Regional Representativeness Hotspots for World's Tetrapod Vertebrate Genera

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PREFACE

The work described in this thesis was carried out in the School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal, Westville Campus, from January 2019 to January 2021, under the supervision of Prof Şerban Procheş.

This study represents original work by Chanelle Ornella Govender and has not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others, it is duly acknowledged in the text.

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28 January 2021

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28 January 2021

Prof. Şerban Procheş

Date

DECLARATION

I, Chanelle Ornella Govender, declare that:

1. The research reported in this thesis, except where otherwise indicated is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other persons' data, pictures, graphs or other information unless specifically acknowledged as being sourced from other persons.
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ABSTRACT

As anthropogenic stress and resulting habitat degradation put pressure on biodiversity, there is a need for urgent and innovative conservation strategies. The integration of the biogeographical concept of bioregionalisation into conservation planning is critical for the successful protection of biodiversity on a global scale. This study looked at zoogeographic regions taken one by one, and combined based on their evolutionary histories, climate, and overall spatial interactions. Representative genera were selected, and their richness calculated for these single and combined regions. Representative genera for a region include genera which exhibit high levels of endemism and regional filling of that region. Regional representativeness hotspots were combined to produce a global hotspot scheme. Combinations of regions such as the Neo-Caribbean, Holarctic and Neotropic-Nearctic included significant numbers of ecoregions with hotspot status. Combinations including the Australian Zoogeographic Region and gradually larger numbers of neighbouring regions resulted in varying spatial hotspot patterns relevant to global regionalisation attempts. Theories and hypotheses, including continental drift, vicariance and dispersal events, and the influence of paleoclimates all contribute important explanations towards shaping the distribution of genera and the delineation of zoogeographic regions. Regional representativeness hotspots can be biogeographical units for robust conservation strategies, representing a proactive approach to the conservation of representative genera and co-occurring taxa worldwide.

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CHAPTER ONE: INTRODUCTION

1.1. Introduction

The accelerated rates of extinction of species and decrease in biodiversity as a whole, call for critical efforts in conservation. Human activities, in general, and the destruction of habitat in particular, have no doubt caused this acceleration (Primm & Raven, 2000). The significant gaps in taxonomic knowledge have been a hindrance to conservation planning strategies (Brito, 2004). The inability to accurately quantify the number of species on Earth, as well as insufficient biodiversity monitoring (Costello, 2015), have resulted in the failure to accurately calculate the biodiversity of the planet as well as extinction rates of species (Mora et al., 2011).

Several researchers have declared the sixth mass extinction to be underway (Barnosky et al. 2011). Evidence of extensive species extinction over the years supports these statements (Ceballos et al., 2015). In order to preserve biodiversity where this is thriving, and to conserve threatened biodiversity, rapid conservation efforts are needed. Various conservation strategies have been attempted over the years, including strategies which target single species, or strategies that take on a holistic approach, by incorporating ecosystem and landscape-level plans (Franklin, 1993). However, conservation strategies centred around representative taxa of a region, ensure the protection of species and their ecosystems.

The current crisis involving habitat degradation, destruction of ecosystems and rapid extinction rates, called for a new approach. Thus, a new discipline could arise, which incorporates principles of biogeographic regionalisation and conservation (Giraudo & Arzamendia, 2018). Conservation biogeography merges data and practical methods of species distribution analyses from biogeography with conservation strategies and planning. This field aims to provide theoretical insights for conservation practices, including ecological restoration, the reintroduction of species to appropriate habitats and the management of invasives species (Richardson & Whittaker, 2010).

Conservation biogeography includes the use of bioregions as target areas for conservation planning (Richardson and Whittaker, 2010). Delineating regions which represent the species which are characteristic to that region is crucial to inform this new angle to conservation. Bioregionalisation aims to classify the Earth into biotic units based on vegetation, and climate, endemic taxa. Recent studies have turned to bioregionlisation for conservation planning as it served the purpose of prioritising protected areas as well as assessing their representativeness of biodiversity and effectiveness in conservation efforts (Giraudo & Arzamendia, 2018).

Bioregionalisation methods and techniques evolved as the purpose of regionalisation evolved over the years. In 1998, IMCRA (Integrated Marine and Coastal Regionalisation for Australia) Technical Group described the purpose of biogeographical regions as a "framework" for conservation planning, which provides structured boundaries for multifunctional management which include protection of biodiversity and human activities (Ebach, 2015).

The theoretical and practical purposes of bioregionalisation in the 19th century focused on discovering regions of high endemism to understand the number of biological resources that could be utilised (Ebach, 2013). However, post-1990's through the early 2000s, bioregionalisation was used to evaluate the urgency of conservation plans and opportunities for the conservation of distinct units (Olson & Dinerstein, 1998).

The process of delineating regions includes questions which target the factors which influence the distribution of species; this may be current environmental / ecological (biotic and abiotic) factors, or intrinsic / historical factors (Antonelli, 2017). A large-scale debate has been ongoing as to which factors have a more significant impact on the distribution of species and the shaping of regions. When the dust settled, two "approaches" or "aspects" arose, those being of a historical foundation and an ecological foundation.

Delineating regions based on these two aspects, ecological or historical, has long been considered an apparent dichotomy, with the two, independent from each other (Daru et al. 2020). However, species distributions are influenced by both aspects simultaneously at different scales. At the historical scale, processes, and events take place across a more considerable temporal and spatial extent (Willig et al., 2003). On the opposite, ecological, end of the scale, processes and events operate at a finer temporal and spatial scale.

At a finer scale, processes become specific to a species, populations, or areas. The ecological approach does, however, incorporate a cross-scale perspective, as it operates with the hierarchy theory, where, at different temporal and spatial scales, a different and unique combination of variables are in operation, shaping and forming regions and influencing distributional patterns (Mucina, 2019). In contrast to ecological approaches, the historical approach assumes species distributions are shaped and influenced by long-term events in history, including speciation and extinction and evolutionary events such as continental drift (Cracraft, 2003).

The question posed by Ebach and Parenti (2015), is whether regions are natural entities or artefacts? Different regional schemes are developed and uniquely represent the method of their origin, which is either through ecological factors or evolutionary processes. Regional schemes associated with ecological factors include biomes and bioclimatic regions (Kreft & Jetz, 2010). Whereas regional schemes delineated using a historical approach include large scale regions such as zoogeographic regions (Lomolino et al., 2006).

Crisci et al. (2006), discussed the results of regionalisation, conducted using these two approaches, an example of regionalisation using historical approach is Takhtajan's biogeographic World map. This scheme yielded six geobotanical regions based on the presence of closely related and endemic species (Lomolino et al., 2006). In contrast to Takhtajan's scheme, Bailey (1998) took an ecological approach to delimit floral regions. This delineation consisted of 8 ecoregions, based on the occurrence of naturally occurring vegetation, at specific prevailing climate conditions (Crisci et al., 2006; Lomolino et al., 2006).

The delimitation of regions using phylogenetic relationships builds a solid foundation when questions regarding spatial analysis, conservation planning and past spatial reconstruction arise. The use of phylogenetic information when dealing with bioregionalisation is a shared belief among several scientists (Webb et al., 2006; Graham and Fine, 2008; Holt et al., 2013). Initially, Wallace did, in fact, take into account the "ancestral relationships" of species when describing zoogeographic regions.

In 2013, Holt et al. for the first-time revised Wallace's zoogeographic regions using available global distributions in conjunction with phylogenetic data. This study resulted in a regional scheme which incorporated areas that consisted of unique regional representative evolutionary histories (Holt et al., 2013). The conservation of evolutionary history has been one of the significant shifts in conservation planning, as many debate importance of protecting phylogenetic diversity of species (Collen et al., 2011).

Incorporating other aspects when delimiting regions may, however, form a more robust rationale as to their conservation value. Bradshaw et al. (2015), suggested recognising centres of endemism which will ensure a strong foundation for the formation of biogeographical regions. Centres of endemism refer to a significant amount of endemic biodiversity, restricted to a small area (Slatyer et al., 2007).

Endemicity is essential when analysing species diversity, explaining distributions, and prioritising conservation strategies—different fields of science focus of various aspects of endemism. When analysing the distribution and evolutionary history, the main question is what factors influence spatial patterns of endemism (Noroozi et al., 2018). Whereas, when conservation is the question, the centres of endemism are the focal point (Bradshaw et al., 2015).

A quantitative approach results in objective analyses as opposed to subjective analyses based on qualitative approaches (Ye et al., 2020). Using endemic species to recognise regions' boundaries contributes to objective analyses (Holt et al., 2013; Abdelaal et al., 2020). Endemic species do not randomly occur, these species specifically inhabit in a particular space and time, due to specified micro-environmental filters and evolutionary history (Abdelaal et al., 2020; Ye et al., 2019, 2020).

Species distribution is shaped by evolutionary events which are accounted for in historical biogeographical hypotheses. Thus, delineating regions based on endemic species distributions, in turn, incorporates evolutionary histories and phylogenetic relationships (Hazzi et al., 2018). An advantage of using endemic species for delineating regions is their specified geographic range, which is shaped by a region's history, whereas taxa which have a cosmopolitan distribution or species which have adapted to a region (Bradshaw et al., 2015). These widespread and adaptative species may not reflect the true integral history of a region. Bradshaw et al. (2015), describes centres of endemism as a foundation for bioregions.

Identifying centres of endemism and phylogenetic relationships will not only answer questions about the distribution of species but also questions regarding representative species. Do biogeographic regions contain species which are representative of that area? If yes, how is this helpful to biogeographers? Biogeography now has a new aim, a new vision, one of deep understanding of species, their origins, conservation, and preservation (Graham and Hijmans, 2006; Gao and Kupfer, 2018; Abdelaal et al., 2020).

Combining previous measures –species distribution, areas of endemism and phylogenetic relationships –of delineating regions into one framework is needed to analyse and verify the viability of current bioregionalisation schemes which are based on endemic species from key genera. Key genera which are representative of a region are significant indicators of the cohesiveness of the region (Mittermeier et al., 2004; Procheş and Ramdhani, 2012). Thus, delineating regions based on representative genera will ensure good structured, cohesive regional units. Representative genera refer to genera known for inhabiting specific habitats or regions and reflect a region's habitat, biomes, and ecosystems.

1.2. Motivation

The use of biogeographic regions in conservation planning is one of the main factors currently influencing this "facelift" of regionalisation. There is a shift in conservation planning, as strategies are no more centred around a single species, but rather, incorporate guild assemblages (Towns and Williams, 1993), endemic species or an entire bioregion (Thackway and Cresswell, 1997). Thus, for conservation purposes, regional schemes need to be objective and accurate, so that conservation of those regions is efficient.

Conservation frameworks use major spatial and biogeographical patterns, including species richness, biodiversity hotspots, geographic, and environmental gradients. This approach aims to protect areas and regions which are representative of larger regional denominations. Thus, it is of utmost importance that biogeographic regions be delineated with accuracy and accurate representation of its species and historical background.

Bioregions are affected differently by climate change. Thus, individual understanding regions and their characteristics are essential in conservation as a bioregional approach to conservation aids in accurate and precise strategies to preserve biodiversity from climate change (Vilhena and Antonelli, 2015). The use of bioregions and representativeness compared to individual species in conservation programs is growing in popularity, as there are several advantages. Focusing on representative hotspots ensures that conservation efforts target protecting characteristic faunas rather than single species.

In this study, we focus on regional representativeness hotspots. Regional representativeness hotspots refer to hotspots of species/ genera which is reflective of the region in which it occurs. Representativeness comes into play when prioritising protected areas. Protected areas need to represent/reflect bioregionalisation frameworks in order to be efficient and conserve threatened species (Ababneh et al., 2016; Giraudo and Arzamendia, 2018).

Integrating this concept of regional representativeness to find hotspots in biogeographical regions could be the key to effective and objective conservation planning. Regional representativeness hotspots may refer to a concentration of characteristic genera. Thus, focusing conservation efforts on these hotspots could prevent significant loss of important species, and of the ecosystems, in which they play a role.

1.3. Aims and Objectives

Aim

This study aims to identify regional representativeness hotspots for World's tetrapod vertebrate genera.

Objectives

1. Identify characteristic genera for each of World's biogeographic regions
2. Map the species richness of these genera globally
3. Compare and contrast these patterns to determine global representativeness hotspots.

CHAPTER 2: LITERATURE REVIEW

2.1. The History of Bioregionalisation

Eighteenth-century naturalists were fascinated by plants' and animals' distributions and the significance of their origins and dispersal patterns. Significant contributors to what is now the discipline of biogeography include Georges-Louis Leclerc, Comte de Buffon, Alexander von Humboldt, Alfred Wallace, and Alfred Wegener, together with many others (Nelson, 1978). Bioregionalisation aims to integrate disciplines that are otherwise considered separate from each other, including, biogeography, ecology, paleo-biology, and taxonomy. As seen today, biogeography and bioregionalisation do not necessarily represent a unification of these various disciplines, but rather a combination of these distinct fields of research.

The first record of any form of bioregionalisation appears in 1761, in the book Histoire Naturelle by the French naturalist, Georges-Louis Leclerc, Comte de Buffon. Comte de Buffon focused on mammals in the Old World and the New World (Ebach, 2015). He noticed that these regions had practically no species of mammals in common. Although they shared locally similar climate conditions, their inhabitants were different (Myers & Giller, 2013).

Similar species inhabit areas with similar conditions; however, the resulting faunas were different (Sanmartín, 2012). This result gave rise to several questions pertaining to the origin of species and their dispersal patterns. Was the distribution of these species their original distribution? Or did they disperse/migrate to these areas? These questions summed up the basic research of the 18th century, as research mainly focused on the distribution of species and explaining how it occurred. Buffon believed that species changed as a result of barriers and changes in circumstances. His statements were possibly early definitions of what we know now as allopatric speciation (Nelson, 1978).

Buffon's statement was vague by today's standards, and at the same time geographically- and taxonomically specific, as it is only concerned species in the Old and New World, and he only referred to mammals. Many naturalists used his statement as a general hypothesis for other regions and species other than mammals. As an example, Alfred Wallace compared the inhabitants of South America and Africa in their equatorial regions. Both these continents at the equator shared similar climatic variations but harboured very distinct species (Nelson, 1978).

Although Wallace did not reference Buffon, arguably this line of thinking was recorded before Wallace, and it was in fact, Buffon who mentioned distinct species inhabiting regions with similar climates and vegetation. In short, his theory mainly consisted of (a) the evolution of species, which accounted for different species in different regions, and (b) migration, which accounted for related species that occurred in different regions (Ebach, 2015).

In years to come, the study of distribution patterns became even more popular, especially as the Age of Enlightenment reached its peak in Europe. In the year 1816, Alexander von Humboldt was making ground-breaking progress in terms of the distribution of animals and plants. In one of his publications, he stated, "these studies of the law of the distribution of forms lead naturally to the question whether there exist plants common to both continents" (Nelson, 1978). Here, Humboldt was referring to the studies and findings of Buffon in the earlier years of two tropical New and Old-World continents, South America, and Africa.

Humboldt revolutionised plant geography, his creation of a new science known as the "Humboldtian Science", began a chain reaction that caused many others who came after him to see the distribution of plants and animals differently. In 1978, Susan Conan described Humboldtian Science as "the accurate, measured study of widespread but interconnected real phenomena to find a definite law and a dynamic cause" (Home, 1995). Alexander von Humboldt viewed environmental events with a cause-and-effect approach. Humboldtian Science is one of correlation. Humboldt tried to explain the distribution of plants based on the physical environment around them.

Humboldt's vegetation diagram entitled *Tableau Physique* (Figure 2.1) laid the foundation for biogeography and regionalisation. It was a cross-sectional profile of the Andes stretching across the latitude of Mount Chimborazo (Moret et al., 2019). The diagram encompassed the distribution of plants and animals on the mountain, and it demarcated the altitudinal vegetation zones, geological structures, physical and meteorological data, and types of agriculture land use. From *Tableau Physique*, Humboldt deduces seven vegetation regions occurring at different elevations of the mountains (Egerton, 2009). The *Tableau Physique* is one of the first forms of regionalisation recorded in history.

From this diagram, Humboldt was able to find correlations between plants and their physical environment. He eventually developed a way to represent his findings, which he termed as, "isotherms". These lines connected regions with the same average temperature and created a pattern (Schulten, 2012). When Humboldt applied these lines to greater Europe, he found something astonishing, and the isolines enclosed not only temperature but also air pressure and its demarcated areas of uniform vegetation. The isolines defined natural divisions on the Earth's surface (Nicolson, 1987). Humboldt's high level of analysis and intense investigations saw the beginning of new thinking (Herbertson, 1905).

While Humboldt's theories focused on vegetation, he investigated regionalisation based on animal distribution too; however, this did not become as popular as his study of flora and vegetation. In 1778, Johan Christian Fabricius divided the Earth into eight regions (Davies, 1961). These divisions include Alpine, Southern, Northern, Egyptian, Indian, Mediterranean, Oriental, and Occidental. Fabricius limited his divisions to insects (Ebach, 2015).

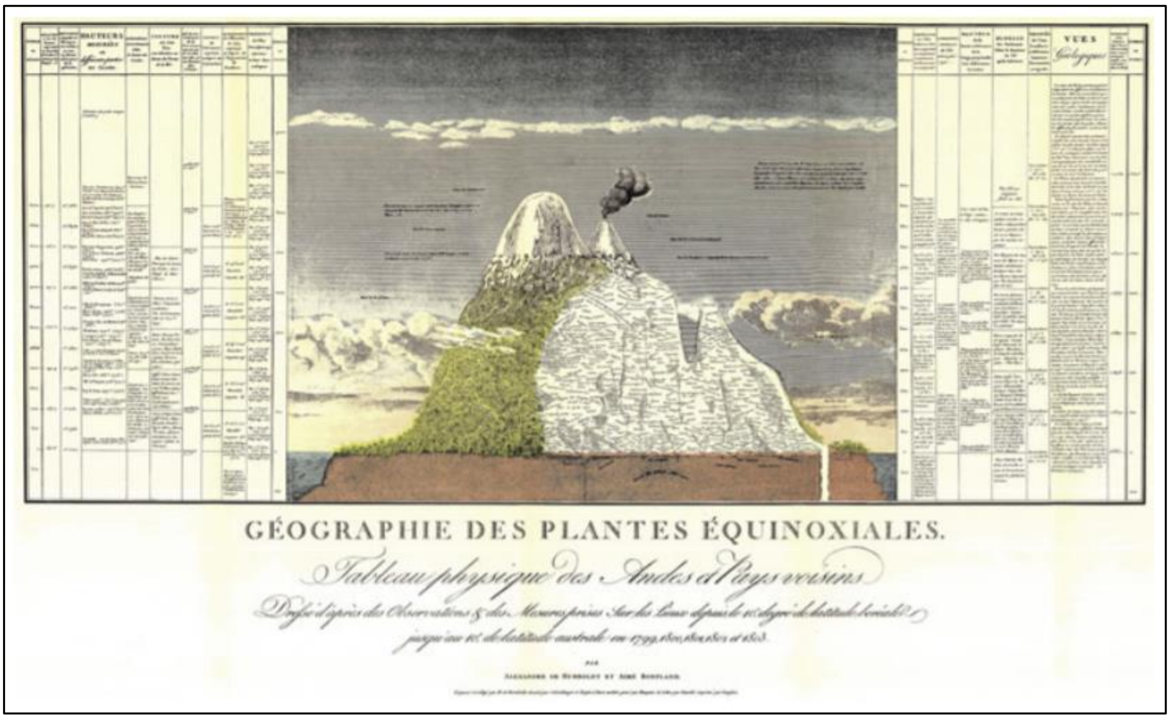


Figure 2.1: *Tableau physique*, a cross-section of Chimborazo in the Andes, presented by Humboldt, 1807 (Nelson, 1978).

Fabricius based his divisions on temperature and climate of each area and focused on insects. It is evident in his Indian region, consisting of the tropics of the Old and New World and the Alpine region consisting of mountains with snow (Swainson, 1835). However, his divisions were considered vague and not well thought out. Scientists during this period stated that Fabricius' divisions lack principle and reason. Regions had similar temperatures, but the insects and other animals within them were different.

Many of Fabricius' successors used his theory which would culminate in their theories of the Earth's regionalisation scheme in the years to come. Sclater, an English zoologist, was one to do this, his divisions were based on the distributional patterns of birds (Darlington, 1957), however, regardless of being limited to birds, it received a great deal of attention (Davies, 1961).

He divided the Earth into six regions: Palearctic, Nearctic, Ethiopian, Indian, Neotropical, and Australian (Sclater, 1858; Darlington, 1957; Davies,1961). During this period, which is called "pre-Darwinian", each region was considered independent from each other. He also stated that each region was a centre of creation (Davies, 1961).

In 1876, British naturalist Alfred Wallace released his theories on the regionalisation of the Earth. Wallace recognised six regional divisions: the Palearctic, Neotropical, Nearctic, Ethiopian, Australian, and Oriental. Wallace combined the schemes of Sclater and Huxley to produce his own (Darlington, 1957). His work focused on non-volant mammals. Wallace subdivided the six regions further, to form 24 subregions (Wallace, 1876). Alfred Wallace discussed the complex process of dividing the Earth into regions based on the distribution of species. Essential principles which he followed, included dividing the Earth as close to the natural regions as possible, the regions should be the same approximate size (Rueda et al., 2013).

The primary rule should be the presence of characteristic genera in the region. Wallace stated that one could also consider the absence of certain groups of animals as a principle to demarcate a region. Wallace focused on the existing distributions. However, he did note, the key to understanding current distributional patterns lies in the past (Darlington, 1957). This explanation was applied to the question of which species are considered "important" when determining zoological regions (Wallace, 1876).

Wallace explained the best way to, in fact, point out important groups of animals were to "consider groups of animals that are best adapted to exhibit, by their existing distribution, the past changes and present physical condition of the Earth's surface, and the abundance of their remains in various tertiary formations" (Wallace, 1876).

Wallace suggested that all significant continents are connected somehow to each other, directly or by archipelagos (Wallace, 1876). According to Wallace, one could probably travel across the continents without losing sight of land. Darlington confirmed this by stating that most of the land on Earth forms a continuous system; one could travel (Darlington, 1957). He suggested that no more than 1,000 years before 1957, the land formed a more continuous system than now, and gaps between the continents were narrower (Darlington, 1957).

Wallace visited the Aru islands is 1857, situated south-west of New Guinea. Spending almost six months investigating and surveying, Wallace found evidence of "relictual riverbeds" (Smith et al., 2019). A relict population of a taxon in biogeography refers to a population that one was part of a wider population and are now occupying a restricted geographic area (Habel & Assmann, 2009). Wallace implied similar tendencies of the riverbeds in the Aru Islands, deducing that the riverbeds were once part of a bigger system and possibly the highlands of New Guinea, thus suggesting a connection of New Guinea and the Aru Islands by an intervening plain (Wallace, 1876).

Wallace proposed the idea of land bridges, which connected continents and archipelagos. Wallace noted that there was a considerable overlap of faunal species of the Aru Islands with Australia and New Guinea, he also found 50% of birds in the nearby parts of New Guinea could be found in the Aru Islands. This particular finding was peculiar, as there was a large integral of water between the two countries. Wallace used varying sea levels and glacial epochs to explain the formation and destruction of land bridges (Habel & Assmann, 2009); however, a better understanding came to light soon thereafter.

In 1912, Alfred Wegener developed the theory we now know as continental drift. Prior to him, in the 1500s, there were suggestions of the movement of continents, but the theory was not picked up, as no real evidence or detailed explanation was provided (Carozzi, 1970). However, later, Wegener, with more evidence, put forward the idea of continental drift. His theory also confirmed the ideal of Wallace in 1876, who suggested a connected system of continents, without requiring continental bridges. It also could explain why Wallace found similar species in different regions (Wegener, 1966). Wegener hypothesised a supercontinent formed by the current continents joined (Hallam, 1975).

The mention of a supercontinent and continental drift changed many zoogeographers' views of species distributions and their origins as several argued whether the continental drift theory was fact or just an opinion (Pellegrini, 2019). One such person who was open about their thoughts with regards to continental drift was Philip Darlington. Darlington openly debated about what he believed were the truths about Wegener's theory (Darlington, 1957). Other scientists welcomed Wegener's theory, and to date, it influences aspects of regionalisation and species distributions (Antonelli, 2017). Ralph Tate, an English naturalist, highlighted the importance of geological aspects to explain historical events and processes of species distributions (Ebach, 2012).

2.2. On Other Key Aspects of Biogeography

Over the years, the discipline of biogeography and the concept of regionalisation gained attention, and thus endured much scrutiny and investigation. Many biologists and geographers have confirmed the main two branches of biogeography to be historical biogeography and ecological biogeography. Both these branches deal with different aspects and highlight different theories, which explain the distribution of species.

De Candolle was one of the earliest authors to differentiate between the two branches. He proposed ecological biogeography to highlight "physical causes operating in present times" and historical biogeography highlights "causes that no longer exists" (Morrone & Crisci, 1995). De Candolle distinguished between two concepts, "stations" and "habitation", where stations dealt with the influence of environmental elements on species distribution and habitation dealt with historical explanations for the current distribution of species (Paine, 2011). Here Candolle clearly distinguishes between ecological biogeography and historical biogeography.

2.2.1. Ecological Biogeography

Ecological biogeography discusses species distribution, explained through environmental factors, on a local or small scale, instead of historical biogeography (Sanmartín, 2012). Ecological factors operate on various spatial and temporal scales (Mucina, 2019). However, ecological biogeography highlights relatively finer scales (Santos & Amorim, 2007). This aspect of biogeography zeros in on abiotic factors, such as vegetation, climate, soil properties, and biotic factors, including other organisms and genetic characteristics, to explain how species could be distributed (Monge-Najera, 2008).

Ecological biogeography hypotheses contribute to species distribution; however, the extent of its contribution is questionable. Several studies argue the significance of ecological approaches, while others see ecological hypotheses secondary to historical hypotheses. Ecological factors shape distributions and spatial patterns of species within their global patterns (Heads, 2015). Bioregionalisation based on ecological concepts mainly occurs at finer scales, resulting in detailed regionalisation (Crisci et al., 2006). Regions based on ecological also may be obtained from a single concept such as climate or vegetation type.

2.2.1.1. Climate

The most prominent factor in ecological biogeography is climate. Climate is closely associated with vegetation structure, which in turn is associated with faunal assemblages (Ferger et al., 2014; Kreft and Jetz, 2010; Mucina, 2019). Current climate-related hypotheses include the relationship between climate its influence on resource availability (Sosa & Loera, 2017). Ferger et al. (2014) discussed the influence of climate on vegetation to indirectly impact species richness, whereas its influence on physiological limitations is a direct impact of species richness.

Several climatic hypotheses reflect indirect effects on species richness, and such hypotheses may impact other factors such as resource availability (Gaston & Blackburn, 2000), productivity (Velasco et al., 2017) and dispersal, thus influencing species distribution. Climate thus influences the distribution of species and their distributional range, but its influence does not end there, climate influences significant events such as the migration of populations and the dispersal of species (Travis et al., 2013). These factors provide valuable insight into bioregionalisation.

Biogeographical schemes which incorporate, or are solely based on, climate, include biomes, bioclimate and ecoregions. In general, these schemes involve delineating regions based but not limited to concepts such as climate, precipitation, temperature, and vegetation physiognomy (Kreft & Jetz, 2010; Mucina 2019). Variations in these complexes created specific habitat ranges and niches in which species occur (Yu et al., 2016; Tonkin et al., 2017).

Variation and climatic seasonality increased in its significance when one moves towards the poles and away from the tropics (Tonkin et al., 2017). These views coincide with the ecogeographical rule called Rapoport's Rule. Stevens (1989) highlighted that pattern of distributional ranges and latitudes when he mentioned distributional range size decreases with increasing latitude (Brown, 1995).

Several theories have been developed to account for this global pattern, with most of them having substantial evidence. Concepts including climate variability, land cover availability, and increased competition among species form the core of these theories (Veter et al., 2013). Once again, the concept of climate variability also comes into play. Due to the smaller geographic ranges in higher latitudes, species become vulnerable to high extinction rates (Purvis et al., 2000). Thus, a visible pattern of lower species diversity in lower latitudes is evident. The movement of species with smaller ranges is restricted. High latitude species may have to travel further to find a habitable space when climate variations force them out of their current habitats (Veter et al., 2013).

With that said, one could analyse major species spatial patterns such as global environmental diversity. The shifts in species distribution along these gradients are strongly associated with climate. The most prominent pattern seen globally is species distribution influenced by the latitudinal gradient. Environmental gradients influence species diversity, thus influencing and contributing to the delineation of regions. Understanding geographical diversity gradients form part of the ecological aspect of biogeography. Species distributed along these gradients play a part in shaping regions.

2.2.1.2.Geographical Diversity Gradients

High species diversity concentrated in the tropics, is a phenomenon which many have tried to explain. Species richness surrounding the equator can be explained through historical hypotheses or ecological hypotheses, very much like bioregionalisation. Historical hypotheses suggest long-term evolutionary events and historical climatic events, spanning over millions of years. Ecological hypotheses focus on the influence of current biological events such as abiotic and biotic factors on the latitudinal diversity gradient. These hypotheses suggest that latitudinal-diversity gradients are caused and maintained by ecological factors (Brown, 2014).

Ecological hypotheses which have been put forward over the years include the geographical-area hypothesis. This hypothesis suggests, a greater area may support more species. Therefore, the tropics cover a large portion of the Earth, having a larger area, promoting high species richness. The larger areas allow species to inhabit more extensive geographic ranges, thus promoting population growth and expansion. Large population sizes protect species from extinction.

Large population sizes present many opportunities for speciation events to occur. This hypothesis is extensively covered. However, some argue that the relationship between geographic area and the latitudinal diversity gradient is weak (Gaston & Blackburn, 1997). Due to the range of tropical species extend into extra-tropical areas, the correlation is compromised, and can be considered inaccurate. This extension of a species range is known as zone bleeding or zonal spill (Willig & Bloch, 2006).

Tropical species boost the number of species in extra-tropical areas, thus, flattening the gradient (Fine, 2001). Rosenzweig (1992) suggested removing tropical species from extra-tropical regions when analysing the latitudinal diversity gradient as it will give an accurate representation of species in higher latitudes, with temperate and polar descent. Gaston and Blackburn (1997) tested this theory and found that excluding tropical species, the analyses did indeed strengthen the correlation between geographic area and latitudinal diversity gradient.

The tropics are known to have specialised and rare species compared to temperate latitudes; this could be due to the specific niches that form in the tropics (Brown, 2014). Niche specialisation is attributed to, and dependant on, climate conditions (Bonetti & Wiens, 2014). With species occupying a specialised niche, their ranges are limited to the specific niches; thus, dispersal and expansion of range are reduced (Brown, 2014). The debate of whether tropical species are particularly specialised is ongoing. Niche Specialisation is dependent on many factors such as ecological interactions, the species in question and ecosystem functionality (Ollerton, 2012).

Hypotheses which invoke climate influence over latitudinal diversity gradient are diverse and covered several possible theories. One of these discusses species tolerance to extreme climates and weather changes. The tropics are known for its humid, some parts moist, climate. As one moves away from the tropics and into higher latitudes, extreme climate conditions present themselves, in the form of both extremely cold and extremely dry conditions. Thus, taxa originating in the humid tropics have difficulties adapting to the colder and drier conditions of the higher latitudes (Brown, 2014). Species ranges coincide with isotherm lines, suggesting that climate does have an impact on species range. Low tolerance to cold and dry conditions of tropical species, act as a barrier to extending their ranges or the colonisation of temperate latitudes (Mittenbach et al., 2007).

Latitudinal gradients have been studied in detail over the years and are one of the most prominent species richness patterns; however, there are other geographical gradients. Altitudinal gradients typically have a humped/ bell shape (Guo et al., 2013). Species diversity increases with altitude until a certain point and then decreases with altitude. Several factors act upon species richness patterns and altitude, including resource availability, climate tolerance, and geographic area (Hu et al., 2011). Species diversity and distribution over the Earth is essential for the understanding of regionalisation. The patterns formed along these gradients are governed by factors that explain the delineation of regions.

An ecological approach has been the primary method to explain geographical diversity gradients and species spatial patterns. Ecological hypotheses explain current events and maintenance of current species distribution. Although extensive research is devoted to these hypotheses relevant to species distribution patterns and regionalisation, research into historical and evolutionary hypotheses of geographic diversity, gradients have also gained attention.

Many hypotheses have been put forward, all with substantial evidence supporting them. Some were receiving more attention than others (Mittenbach et al., 2007). However, a few that stood out, and were highlighted by Jansson et al. (2013), include the "evolutionary time hypothesis", the "tropical conservatism hypothesis", the "out-of-the-tropics model" and, the "diversification rate hypothesis". Other authors have discussed these hypotheses under different names (such as Mittenbach et al., 2007).

Two hypotheses highlighted in both these papers include evolutionary and historical approaches. The "evolutionary time hypothesis" suggested the tropics to be older, due to the most recent glacial events having occurred many millions of years ago. Temperate environments are newer than tropical areas; thus, lineages spent more time accumulating and diversifying in tropical environments. This hypothesis is brought forward by Mittenbach et al., 2007, as the "evolutionary hypothesis". Several studies have proven that particular clades have originated in the tropics and have increased taxa (Jansson et al., 2013).

The second hypothesis is the "diversification rate hypothesis" (Jansson et al., 2013), known as the "historical hypothesis" (Mittenbach et al., 2007). This hypothesis suggests high rates of diversification at the tropics, which means there are higher speciation rates coupled with lower extinction rates, leading to faster accumulation of species richness (Rolland et al., 2014). However, in 2015, Dolph Schluter disputed the mismatched diversification rate in the tropics as opposed to temperate latitudes. His findings were quite the opposite, with higher diversification rates found in temperate latitudes (Schluter, 2015). Schluter highlighted the species diversity latitudinal gradient to be the driving force behind the increased temperate diversification rates (Weir & Price, 2011; Schluter, 2016).

2.2.1.3.Biotic Interactions

The climate plays a significant role in shaping a regions vegetative structure, food web and ecosystem (Uhey et al., 2020). Most, if not all, abiotic attributes are governed in some way by climate, directly or indirectly. However, the impact of climate on species distribution does not act alone but acts in unison with other biotic attributes.

Biotic interactions include several processes and events which involve the connections and associations between and within species. Interaction occurs when not only do the geographic rages and niches of populations of species and species as a whole, overlap, but they actually co-occur at fine scales. Mechanisms of interaction include predation, competition, parasitism, and mutualism (Wisz et al., 2012). Biotic interactions can occur within a tropic level or between different tropic levels (Van der Putten et al., 2010).

Mechanisms which are at work within the same trophic level, include competition and resource-species interactions. Predator-prey interactions and mutualism and parasitism are some of the mechanisms that occur across different tropic levels (Tadesse, 2017). The impact of biotic interactions takes on a cascading effect through trophic levels.

The temporal and spatial scale at which these biotic interactions are active is not explored thoroughly (Godsoe et al., 2015), and biotic interactions may, in fact, be of relevance across all scales (Wisz et al., 2012). However, the question again would be how vital these impacts may be at larger regional scales. However, several studies debate the impact of environmental heterogeneity on the effectiveness of biotic interactions (Soberón, 2010). Biotic interactions are not as effective when a region is spatially discontinuous. A heterogeneous space supports more partitioned niches than a homogeneous space; thus, interactions between species can be limited (Yang et al., 2015).

2.2.1.4.Topographic Heterogeneity

Environmental heterogeneity operates simultaneously at large scales and smaller scales. Heterogeneity is classified as abiotic heterogeneity and biotic heterogeneity. Abiotic heterogeneity refers to processes influencing heterogeneity governed by climate and topography, whereas biotic heterogeneity incorporates factors such as the influence of micro-organisms and herbivores on heterogeneity (Tamme et al., 2010).

Topography, being an abiotic factor in environmental heterogeneity, influences major processes, sensitivity to natural disturbances and edaphic conditions for plant species (Kubota et al., 2004). Topography influencing edaphic conditions indirectly affects the distribution and spatial patterns of larger mammal and bird species. Topographically complex regions typically host a higher species richness (Badgley et al., 2017).

Complex topographies create various niches and habitats, thus creating a barrier to species dispersal and isolating populations (Wan et al., 2018). Various factors govern heterogeneity in a habitat; the combination of factors acting on the habitat is dependent on a spatial scale. At larger spatial scales, such as regional or global, heterogeneity is expressed as gradients (Tamme et al., 2010). Some studies have found that approximately 50-70% of the variation in species richness for both plants and animals, can be explained through environmental heterogeneity (Antonelli et al., 2018).

2.2.2. Historical Biogeography

Historical biogeography focuses on evolutionary processes, with longer/ larger time scales, spatial scales, and distribution. The inclusion of species' evolutionary relationships, which contains essential information regarding historical groupings of species and the formation of these groups, is significant in historical biogeography. Many authors have suggested that species which share similar phylogenetic patterns and distribution patterns could have a similar or related biogeographic history (Ronquist & Sanmartín, 2011). Historical biogeography includes phylogenetic relationships in distributional studies (Ye et al., 2019), thus incorporating the evolutionary structure of biodiversity (Daru et al., 2017).

Methods involved in historical biogeography include 'centres of origin' and dispersalism, phylogenetic biogeography, cladistic biogeography, panbiogeography and comparative phylogeography (Morrone & Crisci, 1995, Morrone, 2005). For several years there has been a great divide in historical biogeography, as scientists split between a dispersalist approach or the vicariance approach.

Concepts such as centres of origin, dispersal, and phylogenetic biogeography, fall under the dispersalist approach. In contrast, concepts such as panbiogeography, vicariance, cladistic biogeography and comparative phylogeography make up the vicariance approach (Morrone, 2005). In panbiogeography, generalised tracks represent a species distribution. When two or more generalised track intersect, it forms a node. A node represents an area where two or more species ranges overlap (Morrone, 2006).

2.2.2.1. Dispersalist Approach

Centres of Origin and Dispersal

Traditionally, two broad-scale hypotheses have been proposed for the existence of disjunct distributions: dispersal and vicariance. Charles Darwin and Alfred Wallace described dispersal and a prominent force which alters and influences species distribution (Nathan, 2013). Dispersalism theories commence with centres of origin, with species moving away from these centres, across a static Earth (Sanmartı̀n, 2012). Speciation then results as populations encounter geographic barriers, forming two isolated populations. In this scenario, there is a possibility of allopatric speciation taking place, resulting in new species' development.

Darwin in his "Origin of Species" stated, "*It is obvious that the individuals of the same species… must have proceeded from one spot, where their parents were first produced*" (Heads, 2009). Each species has its centre of origin, from which it migrates outwards, as would individuals of the same species. Darwin explained how species, through long-distance dispersal mechanisms, crossed geographic barriers, thus forming the species distributions and community structures we see today.

After years of deliberation, the theory of dispersal was rejected by many, as scientists viewed the dispersal modes and methods as impractical for certain species distributions. The event of dispersal was dubbed rare and sporadic, thus unquantifiable. Darwin also acknowledged the dispersal abilities of different species as varying; thus, the dispersal theory was seen as insufficient to explain all species' distribution. Scientists who rejected the theory worked on other hypotheses that shifted focus away from the movement of species and shifted towards theories of plate tectonics and continental drift.

Phylogenetic Biogeography

The early 1960s saw the unification of biogeography and genealogical relationships. In 1966, Willi Hennig revolutionised biogeography's then stagnant field as he merged phylogenetic relationships and species distribution. Hennig put forth the Progression rule and Deviation rule, which forms the basis of phylogenetic biogeography (Morrone & Crisci, 1995). The development of these hypotheses saw a paradigm shift in the biogeography community as Darwin's permanentism theories dominated (Ronquist & Sanmartín, 2011).

The integration of phylogenetics and species distribution provided a new outlook on the mechanisms that shape species ranges and ultimately shape biogeographic regions. Although this approach followed Darwin's "centre of origins" and dispersal hypothesis, it was the first approach to incorporate evolutionary histories of species to analyse their geographic distributions (Sanmartín, 2012). Henning proposed two rules, one of which is the deviation rule which implicates that one group in a sister pair will be more apomorphic or deviated from the ancestor (Pearson, 1999).

Hennig's progression rule explains that species that appear similar to its ancestor (original) species will be found closer to its centre of origin. As one moves away from the centre of origin, species appear less similar to their ancestor. Apomorphic species, species with advanced character traits, begin to develop over time (Pearson, 1999).

Phylogenetic systematics used a comparative methodology, incorporating character-based analyses. The results of analyses were presented on a dendrogram called a cladogram. The cladogram represents phylogenetic relationships and historical relationships of species based on morphology and their biogeographic histories (Contreras-Medina & Luna-Vega, 2012).

Many definitions of the cladogram have been proposed over the years: "The cladogram specifies sister-group relationships on the basis of homologies shared at the correct level of inclusiveness (synapomorphies)" (Rieppel, 1988), while others referred to it as a tree-like structure which displays the relative recency of relationships (Schuh & Brower, 2011).

2.2.2.2. Vicariance Biogeography

The vicariance theory coalesced several years from concepts dealing with continental drift, plate tectonics, and phylogenetic systematics. With the rise of theories such as plate tectonics, the dynamics of biogeographic theories shifted. Traditional theories were then questioned and re-evaluated. Vicariance set out to explain disjunct distribution through the fragmentation of historical spaces (Sanmartín, 2003).

One of the earliest acknowledgements of vicariance was made by de Candolle in 1820. In an essay, he stated, "Stations are determined uniquely by physical causes actually in operation, and… habitations are probably determined in part by geological causes that no longer exist today". De Candolle went on to further state, "According to this hypothesis one may easily conceive why plant species that are never found native in a certain area will nevertheless live there if they are introduced" (Nelson 1978). From these remarks, de Candolle highlights a dynamic Earth, which was once different in ancient times. His remarks follow those of Buffon's who tacitly implied the concept of a malleable system (Farber, 1972).

De Candolle (1820) referred to areas of endemism, where he opposed the idea of a single centre of origin with twenty-two distinct biotic regions. Each of these regions stemmed from natural histories unique from each other (Paine, 2011). De Candolle referred to shifting geological processes to explain the species found in the twenty-two regions; this was one of the first acknowledgement of a possible vicariance event (Nelson and Platnick, 1980). His acknowledgement caused a snowball effect of the development of the vicariance theory. The likes of Joseph Hooker, a British botanist, many scientists alluded to speciation events accruing through vicariance.

Darwin's and Wallace's theories of dispersal took over during the late 18th century and early 19th century. The debate between those who favoured the theory of vicariance and those who rejected it was ongoing. The development of biogeography became stagnant as the concept of permanentism prevailed. In the 1960s a new page was turned for biogeography as scientists released theories that will have forever shaped the field of biogeography.

Croizat (1968), the father of panbiogeography, explained that related species occur different continents due to fragmentation of continents, which splits up the geographic ranges of these species (Poynton, 1983). These species do not disperse, but rather, their places of origin become divided. The movement of tectonic plates is responsible for forming geographic barriers, which take the form of mountain ranges, river valleys (Trewick, 2017), and basins (Poynton, 1983). A vicariance perspective of "barriers" differs from that of a dispersalist perspective. Under the vicariance theory, barriers are "factor of fragmentation prior to speciation" contrasting to the dispersalist viewpoint where barriers impact species after origin (Poynton, 1968). The formation of barriers through historical processes promote events of speciation (Schweizer & Liu, 2018).

In dispersal theories, geographic barriers were pre-existing, whereas, in vicariance theory, barriers arose from Earth's movement. When put on a time-dependent framework, from a vicariance viewpoint, the population of species precedes the formation of the barrier. On the contrary, from a dispersalist viewpoint, the formation of the barrier will precede that of species (Paine, 2011). Currently, phylogenetic analyses are performed to determine the time of divergence of a species population and the formation of geographic barriers.

Cladistic biogeography, as proposed by Rosen (1978) originated from a group of concepts, namely, panbiogeography and phylogenetic systematics. This approach made use of Hennig's cladogram and species-area relationships. A cladistic biogeographical analysis involves finding spatial patterns of species relationships in areas of endemism (Cracraft, 1983; Ebach & Morrone, 2005). The first step in this type of analysis is to create an area cladogram, where the terminal species are replaced by the area in which they inhabit. Multiple area-cladograms are examined and crossed reference with possible vicariance events to formulate hypotheses (Contreras-Medina & Luna-Vega, 2012).

Since the rise of vicariance biogeography and its subdivisions of panbiogeography and cladistic, other historical biogeography approaches have come into the limelight, with the latest being comparative phylogeography, which combines the fields of genetics and biogeography. In 1987, John Avise coined the word phylogeography, a concept which integrates genetics and geographic distribution. However, this concept differed from others as it dealt with genetic variations among populations, i.e., intraspecific phylogeography. The discipline aimed to explore the possible historical/ evolutionary processes which were responsible for genetic variation within a population (Hickerson et al., 2010; Gutiérrez-García & Vázquez-Domínguez, 2011).

In his 2000 work, Avise set the foundation of comparative phylogeography. Comparative phylogeography simply tests whether species with a shared or overlapping geographic range, share a common historical path. In its early development, comparative phylogeography tested the possibility of species with shared evolutionary histories resulting in shared intraspecific phylogeographical patterns (Hickerson et al., 2010). This multi-disciplinary approach includes the combination of several hypotheses, representing the biological, ecological, and geographical approaches. Phylogenetic relationships, gene flow, geographic distribution and evolutionary events are included in the many variables collected and analysed for these studies.

The comparison of Bailey's (1998) and Takhtajan's (1986) schemes contrasts historical and ecological approaches. Takhtajan's bioregionalisation scheme is a historical approach; Bailey (1998) is an ecological approach. Takhtajan delineated his floral regions based on endemic species and closely related taxa (Crisci et al., 2006). Bailey delineated his ecoregional schemes based on the similarity of vegetation type and climatic conditions. Bailey's scheme resulted in a finer resolution scheme as opposed to Takhtajan's broad Earth divisions.

The discipline of comparative phylogeography is the prime example of the integration of ecological and historical biogeography. Comparative phylogeography aims to adopt a holistic, integrated analysis of distribution and genetic variation using ecological and historical factors. Ecological biogeography and historical biogeography are not two independent concepts; rather, events may fall under both categories. Instead, these concepts should be viewed on a spectrum, with one end being ecological biogeography and the other end being historical biogeography. (Morrone & Crisci, 1995).

2.3. Conservation Biogeography

The focal point of scientific study has shifted from gaining knowledge for theoretical purposes to understanding practical applications. In most biological disciplines in operation, the current biodiversity crisis that is drastically affecting species called for a change in the main goal to become conservation. Thus, formally known as conservation biology, a discipline emerged integrating economic, social, and environmental aspects with species conservation.

Conservation biology initially focused on single-species strategies. Conservation philosophy, since then, has evolved from primitive efforts to elaborate plans and procedures. In the early 20th century, Whittaker et al. (2005) formally acknowledged the uses of biogeographical principles and analyses to solve conservation problems (Richardson & Whittaker, 2010). The transition has been from single-species conservation strategies to conservation strategies encompassing entire biological regions and hotspots of endemism.

There are several pros and cons to both approaches. Single-species conservation became a popular method of conservation prioritisation. However, there are those who dispute the accuracy of framing entire conservation strategies around a single species, with the intention of protecting interacting species (Seddon & Leech, 2008). Cozzi et al. (2008), stated that "conservation strategies targeting single species focus on habitat patches and possible neglect effects of the surrounding landscape". Therefore, the shift to multi-species initiatives has become the focus of conservation planning. Although it is impossible to save all species, the various types of habitats and ecosystems must be represented (Olson & Dinerstein, 1998).

While actual conservation areas are delimited locally, micro-scale conservation plans are insufficient (Richardson & Whittaker, 2010). Thus, a different approach introduced to conservation planning includes the discipline of biogeography. In 1975 Udvardy stated, "Biological conservation has then two theoretically founded aims, viz. the preservation of members of the biota (individuals, populations, species) and the preservation of functional ecological systems cataloguing both is a biogeographical task; thus, we now focus on biogeography". His statement reflects the aims that are now taken into account in conservation. Morrone (2001) took on an evolutionary approach to conservation biogeography by incorporating a combination of panbiogeography and cladistic biogeography to conservation biogeography. In his approach, a two-step analysis is used to find areas of endemism for conservation purposes.

The dual system approach to conservation uses panbiogeography and cladistic biogeography as complementary methods to each other, rather than a segregated approach (Morrone, 2015). The first part to the dual system approach includes identifying primary biogeographic homology and biotic components. Primary biogeographic homology, or the hypothesis generation stage, refers to the assumption of a common or related biogeographic history between taxa (Morrone, 2008). Biotic components refer to "spatio-temporally integrated sets of taxa that characterise particular biogeographic areas" (Morrone, 2008). These components are historical taxa which share a common history.

Panbiogeography operates in this part of the system. Individual tracks are analysed, areas which contain several individual tracks forms generalised tracks (Arzamendia & Giraudo, 2012). Nodes of intersecting tracks can be used for conservation strategies as these nodes consist of high-level biotic assemblages. However, panbiogeographic analyses are mere conjecture of coherent histories. Stage 2 formalises the hypotheses made in Stage 1. The second stage is legitimacy, which uses cladistic biogeography by analysing area-cladograms to confirm panbiogeographic analysis findings (Morrone, 2001). These approaches lean towards conservation on larger scales rather than single-species strategies and local scales.

2.3.1. The Influence of Anthropogenic Activities on Biodiversity and Conservation

Threats to biodiversity are have shifted from small scale threats to large-scale exterminations which destroy whole ecosystems, leaving the environment and its biodiversity vulnerable. Understanding the extent of anthropogenic impact on the loss of biodiversity is key to acting against it. A study conducted in 2011 resulted in the prediction of approximately 8.74 million species of eukaryotes inhabit the Earth (Mora et al., 2011), of that, predicted 8.74 million, only an approximate 1.2 million species had been formally described over that last 250 years of taxonomic classification.

These statistics give rise to the belief that 86% of terrestrial species on Earth and 91% of aquatic species are yet to be described (Mora et al., 2011). His estimation, the concern of discovering species before they go extinct arises. The use of extinction rates can determine the measure of anthropogenic impact on the Earth by how much it increases species extinction rates (de Vos et al., 2014). Background extinction rates refer to "the standard rate of extinction in the Earth's geological and biological history prior to human interference and contribution to extinction". Background extinction rates are measured in "E/MSY" (Million species years), which mathematically translates to one species extinction for every one million species on Earth, every year (de Vos et al., 2014).

The predictions of current background extinction rates are between 0.1 and 1 species extinction per 10,000 species per 100 years. That is equivalent to 0.1 to 1 species extinction per one million species annually (Ceballos et al., 2015). Thus, with current extinction rate, we are now exceeding the background rate by a factor of 100 to 1000; thus 1000 to 10000 times the background rate of extinction and dozens of species are going extinct every day (Pimm et al., 2014).

Various taxa have different extinction rates. Bird species are predicted to have an extinction rate of approximately 100 E/MSY. If not for conservation efforts, these rates would be up to

150 E/MSY (Pimm et al., 2006). This study predicts extinction rates to reach approximately 1000 E/MSY during the 21st century. However, the continuation of habitat degradation and destruction, such as forest destruction could see the extinction rate rise to 1500 E/MSY (Pimm et al., 2006). The IUCN Red List reported that 13% of the approximately 10,400 living bird species face the reality of extinction.

Ondei et al. (2019), highlighted the two-concept approach, including irreplaceability and vulnerability. Vulnerability refers to the threats which the region faces, these range from land-use related threats to biological threats such as invasive species. Irreplaceability can refer to the level of endemism in a region. The number of endemic species and the uniqueness of habitat can determine the level of irreplaceability (Ondei et al., 2019). Combining these two concepts aid in establishing priority areas which are of high value and most threatened.

Incorporating regionalisation in conservation has become a new direction in conservation planning. As mentioned above, there is a transition to focusing on conservation priorities across whole regions and hotspots rather than single species. Biogeographical patterns such as biodiversity hotspots, environmental gradients, and spatio-ecological patterns play a critical role in bioregionalisation (de Mello et al., 2015). The need to understand the processes and planning behind regionalisation has increased with its importance in conservation planning (Giraudo & Arzamendia, 2017).

2.4. Bioregionalisation

2.4.1. Biogeographical Units

The past decades have seen many innovative ideas of Earth regionalisation, with only a few recognised among the biogeography community. Regional schemes developed based on several hypotheses and theories. From the days of Humboldt to Darlington, regional schemes have been a hot topic of debate. The development of regional schemes often came from previous visions and from the ideas of earlier naturalists and scientists. These schemes were and still are, dependent on the data used.

Regionalisation schemes formed using biogeographical units denote the nature of the regionalisation scheme and form the framework of its creation. Concepts such as vegetation, ecology, climate, spatial scale, and biodiversity type, form biogeographic units (Mucina, 2019). As seen in the foundation stages of regionalisation, different theories contributed to the regionalisation, from Humboldt to Wallace. With a common goal, but using different approaches, these naturalists were able to find regional patterns on scales as small as on a mountain to global scale regionalisation schemes.

Bioregionalisation schemes often adopt a hierarchical approach as subregions are nested within the broader regions. These subregions are delineated based on its own set of concepts—one of the earliest acknowledgements of a hierarchy system in bioregionalisation made by Alfred Wallace. Wallace's regionalisation scheme included six regions and 24 subregions; his subregions were based on "the distribution of more important genera and the materials, both zoological and geographical" (Wallace, 1876).

Morrone, 2015 proposed a regional scheme containing three kingdoms, the Holotropical, including Indo-Malaysian (Oriental), Neotropical and Ethiopian; the Holarctic including the Palearctic and Nearctic region; and the Austal including the Australian, Andean, Cape, and Antarctic regions (Morrone, 2015).

Another broad biogeographical unit would be biogeographical realms, which divides the Earth into eight regions: the Nearctic, Neotropical, Palearctic, Afrotropical, Australian, Indomalayan, Oceanic and Antarctica regions. Large regions were delimited by combining geographical and historical concepts (Udvardy, 1975). Realms introduced during Sclater and Wallace's time, at the time Sclater (1858) scheme divided the Earth into two major divisions. He believed to be centres of creation; these included Creatio Paleogeana and Creatio Neogeana.

Creatio Paleogeana included the western hemisphere regions, the Palearctic, the Western Paleotropical (Ethiopian Region), the Middle Palaeotropical (Indian region) and the Eastern Paleotropical (Australian region). The Neogeana region included the Nearctic and Neotropical regions. In 1868 Huxley, put forward a scheme of two divisions, namely, Arctogea (Africa + Eurasia+ North America) and Notogaea (South America + Australia) (Osborn, 1900). The dispute with this scheme was the grouping of South America and Australia. Although these regions' fauna was different from the regions in the Arctogea region, the fauna that inhabited these regions were also very different (Darlington, 1957).

After much deliberation, Blanford (1890) suggesting separating the South American region and the Australian region. It was then when the term "Realm" was put forward by Lydekker (1896). Zoogeographic regions are held in a similar rank to realms. It is not clear who had initially used the term Zoogeographic Regions; however, many points towards Philip Sclater and Alfred Wallace. Realms or zoogeographic regions and further subdivided into biogeographic provinces (Udvardy, 1975), ecoregions (Olson et al., 2001) and biomes (Clements, 1916).

Udvardy, 1975, described eight realms and biogeographic provinces subdivided into 193 biogeographic provinces. Udvardy described the scheme as "ecosystematic", referring to the relations between fauna, flora, vegetation type, physiography, and ecological climax (Udvardy, 1975). Biogeographic provinces similarly paralleled Dice's 1943 biotic provinces, such a province being described as "continuous geographic area and is characterised by the occurrence of one or more ecologic associations that differ, at least in a proportional area covered from the associations of adjacent provinces" (Dice, 1943).

Each biogeographic province is assigned to one of 14 biomes, which were adapted from Dasmann, 1973. Biomes are large areas delineated based on characteristic vegetation and wildlife assemblages. Frederick Clements was the first to mention the concept "biomes"; however, the concept was refined by many who came after him (Mueller-Dumbois, 1984). The modified concept of a biome is the categorisation of vegetation, animals, and climate. The land is classified based on the prominent land feature and predominant vegetative types (Hanks, 2011).

In 1998, Olson and Dinerstein subdivided biomes into regional-scale biogeographic units called ecoregions. An ecoregion refers to "a relatively large area of land or water containing a characteristic set of natural communities that share a large majority of their species, ecological dynamics, and environmental conditions" (Olson & Dinerstein, 1998). Olson et al., 2001 subdivided the eight biogeographical realms into 867 ecoregions, classified according to the region's biome. The purpose of the delineation of ecoregions was to establish a fine scheme biogeographical unit that incorporated complex distributions and vast cosmopolitan biodiversity distributions (Olson et al., 2001).

2.4.2. Steps of Bioregionalisation

Each bioregionalisation scheme requires a vast amount of background knowledge, a purpose, and a structured framework, to be constructed. An aim or purpose for the regionalisation scheme aids in its delineation (Kreft and Jetz, 2010). The delineation of regionalisation schemes requires a procedure to ensure the accuracy of the regions. Bioregionalisation steps involve understanding the temporal and physical scale of the regions, the taxon classification, and clustering methods.

2.4.2.1. Spatial Scale and Resolution

The purpose of understanding the Earth's spatial and distributional biodiversity patterns, called for the need for global scale schemes, as large-scale climatic patterns influence species distributions. As mentioned above, the spatial scale of a regionalisation scheme depends on the purpose of the scheme. A local study will require a small study area. In comparison, large scale studies require regional or global regional schemes. Global and regional scale schemes prevailed in past studies, as Sclater, Wallace, Darlington, presented global scale schemes. Species spatial patterns, such as environmental gradients, are only evident globally (Hillebrand, 2004).

One of Alfred Wallace's regionalisation scheme criteria was that the regions follow similar geographic patterns as the natural divisions of the Earth, with a similar size (Rueda et al., 2010). In recent studies, the purpose of global-scale regionalisation schemes mainly has been for global conservation plans, as many large-scale organisations partnered with biogeographers to delineate broad regionalisation schemes that serve the purpose of understanding as an application in conservation. One example is, Olson et al.'s (2001) Terrestrial ecoregions of the World, where similar size is still of relevance.

Modern regionalisation schemes on smaller spatial scales are delineated for specific countries for national plans. An example would be Australia, as a country developed bioregional planning for biodiversity protection on a national scale (Craig, 1996). An Interim Biogeographical Regionalisation of Australia developed to support the national movement towards ecological sustainability. The regional scheme developed with the intention to prioritise protected areas for biodiversity conservation planning (Thackway & Cresswell, 1995).

As spatial scales of regionalisation schemes may differ based on the schemes' purpose, so too may the resolution of the schemes differ. A coarse resolution of a bioregionalisation scheme lacks detail, as complex species distributions are overlooked. Schemes such as biomes and biogeographic realms are considered coarse-scale schemes, as the Earth is divided into broad regions. An example of edaphic conditions may cause forest patches within a savanna or grassland biome (Mucina, 2019), while the rainforest biomes in the South American Amazon region may contain patches of savannas (Olson et al., 2001).

Shifts to finer resolution schemes arose when conservation planning merged with bioregionalisation. A need for complex distributions, unique assemblages, distinct vegetative, climatic, and biotic relationships, were required (Olson & Dinerstein, 2002). Compared to the Udvardy's 1975 biotic province scheme, the difference in resolution is evident, as, biotic provinces included 117 provinces in the tropics, while there was a total of 463 in the tropic's terrestrial ecoregions (Olson et al., 2001) presented in the terrestrial ecoregions of the World scheme (Olson & Dinerstein, 2002).

2.4.2.2. Identifying Significant Areas

Bioregionalisation includes three types of significant areas: biogeographical units, centres of endemism, and endemism. Biogeographical units, as mentioned above, form an all-inclusive hierarchy system, that is, any given point on land, anywhere on Earth, belongs to one such unit. There are several types of biogeographical units classified according to spatial scale and resolution. The second type, centres of endemism, has seen a rise in popularity in recent research. Centres of endemism refer to areas with a high concentration of endemic species but are also common in the area. However, areas of endemism are areas with two or more congruent endemic species (Casagranda & de Grosso, 2013).

Determining areas that are significant in terms of faunal and floristic composition and climatic conditions is vital in delineating regions. Positioning a border around an area and describing it as a region needs accurate calculations to determine that area unique from adjacent areas. Quantitative techniques accurately find areas with unique species distributions, climate, and vegetation, which is widely used in clustering analysis.

Cluster analyses is a grouping technique, as objects are groups into respective categories based on similarity indices (Kreft & Jetz, 2010). There are two main types of clustering analyses, non-hierarchical and hierarchical clustering methods. Under each of these are several methods. A non-hierarchical method requires a *priori* of the number of clusters. It is known to produce discrete results (Kreft & Jetz, 2010). A hierarchical method clusters groups in a hierarchy suitable for biogeographical regions as it forms a hierarchy.

Hierarchical clustering analysis comprises two categories, agglomerative clustering algorithms and divisive algorithms where agglomerative clustering refers to method take on a bottom-up approach. Objects (in regionalisation, operational geographical units) form clusters and are grouped based on similarity (Kaufman & Roussew, 1990). Divisive hierarchical algorithms adopt a top-down approach, where at the beginning of the analysis, objects placed into one cluster and separated into specific clusters (Kreft & Jetz, 2010).

Identifying areas of endemism has become a practical approach to bioregionalisation and the identification of conservation priorities. Delineating a region with an accurate representation of its species assemblages, climate, and vegetation requires non-random data. The goal is to locate areas of endemism within the hierarchy of regions. The use of centres of endemism in bioregionalisation has become a foundation phase to delineating regions. The use of endemic species allows for a better representation of a region's history and evolution. Thus, centres of endemism will be the core of a region delimited using endemic species.

A method introduced recently, the Parsimony Analysis of Endemism (PAE). The PAE deals with presence and absence data, which is labelled non-random. A parsimony analysis assumes that a phenomenon's most basic explanation or hypothesis should be accepted (Siddall, 2002). The resultant feature of a parsimony analysis of endemicity is a cladogram (Morrone, 2014). Same as in phylogenetics, the shortest tree is generally accepted (Kannen & Wheeler, 2012).

This analysis highlights significant historical relationships (Kreft & Jetz, 2010) and meaningful relationships between species assemblages. A PAE aims to locate areas of endemism. Areas of endemism have become an effective approach in the delineation of regions. Realms contain small regions, identifying areas of endemism within these regions accurately for conservation purposes (Morrone, 2014).

2.4.2.3. Identifying Transitional Zones

Transitions zones refer to areas at the boundaries of biogeographical regions which share biota. These are areas of overlap. Transition zones occur due to the historical and ecological processes of biogeographic regions which result in blurred boundaries (Ficetola et al., 2014). Morrone defined the area as a zone of the mixture due to historical and ecological change, causing biota mixing from both biogeographical regions (Morrone, 2006).

Darlington referred to transition zones as complex concepts. Research on transition zones has been limited, with no real extensive studies until recently. Some of these zones are species-rich, while others are lacking in diversity. However, a transition zone is a natural phenomenon as it forms an area of constraint and agglomeration. Biota from different regions is found here; however, various factors keep the biota from further infiltrating the opposing biogeographical region (Ferro & Morrone, 2014).

Transition zones can vary in size, in terms of width and length. Various aspects contribute to the broadness pr narrowness of a transition zone or how much it infiltrates into a region's boundary. Transition zones contain biotic gradients of change, as there is a gradual change in species composition (Ferro and Morrone, 2014). In a panbiogeographic approach, a transition zone can be identified using nodes (Morrone, 2006).

Peters et al. (2006) highlighted the term "biotic transition" which they had defined as an area inclusive of the boundary and adjacent areas of two regions, consisting of patches with uniquely arranged species assemblages and climate conditions. A transition zone can overlap biotic fauna and flora, ecosystems, biomes, and climate. A related concept, an "ecotone", mentioned elsewhere, is defined as a transition zone of vegetation (Allen & Starr, 1982), ecological systems and ecosystems (Odum, 1971).

Transition zones are subject to the edge effect, which refers to a high species diversity ecotones/ transitions zone. This phenomenon is due to the overlap of species distribution at transitions zones, thus creating a higher species diversity (Riesch et al., 2018). Due to this, several scientists find it necessary to treat transition zones as discrete regions (De Mendonca & Ebach, 2020).

Identifying transition zones is critical in the bioregionalisation process, as these zones comprise unique species assemblages and thus may require specific conservation action. In marine biogeography, transition zones are conservation priorities (Golla et al., 2020). These areas are significant in evolutionary and geological studies to understand and analyse historical events that have shaped these zones (De Mendonca & Ebach, 2020). The Wallacean region is an example of this, it once was classified as a transition zone, but many biogeographers find it to be a primary region (De Mendonca & Ebach, 2020).

2.5. Modern Movements in Bioregionalisation

2.5.1. The International Code of Area Nomenclature

A shift in the purpose of bioregionalisation has brought about innovation and invention in the field. Along with this shift has come the need for accuracy and efficiency. One such innovation is the ICAN, International Code of Area Nomenclature, a classification and naming system for endemism regions and areas of endemism. An accurate naming system was needed to bring about order in the biogeography field. The ICAN created a standard system for naming regions to avoid conflicts experienced in bioregionalisation.

As research in bioregionalisation increased, so too was there an increase in related conflict. These conflicts included redundancy, a lack of order and confusion. One name can have a different meaning to different researchers; thus, there is a need for standardisation. Thus, each study is required to redefine its study area to indicate what regions are included. Ebach et al. (2008), used the term the Mediterranean as an example. Different studies were discussed, highlighting how each of these studies had a different view of which areas make up the Mediterranean region. A few examples highlighted in this paper included Zotier et al., (1999), who referred to the Mediterranean in the context of the Sea of Azov and the Black Sea.

Another example is from Sanmartin, 2003 who described the Mediterranean region, to include "North Africa, the western Mediterranean, Balkans–Anatolia, Middle East, Caucasus, the Iranian Plateau, and Central Asia". Another example includes the supercontinent Gondwana. Two research pieces presented by Philippe et al., 2003 and Barker et al., 2007 illustrate ambiguity in classification in this case. Gondwana Included regions: Australia, New Guinea, New Zealand, sub-Saharan Africa, Madagascar, India, Arabia, South America, and Antarctica. However, Barker et al., 2007 did not include India (Ebach et al., 2008).

Ambiguities in the naming system do occur, thus the need for a naming system. Rules of the ICAN included ranking regions, availability of names and the rejection of names. The ranking system includes the following ranks: district, province, dominion, region, and realm. Smaller ranked regions may be groups under lager rank regions. The ICAN states that a region must be ranked in order to receive a name. A name can get rejected if there is an existing name (Ebach et al., 2008). Up to this point, however, the ICAN has not been widely employed.

2.6. The Evolution of Bioregionalisation Schemata

Several bioregionalisation schemes have been proposed as the discipline evolved. New bioregionalisation schemes came as either newly developed schemes or an improvement or changes to existing schemes. One of the very first significant regionalisation schemes was made by Fabricius, 1778. He divided the Earth into eight regions namely, Indian (The tropics of the Old and New World), Egyptian, Southern, Mediterranean (Countries adjacent to the Mediterranean and part of Asia Minor), Northern (Northern regions of Europe), Oriental (Coldest region in the North), Occidental (North America, Japan, and China) and the Alpine region (Mountains containing snow) (Swainson, 1835).

Fabricius' divisions, however, were based on climate and limited to the insect World. Naturalists of the time ruled Fabricius' scheme as vague and lacking background information and subjection. One such naturalist was Latreille who stated Fabricius' divisions to be arbitrary. However, Latreille’s own regional scheme followed a similar concept to that of Fabricius, as he divided the Earth in terms of its climate, creating climatic regions such as polar and subpolar few (Swainson, 1835). Each climatic region has had a latitudinal span of 12 degrees and a longitudinal one of 24 degrees.

In 1826, James Prichard was one of the first naturalists to delineate regions based on the distributions of larger animals (Ebach, 2015). There were six regions in total, namely the Arctic regions of the New and the Old World, the temperate, the equatorial or tropical, the Indian Ocean Islands (Indo-Malay Archipelago), the islands of New Guinea New Britain and New Ireland and those more remote in the Ocean, Australia and the southern extremities of America and Africa (Swainson, 1835).

After that, several naturalists proposed regionalisation schemes, based on various aspects such as acclimate, vegetation and animal distributions, but, in 1858 Sclater proposed a bioregionalisation scheme which revolutionised the field of biogeography (Figure 2.2). Sclater was a believer in centres or creations. His divisions formed a hierarchy system, with two significant divisions separating the Old World and the New World, i.e., the Creatio Palaeogeana and the Creatio Neogeana.

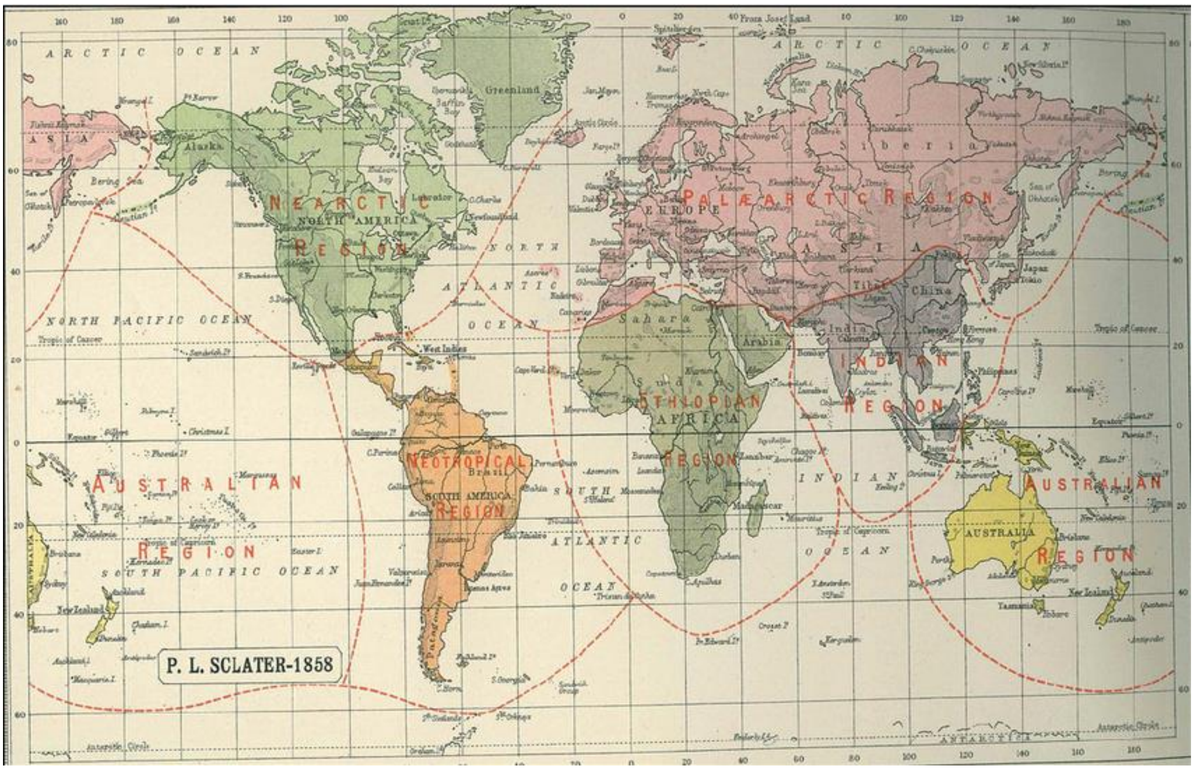


Figure 2.2: Zoogeographic divisions of the Earth by Philip Sclater, 1858 (Greer, 2013).

The Creatio Paleogeana regions comprised of regions: Palearctic region, which consists of temperate Europe and Asia, north of the Atlas Mountains and the northern part of Algeria and Morocco in Africa, Western Paleotropical/ Ethiopian, which consists of Africa excluding the northern part and southern Arabia, Middle Paleotropical/Indian region, which consists of tropical Asia and surrounding islands and Eastern Palaeotropical/ Australian, consisting of New Guinea, Australia and Tasmania. The Creatio Neogeana region comprised of regions: Nearctic/ North America region which consisted of North America, south to central Mexico, which Greenland, Neotropical/South American region which consists of South and Central America and southern Mexico.

Sclater proposed centres of creation from which species dispersed outwards. Species that originated from the same creation centre will possess the same attributes (Greer, 2013). Sclater's bioregionalisation scheme focused on birds. In 1868, Huxley disputed Sclater's divisions, as he suggested another scheme. Huxley (1868) grouped four major regions, Europe, Asia, Africa, and North America, calling it Arctogea. He also grouped South America and Australia, calling it Notogea (Darlington, 1957).

Huxley supported his scheme by comparing the species distribution in each region. Huxley found similar species in South America and Australia which were noticeably different from the Arctogea region. However, this scheme fails to consider the complex distributions in the Arctogea, as it groups the major regions into one. In 1876 Wallace developed a bioregionalisation scheme that combined the ideas of both Sclater and Huxley (Wallace, 1876). Wallace's faunal regions were six, namely the Palearctic, Nearctic, Neotropical, Ethiopian, Australian and Oriental (Figure 2.3).

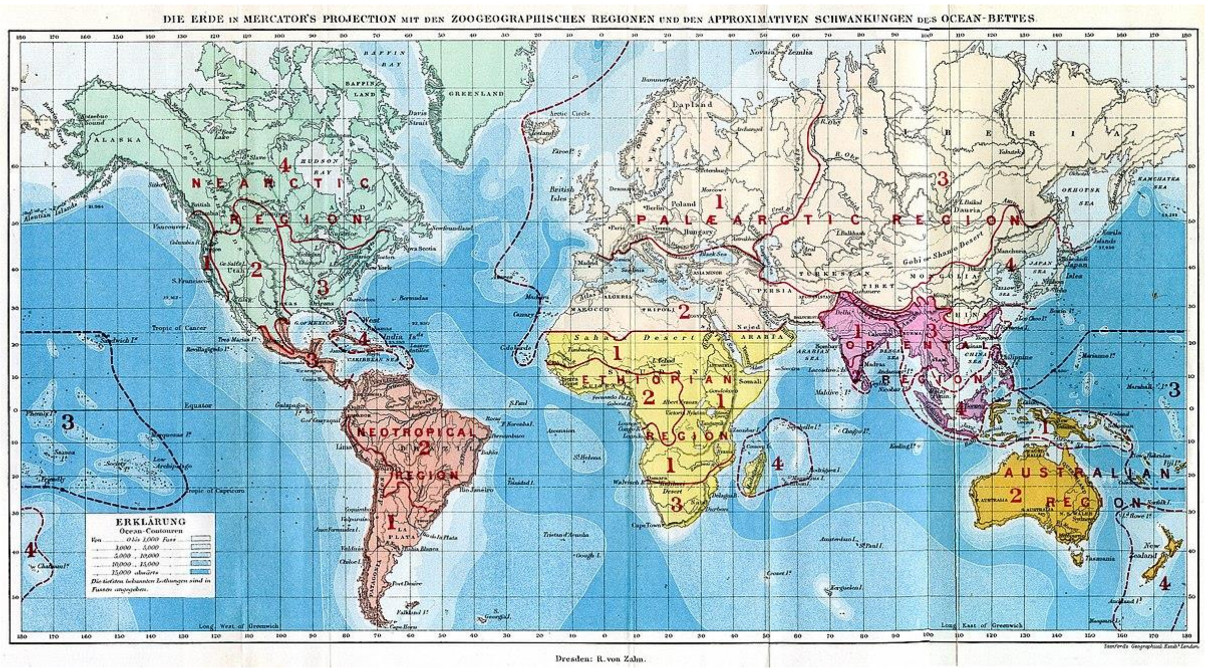


Figure 2.3: Zoogeographic regions delineated by Wallace, 1876 (Source: https://commons.wikimedia.org/wiki/File:Wallace03.jpg).

Wallace made an extension to Sclater's scheme, by including all types of mammals; however, he focused on non-volant mammals. Wallace based his scheme on similarities at the level of families and genera. Thus, he debated pronouncing the Arctic as a primary region, as there are no species classified as "Arctic" (Wallace, 1876). Wallace further divided the six regions into 24 subregions. Wallace's bioregionalisation scheme incorporated some quantitative information, although it was not analysed as it would currently be.

Subsequent to Wallace's scheme, several naturalists made minor changes to the framework of bioregionalisation. In 1890, Blandford suggested three major Earth divisions as opposed to Huxley's two divisions. Blandford debated that even though South America and Australia display a similar species composition from those of the Arctogea regions, South America and Australia are not particularly similar. For this reason, he proposed splitting South America and Australia into individual primary regions, which later were classified as Neogea and Notogea, respectively.

Darlington proposed a bioregionalisation scheme that included aspects of previous schemes (Darlington, 1957); however, minor changes were made. One of Darlington's significant changes was changing the name of the previously known Arctogea, to Megagea (Darlington 1957). Darlington stated that the name Arctogea was inappropriate as the main part of the Old World fell under this region (Müller, 1974). Darlington delineated regions based on the distinctness of each region, and he highlighted the reason behind each region's uniqueness.

The Palearctic and Nearctic regions are climate-limited regions, which attributes to their distinctiveness. The Neotropical and Australian have been isolated via an ocean barrier, thus having unique faunas (Cox, 2001). The Ethiopian and Oriental regions are part of the Old World; this could be mainly the result of dispersal (Darlington, 1957). Compared to Sclater and Wallace, Darlington's regions appear similar; however, the science behind it differs.

The 20th century experienced several breakthroughs in bioregionalisation. 1947 Holdridge, presented a scheme called "Life Zones", whereby he found a need for basic natural units for research (Parry et al., 1988). A natural unit should be one of association; however, the association should be the unique combination of interrelationships among vegetation, biotic activities, climate, ecological physiography, soil, and geological formation (Holdridge, 1967). Holdridge aimed to achieve a discrete regionalisation scheme assuming that specific vegetation required specific climatic and edaphic conditions (Parry et al., 1988).

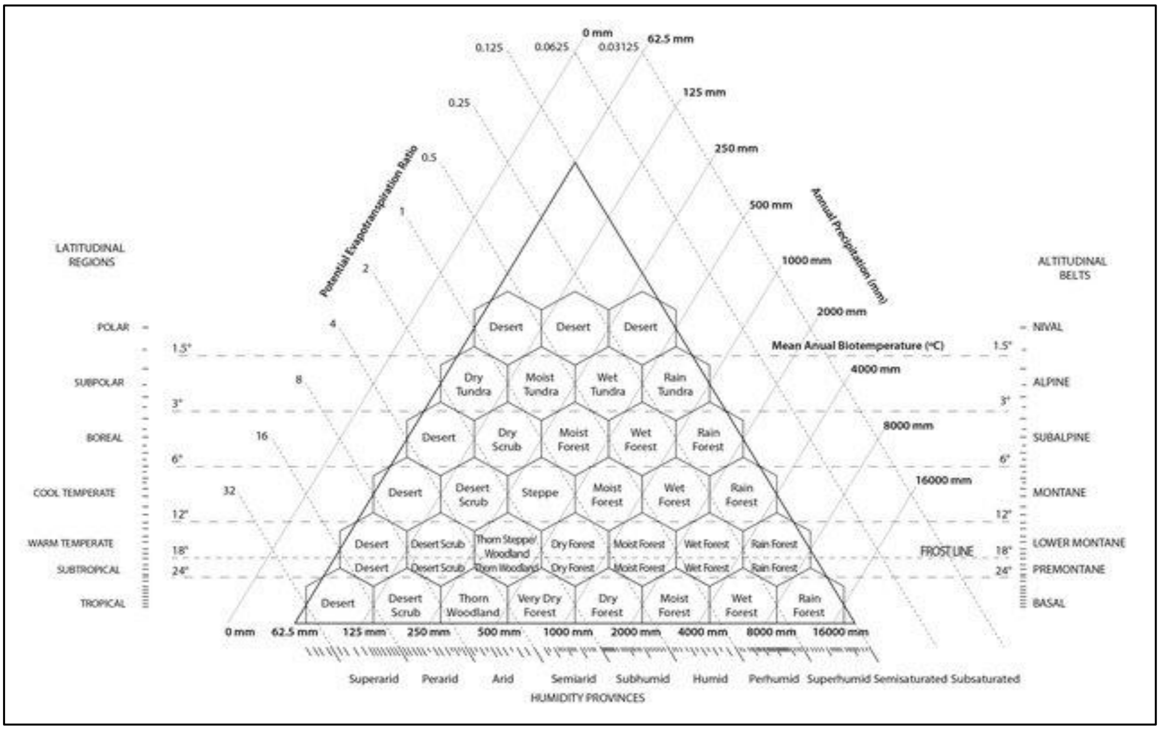


Figure 2.4: Life Zones delineated by Holdridge, 1975 (Derguy et al., 2019).

These life zones were essentially determined by two factors, precipitation and biotemperature. The third factor is potential evaporation (as stated by Holdridge, 'moisture'), calculated from precipitation and temperature (Figure 2.4). Holdridge presented a tri-axial diagram with precipitation, evapotranspiration and humidly on each axis of these factors on an axis (Parry et al., 1988). He divided the Earth into seven latitudinal regions and six altitudinal belts. Within the diagram, hexagons represent the vegetation types. The life zone diagrams prove that

Holdridge assumed that precipitation and biotemperature have a linear relationship (Parry et al., 1988).

Not long thereafter, Whittaker (1970), developed a scheme of his own adopting similar principles to that of Holdridge. Whittaker's biome-type scheme is a two-dimensional system that considers two factors, annual precipitation, and annual temperature. Whittaker's biome types take on a much more simplistic approach when compared to Holdridge's life zones. Whittaker defined 21 biome types (Ward et al., 2003), he also classified nine main biomes: Tropical Rainforest, Tropical Seasonal Forest, Temperate rainforest, Temperature Deciduous Forest, Tropical Savanna, Temperate grasslands & Temperate Desert, Taiga, Tundra and Subtropical Desert. Whittaker's biome types were delineated based on biotic community structure and its response to precipitation and temperature (Whittaker, 1975).

In 1943, Dice described nine biotic provinces based on vegetation structure, climate, ecological complex, and biotic interactions. Dice, however, delineated these biotic provinces for North and Central America only. Dice based his delineation on dissimilarity, by the occurrence of biotic relationships in one region that may differ from relationships in adjacent regions (Udvardy, 1975). In 1975, Udvardy described a system of biogeographic provinces similar to that of Dice. There are 193 provinces in total, classified into 14 biomes. Udvardy stated that biogeographical provinces should strictly be delineated based on a faunal, floral, and ecological basis.

He had shared Dasmann's (1974) views, as he suggested using faunal and floral difference when diving a biome and using differences in vegetation structure to divide areas with even biotic distribution. Udvardy developed a coding system to identify provinces. Biogeographical provinces located in one of the eight biogeographical realms is classified according to the area's major biome. Biogeographical realms were assigned numbers (1 to 8), biomes were assigned numbers (1 to 14), and provinces were assigned numbers in each realm. The code formation was realm.province.biome.

In 2001, Olson et al. described a bioregionalisation scheme that was going to play a significant role in conservation. The scheme became known as the Terrestrial Ecoregions of the World (TEOW, Figure 2.5). Olson et al. defined ecoregions as "relatively large units of land containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change". The TEOW was delineated based on unique biodiversity and representative ecological communities. Compared to other schemes, ecoregions focus on endemic species, whereas Holdridge and Bailey's schemes ignore these. These bioregionalisation schemes fail to highlight the significance of endemic species, representative genera, and unique community compositions.

Olson et al. (2001) proposed the ecoregion scheme as an alternative to biogeographic provinces. The Terrestrial Ecoregions of the World were delineated on a finer scale compared to Udvardy's (1975) biogeographic provinces, thus making the TEOW more suitable for conservation planning. The bioregionalisation scheme was built from previous delineations to form an integrated, well established, and representative scheme.

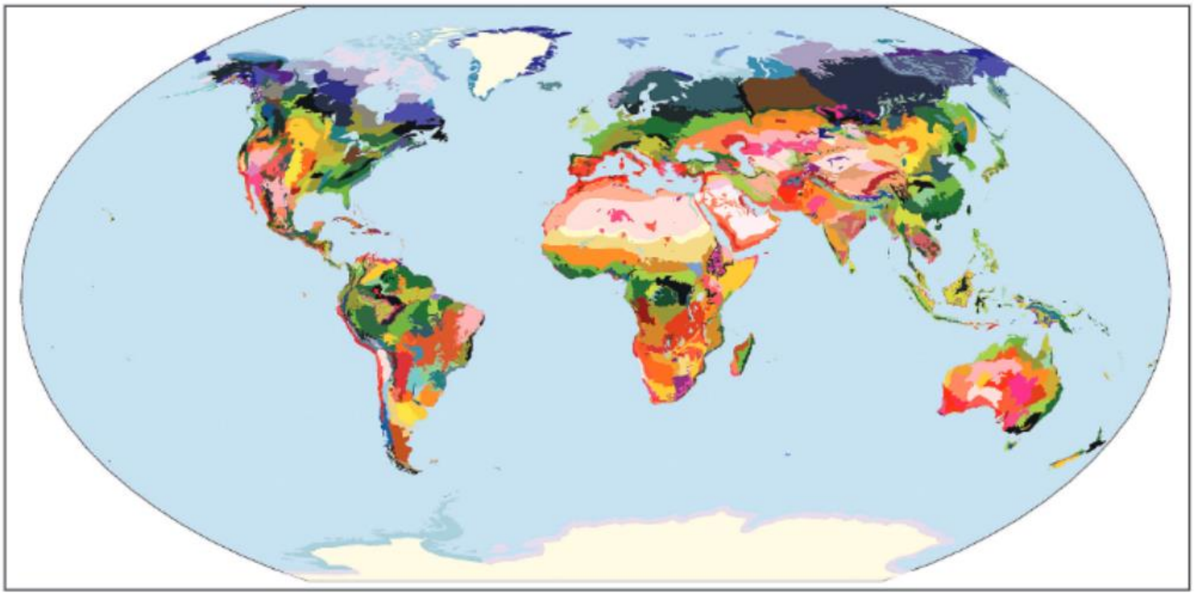


Figure 2.5: Terrestrial Ecoregions of the World (Olson et al., 2001).

In recent studies, scientists have aimed to update or improve Sclater's and Wallace's zoogeographic regional scheme. This notion comes with the advancements in scientific knowledge and understanding, such as fossil evidence and phylogenetic information. It is evident that Sclater based his schemes on gathered knowledge, but Wallace used this and built upon it using knowledge of species compositions and past relationships (Darlington, 1957); however, it lacked quantitative analyses.

In 2012, Procheş and Ramdhani set out to confirm Wallace's zoogeographic regions using cluster analyses (Figure 2.6). Clusters of ecoregional similarities were obtained for four vertebrate groups, and congruent clusters found in all the analyses were marked as zoogeographic regions. These regions included the Palearctic, Nearctic, Neotropical, Caribbean, Arctic, Andean, Afrotropical, Madagascan, Wallacean, Australian, New Guinean, Indo-Malaysian, Polynesian, and Antarctic (Procheş & Ramdhani, 2012). Compared to the original bioregionalisation scheme of Wallace 1876, regions categorised by Wallace as subregions are now primary regions, i.e., Polynesia and Indo-Malay.

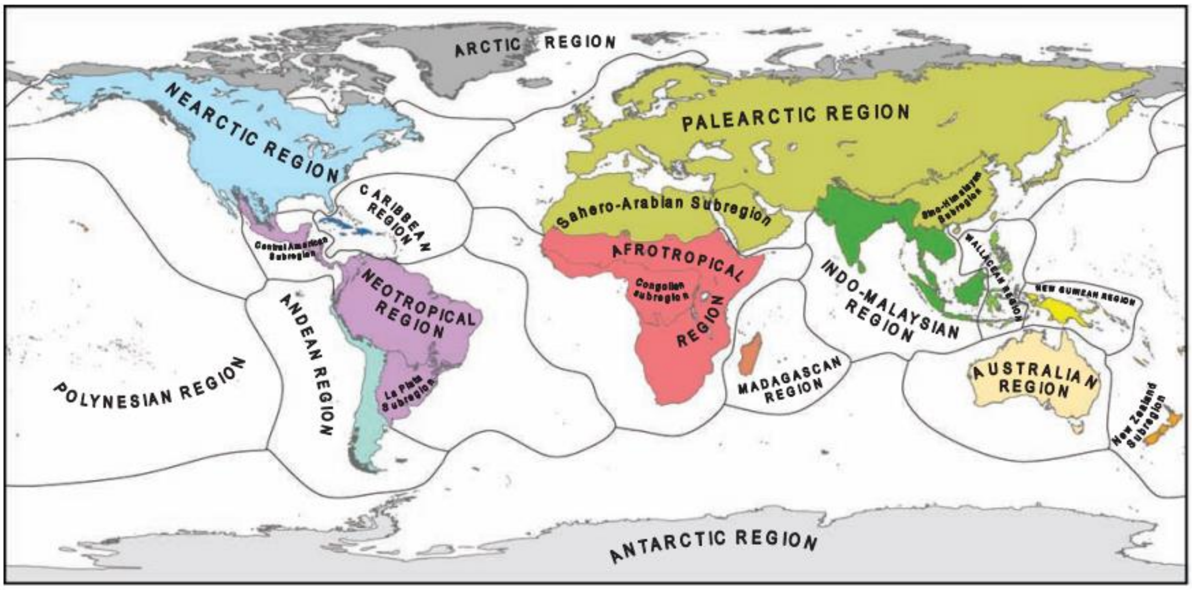


Figure 2.6: *Zoogeographical regions delineated by Procheş and Ramdhani, 2012.*

Holt et al. (2013) aimed to improve Wallace's zoogeographic regions using phylogenetic information and global distribution data for three vertebrate groups (amphibians, non-pelagic birds, and non-marine mammals). The study aimed to quantify phylogenetic uniqueness and delineating regions. A Pairwise phylogenetic beta diversity metric was used to find 11 realms; within it, 20 regions (Holt et al., 2013). The 11 main realms include Oceanian, Panamanian, Nearctic, Neotropical, Palearctic, Saharo-Arabian, Afrotropical, Madagascan, Sino-Japanese, Oriental, and Australian (Figure 2.7).

One of the main differences found between Holt et al. (2013) and Wallace (1876), is the Palearctic region's boundaries. The more recent map shows the Palearctic regions extending across to the polar regions in the map's western part, as arctic biotas are primarily of Palearctic descent. In Wallace (1876), the Palearctic region was restricted to the Eastern Hemisphere. The Saharo-Arabian and Sino- Japanese regions are recognised as realms; these are not present in Wallace's 1876 scheme.

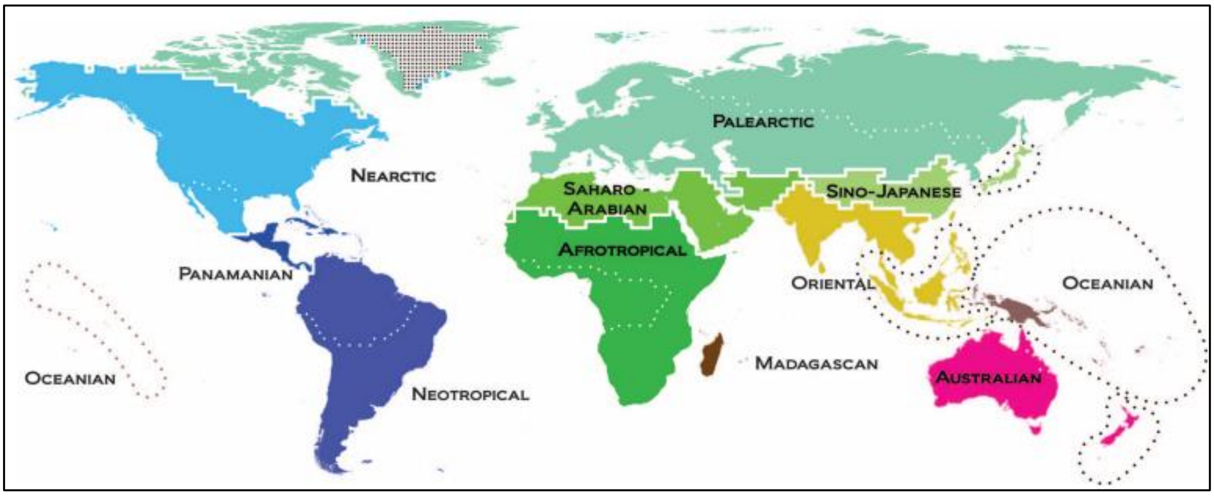


Figure 2.7: Zoogeographic Regions delineated by Holt et al., 2013.

Wallace and Sclater provided a foundation for new bioregionalisation schemes; however, their system is still used to date. Improvements and analyses will be made as new scientific breakthroughs occur, as with any bioregionalisation scheme—the purpose of bioregionalisation shifts with the shifting in the current circumstance. Accordingly, so will the methods, approaches and variables shift as well.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Data Collection and Preparation

Tetrapod genera, distributed across the Zoogeographic Regions of the World, were analysed to calculate regional representativeness hotspots. The Zoogeographic Regions confirmed by Procheş and Ramdhani (2012) were used as the major zoogeographic units, whereby characteristic genera were defined (Figure 2.6). The Terrestrial Ecoregions of the World described by Olson et al. (2001) were used as operational geographical units within the former (Figure 2.5).

The data for this study was obtained from WildFinder dataset (World Wildlife Fund, 2006). This data set included presence-absence data for species in the Terrestrial Ecoregions of the World (Olson et al., 2001), and was subsequently summarised at the genus level. Thus, the data set included presences and absences of genera in the Terrestrial Ecoregions of the World. The secondarily processed data set included representative genera calculated for each Zoogeographic Region, using the presence-absence data, as in Procheş and Ramdhani (2012).

Representative genera were calculated using ecoregional presences for major Zoogeographic Regions. These included: Nearctic, Neotropical, Afrotropical, Palearctic, Madagascan, Australian, New Guinean, Wallacean, Polynesian, Caribbean, Arctic, Antarctic, Andean, and Indo-Malayan regions. These Zoogeographic Regions were then merged, representative genera for the combined zoogeographic region were then calculated. Representative genera for each region were calculated using genera endemicity and regional filling (Procheş & Ramdhani, 2012), using the formula.

$$Measure\ of\ Occupancy\ \times Measure\ of\ Endemicity$$

$$\text{Measure of Occupancy} = \frac{Number\ of\ ecoregions\ occuplied\ in\ X\ Zoogeographic\ Region}{Total\ number\ of\ ecoregions\ in\ X\ Zoogeographic\ Region}$$

$$\text{Measure of Endemicity} = \frac{Number\ of\ ecoregions\ occupied\ in\ X\ Zoogeographic\ Region}{Total\ number\ of\ ecoregions\ occupied}$$

Regional filling of genera for each Zoogeographic Region was calculated by dividing the number of ecoregions occupied by a genus in a Zoogeographic Region, by the total number of ecoregions in that Zoogeographic Regions. Simply put, the number of occupied ecoregions in "x" Zoogeographic Region divided by the total number of ecoregions in "x" Zoogeographic Region. An example would be finding the regional filling of *Glossophaga* in the Neotropical region, the total number of occupied ecoregions in the neotropical region is 123 (out of a total of 136 ecoregions) is divided by the total number of ecoregions in the Neotropical region is 124, resulting in a regional filling value of 0.99. Thus, the genus occupies 99% of the Neotropical region.

The measure of endemicity of a genus in a particular Zoogeographic Region was calculated using the number of ecoregions occupied in a specific Zoogeographic Region divided by the total number of ecoregions occupied by that genus. Thus, the number of occupied ecoregions in "x" Zoogeographic Region, divided by the total ecoregions in the World, occupied by the genus. The endemicity of *Glossophaga* in the Neotropical Region would be, occupied regions in the Neotropical Region –123, divided by total occupied ecoregions in the World –136, resulting in 0.9 level of endemicity. *Glossophaga* is, therefore, 90% endemic to the Neotropical Zoogeographic Region.

A product of the match was then calculated by multiplying the endemicity value and the regional fill value. This is done to test if a genus simultaneously fills a region and has a high endemicity. The representativeness of genus *Glossophaga* would be calculated as its regional filling, 0.99 multiplied by the measure of endemicity, 0.9, resulting in a product match of 0.89

Genera with high product match values were considered representative. A baseline value of 0.5 was used in this study to decipher between representative genera and non-representative genera. Genera with a product match of 0.5 and above were considered representative. Once the product match values for each genus in the respective Zoogeographic Regions were calculated, genera were ranked according to the product match values.

3.2. Region and Combined Regions Selection

Combined zoogeographic regions were formed by merging Zoogeographic Regions in various combinations, and regions were merged according to their evolutionary histories and geographical positions on Earth. Highlighted Zoogeographic Regions of the study included those with questionable boundary limits; these may include the Palearctic and Nearctic. The boundaries of zoogeographic regions are highly subjective (Ficetola et al., 2017). The southern limit of the Nearctic region has come into question as there are no physical/visible boundaries which indicate a separation (Ficetola et al., 2017). Thus, regional representativeness hotspots were calculated for the combination of the Nearctic and Neotropical region, to find a correlation of representative genera in both regions.

Holt et al. (2013), highlighted the extension of the Palearctic region across the Nearctic arctic region, noting the discrepancies of the Palearctic boundary. The limits between the Palearctic region and the Indo-Malaysian region have also come into question as physical features make it difficult to demarcate boundaries (Chen et al., 2008). Mountain chains created by the collision of tectonic plates have blurred the delimitation of boundaries (Ficetola et al., 2017). The Palearctic region was, therefore, combined with the region including Indo-Malaysian and Afrotropical to find hotspot patterns which may result in these otherwise separated regions.

Combinations including Australia and New Guinea were chosen to analyse the correlation of these regions with surrounding islands as well as highlighting their Gondwanan history (Sanmartín, 2012). Combinations including smaller isolated regions such as Madagascar and the Caribbean were selected to analyse the relationship between these regions and mainland regions and the influence on regional representativeness hotspots. The Wallacean Region was selected as there have been several debates with regards to the status of the area. Some studies recognize Wallacea as a transition zone, and some recognize it as primary Zoogeographic Region.

3.3. Regional Representativeness Hotspots for Combined Zoogeographic Region

The data for the combined zoogeographic region were combined accordingly, and representative genera were calculated and ranked, following the above-mentioned calculations. Once ranked, genera with a product match of 0.5 and above were listed for each region. The total number of representative genera in each ecoregion (for each region) was calculated for the original and combined zoogeographic regions. An Excel spreadsheet for each region was created, containing ‘Ecoregion Code’, Ecoregions Name’ and Number of representative genera.

3.4. Data Analyses and Visualisation

ArcGIS version 10.6 (Esri Inc, 2017) was used for the analyses and visualisation of the data of representative genera. Two types of maps were created in ArcMap, the first displaying the number of representative genera in each ecoregion for the various combined zoogeographic regions, and the second as the result of a hotspot/cold spot analysis being performed using the number of representative genera in ecoregions for the combined zoogeographic regions (see below).

A shapefile of the terrestrial ecoregions of the World was attained from the World Wildlife Fund resources (*https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world*). This shapefile was then projected into ArcMap using the 'project' tool. The output coordinate system selected for the projection was the WGS 1984 World Mercator. Thereafter, using the 'Excel to Table' tool, the MS Excel spreadsheet was added to ArcMap. The resulting table was then joined to the projected shapefile via the common field 'Ecoregion-Code'.

The distribution map was created by manipulating the symbology of the shapefile-table join layer. The 'quantities' option was selected, which was used to symbolize numeric data with a graduated colour scale. Once the field value was selected at 'Number of genera', classification was done. Ten classes were chosen; thus, producing ranges for the number of representative genera, the sample size was changed to 1 000 000 so that all records were reflected on the map. Distribution maps of representative genera of all combined zoogeographic regions and Zoogeographic Region were created.

A hotspot analysis was then carried out for combined zoogeographic regions and Zoogeographic Regions. The Terrestrial Ecoregions of the World shapefile was projected and joined to an Excel spreadsheet created, containing the number of representative genera in for ecoregion, of that combined zoogeographic region or Zoogeographic Region.

The 'Optimized Hot Spot Analysis' tool, with the analysis field selected as 'number of genera', was used to carry out the hotspot analysis for each region. The optimized hotspot analysis identifies areas of statistically significant hot spots and cold spots of the incident (number of representative genera) data (Pimpler, 2017). On the optimized hotspot analysis window, the input feature was selected as the second ecoregion-table join layer, and 'Number of genera' field was selected as the 'Analysis field'.

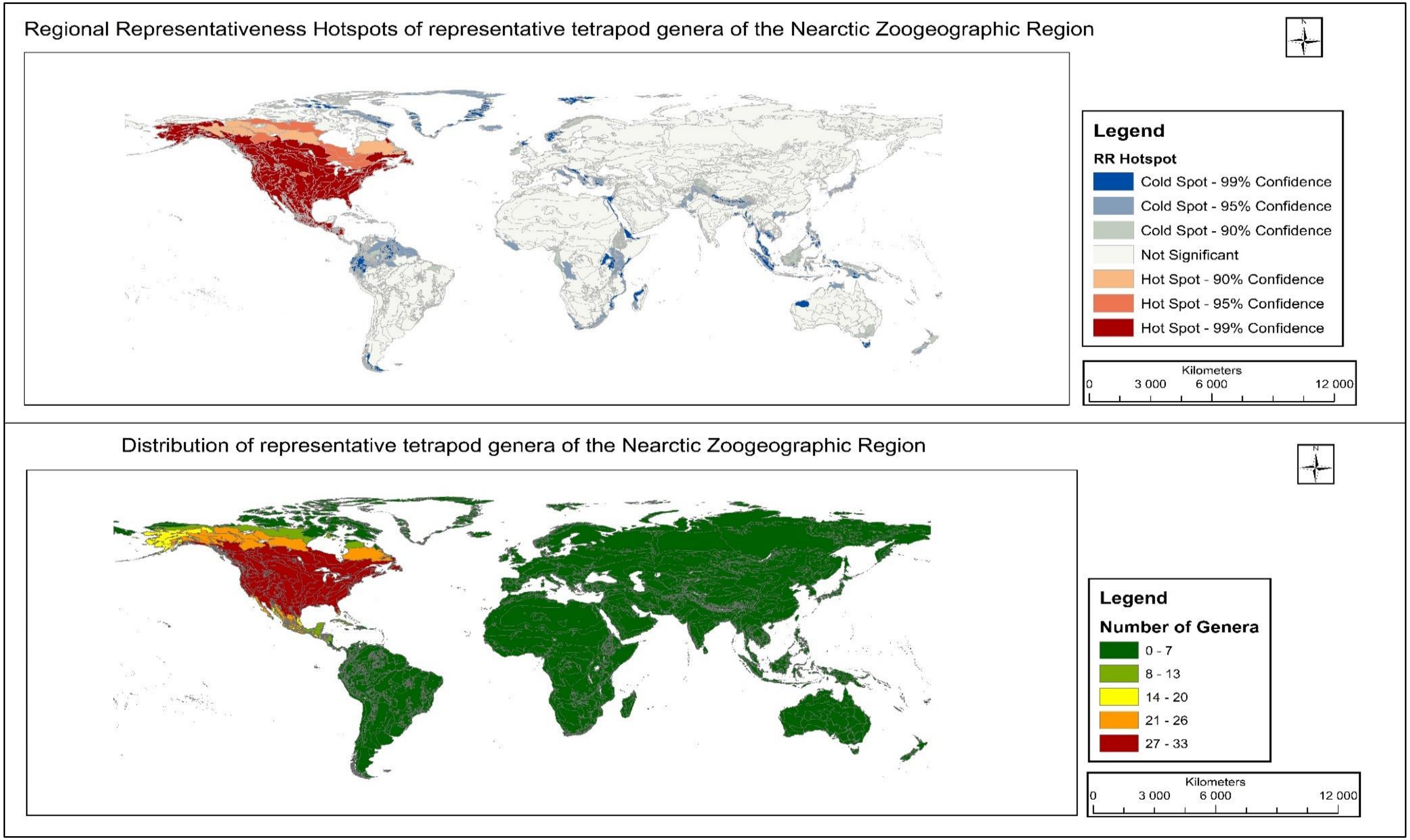
Z-scores and p-values were produced at different confidence levels to identify significant hotspots and cold spots. At the confidence levels of 90%, 95% and 99%, very high Z-scores accompanied by small p values, indicated the events or patterns illustrated are not produced by random processes. Regional representativeness hotspots were demarcated using the 99% confidence level. At this confidence interval, there is only a 1% probability at which the patterns produced are caused by random processes.

Different combined zoogeographic regions (merged regional combinations) yielded different patterns in regional representativeness hotspots. The regional representativeness hotspots of these regions were compared with each other as well as with the hotspot patterns produced from the Zoogeographic Regions confirmed by Procheş and Ramdhani (2012).

CHAPTER 4: RESULTS AND ANALYSES

In this chapter, the results and analyses performed in ArcMap are presented in the form of maps. The following series of maps display the regional representativeness hotpots (RR hotspot) and the representative tetrapod genera of the respective Zoogeographic Region, across the terrestrial ecoregions of the World (Olson et al., 2001).

Figure 4.1 displays the regional representative hotspots and the distribution of representative tetrapod genera of the Nearctic region, respectively. The hotspot analysis map illustrates a statistically significant hotspots of representative genera. The ecoregions coloured in dark red are hotspots with a confidence interval of 99%. As displayed on the map, this RR hotspot covers the most part of the Nearctic region. The distribution map illustrates detailed spatial patterns of representative genera. The number of representative genera in each ecoregion decreases as one moves away from the central Nearctic region.



Regional Representativeness Hotspots of representative tetrapod genera of the Nearctic Zoogeographic Region

Distribution of representative tetrapod genera of the Nearctic Zoogeographic Region

Figure 4.1: Regional Representativeness Hotspots and distribution of tetrapod genera which are representative of the Nearctic Zoogeographic Region.

The Caribbean region's RR hotspot illustrates a major hotspot that covers the entire region, including Cuba, the Dominican Republic, Puerto Rico, and surrounding islands. The hotspot also includes the southern tip of Florida. The distribution map of Figure 4.2 clearly indicates a concentration of representative genera in the Bahamas and Cuba. The Dominican Republic and Haiti also fall under areas which host a significant number of representative genera. Western ecoregions of the Caribbean region display a decrease representative genera presence, including, Puerto Rican moist forests and Caribbean shrublands ecoregion.

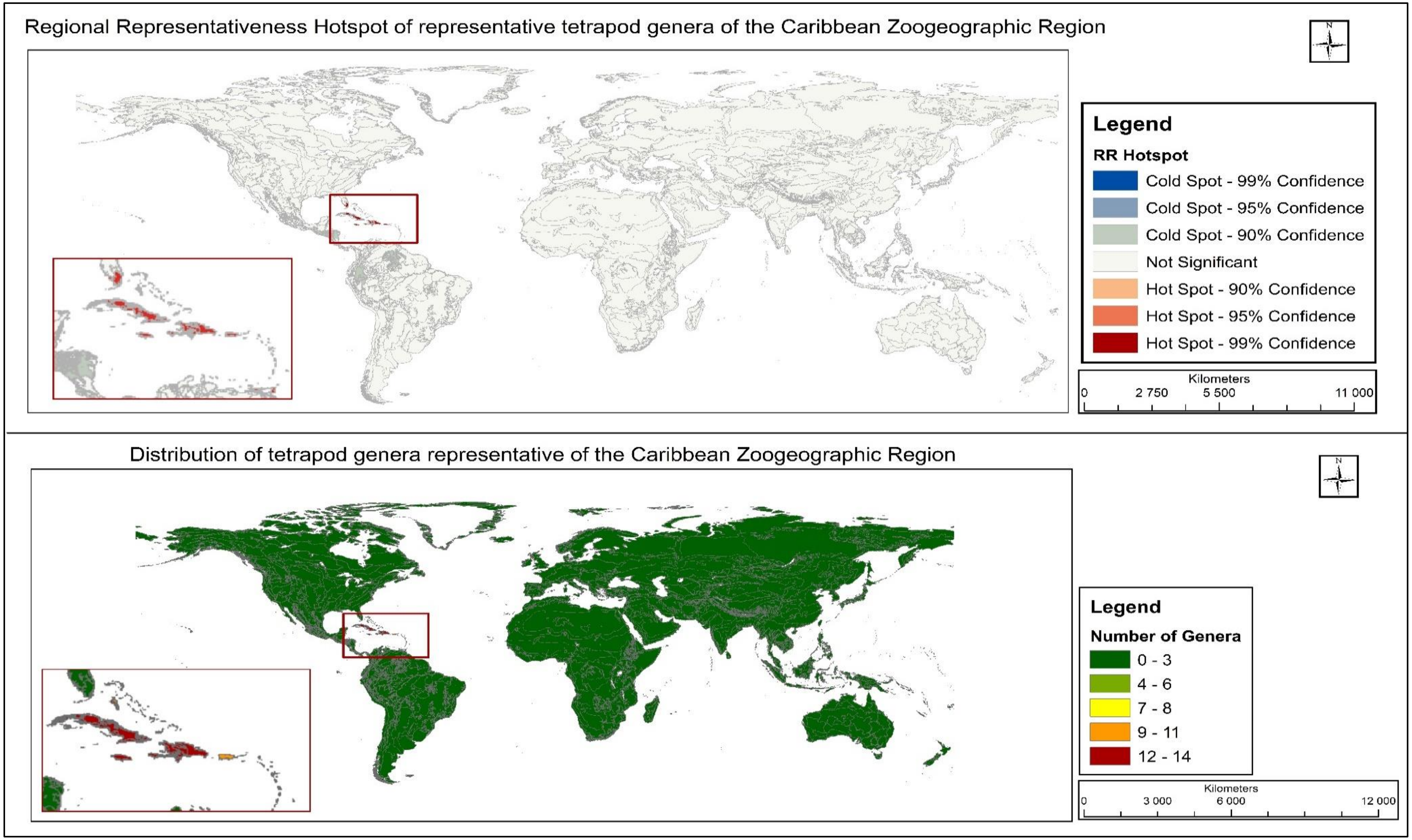
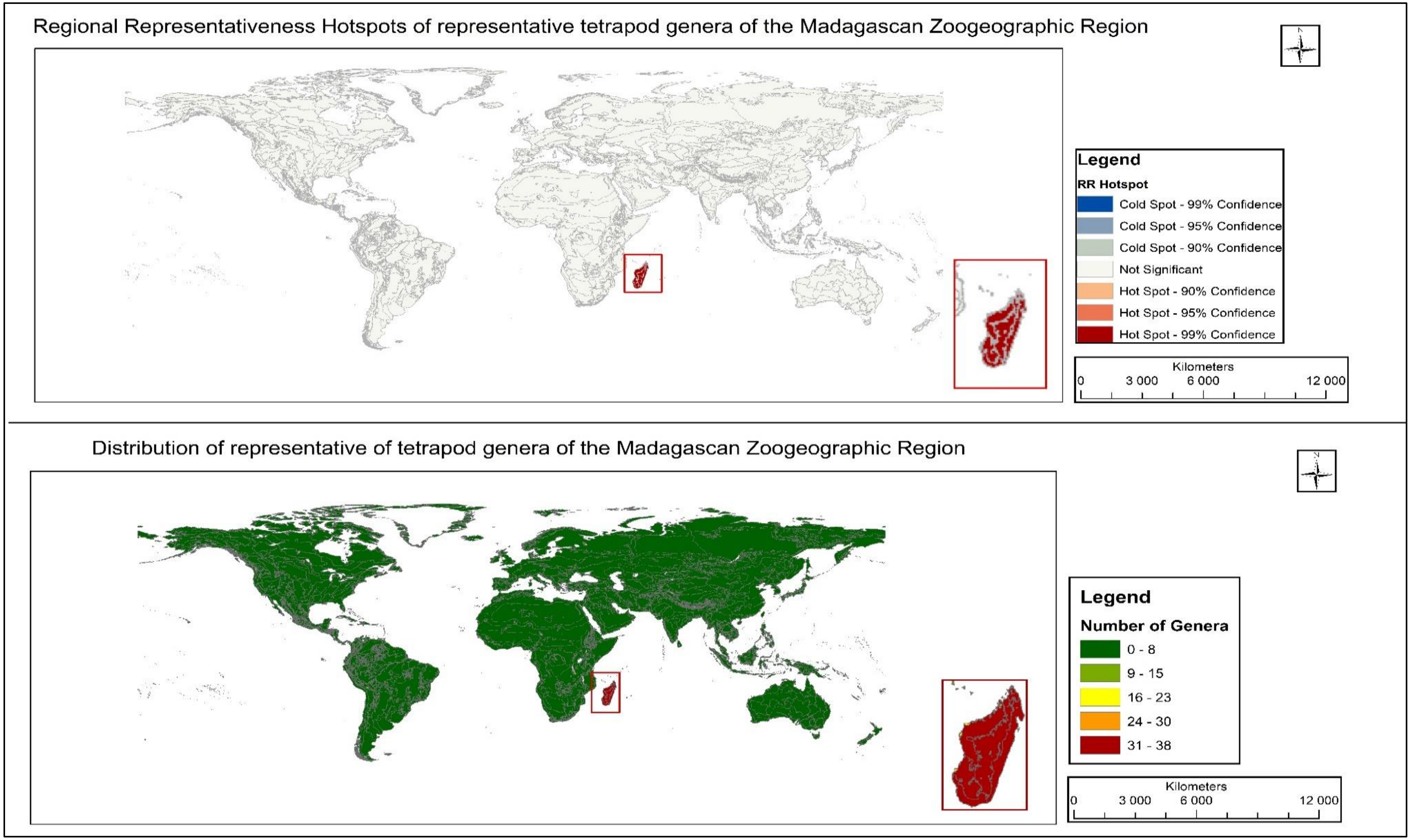


Figure 4.2: Regional Representativeness Hotspots and distribution of tetrapod genera which are representative of the Caribbean Zoogeographic Region.

The Hotspot analysis map in Figure 4.3 illustrates a large hotspot which covers the Madagascan Zoogeographic Region. The distribution map exhibits the high number of representative genera throughout the Madagascan Zoogeographic Region. Figure 4.4 shows the maps display the RR hotspot and distribution map of genera representative of the Palearctic region. The hotspot analysis map exhibits several hotspots which span across Asia and Europe. Smaller hotspots are found in northern Afrotropical ecoregions and the Indo-Malaysian Zoogeographic ecoregion.

The distribution map displays a spatial pattern of representative tetrapod genera consistent with the RR hotspot map. Ecoregions such as East Siberian taiga, Scandinavian and Russian taiga and the Taklimakan desert contain high genera counts. Eastern ecoregions of the Palearctic region contain high numbers of representative genera as opposed to central ecoregions.


Regional Representativeness Hotspots of representative tetrapod genera of the Madagascan Zoogeographic Region

Distribution of representative of tetrapod genera of the Madagascan Zoogeographic Region

Figure 4.3: Regional Representativeness Hotspots and distribution of tetrapod genera which are representative of the Madagascan Zoogeographic Region.

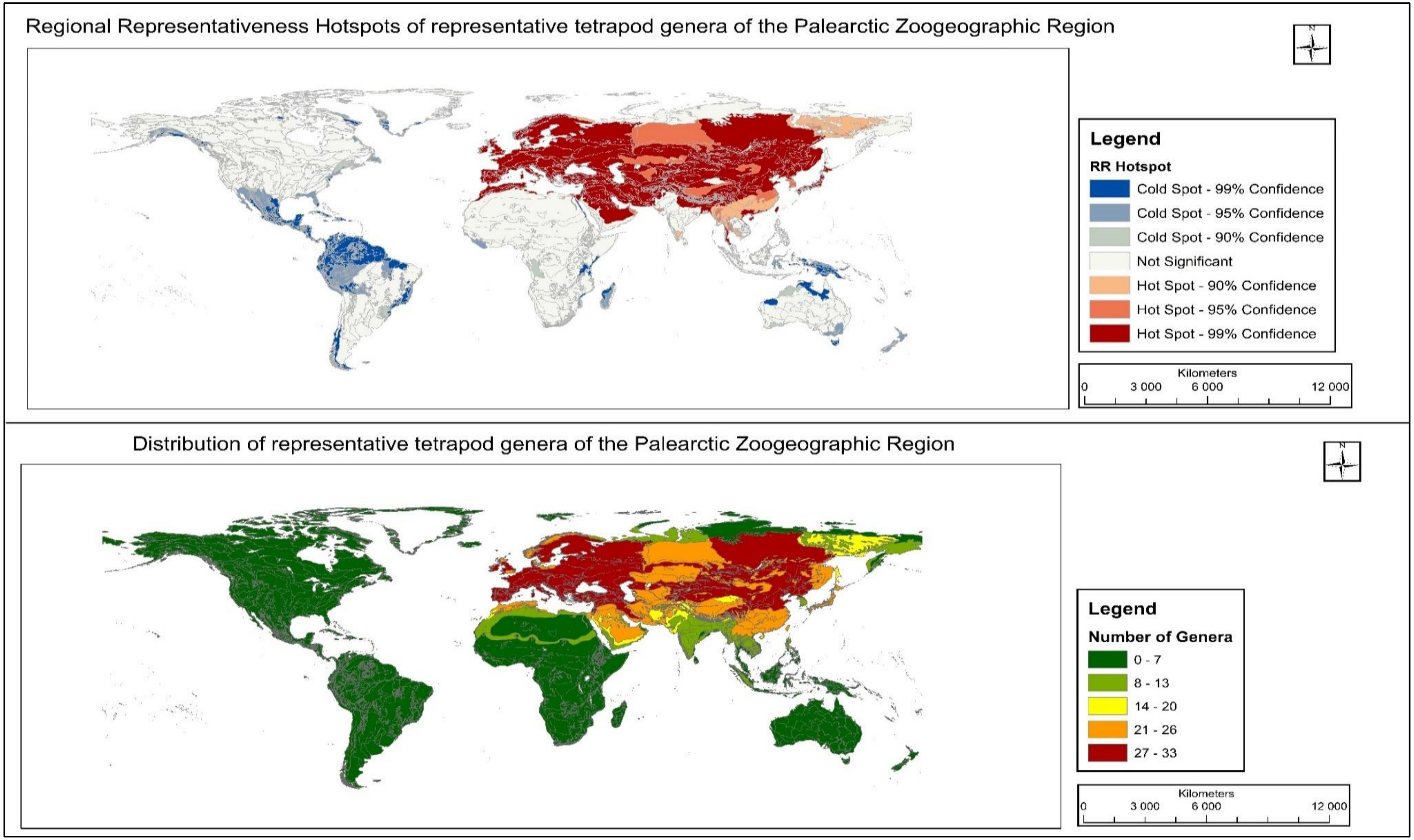
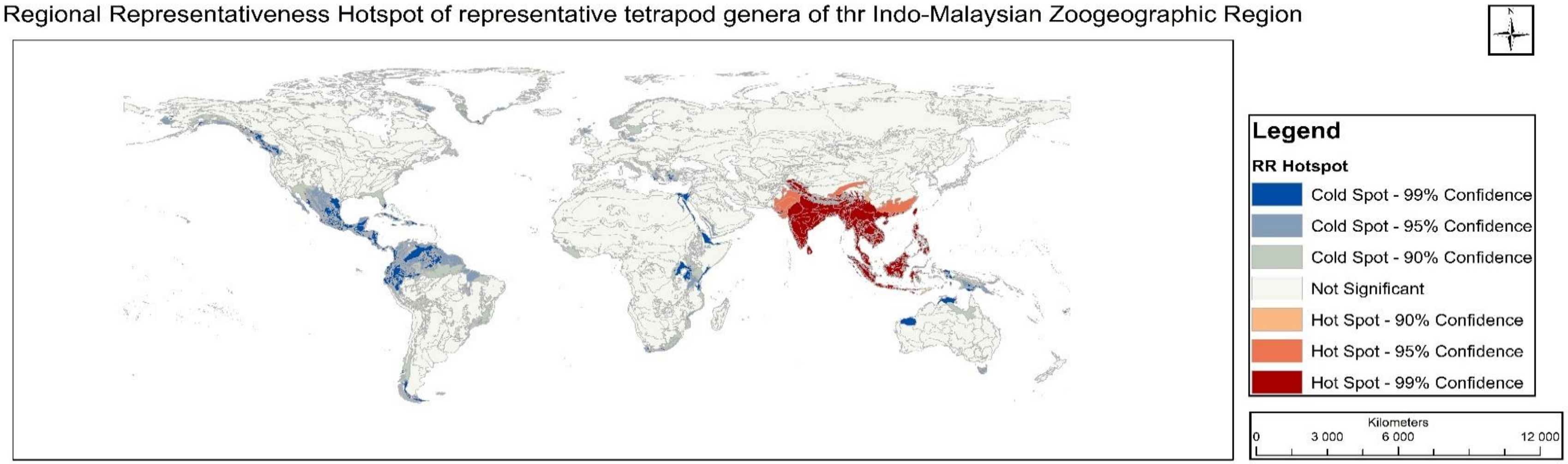


Figure 4.4: Regional Representativeness Hotspots and distribution of tetrapod genera which are representative of the Palearctic Zoogeographic Region.

The Indo-Malaysian hotspot analysis presented in Figure 4.5 displays a regional representativeness hotspot, spanning across the Indo-Malaysian region. The hotspot covers countries including India, Thailand, Indonesia, the Philippines, and Sumatra. The ecoregions which fall within the hotspot include Northern Indochina subtropical forests, Deccan thorn scrub forests, Borneo lowland rain forests.

These results coincide with the patterns seen in the distribution map of tetrapod genera, representative of the genera. A range of 35-43 representative genera inhabits approximately all ecoregions. These hold the highest number of representative genera in the entire Indo-Malaysian region. As one moves away from the centre of the clustered genera, the number of genera decreases. India is highlighted as a hotspot; however, most Indian ecoregions fall within the second-highest range of representative genera presences.

Regional Representativeness Hotspot of representative tetrapod genera of thr Indo-Malaysian Zoogeographic Region



Distribution of representative tetrapod genera of the Indo-Malaysian Zoogeographic Region

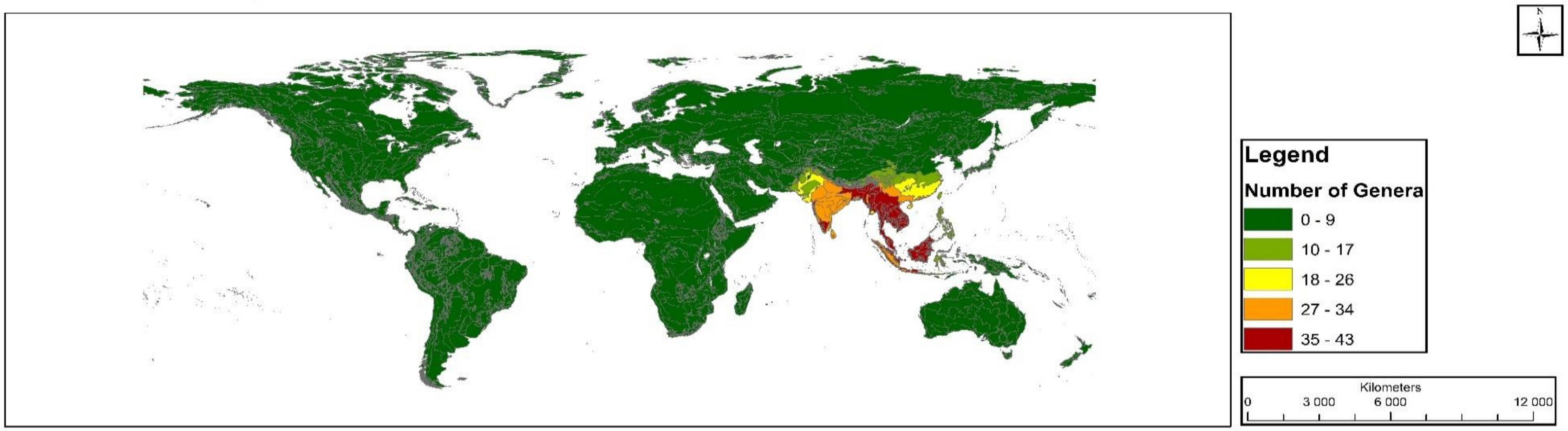
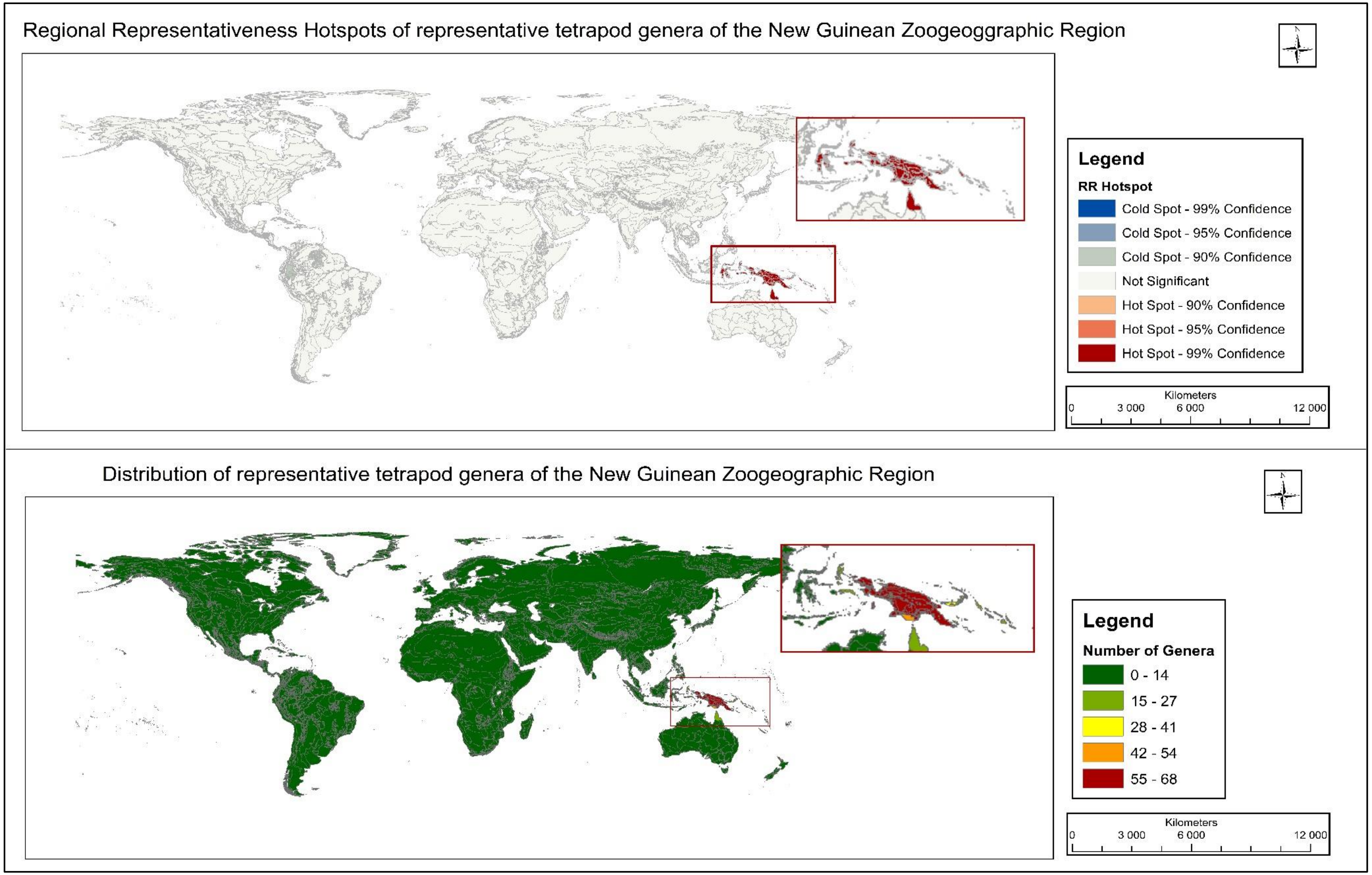


Figure 4.5: Regional Representativeness Hotspots and distribution of tetrapod genera which are representative of the Indo-Malaysian Zoogeographic Region.

Figure 4.6 focuses on the RR hotspots and genera distribution, representative to the New Guinean Zoogeographic Region. Hotspots are spread across the region encompassing ecoregions such as the Southern New Guinea lowland rain forests, located in New Guinea, and the Southern New Guinean Lowland forests and Central Range montane rain forests, located in New Guinea. The distribution map strongly correlates with these results as the highest number of representative genera are found in New Guinean ecoregions. A few ecoregions in New Guinea contain less than 55 representative genera. The New Guinean ecoregion New Britain-New Ireland, lowland rain forests ecoregion, tends to have low representative genera count.


Regional Representativeness Hotspots of representative tetrapod genera of the New Guinean Zoogeoggraphic Region

Distribution of representative tetrapod genera of the New Guinean Zoogeographic Region

Figure 4.6: Regional Representativeness Hotspots and distribution of tetrapod genera which are representative of the New Guinean Zoogeographic Region.

Figure 4.7 illustrates the regional representativeness hotspots of the Wallacean Zoogeographic Region. The RR hotspots cover regions such as Sulawesi, the Philippines, and the Lesser Sunda Islands. One can clearly distinguish a shift to the west of the hotspot areas of representative genera of Wallacea, as opposed to New Guinea. The RR hotspots in this map highlight the western region of Western Papua New Guinea as a RR hotspot. As seen on the map, the Luzon rain forests ecoregion falls within the highest range of a number of representative genera. As one move to the south of the Wallacean Region, the number of representative genera decreases drastically.

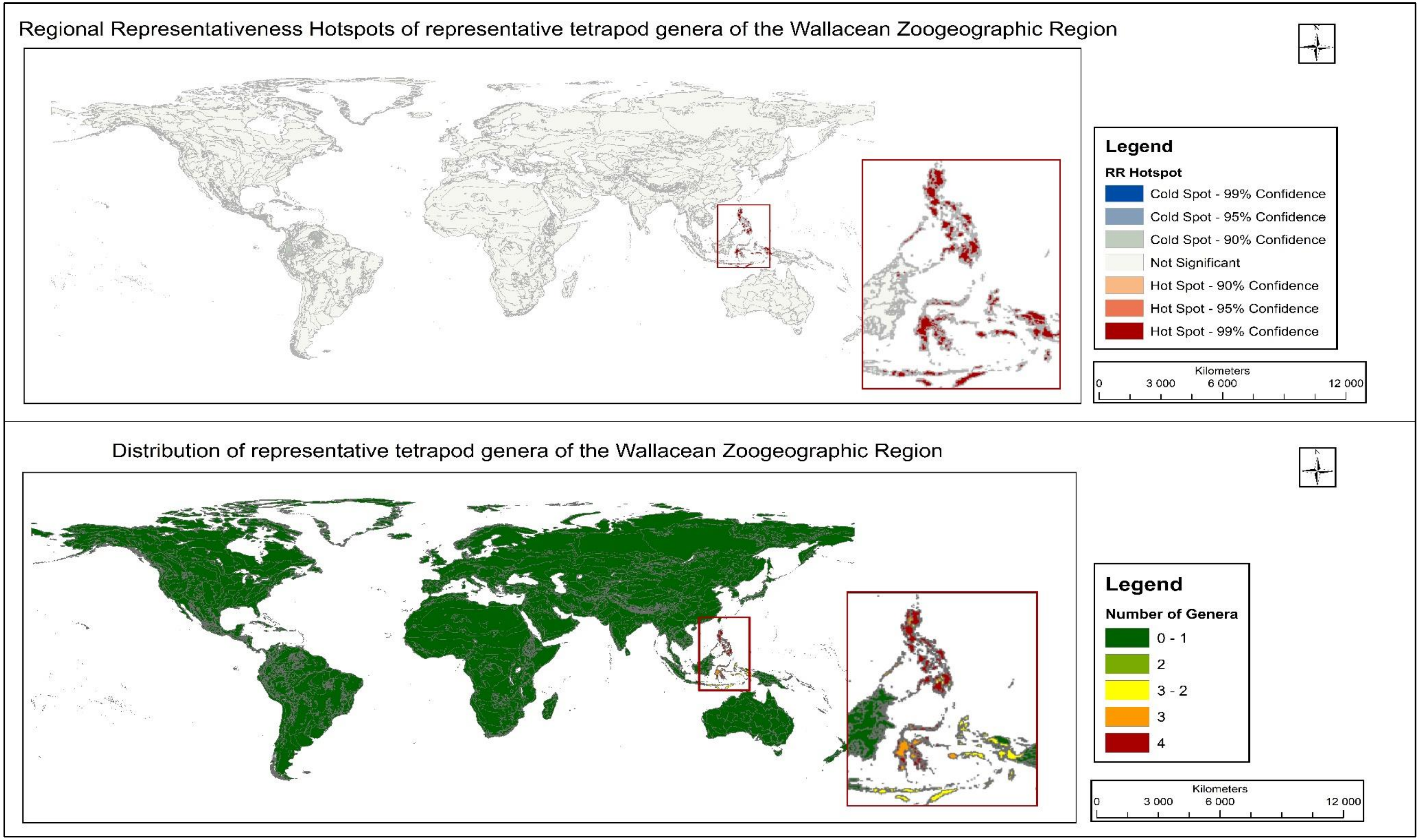


Figure 4.7: Regional Representativeness Hotspots and distribution of tetrapod genera which are representative of the Wallacean Zoogeographic Region.

The Australian hotspot map and genera distribution map in Figure 4.8 displays regional representativeness hotspots which cover the Australian continent and the New Guinean region. The distribution map of tetrapod genera which are representative to the Australian Zoogeographic Region displays high numbers of representative genera within the whole Australian Region. Ecoregions such as Southeast Australia temperate savanna, Brigalow tropical savanna and the Tirari-Sturt stony desert contain a high percentage of representative genera.

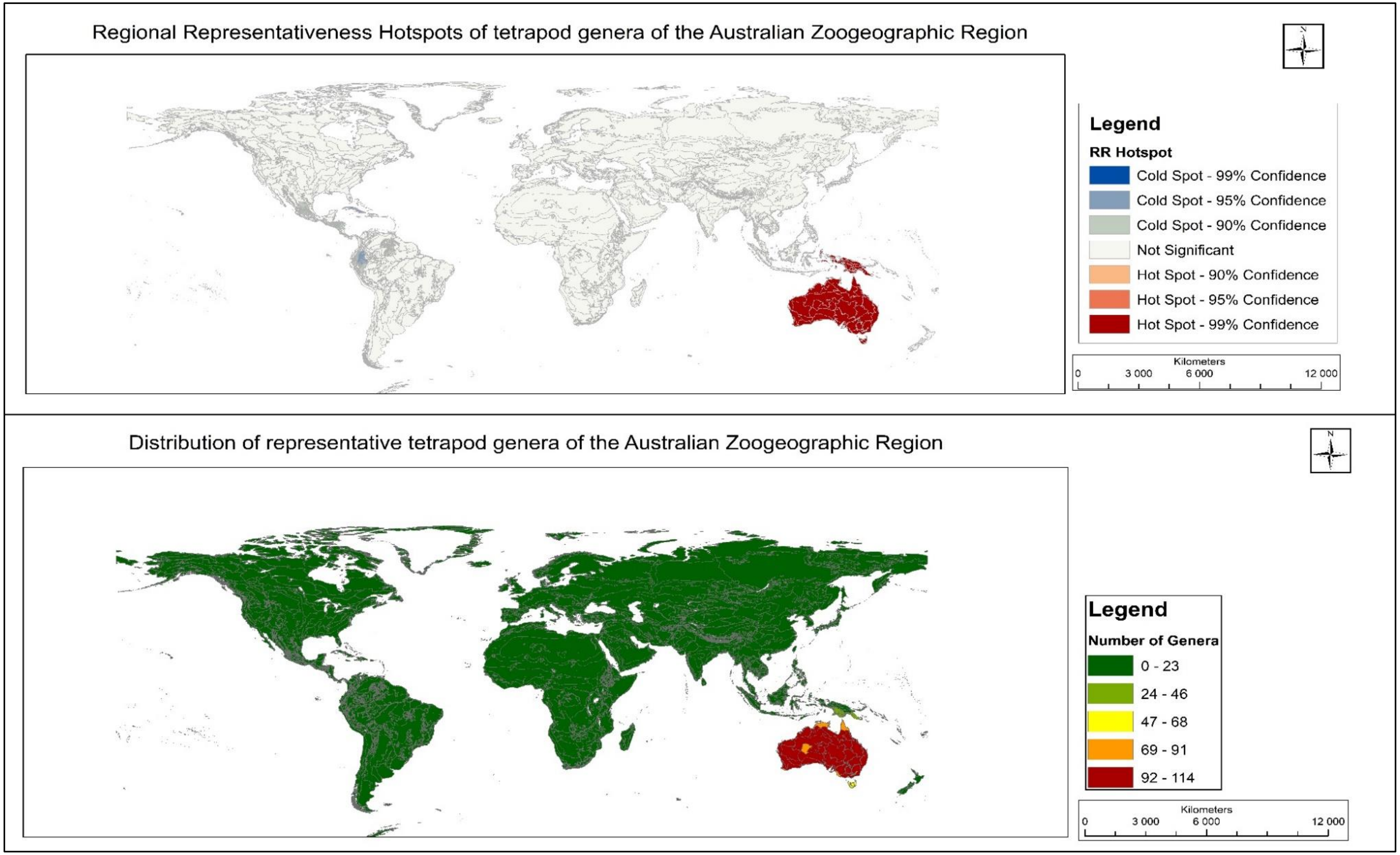


Figure 4.8: Regional Representativeness Hotspots and distribution of tetrapod genera which are representative of the Australian Zoogeographic Region.

The table below defines the combined zoogeographic region, which was generated for this study. The table displays the collective zoogeographic region which forms each of the 14 combined zoogeographic regions analysed in this study.

Table 4.1: Combined Zoogeographical Regions

Combine Zoogeographic Region	**Zoogeographic Regions**
Extended Paleotropical CZR	Australian+ Indo-Malaysian+ Afrotropical+ Madagascan+ Neotropical+ Andean+ Wallacean+ Polynesian
Australasian CZR	Australian+ New Guinea+ Polynesian+ Wallacean
Australasian region excluding Wallacea	Australian+ New Guinean+ Polynesian
Australasian region excluding Polynesia	Australian+ New Guinean+ Wallacean
Afro-Madagascan CZR	Afrotropical+ Madagascan
Paleotropical CZR	Afrotropical+ Madagascan+ Indo-Malaysian
Afro-Eurasia CZR	Afrotropical+ Palearctic
Holarctic CZR	Nearctic+ Palearctic
Neotropic-Nearctic CZR	Neotropical+ Nearctic
Neogea CZR	Neotropical+ Nearctic+ Arctic+ Caribbean+ Andean
Neotropic-Caribbean CZR	Neotropical+ Caribbean
Indopaleo-Wallacean CZR	Palearctic+ Indo-Malaysian+ Wallacean
Malayo-Polynesian CZR	Wallacean+ Polynesian+ New Guinean+ Indo-Malaysian

The first combined zoogeographic region in Figure 4.9 comprises all zoogeographic regions located just above the equator and regions to the south of the equator. The hotspot analysis results display several hotspots located in the Australian, Neotropical and Afrotropical zoogeographic regions. Hotspots are dominated by savanna and woodland ecoregions. Regional representativeness hotspots are restricted to southern regions, with an evident absence of hotspots in the Arctic regions. Figures 4.10 to 4.12 focuses on the Australian, New Guinean, Wallacean and Polynesian zoogeographic regions. Several combinations were compiled to attain a significant coverage of hotspots of representative genera. Inland ecoregions of Australia do not contain any significant hotspots. The eastern ecoregions of the Afrotropical and Neotropical region are highlighted as hotspots.

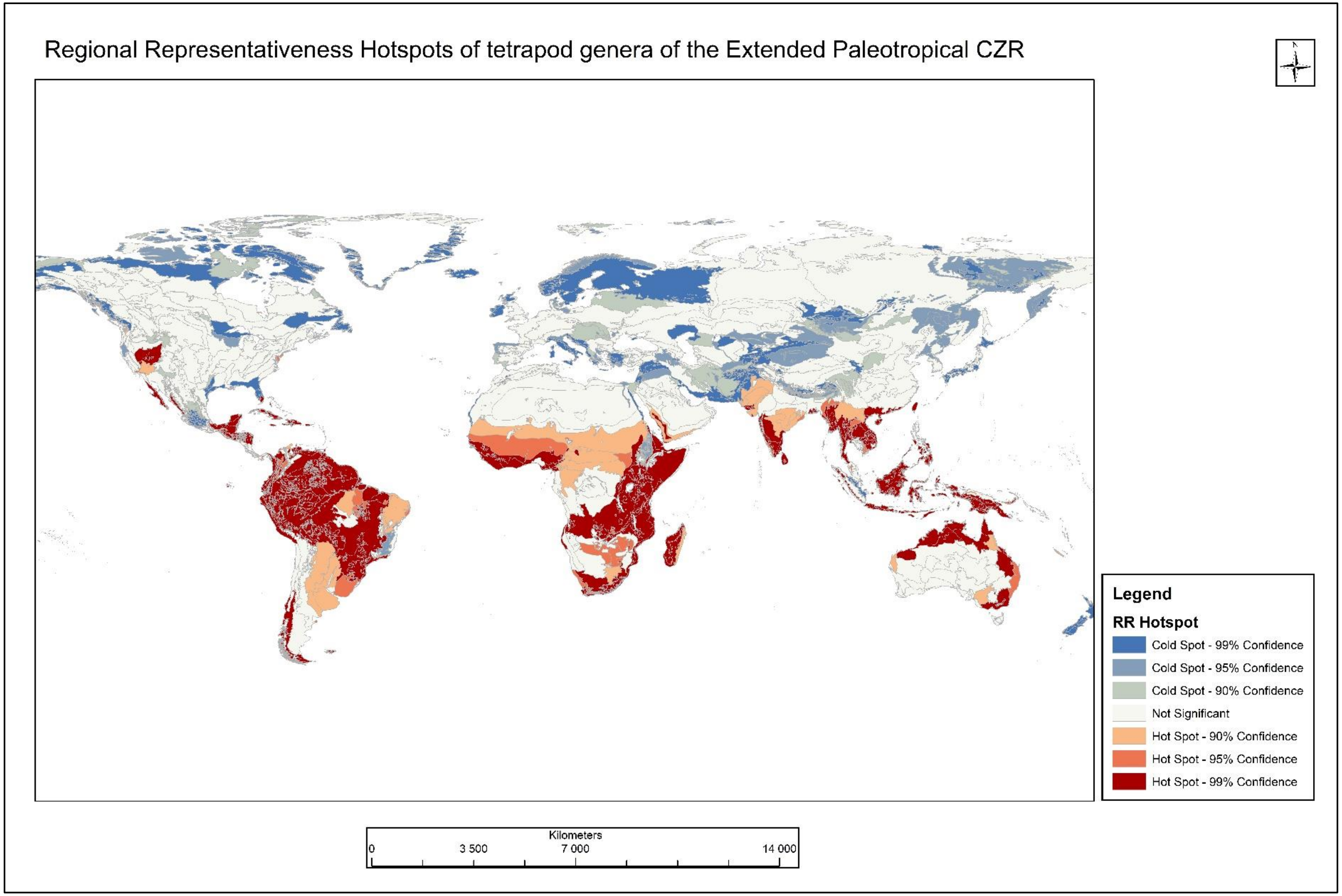


Figure 4.9: Regional representativeness hotspots of representative tetrapod genera of Extended Paleotropical combined zoogeographic region.

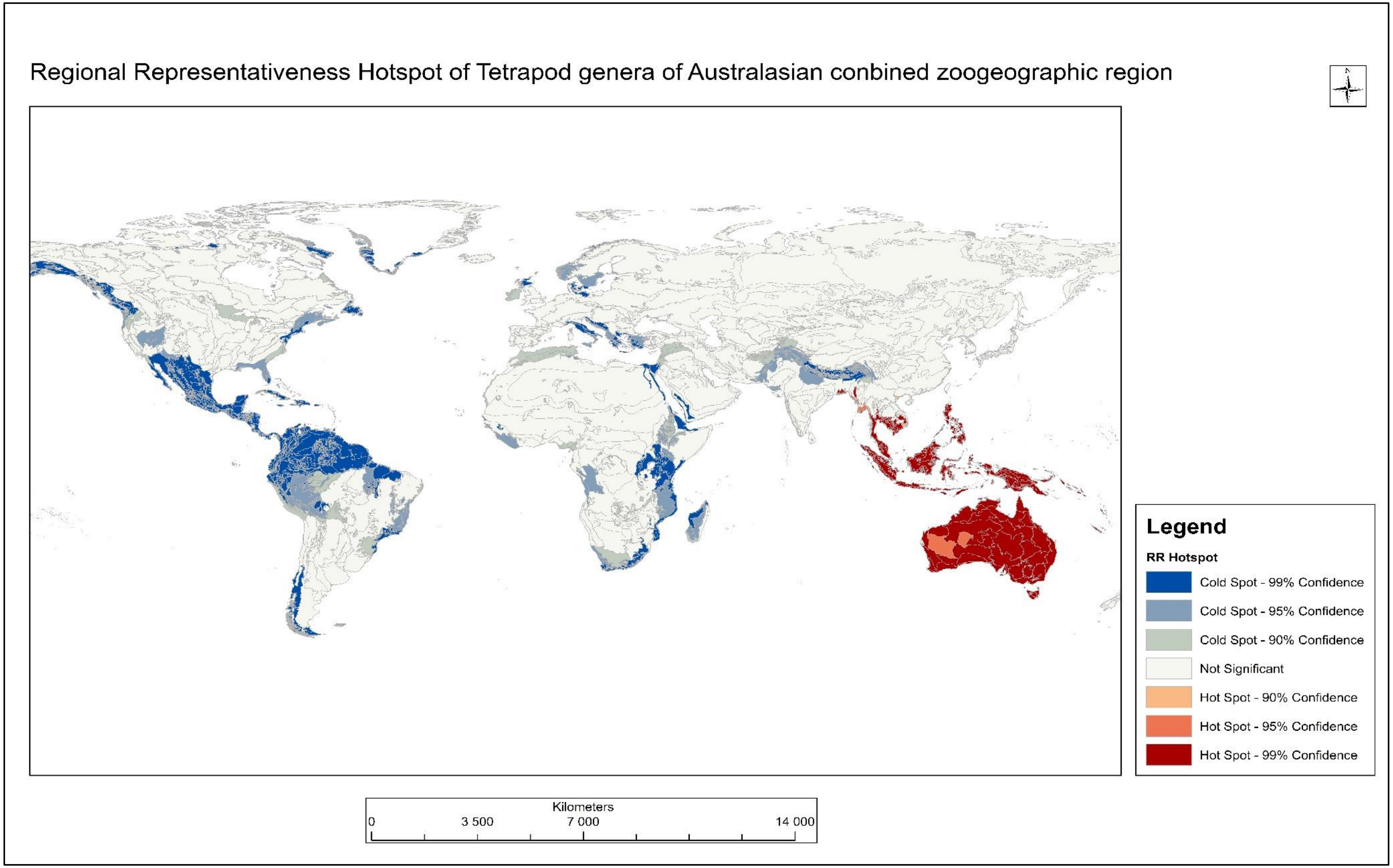


Figure 4.10: Regional representativeness hotspots of representative genera of the Australasian combined zoogeographic region.

Figure 4.10 displays the regional representative hotspot of tetrapod genera which are representative of Australian New Guinea Polynesian and Wallacean zoogeographic regions. The hotspot analysis results show evidence of hotspots located in Australia's coastal ecoregions, the New Guinean region, the Philippines, and surrounding islands. All ecoregions within the Australian region are highlighted as hotspots excluding the Gibson desert and Western Australian Mulga shrublands ecoregion.

This result contrasts with that of the map produced when Wallacea is excluded from the Australasian CZR in Figure 4.11. The entirety of the Australian region is a hotspot. However, the Indo-Malaysian region is not a hotspot, along with surrounding islands such as Fiji and New Caledonia. The RR hotspot includes other regions such as Sulawesi, New Guinea and Tasmania.

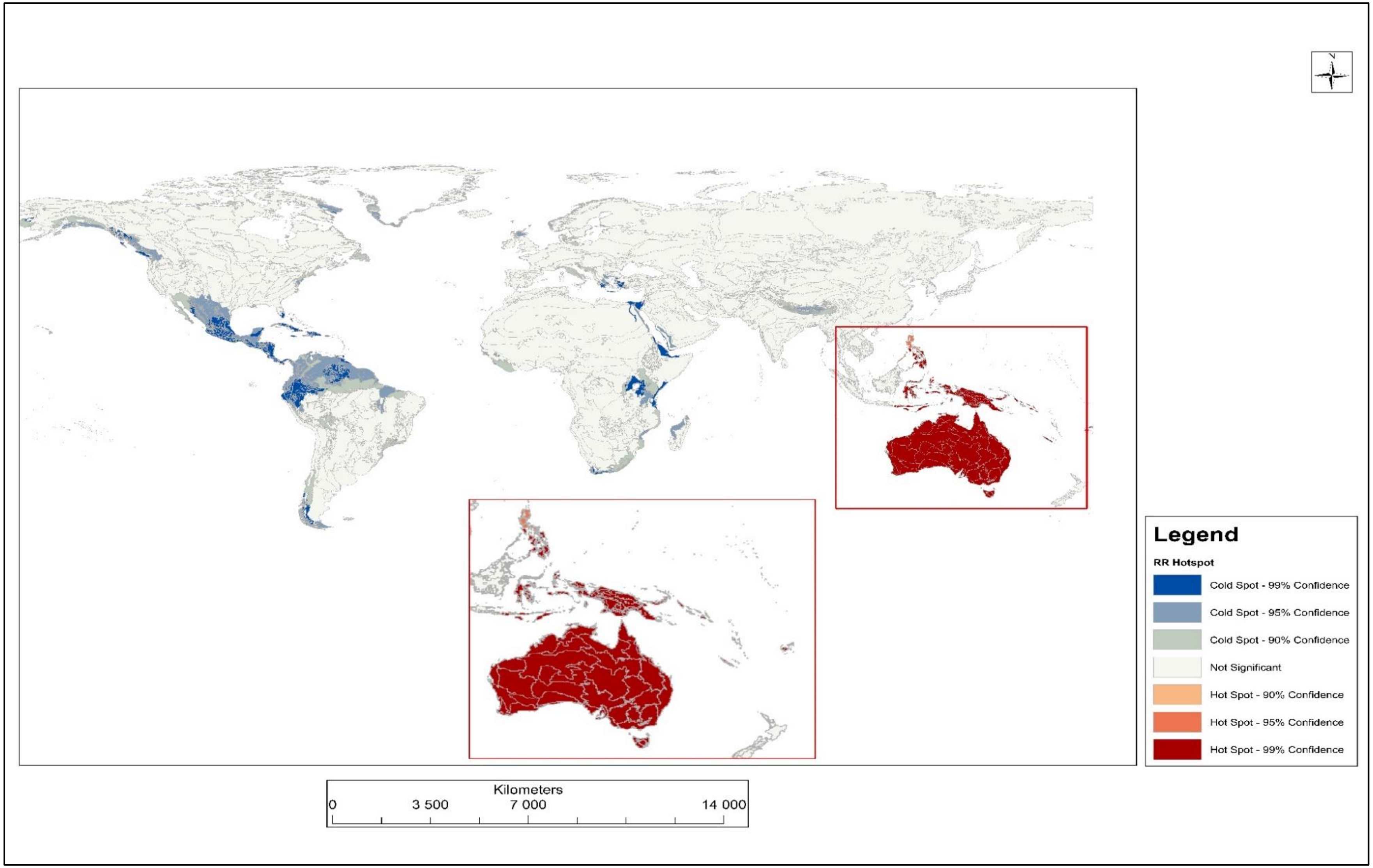


Figure 4.11: Regional representativeness hotspots of representative tetrapod genera of the Australasian CZR excluding Wallacea.

Figure 4.12, is the resultant map of the Australasian CZR excluding Polynesia, which consists of regional representativeness hotspots in the Australasian Region, highlighting New Guinea, Tasmania, and the Sulawesi islands. The distribution map of these regions shows greater detail of the distribution of representative genera. There is a relatively low number of representative genera within Tasmania and New Guinea. Sulawesi contains a high number of representative genera along with Australia.

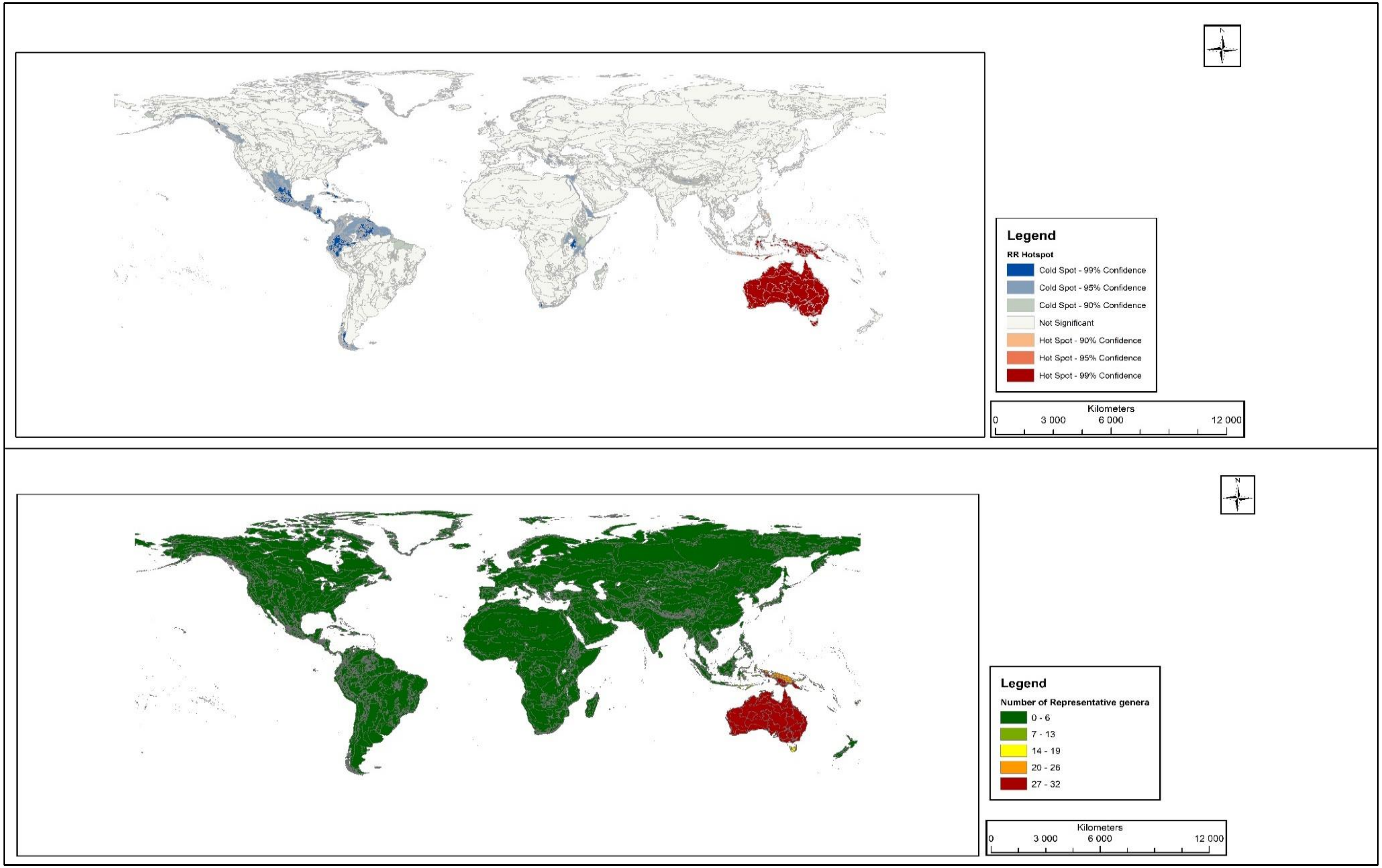


Figure 4.12: Regional representativeness hotspots of tetrapod genera of the Australasian CZR excluding Polynesia.

Figure 4.13 shows the resulting hotspots of the Afro-Madagascan CZR display a large hotspot located in the Afrotropical and Madagascan region. Within the Afrotropical region ecoregions such as Nama Karoo Southern Congolian forest-savanna mosaic North-western Congolian lowland forests.

The region generated from the Afrotropical, Madagascan, and Indo-Malaysian region is illustrated in Figure 4.14. Regional representativeness hotspots are distributed within the Afrotropical, Indo-Malaysian and Wallacea. Representativeness hotspots are located in the northern Arabian-African region, including ecoregions, Southwestern Arabian foothills savanna and Southwestern Arabian montane woodlands. Hotspots are also distributed across the Indo-Malaysian regions including ecoregions, Deccan thorn scrub forests, Upper Gangetic Plains moist deciduous forests and Central Indochina dry forests; and in the Wallacean region including ecoregions Borneo lowland rain forests and Luzon montane rain forests.

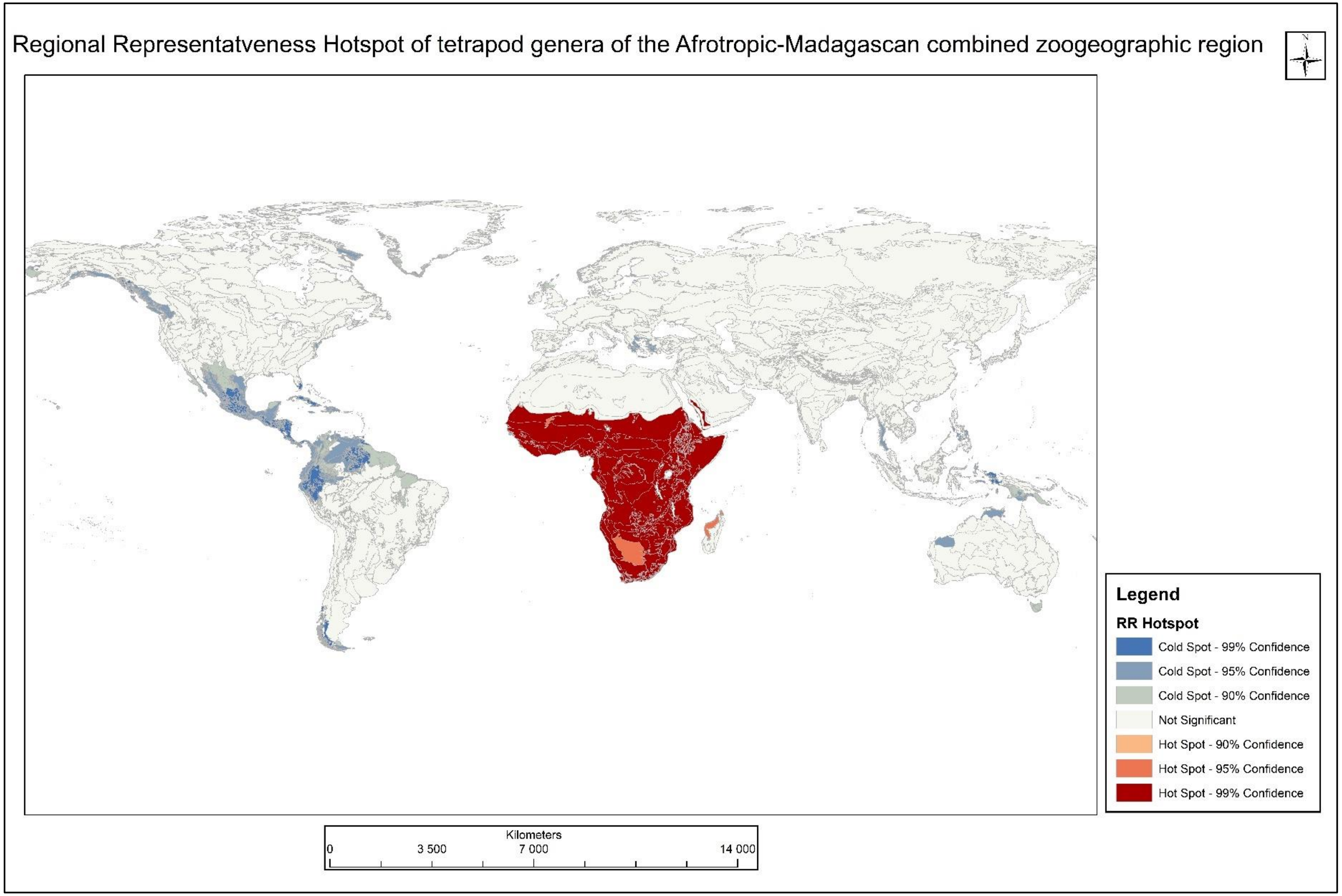


Figure 4.13: Regional Representativeness hotspots of representative tetrapod genera of the Afro-Madagascan combined zoogeographic region.

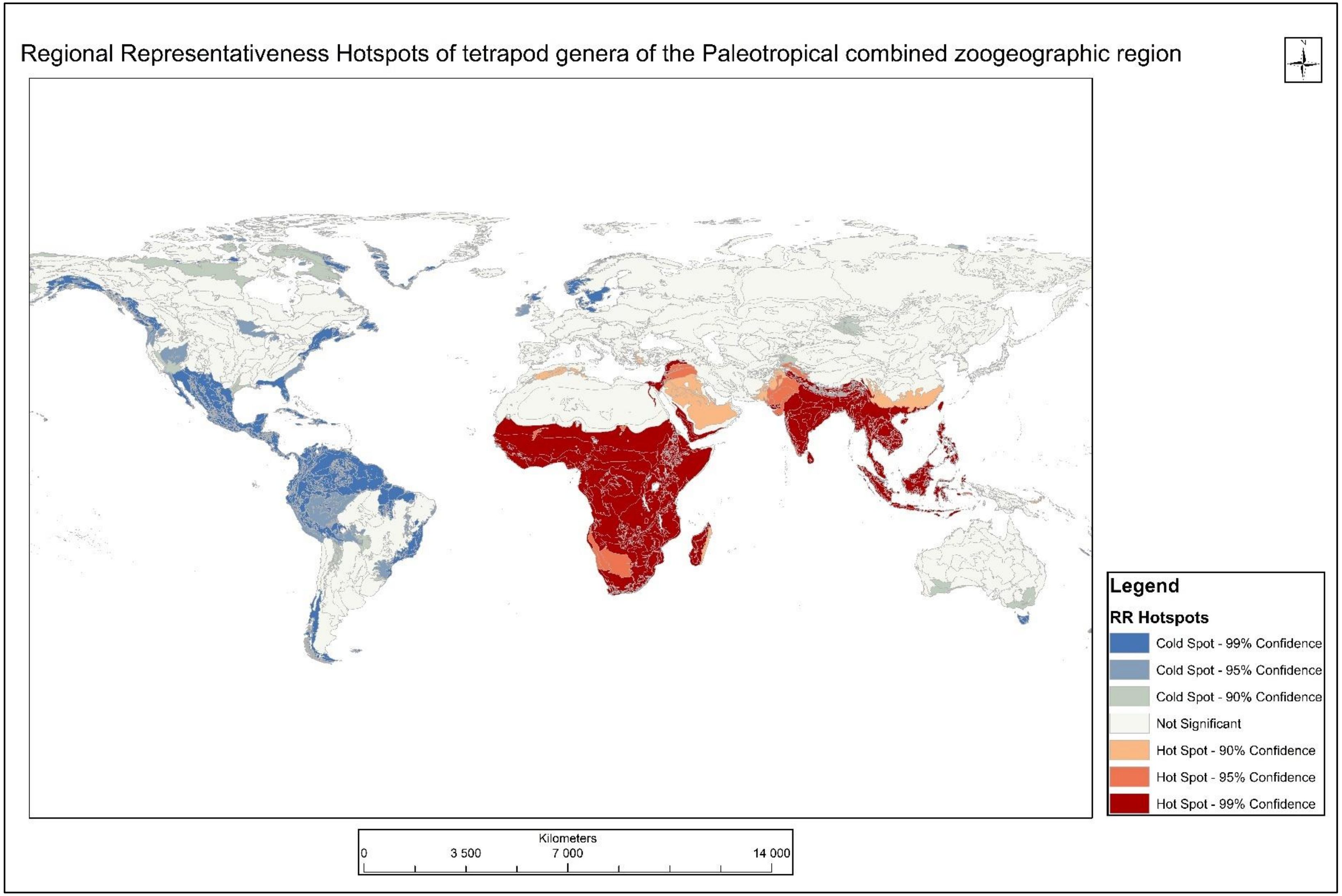


Figure 4.14: Regional Representativeness hotspots of representative tetrapod genera of the Paleotropical combined zoogeographic region.

The Afro-Eurasian combined zoogeographic region (Figure 4.15) contains significant hotspots in Europe, Asia, southern and central Africa. In the Palearctic region, hotspots are distributed in northern and western Europe. Ecoregions in these parts include Scandinavian and Russian taiga, Atlantic mixed forests, and the Sarmatic mixed forests ecoregions. Hotspots are also distributed along western and northern Asian, and the Indo-Malaysian region, including ecoregions Southeast Tibet shrublands and meadows, Manchurian mixed forests, and Deccan thorn scrub forests.

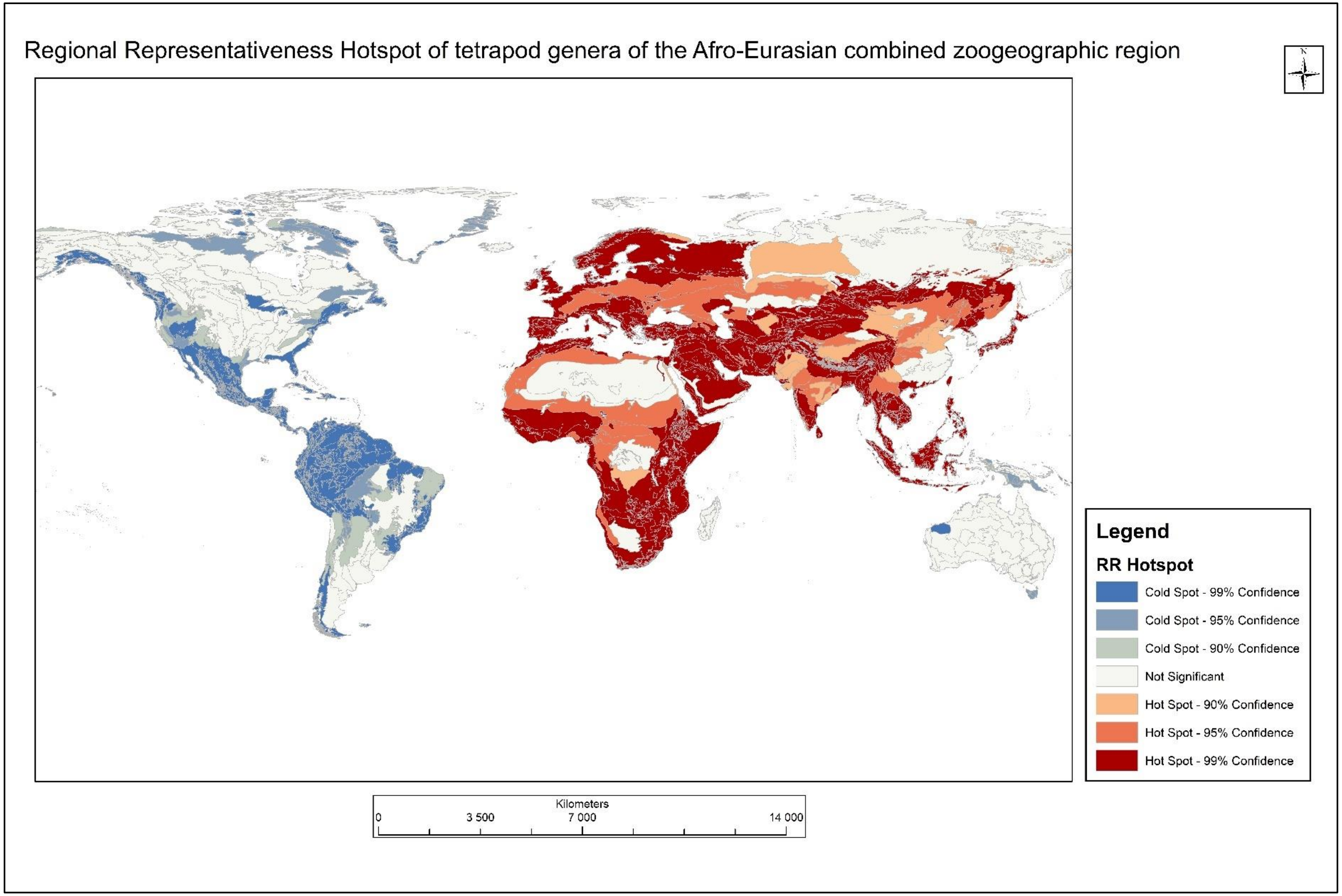


Figure 4.15: Regional Representativeness hotspots of representative tetrapod genera of Afro-Eurasian combined zoogeographic region.

The Holarctic combined zoogeographic was created by combining the Nearctic and Palearctic zoogeographic regions. Ecoregions which form regional representativeness hotspots are scattered in the Nearctic and Palearctic regions, as seen in Figure 4.16. In the Palearctic region, ecoregions which are hotspots are concentrated in the eastern and western part of the region. In the Nearctic Zoogeographic Region, regional representativeness hotspots are concentrated in the central Nearctic region. Northern ecoregions of the Nearctic region that are highlighted as RR hotspots include Beringia upland tundra and Alaska-St. Elias Range tundra. A strong latitudinal gradient is seen across northern Nearctic and Neotropical region, as northern tundra and taiga ecoregions are highlighted as RR hotpots.

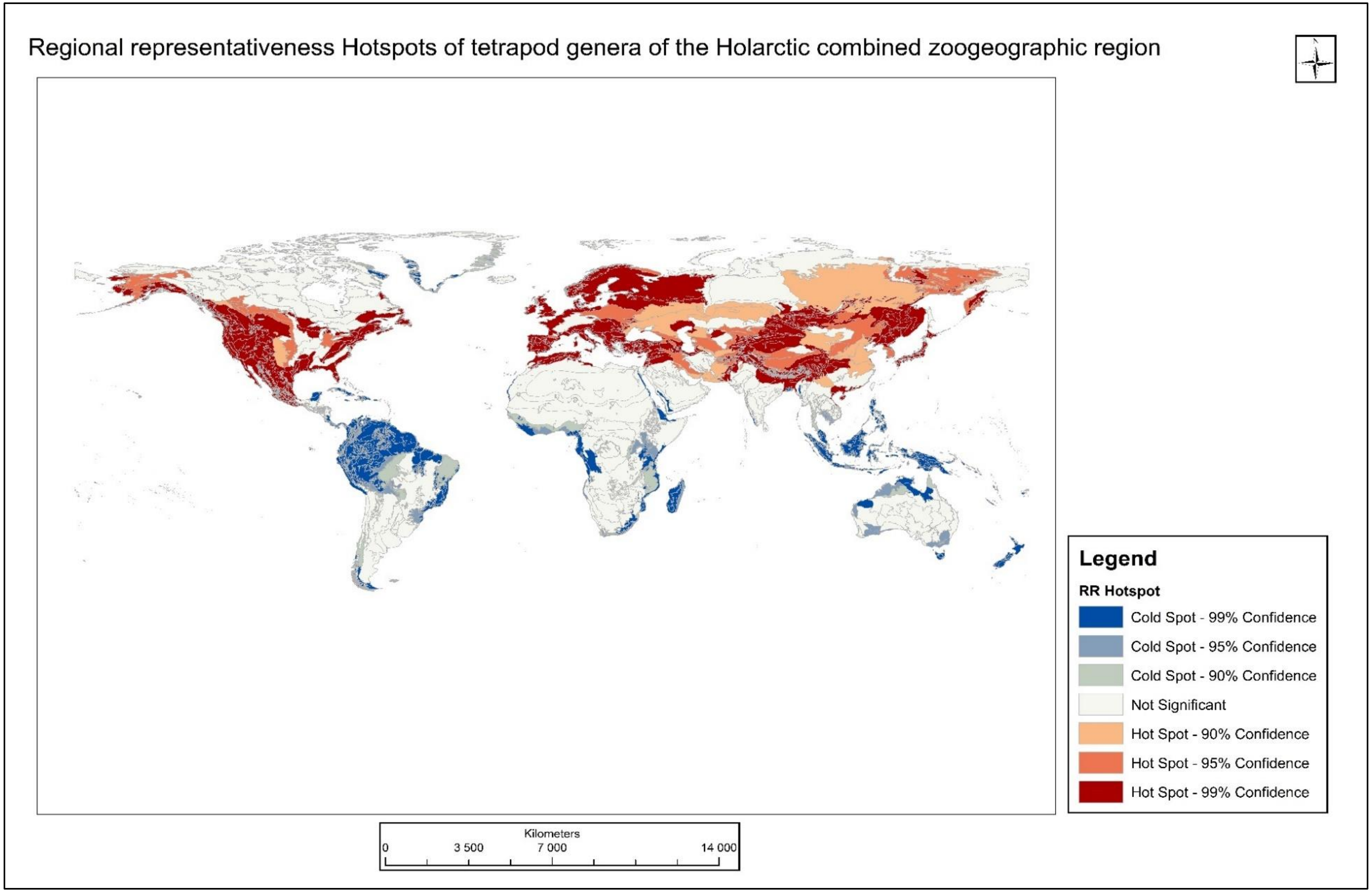


Figure 4.16: Regional Representativeness hotspots of representative tetrapod genera of the Holarctic combined zoogeographic region.

The regional representativeness hotspots of the Neotropic-Nearctic in Figure 4.17 are concentrated in the Neotropical and Nearctic region; hotspots are also located in the Caribbean region. Forest ecoregions in the northern Neotropical region are highlighted as hotspots. Regional representativeness hotspots in North America are mostly in coastal forest ecoregions, with few inland ecoregions being highlighted as RR hotspots. Ecoregions such as Northern short grasslands, Appalachian-Blue Ridge forests and the Blue Mountains forests are highlighted as regional representativeness hotspots in North America. Central ecoregions in the Nearctic region, however, are not included as hotspot regions.

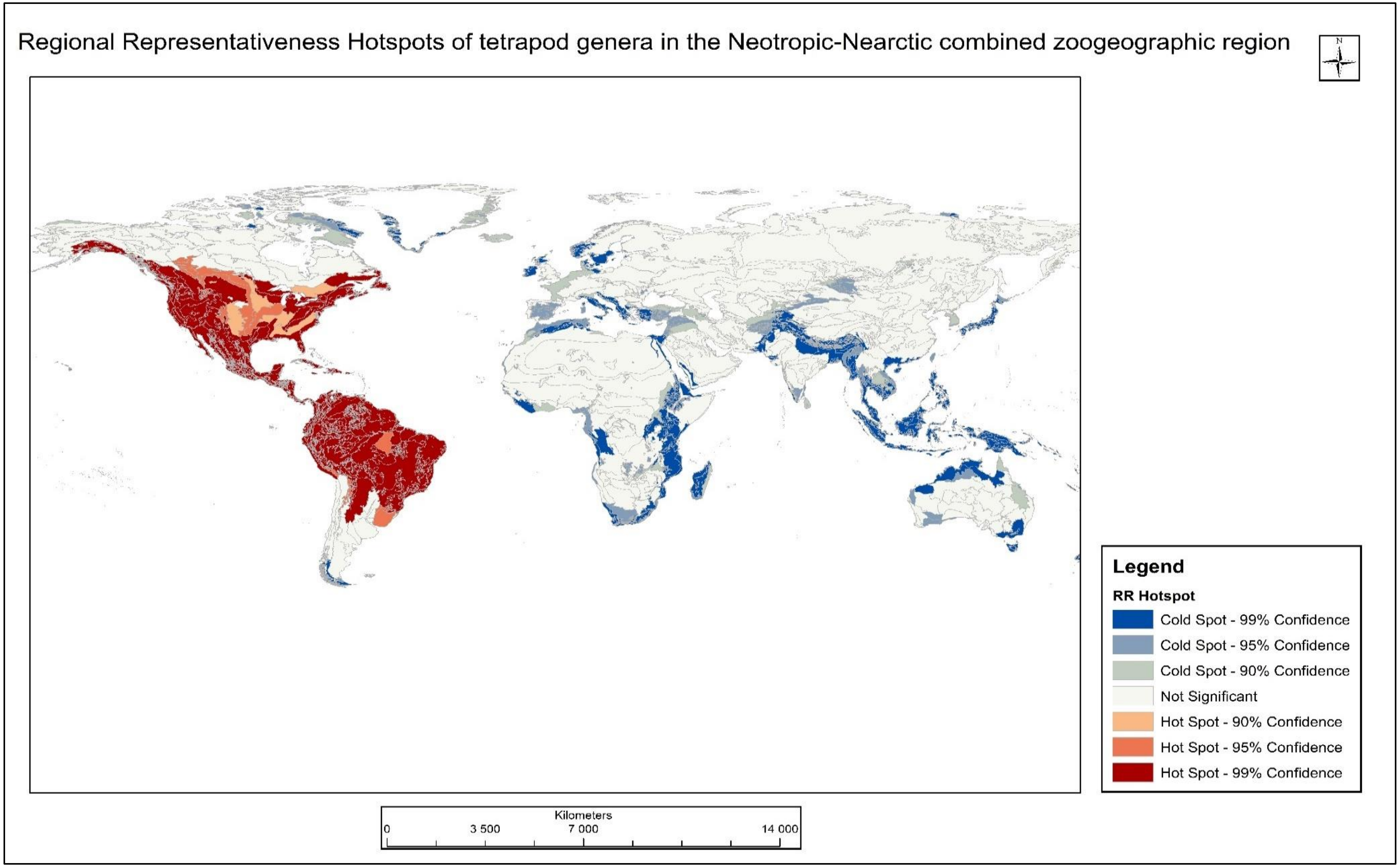


Figure 4.17: Regional Representativeness hotspots of representative tetrapod genera of Neotropic-Nearctic combined zoogeographic region.

Neogea combined zoogeographic region in Figure 4.18 displays a similar pattern to that of the Neotropic-Nearctic CZR. However, significant ecoregions such as Cerrado and Tapajós-Xingu moist forests are not included as hotspots in the Neotropical region. The distribution of hotspots in the Nearctic region within the Neotropic-Nearctic CZR and Neogea combined zoogeographic region are similar as ecoregions such as the Northern short grasslands, Chihuahuan desert, and the Great Basin shrub-steppe are highlighted as RR hotspots in both combined zoogeographic regions.

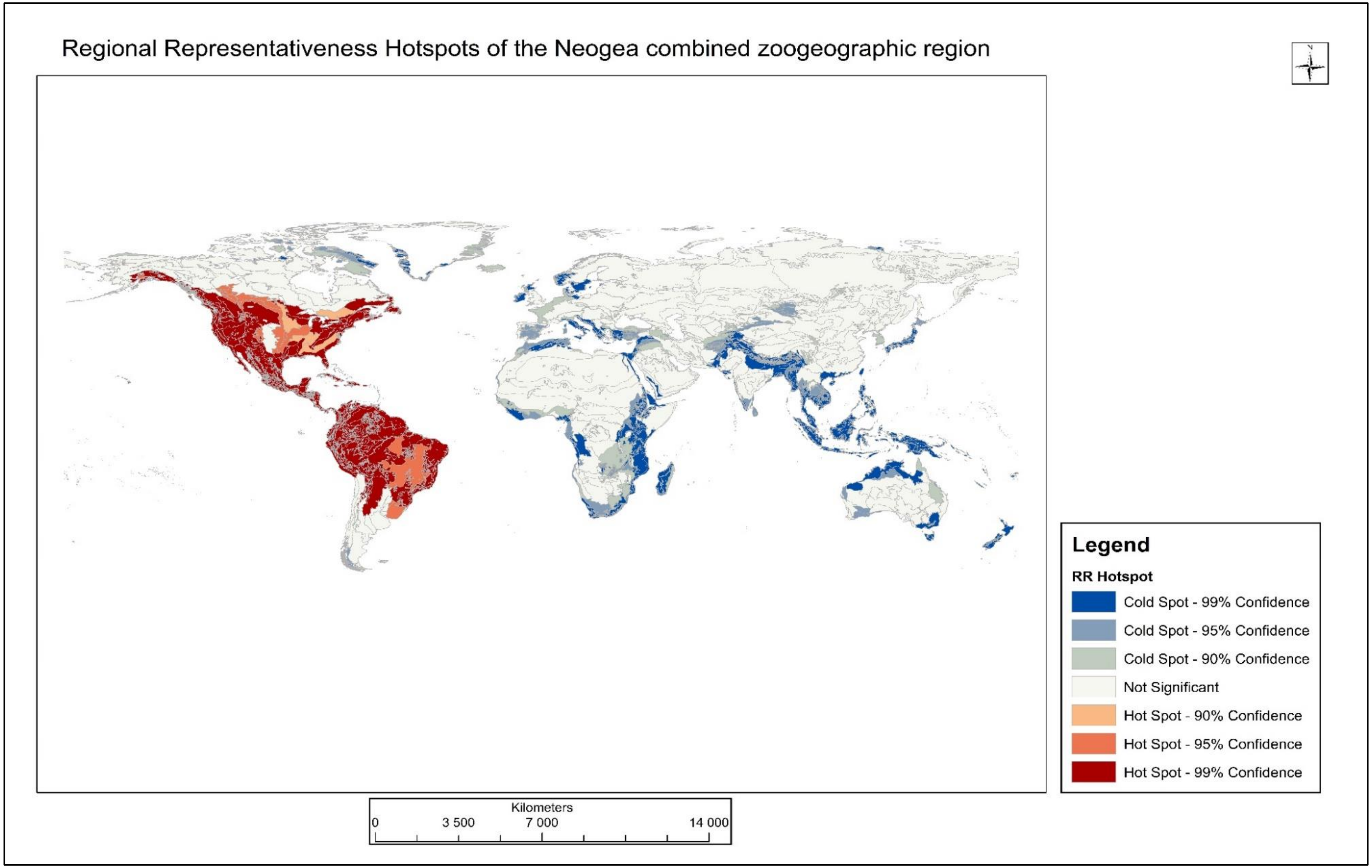


Figure 4.18: Regional Representativeness hotspots of representative tetrapod genera of Neogea combined zoogeographic region.

The Neotropic-Caribbean region (Figure 4.19) illustrates a significant difference in hotspot patterns to Neogea CZR, as hotspots are restricted to the southern Nearctic ecoregions. Regional representativeness hotspots are concentrated in the Neotropical and western Caribbean ecoregions. In the Caribbean region, the Cuban dry forests and Bahamian-Antillean mangroves are highlighted as RR hotspot. Although the Nearctic region is not included in the CZR, there is a southern ecoregion in the Nearctic region, highlighted as regional representativeness hotspots.

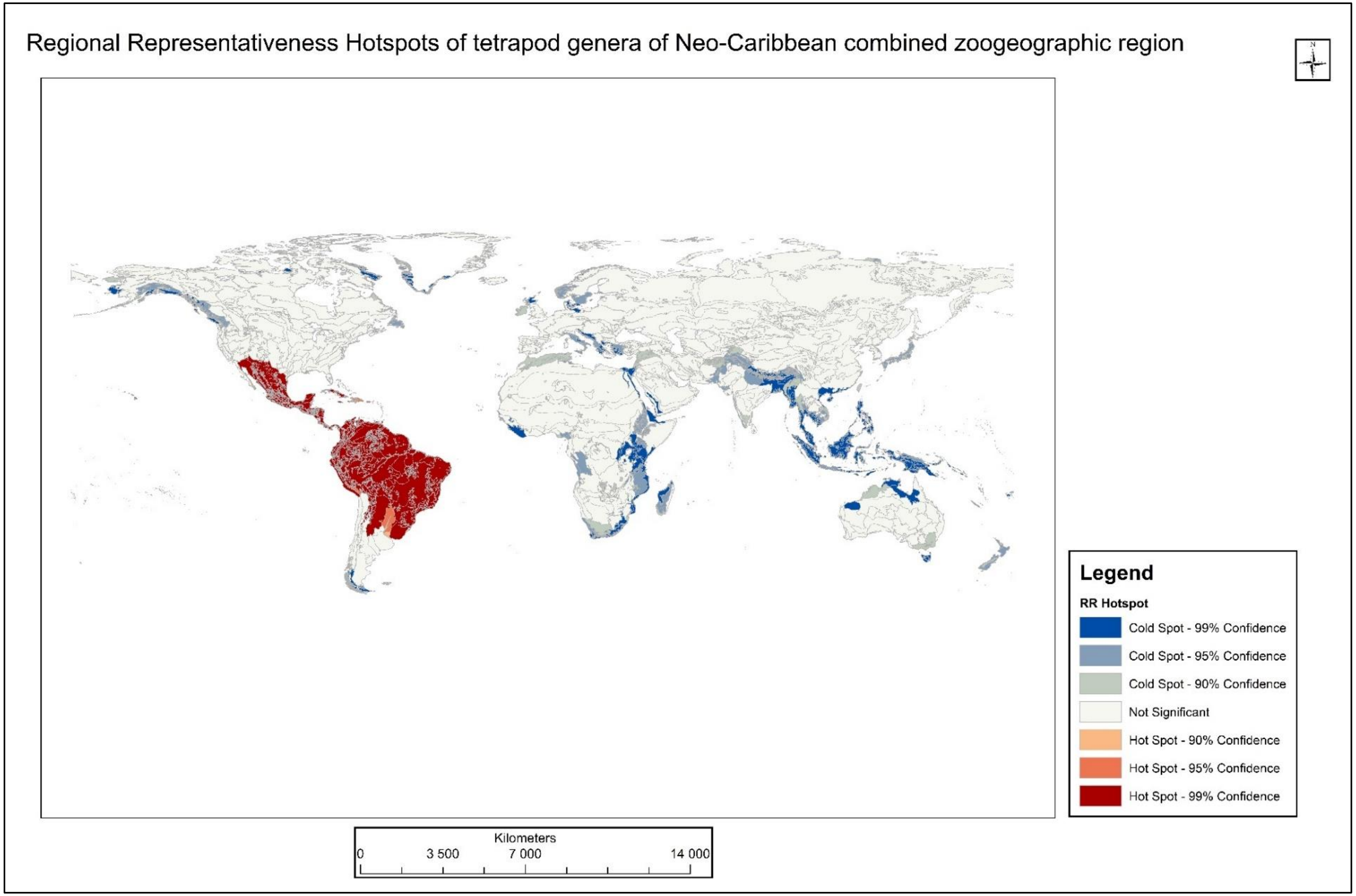


Figure 4.19: Regional Representativeness hotspots of representative tetrapod genera of Neotropic-Caribbean combined zoogeographic region.

Figure 4.20 displays regional representativeness hotspots of Indopaleo-Wallacean CZR, which are distributed across several zoogeographic regions. Hotspots are scattered amongst the Afrotropical, Palearctic, Indo-Malaysian and Wallacean regions. Ecoregions in eastern Asia are highlighted as regional representativeness hotspots and ecoregions in Europe and western and northern parts of the Afrotropical region. In the Afrotropical region, hotspots are distributed along the Eastern coast and Mediterranean region in north Africa.

The regional representativeness hotspots of Malayo-Polynesia CZR (Figure 4.21) are located in the western and northern coastal ecoregions of Australia, New Guinean ecoregions, Wallacean ecoregions, and Indo-Malaysian ecoregions.

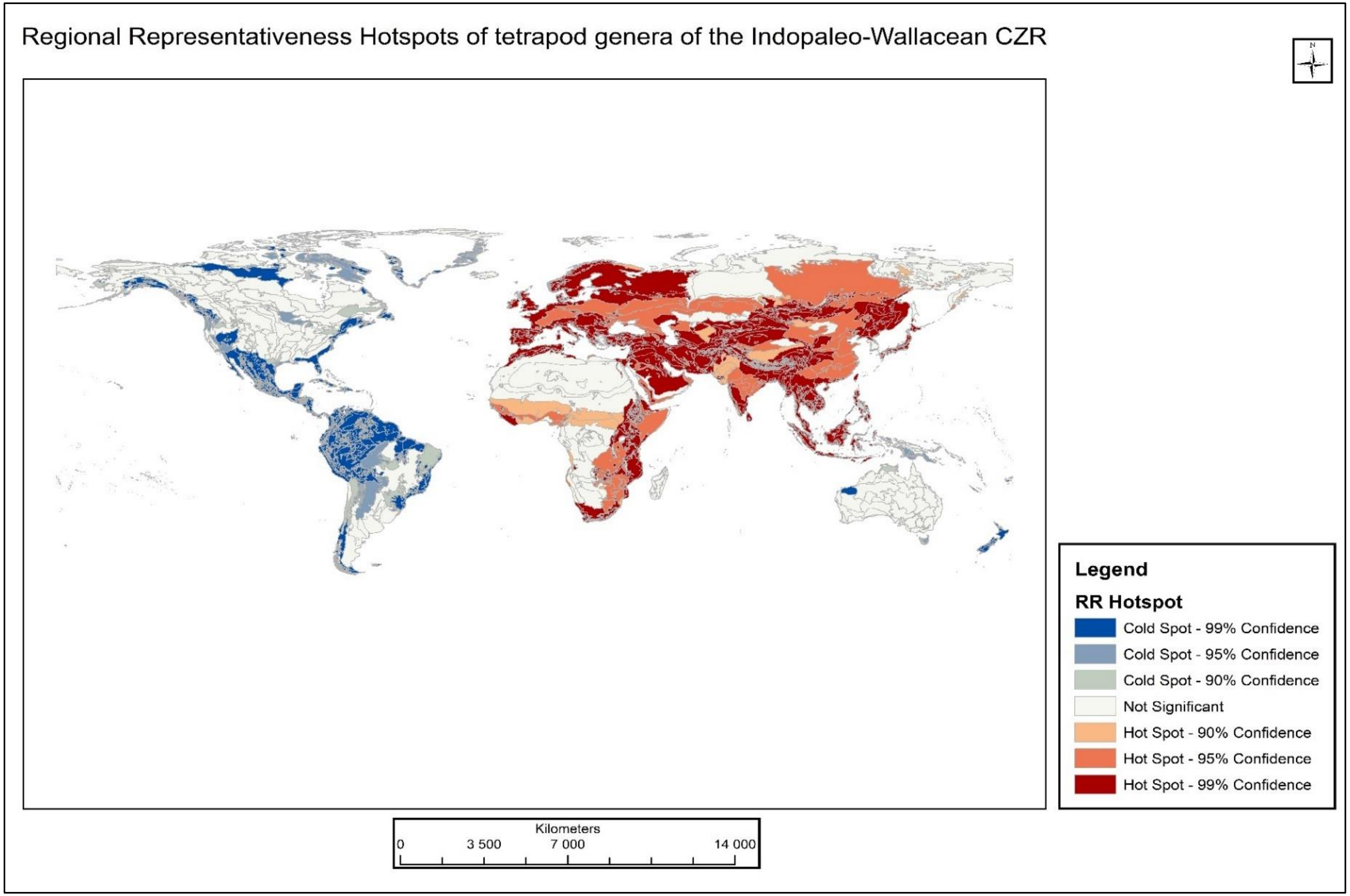


Figure 4.20: Regional Representativeness hotspots of representative tetrapod genera of Indopaleo-Wallacean combined zoogeographic region.

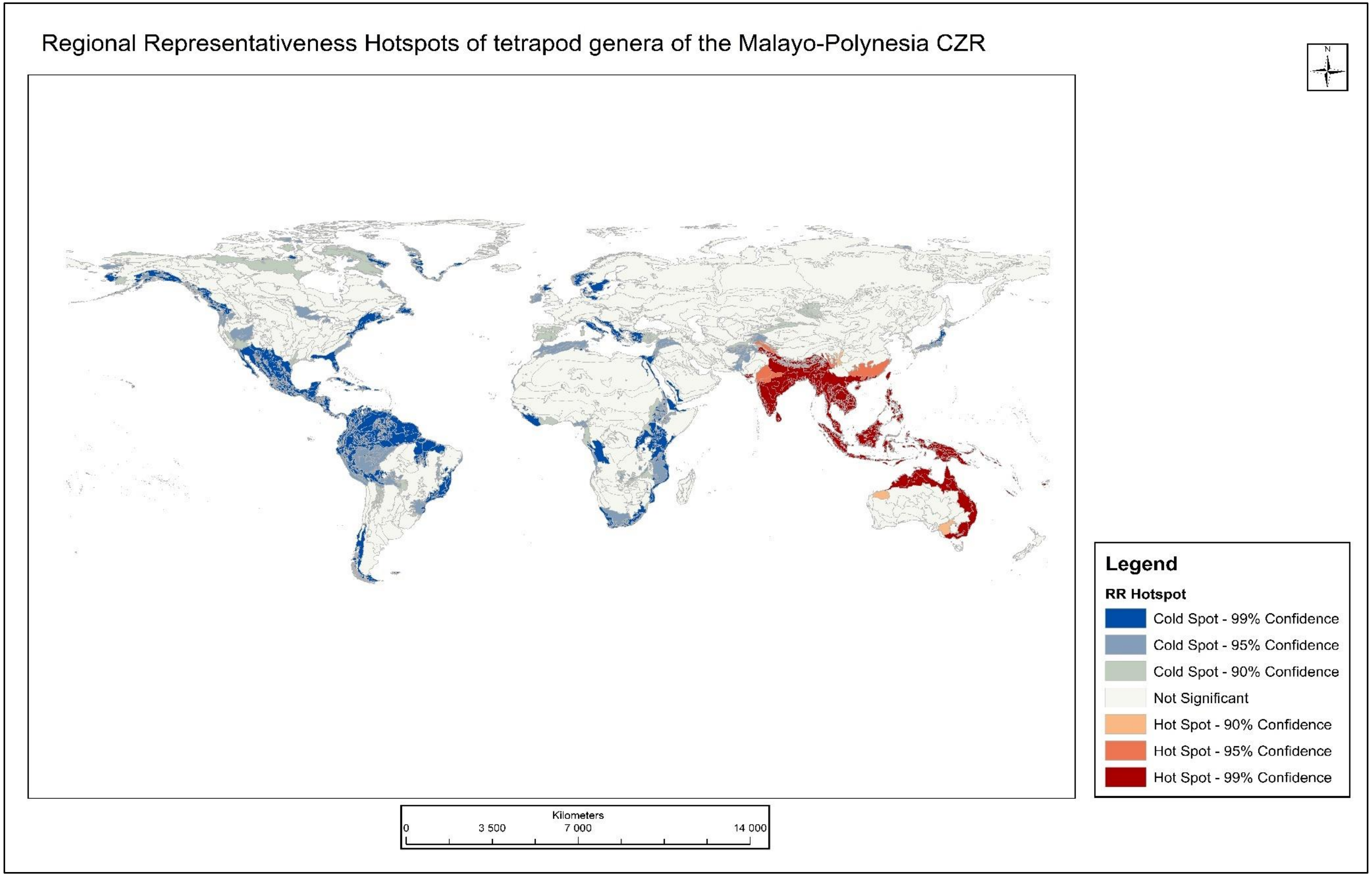


Figure 4.21: Regional Representativeness hotspots of representative tetrapod genera of the Malayo-Polynesian combined zoogeographic region.

CHAPTER 5: DISCUSSION

5.1. Regional representative hotspots

The hotspot analysis conducted on the combined zoogeographic regions (CZR) resulted in peculiar hotspots of representative genera. The regional representativeness hotspots are distributed across the southern hemisphere, located mainly along coastal ecoregions in the Neotropical, Afrotropical, Australian and Oriental regions. The *Bubulcus*, a non-passerine Aves genus, scored the highest product match of 0,64. Thus, the genus *Bubulcus* is the most representative of the Expanded Paleotropical Region. There are eight genera in total that are representative of Expanded Paleotropical Region, with all eight genera belonging to class: Aves. The *Elanus* genus representative to this region inhabits savannah-type biomes (Negro et al., 2006), which coincides with the regional representativeness hotspots' patterns.

A total of 123 ecoregions within the RR hotspots contain all eight representative genera. There are 329 ecoregions which form the regional representativeness hotspots of the combined zoogeographic region. The 282 ecoregions are predominantly located in the Neotropical Region, where there are 134 ecoregions which were highlighted as regional representativeness hotspots. Many ecoregions are highlighted as hotspots distributed in the Afrotropical and Indo-Malaysian with 76 and 71 ecoregions respectively.

The Australasian regional representativeness hotspots include six representative genera including *Myiagra*, *Todirhamphus*, *Cacatua*, *Pachycephala*, *Litoria and Lalage*. The *Myiagra* genus is the most representative genus of the Australasian Region. The *Todirhamphus* genus occupies 99 ecoregions in the Australasian Region compared to the *Myiagra* which occupies only 69 ecoregions in the Australasian Region. Although all ecoregions in which the *Myiagra* genus occupies are located in the Australasian Region, some species of the *Todirhamphus* are found in the Indo-Malaysian and Palearctic regions. This combined region essentially highlights the genera able to cross Wallace's line, and, unsurprisingly, most of these are birds, which have better dispersal abilities.

In total 123 ecoregions comprise of the regional representativeness hotspots, with 67 ecoregions located in the Australasian Zoogeographic Region. Removing the Wallacean Region from the Australasian region, as seen in Figure 4.13, increases the number of representative genera to 11. However, contrasting to the Australasian region's RR Hotspot, *Todirhamphus* and *Lalage* are not representative genera. The genus which is most representative of the Australasian Region excluding Wallacea is *Cacatua.* The Australasian excluding Wallacea produced regional representativeness hotspots comprising 84 ecoregions, where 69 ecoregions of the 84 are found in the Australian Region.

In a region which consists of Australia, New Guinea and Wallacea only, excluding Polynesia, the number of ecoregions which contain representative genera is 72, 69 of which fall in the Australasian Region. In this combined zoogeographic region, there is a total of 32 representative genera, 12 ecoregions in this combined zoogeographic region are inhabited by all 32 representative genera. The most representative genus remains *Cacatua*, the non-passerine bird genus.

The regional representativeness hotspots of the different combined zoogeographic regions in the Australasian Region show various distribution patterns. The combined region which contains the highest number representative genera and covers many ecoregions is the Austral-New Guinean combined zoogeographic region. This region can be useful for conservation purposes, as it includes a significant number of ecoregions distributed across the globe.

The Afro-Madagascan combined zoogeographic region includes 94 ecoregions, of which 91 belong to the Afrotropical Region. The ecoregions included in the regional representativeness hotspots are predominately forest, savanna, and woodlands ecoregions. Three ecoregions in the Afrotropical Region contain over 100 representative genera including Central Zambezian Miombo woodlands, East Sudanian savanna and Zambezian and Mopane woodlands ecoregion. The Central Zambezian Miombo woodlands ecoregion is one of the largest ecoregions in Africa.

There is a total of 113 genera which are representative of this region. The most representative genus is *Eidolon*, a megabat genus. The *Eidolon* genus contains two species, *Eidolon dupreanum* and *Eidolon helvum.* The *E. dupreanum* is endemic to Madagascar, and it occupies western and central island. The *E. helvum* is a wide range of bat species, which occupies the greater parts of the Afrotropical Region. The fruit bat is known to migrate to the northern savannah in Africa (Fahr et al., 2015), this movement coincides with the RR hotspots patterns, which show hotspots nested within savannah-type biomes. Once again, this highlights how animals with good movement abilities are more often representative of combined regions.

When the Indo- Malaysian Region is included to form the Paleotropical combined zoogeographic region, the number of ecoregions which form the regional representativeness hotspots increase to 225 ecoregions. There is a total of 26 representative genera of the region.

Fifteen ecoregions in total contain all 26 representative genera. The most representative genus of the region is the non-passerine bird genus *Cypsiurus*, an excellent flier.

A larger number of ecoregions are located in the Indo-Malaysian Region, i.e., 101 of the 225 ecoregions, while 97 ecoregions are situated in the Afrotropical Zoogeographic Region. In the Afro-Eurasian Region, the regional representativeness hotspots consist of 329 ecoregions, 146 ecoregions are distributed in Palearctic, and 83 ecoregions in the Afrotropical Region and 95 ecoregions in the Indo-Malaysian Region. In total there are 25 representative genera which make up the regional representativeness hotspots of the Afro-Eurasian Region.

The most representative genus is a passerine bird genus, *Sylvia*, which exhibits a centre of distribution in the Mediterranean Region, mostly migrant birds, often migrating over long distances and recorded in the data set used here for both the breeding and wintering ranges. Bird migration has been already shown to represent an important means of range expansion – even in the expansion of breeding ranges (Böhning-Gaese et al., 2006).

The Holarctic combined zoogeographic region's regional representativeness hotspots contain 268 ecoregions distributed across the Nearctic and Palearctic region. A total of 133 ecoregions are located in the Palearctic Region, 91 within the Nearctic Region and the remainder distributed within the Indo-Malaysian and Neotropical zoogeographic regions. There are 25 representative genera, with the most representative genus is a passerine bird genus, *Regulus*. Large mammal genera such as *Canis* and *Ursus* are included as representative genera.

The interchange of mammalian genera between Eurasia and North America is attributed to the Bering land bridge (Pires et al., 2015). Dispersal across this land bridge is evident from the fossil record, closely related taxa in both Eurasia and North American (Jiang et al., 2019). Large mammal families such as Ursidae and Canidae entered the Palearctic Region and diversified. The Ursidae family immigrated and diversified in the Oligocene era, whereas Canidae entered Eurasia in the Late Miocene period. Families which migrated to North America include Procyonidae and Felidae (Pires et al., 2015).

A total of 239 ecoregions are included in the RR hotspots of the Neotropic- Nearctic combined zoogeographic region, 81 are located within the Nearctic Zoogeographic Region, and 158 are located within the Neotropical Zoogeographic Region. There are 60 representative genera of the Neotropic- Nearctic Region; the most representative genus is a small mammal genus, *Procyon*. The *Procyon* genus is said to have entered the Neotropic Region during the great American biotic exchange. At this time, the isthmus of Panama was raised, and land mammals freely cross between North and South America (Newton. 2003; Cione et al., 2015). Other representative genera from the Neotropic- Nearctic CZR involved in this interchange include *Pecari*, a New World pig and *Didelphis*, a New World marsupial (Woodburne, 2010).

When surrounding islands and the Andean Zoogeographic Region are included in the Neotropic- Nearctic Region to form the Neogea CZR, the number of ecoregions included in the RR hotspots is 237. One hundred and fifty-eight ecoregions of the 237, fall within the Neotropical Zoogeographic Region and 79 ecoregions fall within the Nearctic ecoregions. An interesting finding is the lack of ecoregions highlighted as hotspots in the Andean, Caribbean, and Arctic region, although these regions are included in Neogea combined zoogeographical region.

There are 49 representative genera which form the regional representativeness hotspots, and the most representative genus is the bird genus *Podilymbus*. The Neotropical region's representative genus, *Glossophaga* (a bat) and the representative genus, *Junco* (passerine bird), of the Nearctic region are not included in the representative genera that form the regional representativeness hotspots of Neogea combined zoogeographic region. The Sierra Madre de Oaxaca pine-oak forests ecoregion contains 155 representative species, the highest number of representative species found in a single ecoregion of Neogea combined zoogeographic region.

In the Neotropic-Caribbean region, regional representativeness hotspots consist of 167 ecoregions, the majority of these ecoregions are found in the Neotropical Zoogeographic Region. There are 164 representative genera which form the RR hotspots, with the first three most representative genera consisting of bat genera. The genus which is the most representative of the Neotropic-Caribbean Region is the genus *Noctilio*. There is a total of 35463 species distributed within these regional representativeness hotspots. The Southwest Amazon moist forests ecoregion contains a high number of 478 representative species.

In the Indopaleo-Wallacean combined zoogeographic region, the regional representativeness hotspots cover 316 ecoregions located within the Palearctic, Afrotropical and Indo-Malaysian zoogeographic regions. The Afrotropical Region is not included in this combined zoogeographic region; however, a substantial number of ecoregions are distributed within the Afrotropical Zoogeographic Region, which forms the regional representativeness hotspots. A similar pattern observed in the Afro-Palearctic combined zoogeographic region, illustrating a large number of ecoregions, that form the regional representativeness hotspots, to be found in the Palearctic Zoogeographic Region, followed by the Afrotropical Zoogeographic Region.

The regional representativeness hotspots of the Indopaleo-Wallacean CZR are nested within a range of biomes, including Deserts and xeric shrublands, Tropical and subtropical grasslands, savannas and shrublands, Mediterranean Forests, woodlands and scrubs and Temperate broadleaf and mixed forests. The representative genus *Passer* possesses a similar regional pattern to that of the RR hotspot, as it inhabits mixed habitat types within the Palearctic Region. The genus's ancestral area is said to be the Saharo-Arabian belt (Finlayson, 2011).

In total, 31 genera represent this combined zoogeographic region, with the most representative genus being, *Dendrocopos*, a genus of woodpeckers. Two species of the *Dendrocopos* genus is found in the Afrotropical Region. The Malayo-Polynesian combined zoogeographic region's regional representativeness hotspots consist of 164 ecoregions, with the majority of the ecoregions located in the Indo-Malaysian Zoogeographic Region, followed by the Australasian Zoogeographic Region.

5.2. Diversification of Representative genera

Representative genera of combined zoogeographic regions are genera that are endemic to a region and possess a sizeable regional filling. These genera include two characteristics which make them unique; a) they display high levels of endemism to combined zoogeographic regions b) they have diversified and occupied large portions of the region to which they are endemic to. Representative genera not only have survived but thrived in their regions. Two concepts are highlighted endemism and diversification.

5.2.1. Historical biogeography and diversification of representative genera

Historical biogeography hypotheses have influenced the diversification of taxa. Historical events such as the formation of land bridges, vicariance events, and the movement of plate tectonics have attributed to the radiation and establishment of species (Sanmartín, 2012). Representative genera distributions are clearly trans-regional, due to the evolutional processes, which the genera and region experience. Several hypotheses contribute to the extensive range of representative genera, niche-conservatism, species interaction (Carrillo et al., 2020) and the influence of paleoclimates.

In this study the genus, *Sylvia* is representative genera highlighted in the Afro-Eurasian CZR. *Sylvia* is a megabat genus distributed in the Palearctic and Afrotropical region. The diversification of the genus is attributed to historical vicariance and dispersal events and the influence of paleoclimate shifts (Voelker & Light, 2011). The species belong to the genus *Sylvia* in particular diversified and extended its range across the Mediterranean Sea. The

Messinian Salinity Crisis (MSC) involved the desiccation and filling up of the Mediterranean Sea. Thus, forming a land bridge connecting Eurasia to Africa. The diversification of species within the *Sylvia* genus coincides with the MSC event, thus alluding to the MSC theory causing diversification within *Sylvia*.

As mentioned earlier, this genus originated in Asia. However, it extended its range crossing the Mediterranean land bridge, one the Mediterranean filled up, populations isolated from each other, thus prompting a speciation event. Diversifications of the other species within the genus are attributed to the climate variability in Asia and Northern Africa. The ancient lineage *S. communis* split thus forming a trans-Mediterranean species, approximately at a similar time to the aridification and filling of the Mediterranean, both events occurred about 5.3 and 4.9 mya (Gargani and Rigollet, 2007; Finlayson, 2011). Aridification in Asia, 3.2mya- 3 mya could be the driving force behind the formation of *S. nana* and *S. nisoria* (Voelker & Light, 2011).

In this scenario, diversification of genus *Sylvia* occurred due to climate variability and geographic barriers. Diversification of representative genus *Cacatua* was attributed to dispersal and the movement of plate tectonics. The origins of the *Cacatua* genus are said to be in the Australian region. Majority of the species within the genus are distributed among the surrounding regions of New Guinea, the Philippines, and islands in the Indonesian area (Brown & Toft, 1999). This unique pattern is due to radiation events which occurred post-dispersal.

The Australian tectonic plate detached from Antarctica and migrated towards south-east Asia around 36-41 mya (Tavarez et al., 2006), the separation triggered the development of a mosaic of vegetation, promoting the growth and expansion of vegetation such as grasslands, eucalyptus and sclerophylls thus triggering the speciation of the genus *Cacatua* (Wright et al., 2008; White et al., 2011). The presence of several species in surrounding islands challenged the Australian ancestral area of *Cacatua*.

However, fossil evidence provides evidence that the evolution of cockatoos occurred at a time when New Guinea was submerged under water (Brown & Toft, 2011; Toussaint et al., 2014). Speciation of *Cacatua* species have been explained through two hypotheses, dispersal from Australia to surrounding islands or vicariance events occurring when Australia collided into south-east Asia (Brown & Toft, 2011). As tectonic plates of New Guinean and Indonesia shifted to the position their hold currently dispersal and radiation events of *Cacatua* species took place (Brown & Toft, 2011).

Diversification of tetrapod genera is influenced by their ability to colonize and adapt to new regions. Representative genera of combined zoogeographic region display a correlation of the type of genera dispersed and the regions combined. Combinations including islands such the Wallacea, the Caribbean islands, New Guinea and Madagascar contain representative genera dominated by the class, Aves, contrary to this, combined zoogeographic regions with the absence of islands mainly contain representative genera belonging to classes, Mammalia, Rodentia Reptilia and Amphibia.

The Holarctic combined zoogeographic region displays this pattern as there are several Mammalian genera which are representative to the region including *Ursus, Canis*, *Cervus* and *Mustela*. This pattern of distribution can be attributed to the dispersal abilities of land animals. These classes are somewhat limited in their ability to migrate to another region without a land bridge of physical connection of the two regions. Pires et al. (2015), discussed the migration of mammals from Eurasia to North America and vice versa, highlighting the key mammal families which migrated. The Great America Interchange mainly consisted of the migration of mammal species (Webb, 1976; Carrillo et al., 2015).

The Australasian combined zoogeographic region's representative genera are only from class: Aves. Birds are considered highly vagile taxa which promotes dispersal within and between islands (Valente et al., 2017). Combined zoogeographic region's representative genera are majoring from Class: Aves. The combinations of the Malayo-Polynesian combined zoogeographic region contain only volant taxa, thus confirming the predominant presence of birds as representative genera on combined zoogeographic region with islands.

Climate variability and diversification

Climate variability across millennium timescales have long been thought to promote diversification and specification patterns of species seen today; however, the role of periods of long-term climate stability is the driving force which maintains diversity (Theodoridis et al., 2020). Periods of climate stability are viewed as refugia for older species and a driver for the generation of new species (Fordham et al., 2019). Milankovitch climate oscillations are large scale climate variations which impact species geographic distribution.

An extended period of lasting climate conditions post-variation increases speciation, as new conditions isolate species. Isolation due to the new condition lasts long enough for speciation to be completed (Dynesius & Jansson, 2000). Regions with lasting climate stability are hosts for diversity hotspots. The regional representativeness hotpots found in this study coincide with this theory. Fordham et al. (2019) mapped climate stability patterns over the Earth between the last Glacial Maximum and large-scale industrialisation (Fordham et al., 2019).

The map produced highlighted regions with extreme climate stability, which were restricted to the tropics. Highlighted regions included northern Neotropical, central Afrotropical, the Australasian region, and south-east Asia (Fordham et al., 2019). This resemblance coincides with the regional representativeness hotspots of this study, corresponding to northern Neotropical, central Afrotropical, and the Australasian regions. Fjeldså and Lovett (1997) discussed the museums and cradles of diversity in Africa, which was attributed to stable eco climates, thus confirming the findings found regarding hotspots in the Afrotropical region.

5.3. Combined zoogeographic regions

Zoogeographic regions were combined to analyse the possible differential hotspot patterns that may result. Regional representativeness hotspots produced, used ecoregions as geographic units. Regional representativeness hotspots differ from prior biodiversity hotspots schemes, as it accounts for endemicity and regional filling. On the contrary, other hotspot schemes account for only endemic species (Myers, 1990; Mittermeier et al., 2011; Williams et al., 2011).

The number of ecoregions which form hotspots of combined zoogeographic regions differs with different combinations of the zoogeographic region. The Australian CZR, when combined with New Guinea and Polynesia, contains a higher number of ecoregions than the Australian, New Guinea and Wallacea combination. However, when all regions are combined, Australian, New Guinean, Wallacean and Polynesia, is consists of a higher number ecoregions within the RR hotspot.

The Neotropical Zoogeographic region's regional representativeness hotspots consist of 171 ecoregions, however, when combined with the Nearctic Region, the number of ecoregions increase to 239. There is a significant increase in ecoregions within hotspots when the Palearctic Region is combined with the Afrotropical Region, the number ecoregions increase to 329, contrary to the Palearctic Region's regional representativeness hotspots covering only 193 ecoregions.

Zoogeographic regions share a common evolutionary history, as all regions were joined at one frame in time. Several taxa share common evolutionary histories which account for sister lineages distributed across the World. The interactions between zoogeographic through time have shaped the ecosystems, landscape, and species distribution patterns visible today. Thus, it is imperative to account for these interactions when delineating representative hotspots.

Regional-based conservation requires a representative scheme (Groves et al., 2002). Thus, the footprint of significant historical events such as land bridges, dispersal, vicariance and significant climate variations is incorporated in regional representativeness hotspots. Regional combinations such as Neotropical and Nearctic, Afrotropical, and Palearctic and the Nearctic and Palearctic, share a history of vicariance and dispersal events. These interactions are confirmed by He et al. (2020), who states the presence of relict species in India, closely related to African and Madagascan lineages (He et al., 2020).

Compared to other biodiversity hotspots, regional representativeness hotspots include a greater number of ecoregions within the hotpots. Global biodiversity hotspots scheme described by Mittermeier et al. (2011) based on Myers' 1990 scheme, is currently one of the schemes used for conservation. Myers (1988) described one of the first biodiversity hotspots schemes. The criteria used for his scheme included endemic species plants and high levels of habitat loss.

Conservation International adopted Myers hotspots and created more structured criteria to recognize hotspots. A hotspot had to have experience at 60% or more habitat loss while containing at least 1500 vascular plants. Mittermeier et al., 2004, revised the biodiversity hotpots by adding regions and redefining the then-current hotspot scheme's borders. The revision highlighted 34 biodiversity hotspots, 25 of which contain 35% of endemic vertebrates. Global priorities for conservation include biodiversity hotspots, which have a high diversity of specialised species (Noroozi et al., 2018). Williams et al. (2011), added a 35th hotspot in the form of the Forests of East Australia.

Biodiversity hotspots are distributed across all zoogeographic regions. Mittermeier et al., 2011, biodiversity hotspots contain 374 ecoregions in total (Mittermeier et al., 2011); in contrast, the regional representativeness hotspot of one combined zoogeographic region, Afro-Eurasia, includes 329 ecoregions. The combination of regions, as opposed to singular regions, results in highlighting more hotspots.

The recognised global biodiversity hotspots (Mittermeier et al., 2011) highlight at most ten hotspots per continent, which are mainly concentrated in the tropics, with few in temperate regions. This is evident when the biome types of the global biodiversity hotspots are analysed (Mittermeier et al., 2004). Biomes not included in global biodiversity hotspots consists of the mangroves, tundra, boreal forest/taiga and flooded grasslands and savannas.

Regional representativeness hotspots include all 14 biomes described by Olson et al. (2001). The biomes which are not included in the global biodiversity hotspots can be found within combined zoogeographic region Australasian (Mangrove biomes), Holarctic (Tundra and Boreal forest/Taiga) and the Neotropic- Nearctic (Flooded grasslands and savannas).

The global biodiversity hotspots within the Neotropical are concentrated around the Cerrado ecoregion and the eastern coast of the Neotropical and Andean region. Ecoregions which form the Amazon rainforest is not included as a hotspot. On the contrary, regional representativeness hotspots of the Neotropic- Nearctic combined zoogeographic region, include the Cerrado ecoregion and the ecoregions that the Amazon rainforest.

The Afrotropical zoogeographic regions contain eight biodiversity hotspots, with the coastal ecoregions around Africa highlighted as hotspots and one hotspot, Eastern Afromontane, within the continent. Several ecoregions are excluded from the biodiversity hotspot, leaving these regions prone to biodiversity loss. Regional representativeness hotspots of the Afro-Eurasian combined zoogeographic region includes 83 ecoregions within the Afrotropical region, thus covering more areas.

Regional representativeness hotspots of combined zoogeographic regions cover a larger area than global biodiversity hotspots. A significant omission to biodiversity hotspots is the Amazon and Papua New Guinean. These regions are rich in evolutionary history and biodiversity. This poses the question of the nature of this scheme, and the weighting of habitat loss and conserving endemicity in delineating hotspots.

High biodiversity areas which are not threatened to the extent specified by the criteria for global biodiversity hotspots are recognized as "major tropical wilderness areas" (Mittermeier et al., 2004). These areas are still considered a prioritization for conservation. These wilderness areas include The Congo Forests of Central Africa, The island of New Guinea and the Amazon basin (Mittermeier et al., 2004).

The Amazon basin ecoregions, due to the presence of a significant number of representative genera, is a regional representative hotspot. The island of New Guinean is highlighted as a RR hotspot of the Australasian combined zoogeographic region. All ecoregions of the Congo forest are included as RR hotspots, including the swamp forest ecoregions, central lowland, and the boarding savanna-mosaic forest ecoregions.

5.4. Conservation of Regional Representativeness Hotspots

Diversity hotspots are comprised of specialised taxa with small geographic ranges. High specialisation of species increases vulnerability to climate change, anthropogenic activities, and other environmental disturbances (Dynesius & Jansson, 2000). Mittermeier et al., 2004, highlighted 34 biodiversity hotspots, 25 of which contain 35% of endemic vertebrates. Conservation planning was structured around these biodiversity hotspots. Global priorities for conservation include biodiversity hotspots, which have a high diversity of specialised species (Noroozi et al., 2018). As mentioned above the extensive ecoregional cover of regional representativeness hotspots differs from global biodiversity of hotspots of Mittermeier et al. (2011).

The Afrotropical Zoogeographic Region contains 288 ecoregions which fall under regional representativeness hotspots, as mentioned above when combined with the Palearctic (Eurasia), the number of ecoregions within RR hotspots increase to 329. Global biodiversity hotspots contain eight biodiversity hotspots, with the coastal ecoregions around Africa highlighted as hotspots and one hotspot, Eastern Afromontane, located deep within the continent.

Several ecoregions are excluded from the biodiversity hotspot, leaving these regions prone to biodiversity loss. The 83 ecoregions within the regional representativeness hotspots of the Afro-Eurasian combined zoogeographic region thus covers a more extensive area. Conservation of regional representativeness hotspots could result in the protection of a more significant area.

The conservation of hotspots entails protecting levels of endemism within its ecoregions. Two types of endemic taxa are present within the regional representativeness hotspots, paleo-endemic or neo-endemic taxa. Paleo-endemic taxa refer to ancient lineages which had diversified over millions of years, neo-endemic taxa are newly formed taxa which are rapidly diversifying (Harrison & Noss, 2017).

The diversification patterns seen in representative genera, *Cacatua* and *Sylvia* as well as families including Felidae, Canidae and Ursidae are considered neo-endemic. Diversification patterns illustrated on islands give rise to several neo-endemic species, as islands promote burst diversification post-migration (Veron et al., 2019). The importance of conservation of these types of endemics has been a topic of debate. Efficiency and effectiveness are the questions often asked. However, several scientists believe that conserving paleo-endemic taxa results in conserving ancient lineages, multiple character states and years of evolutionary adaptation (Kier et al., 2009).

A mixture of neo- and paleo-endemic taxa inhabit these RR hotspots; representative genera may be considered paleo-endemic; however, on a species level, neo-endemism prevails. The lack of neo-endemics in regions with highly diversified taxa was also noted by Veron et al. (2019).

5.5. Recommendations

The efficiency and definition of global biodiversity hotspots have long been critiqued, and there has been a call for change in an approach for delineating hotspots. The popularity and immense financial back led to significant scrutiny of the science behind these hotspots (Kareiva & Marvier, 2003). Global biodiversity hotspots cover already degraded habitat but fail to highlight the currently degrading habitats.

Regional representativeness hotspots cover regions which are under immense anthropogenic pressure and those which have increasing anthropogenic pressures. Ecoregions included in the biodiversity hotspots and those regions that fall under the category of increasing degradation are included in regional representativeness hotspots. Regions including The Congo Basin and the Amazon Basin which are experiencing an increase in habitat degradation due to increase in human population (Williams, 2013), are highlighted as representative hotspots whereas, in the global biodiversity hotspots scheme, these regions do not meet the criteria to be included as hotspots.

There are multiple approaches in using regional representativeness hotspots, the particular characteristic which should take precedence is the holistic nature of the RR hotspots. Regional representativeness hotspots can be used for its representative genera or conservation centred around the ecoregions which are included in these hotspots. There are two approaches when using regional representativeness hotspots for conservation, one of a reactive nature and one of a proactive nature (Brooks et al., 2006).

A proactive approach to conservation planning should use regional representativeness hotpots as biogeographic units. Regional representativeness hotspots exhibit a coarse resolution; thus, hotspots within the hotpots can be demarcated for a finer-scale and more accurate planning (Noroozi et al., 2018).

Brooks et al. (2006) defined proactive planning as "prioritising areas of low threat but high irreplaceability". Regional representativeness hotspots are areas with high irreplaceability and therefore, should be conservation priorities. Prioritizing regional representativeness hotspots could preserve biodiversity while providing aid to the communities within priority ecoregions. Funding for hotspots channels financial aid in the form of incentive programs for communities to protect representative species in their areas.

The involvement of local communities and their environmental education is vital in achieving the overall goals of sustainability and biodiversity conservation (Willis et al., 2007; Navarro-Perez & Tidball, 2012). The education of communities contributes to their understanding of the biodiversity crisis and their participation in alleviating anthropogenic pressures on biodiversity. Biodiversity hotspots can be utilized as a tool in environmental education, regional representativeness hotspots contain genera which hold great environmental value and possess a rich historical value.

Regional representativeness hotspots can be used as a tool in teaching the of biogeographical concepts. The holistic approach with which regional representativeness hotspots are derived, makes the concept ideal for understanding a regions ecosystem, processes, and history. Biogeographical research discusses the possible evolutionary events which shaped species distribution in a region. Regional representativeness hotspots can highlight these events and can be useful in gaining in-depth understanding and a holistic perspective, by analysing representative genera and their evolutionary histories (Willis et al., 2007).

Ultimately, regional representativeness hotspots utilized as a tool in biogeographical research and in the education of communities, creating awareness of a region’s biodiversity. However, both uses aim to achieve one goal, the protection of biodiversity.

CHAPTER 6: CONCLUSION

This study aimed to investigate a gap in conservation biogeography and address it by delineating regional representativeness hotspots. These consist of areas with high diversity of genera with high levels of endemism and regional filling. The versatility and suitability for conservation planning, of these hotspots, is attributed to the rich evolutionary history they contain.

The combined zoogeographic region, including the Neotropic-Nearctic, the Afro-Eurasia and the Holarctic regions displayed high numbers of representative genera. Regional representativeness hotspots are nested within similar biomes to which representative genera are known to inhabit. Ecoregions which highlighted as hotspots are mainly located in the tropics. RR hotspot patterns also resemble biodiversity hotspots described by Mittermeier et al. (2004), while also showing marked differences in some cases.

The evolutionary history within and across regions can be illustrated by the diversity of characteristic taxa they hold. Events such as continental drift, plate tectonics, climate oscillations (Dynesius & Jansson, 2000) and dispersal (Cione et al., 2015) were responsible for the unique array endemism patterns found within combined zoogeographic regions. Diversification was triggered by several events, including aridification and vicariant processes (Tavarez et al., 2006).

Species are going extinct at a faster rate than projected (Ceballos et al., 2015). This accelerated extinction rates caused by climate change and anthropogenic activities has shifted the dynamic of every discipline, to focus on conserving and preserving biodiversity. The need for innovative conservation strategies has increased rapidly as the loss of biodiversity increases. Regional representativeness hotspots cover extensive areas within regions, thus bringing aid to these regions' biodiversity and social communities. The need for robust and dynamic conservation action is long overdue, and this can be achieved by incorporating regionalisation into conservation strategies.

Regional representativeness hotspots can serve as a tool for conservation planning. There is a shift from conserving single species to conserving whole regions. Single-species conservation strategies are a reactive approach to conservation and should be reserved for urgent conservation action (Brooks et al., 2006). On the contrary, conservation which focuses on hotspots and regions is a proactive approach, which serves as a preventative measure to biodiversity loss. It is hoped that this study has contributed to incorporating bioregionalization into this proactive approach.

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