 × 50 km planning units provide a consistent continental-scale framework but are not intended to identify fine-scale habitat patches or management sites. Changing planning-unit size could alter the number of occupied units per species, the degree of apparent spatial restriction, and the amount of overlap among distributions, potentially producing different priority networks (Shriner et al. 2006; Cheok et al. 2016). Multi-scale analyses would therefore be valuable for evaluating the stability of the most important areas before translating continental priorities into regional conservation actions.

The current framework also treats planning units as equal-cost areas and does not incorporate habitat condition, land use, protected-area status, connectivity, conservation costs, threats, or climate change. Consequently, the selected units represent efficient solutions for achieving species-specific spatial representation under the assumptions of the occurrence-based minimum-set problem, rather than immediately implementable conservation areas. Incorporating these additional factors through cost layers, connectivity constraints, habitat

models, or future climate scenarios would provide a more realistic basis for operational conservation planning (Carwardine et al. 2009; Game et al. 2013).

Despite these limitations, the results provide a useful baseline for conservation planning of *Apiomerus* and *Zelus*. The six target scenarios make the spatial consequences of conservation ambition explicit, while the contrast between restricted and widespread species demonstrates how species distributions influence network configuration. The analysis also shows that richness alone is insufficient, and that complementarity is necessary for representing heterogeneous species distributions. These findings are particularly relevant for insect groups for which comprehensive conservation assessments remain limited (Samways 2007; Leather 2018).

The framework can be extended by integrating additional Reduviidae, environmental predictors, habitat suitability, protected areas, land-use pressures, connectivity, and projected climatic changes. Such extensions would transform the current documented-occupancy analysis into a more comprehensive assessment of conservation opportunity and feasibility. For *Apiomerus* and *Zelus*, the present results therefore constitute a spatial representation baseline against which future, more detailed conservation-planning scenarios can be evaluated (Pressey and Bottrill 2009; Kukkala and Moilanen 2013).

Conclusion

Systematic conservation planning revealed substantial differences in the spatial requirements for representing *Apiomerus* and *Zelus* across the Americas. The focal species occupied between one and 507 50 × 50 km planning units, and increasing representation targets expanded the minimum-set network from 118 planning units at 10% to 2,592 at 100%.

Species occupying one or a few planning units showed greater realized representation because individual planning units encompassed large proportions of their documented occupancy, whereas widespread species generally showed greater spatial flexibility and closer correspondence between nominal and realized targets. These patterns demonstrate how species distributions, planning-unit structure, and complementarity jointly shape conservation-network configuration.

Species richness alone was insufficient to capture these spatial requirements. The resulting networks therefore provide an occurrence-based representation baseline for *Apiomerus* and

Zelus while demonstrating the value of evaluating alternative representation targets and complementarity when planning conservation for heterogeneous insect assemblages.

Supplementary Information

The supplementary information includes the analytical workflow, R script, datasets, and outputs archived in Zenodo (10.5281/zenodo.22781859) to facilitate reproducibility.

Acknowledgements

Author contributions

Alexandre Silva de Paula: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Software, Validation, Visualization, Resources, Writing – original draft, Writing – review & editing.

Funding

No funding was received for this study.

Data availability

The datasets, R script, and analytical outputs generated during this study are available in Zenodo (10.5281/zenodo.22781859).

Competing interests

The author declares no competing interests.

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Figure 1. Study area and occurrence records of Reduviidae in the Americas. Spatial distribution of the 10,327 unique species-coordinate occurrence records representing 181 Reduviidae species used in the spatial prioritization analysis. The study area corresponds to the geographic extent defined by the occurrence records.

Figure 2. Spatial planning units used in the prioritization analysis. Distribution of the 50 × 50 km planning units covering the study area. Planning units containing at least one Reduviidae occurrence were used to construct the species-by-planning-unit representation matrix and subsequent prioritization analyses.

Figure 3. Spatial distribution of Reduviidae species richness. Number of Reduviidae species represented in each 50 × 50 km planning unit. Species richness was calculated from the presence–absence of each of the 181 species across planning units.

Figure 4. Spatial prioritization maps under alternative representation targets. Planning units selected to achieve representation targets of 10%, 20%, 30%, 50%, 75%, and 100% for the 181 Reduviidae species. Each panel shows the spatial distribution of planning units included in the corresponding prioritization solution.

Figure 5. Relationship between representation targets and the number of selected planning units. Number of 50 × 50 km planning units selected under representation targets of 10%, 20%, 30%, 50%, 75%, and 100%. The number of selected planning units increased progressively as the representation target increased.

Figure 6. Relationship between representation targets and mean species representation. Mean proportion of occupied planning units represented across the 181 Reduviidae species under each prioritization target. The dashed line indicates the nominal representation target. Mean realized representation exceeded the nominal target at targets below 100%.

Figure 7. Relationship between representation targets and minimum species representation. Minimum proportion of occupied planning units represented among the 181 Reduviidae species under each prioritization target. The dashed line indicates the nominal representation target. All species achieved at least the specified representation target in every scenario.

Figure 8. Distribution of realized species representation under alternative representation targets. Distribution of the proportion of occupied planning units represented for the 181 Reduviidae species under representation targets of 10%, 20%, 30%, 50%, 75%, and 100%.

828 The distributions illustrate the variation in realized representation among species and the
829 progressive increase in representation as the target increased.
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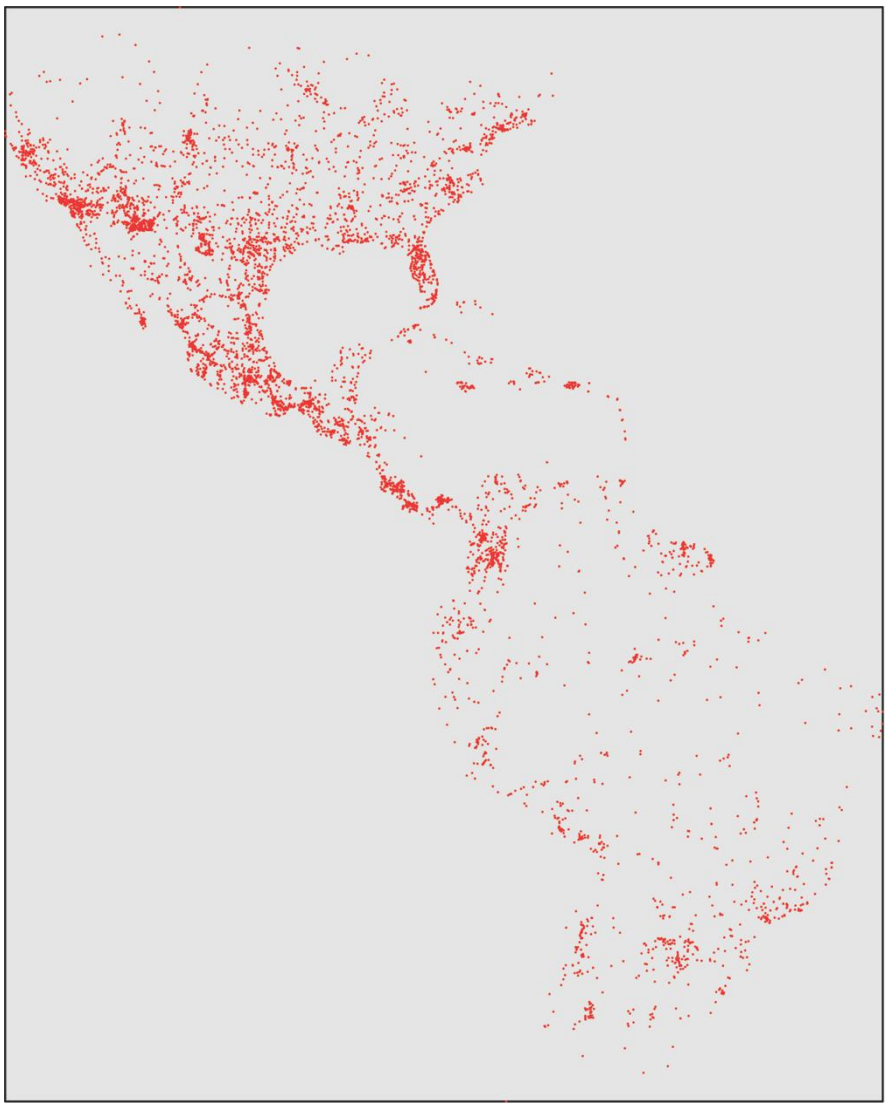


Figure 1

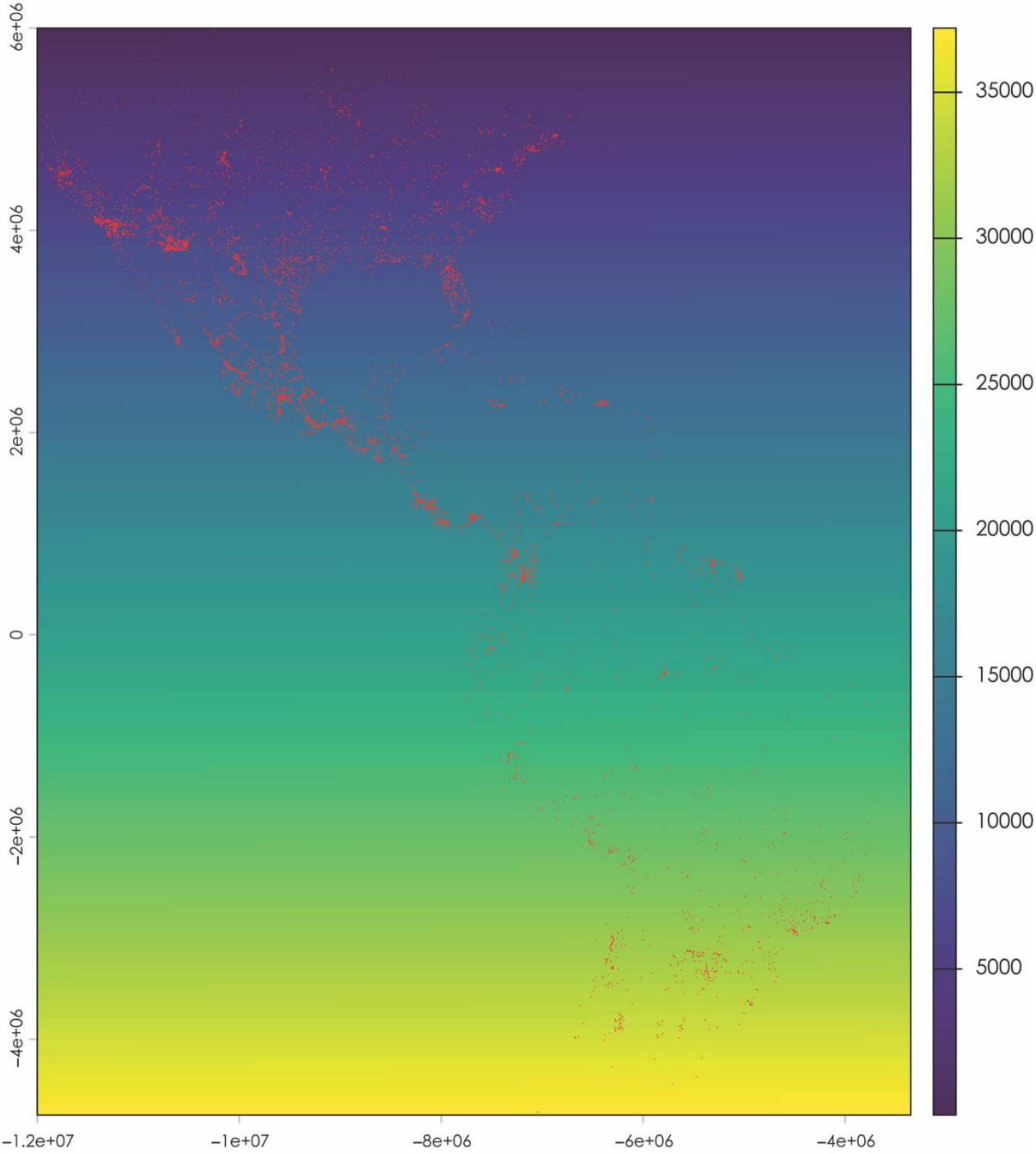

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Figure 2

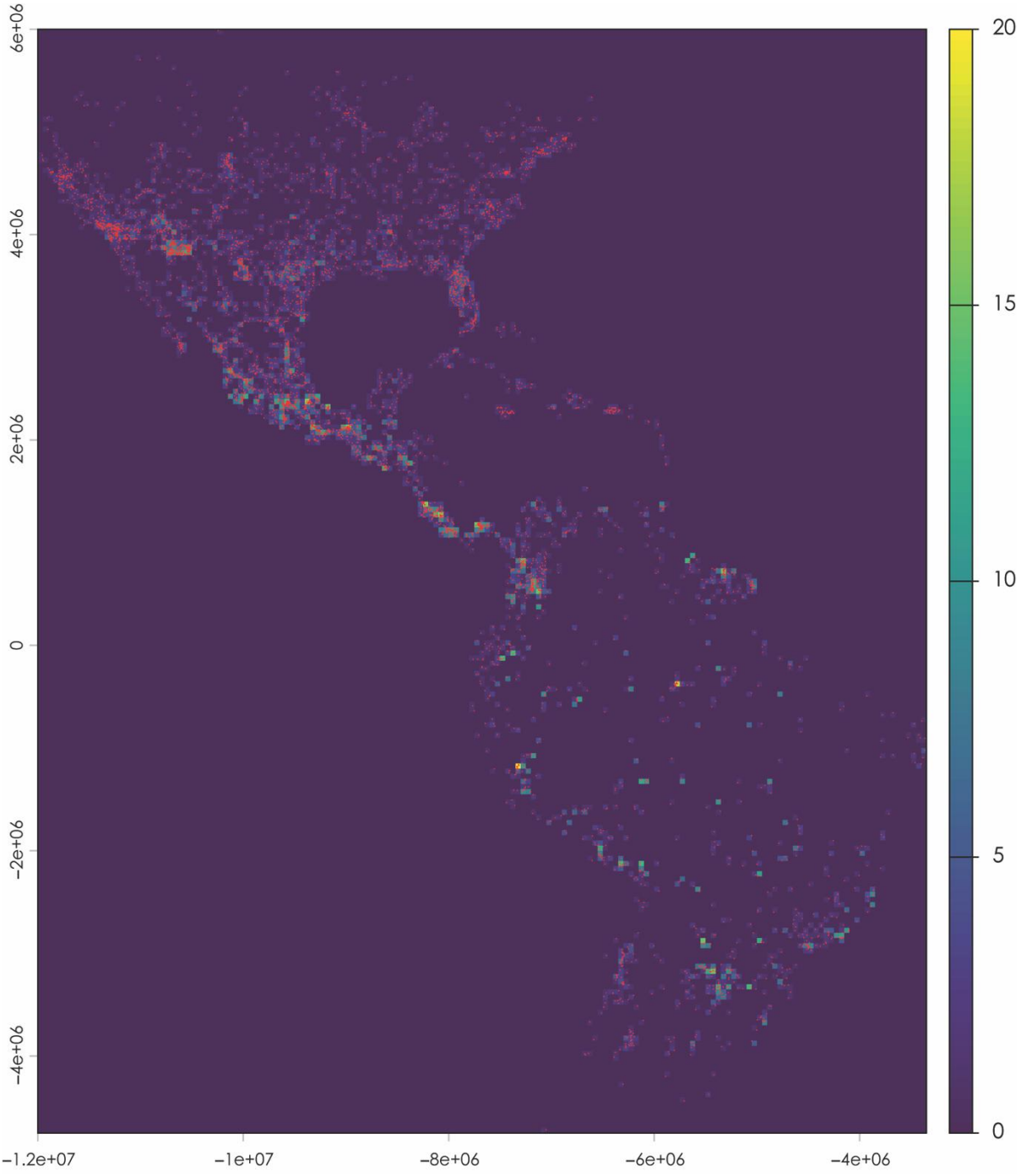
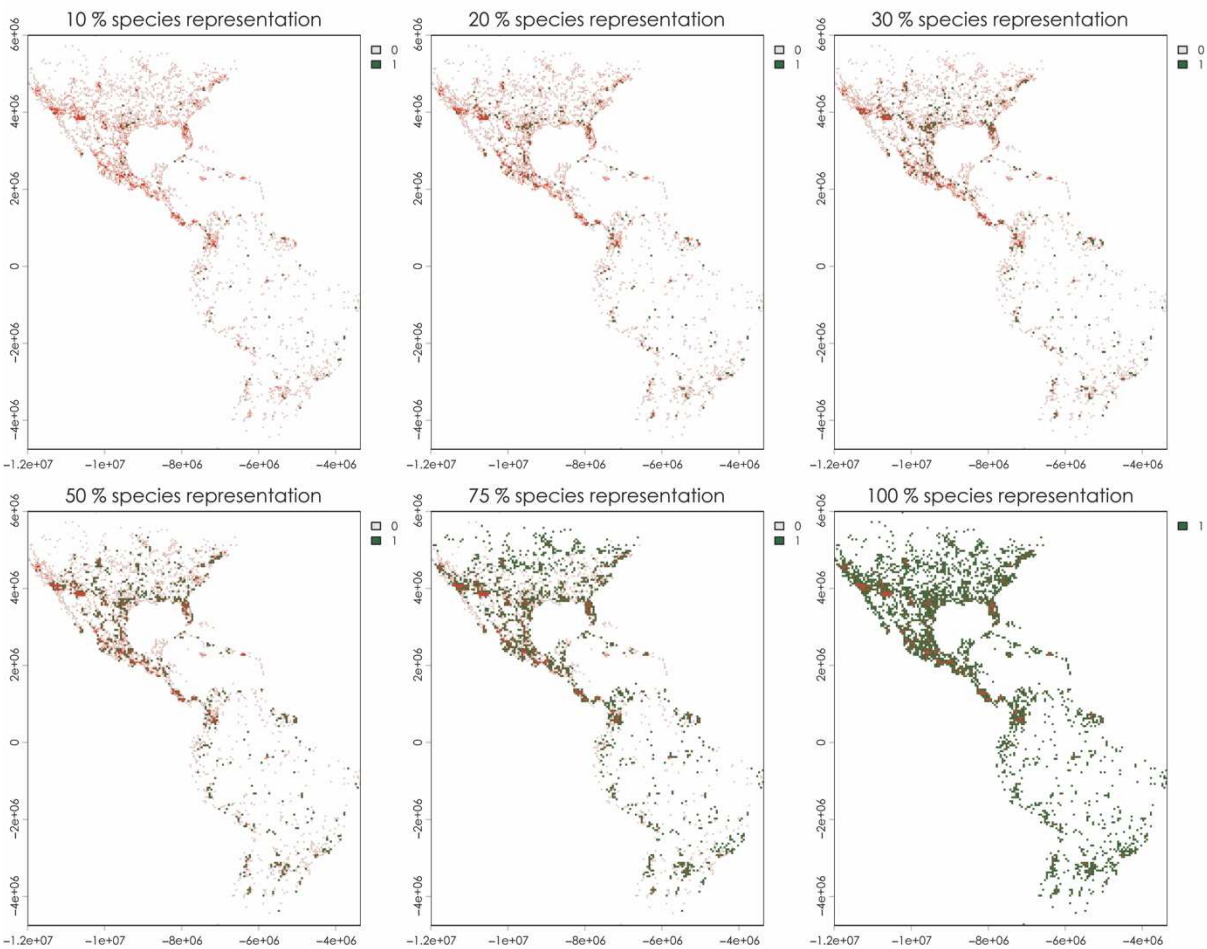

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Figure 3

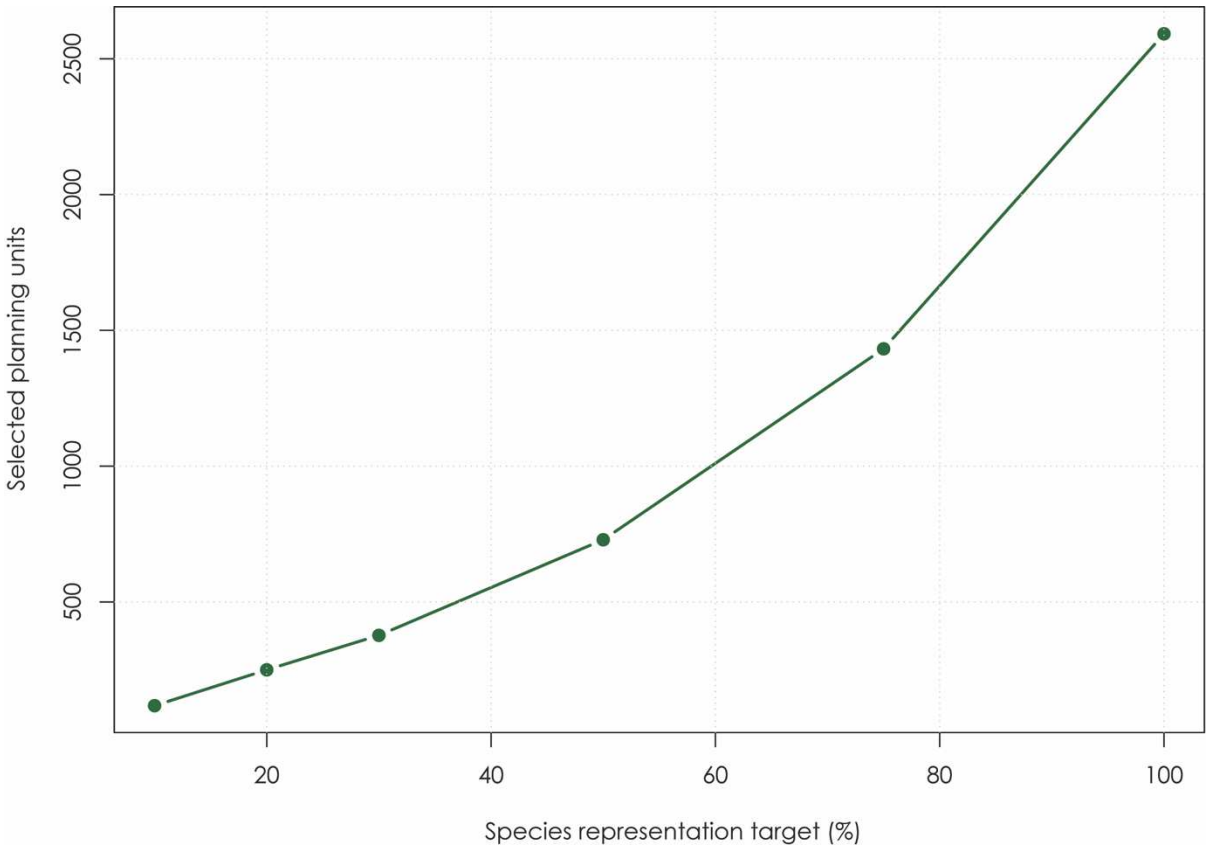


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846 **Figure 4**

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850 **Figure 5**

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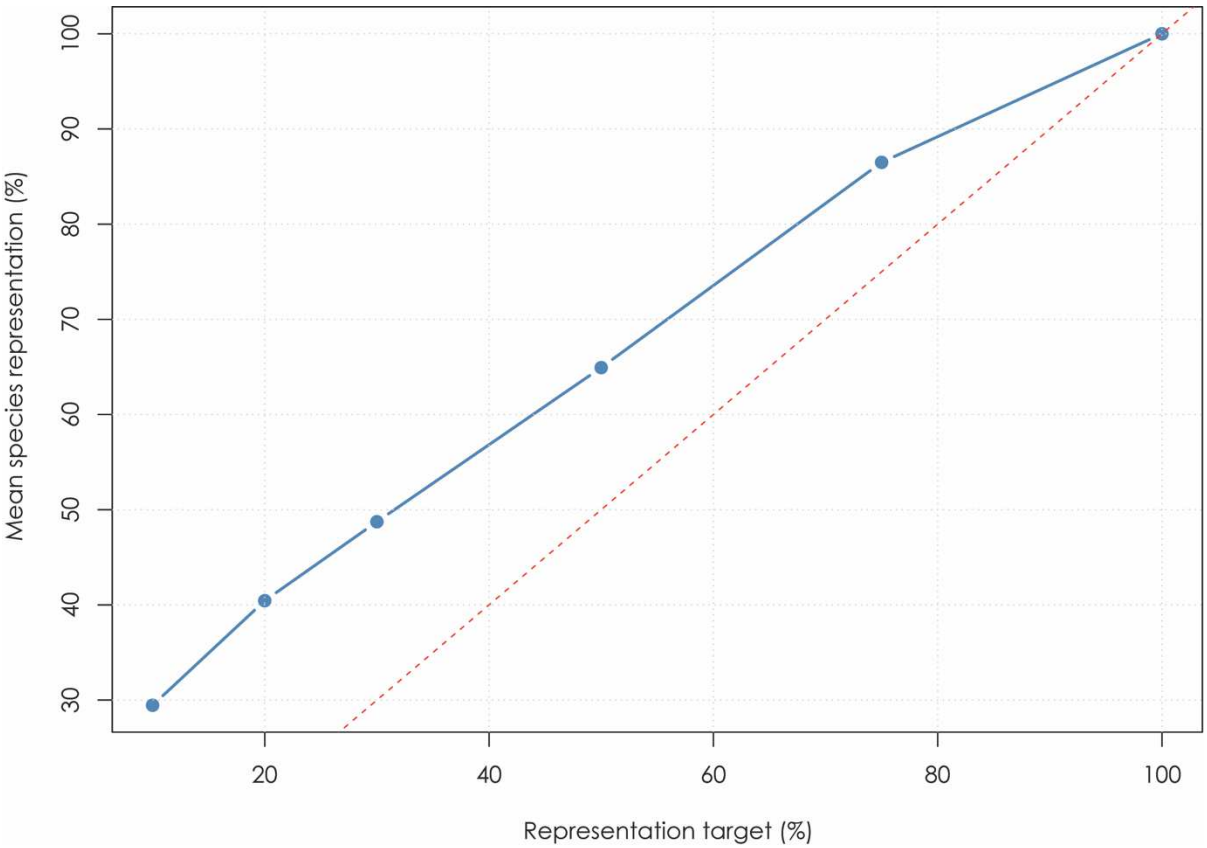

Mean species representation (%)
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Representation target (%)

Figure 6

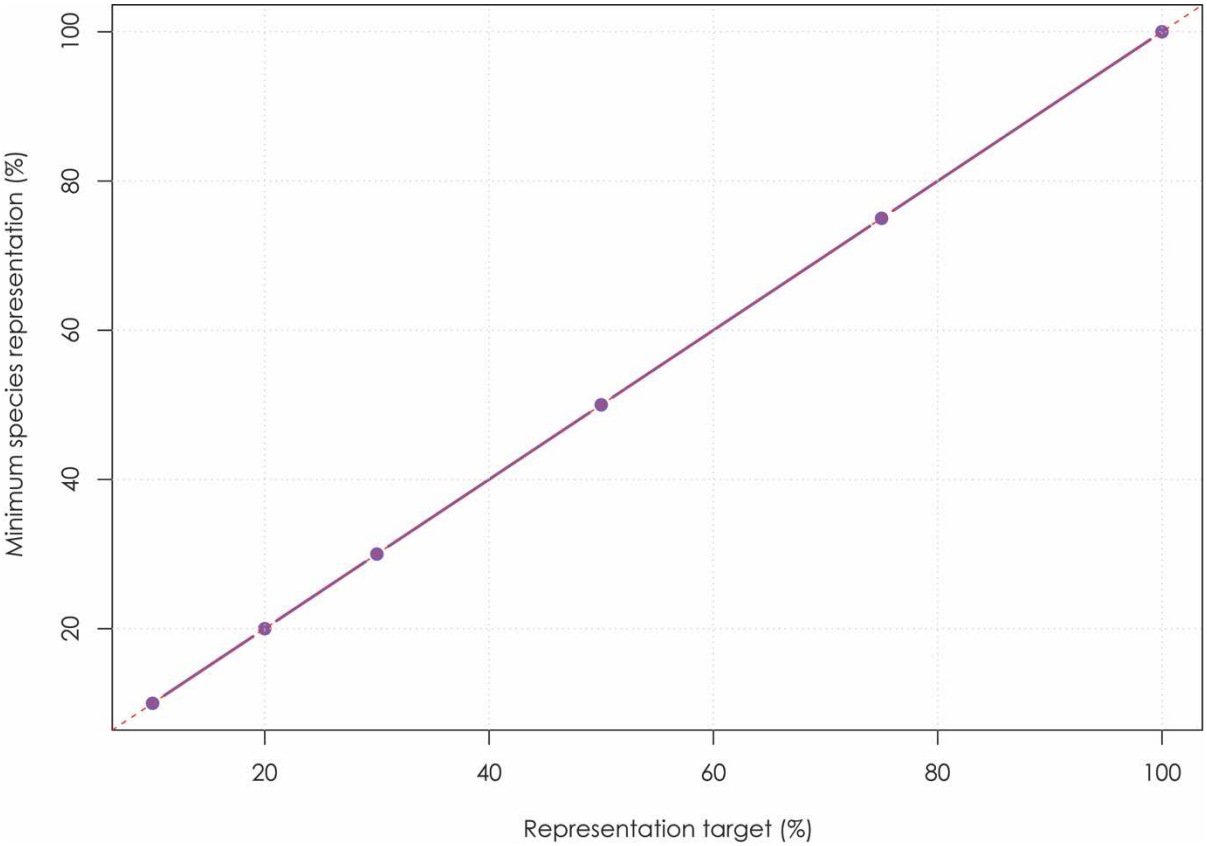
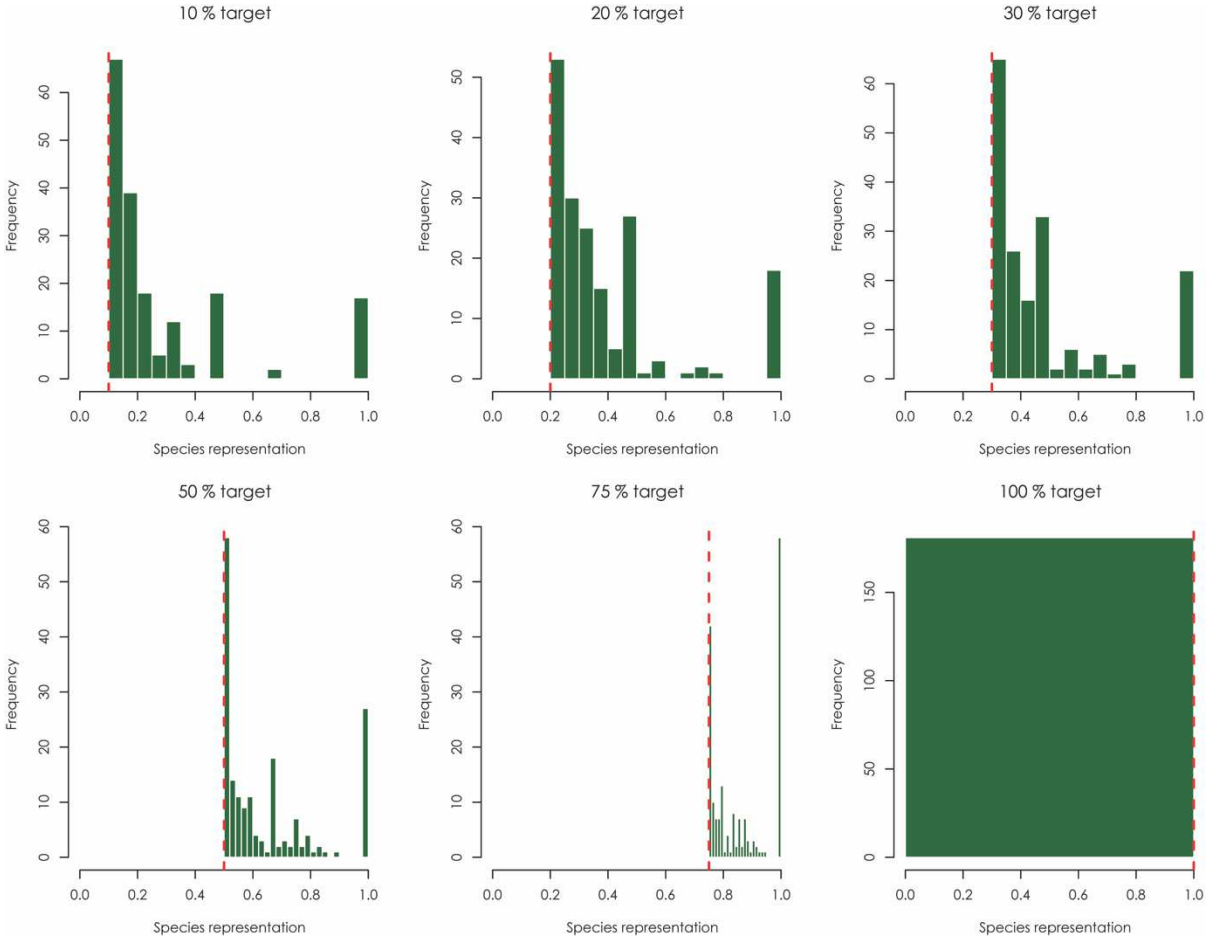

Minimum species representation (%)
20
40
60
80
100
20
40
60
80
100
Representation target (%)

Figure 7



861

862 **Figure 8**

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864

Table 1. Representation targets and spatial prioritization outcomes for 181 Reduviidae species.

Representation target	Selected planning units	Species meeting target	Species meeting target (%)	Minimum representation (%)	Mean representation (%)	Median representation (%)
10%	118	181	100	10.00	29.45	18.18
20%	250	181	100	20.00	40.44	33.33
30%	377	181	100	30.00	48.73	40.00
50%	729	181	100	50.00	64.93	57.14
75%	1,432	181	100	75.00	86.49	83.33
100%	2,592	181	100	100.00	100.00	100.00

Note: Representation was calculated as the proportion of each species' occupied planning units included in the prioritization solution. The minimum representation corresponds to the lowest realized representation among the 181 species. All scenarios achieved the specified representation target for all species. Planning units were 50 × 50 km cells.