Chapter 14
The Future of New Zealand Lizard Research

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Abstract This book provides the first detailed synthesis of the history, fossil record, taxonomy, biogeography, ecology, diseases, physiology, sampling methods, life history, and reproduction and conservation of the New Zealand lizard fauna. In collating our current knowledge of New Zealand lizards, it has been possible to critically assess the lizard research that has been conducted on New Zealand species. Conservation, the development of sampling and monitoring methods, and the pioneering ecological studies conducted in the 1950s–1970s represent the clear strengths of this research. In contrast, the main areas of deficiency relate to a failure to publish research findings, a narrow focus on conservation-related research, a slow rate of species description, and a limited awareness of the value of natural history collections. To rectify these weaknesses, several priority research directions are outlined. These include (1) comparative osteological studies; (2) taxonomic research; (3) biogeographic studies; (4) detailed investigations of ecology, physiology, reproduction, and life history; (5) research into how lizard populations persist on the main islands in the presence of mammalian predators; (6) quantitative studies examining the value of mainland conservation sanctuaries; and (7) quantification of the impact of the plague skink on the native New Zealand biota.

Keywords Biogeography • Conservation • Disease • Ecology • Fossil record • Gecko • Life history • Physiology • Reproduction • Sampling methods • Skink • Species discovery • Taxonomy

14.1 Our Current Knowledge of the New Zealand Lizard Fauna

This book represents the first comprehensive synthesis of the New Zealand lizard fauna and outlines the current state of our knowledge of its history, fossil record, taxonomy, biogeography, ecology, life history and reproduction, diseases,

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physiology, sampling methods, and conservation. Here I summarise the key aspects of each chapter, provide a critical assessment of the strengths and weaknesses of lizard research in New Zealand, and outline several priority areas for future research.

Shea (2016) outlined that discovery of lizard species in New Zealand began with Māori in the thirteenth century and continues through to today. A key moment in the history of New Zealand lizard research was the transition from European-based scientists (who were predominant during the 1800s) to the locally based researchers who have progressed our knowledge of the fauna since the 1950s. As knowledge of the New Zealand lizards increased in the 1970s, upsurge in the number of field-based ecological studies occurred. Similarly, the rise of the molecular age in the 1980s was accompanied by a large spike in taxonomic activity and species description, a trend that has continued (albeit slowly) through to the present day. Interestingly, different authors in the book hold divergent views as to the origin of the world's largest known gecko, the kawekaweau, or *Hoplodactylus delcourti*. Shea (2016) concludes that it is a New Zealand species, whereas Worthy (2016) argues that, due to the lack of fossil material, it most likely originates from elsewhere in the Pacific (e.g. New Caledonia). Ancient DNA methods may hold the key to solving the mystery of the origin of this enigmatic specimen.

Worthy (2016) provided the first detailed review of the available fossil material for New Zealand lizards. The oldest known fossil deposit containing lizards is from the Miocene (19-16 mya; St Bathans Fauna), with representatives of both extant lineages present (diplodactylid geckos and Eugongylinae skinks). There is then a large gap in the lizard fossil record until the quaternary (within the last 50,000 years). The quaternary fossil record provides us with a glimpse of the diversity and distribution of lizards prior to the arrival of humans. However, this record is biased towards large-bodied species, and our ability to interpret it is hindered by the limited comparative osteological material held in museums for extant species. Thus, it is currently difficult to confidently assign fossil material to, or distinguish from, currently recognised species.

In Chap. 4, Hitchmough et al. (2016a) discussed how a wealth of recent taxonomic activity and new species descriptions, driven by molecular studies, has resulted in a near trebling of the known extant lizard fauna in New Zealand (from 38 in the 1980s to 104 at last count). This massive increase in species discovery is due to both the splitting of previously widespread, single species into multiple taxa (i.e. the identification of cryptic taxa) and the discovery of new taxa, generally in remote regions of the country. Unfortunately, the rate of species description has not kept pace with the accelerated rate of species discovery, and almost half (45 %) of all recognised lizard species remain to be formally described. All native skinks in New Zealand are currently assigned to *Oligosoma*, with eight main genetic clades within the genus. The relationships among clades are poorly resolved, and no reliable characters have been identified to distinguish among each genetic clade. Taxonomic work is currently in progress to formally describe the ~22 undescribed taxa (G.B. Patterson and S. Melzer, unpublished data; B. Barr, R. Hitchmough, D.G. Chapple, unpublished data). Seven gecko genera are recognised in

New Zealand, with each readily diagnosable. A taxonomic monograph is currently in preparation, which will formally describe the majority of the ~25 undescribed gecko taxa in New Zealand (R.A. Hitchmough, S.V. Neilsen, A. Bauer, unpublished data).

Geckos colonised New Zealand during the Eocene-Oligocene, well before the skinks, which arrived in the country during the Miocene. In Chap. 5, Chapple and Hitchmough (2016) highlighted how previous studies of the processes that have influenced the biogeographic patterns of New Zealand lizards have been hampered by post-human range contractions and extinctions, as well as by a limited grasp on the true diversity of the native fauna. However, improved knowledge of the quaternary lizard fossil record (Worthy 2016) and species boundaries and distributions (Hitchmough et al. 2016a) has allowed more detailed biogeographic analyses to be conducted. Key historical processes that have been identified include (1) sea level changes during the Pliocene-Pleistocene in northern New Zealand, (2) the Pliocene marine inundation of the lower North Island, (3) the impact of water barriers such as Cook Strait (separating the North and South Islands) and Foveaux Strait (separating the South Island and Stewart island), (4) tectonic activity along the Alpine Fault, and (5) regional north–south differentiation within the South Island. In addition, an updated list of 22 biogeographic categories was provided for New Zealand lizards. Interestingly, New Zealand lizards exhibit the signature of allopatric speciation, with minimal overlap in geographic distribution among species within the same genus or clade, but substantial geographic overlap (and widespread sympatry) among species from different clades or genera.

Hare and colleagues (2016) emphasised that detailed information on a range of fundamental ecological traits, such as habitat use, is still lacking for the majority of New Zealand lizard species. Indeed, few detailed, long-term ecological studies have been completed, and the vast majority of our knowledge stems from short-term, or anecdotal, studies. Despite these issues, New Zealand lizards appear to display a range of interesting, or rare, ecological traits. A small number of species are habitat generalists, but most have specific habitat requirements, and high levels of sympatry exist in some environments. Although most skink species are terrestrial, only 30 % of geckos are classed as terrestrial. Many New Zealand lizard species exhibit evidence for strong site fidelity, often over a period of several years. Diet has only been reported for ~40 % of species, with most appearing to be omnivorous. New Zealand lizard species may play a key role in seed dispersal and pollination; such lizard-plant interactions have rarely been reported elsewhere in the world. Temporal niche shifts appear to be widespread in New Zealand lizards. The lizard fauna comprises both nocturnal skinks (7 %; globally, most skinks are diurnal) and diurnal geckos (36 %; geckos are ancestrally nocturnal). The courtship and mating behaviours of native species are poorly known, though sociality, which is rare internationally (Gardner et al. 2016), is present in some New Zealand lizards. A range of avian, mammalian, reptilian, and invertebrate predators of New Zealand lizards have been documented. New Zealand lizards, and particularly geckos, use colour for crypsis and camouflage. Finally, Hare et al. (2016) described vocalisations and defence behaviour in geckos.

Cree and Hare (2016) highlighted that New Zealand lizards are characterised by 'slow' life histories. Many species exhibit low annual reproductive output when compared with similar species overseas, and several gecko species have fewer than two offspring each year (gecko species worldwide are limited to a maximum clutch size of two). However, New Zealand lizard species are generally long-lived, with several species documented to live for as long as 30–50 years, and this may, in part, explain the 'slow' life histories. Probably as a consequence of New Zealand's cold climate, virtually all native lizard species (except *O. suteri*) are viviparous. Temperature also influences gestation length in females, and some species exhibit prolonged pregnancies, where fully developed young are retained in utero over winter (i.e. biennial reproduction). Although it is difficult to determine the sex of juvenile or subadult lizards, sexual dimorphism is common in adults of some species. Where sexual dimorphism is present, males generally have larger heads and females larger body size (snout-vent length). Information on reproduction and life history is essential for effective captive breeding programmes and to assess the vulnerability of species to decline.

Gartrell (2016) provided a detailed overview of the diseases and parasites of native, and captive, reptiles in New Zealand. He summarised the leading causes of mortality and provided a review of the specific diseases that can impact reptiles in New Zealand. This information is not only important to ensure the health of wild populations, but it can assist in the husbandry of captive populations maintained as part of conservation programmes. The chapter also highlights the risks posed by diseases and parasites that are carried by exotic species entering New Zealand and emphasises the need for strong biosecurity protocols (see Heath and Whitaker 2015; Chapple et al. 2016a).

Hare and Cree (2016) examined the thermal and metabolic physiology of New Zealand lizards, providing details of how the lizards may have adapted to cold climates, as well as information that is useful for the conservation of native species. New Zealand lizards maintain lower field body temperatures (no species voluntarily exceeds 34 °C) than lizards elsewhere in the world, with New Zealand species displaying low critical thermal minimums and left-shifted thermal performance curves for sprint speed. As expected, metabolic rate increases with body temperature, and warm daytime temperatures, coupled with active basking in most species, assist lizards to maintain essential physiological functions, including embryonic development and digestion. The nocturnally foraging lizard species, in particular, have physiological adaptations (including low energetic cost of locomotion, but high rates of evaporative water loss) to improve performance at the low temperatures at which they are active. Understanding the thermal biology of lizards is useful for many aspects of the conservation of New Zealand species.

The ability to catch lizards, and identify individuals, is an essential component of virtually all studies on New Zealand lizards. Lettink and Hare (2016) provided an overview of the main methods used to sample lizards: systematic searching, live trapping, and artificial retreats. Given the growing ethical concern over toe clipping as a permanent identification method for lizard studies, the chapter also provided consideration of alternative methods for marking lizards for identification.

However, the chapter also highlighted how toe clipping has allowed long-term marking of individuals (which is important in New Zealand, where there is a predominance of long-lived species) and contributed to our knowledge of species longevity, delayed maturity, biennial reproduction, habitat use, dispersal, and population dynamics. The methods outlined in the chapter will allow effective sampling and study of the entire New Zealand lizard fauna, which is vital for effective conservation management.

Towns and colleagues (2016a) emphasised that 83 % of the New Zealand lizard fauna is currently listed as threatened or at risk. The key drivers of decline are invasive mammals, habitat clearing, and climate change. Case studies were used to examine the effectiveness of conservation management of New Zealand lizard species over the past 30 years. Of the five skink species that have been managed continually over this time, two of them now have improved conservation status; two initially declined, but then improved in response to adaptive management; and the plight of the final species has worsened. Clear evidence that conservation efforts can improve the fate of threatened species exists, particularly for those that inhabit offshore islands. Nelson et al. (2016) examined the potential for lizard conservation within mainland sanctuaries. Although the approach holds promise, as mainland conservation sanctuaries occupy a larger area than all offshore island reserves combined, several issues exist. Again, using a case study approach, it is suggested that low-medium predator control is insufficient to ensure positive conservation outcomes for lizards in unfenced sanctuaries. Whilst the conservation benefits for lizards are greater within fenced sanctuaries, the establishment and maintenance of such reserves is very expensive and yet fails to permanently exclude mice, which may be a significant issue for lizard populations. To date, most research on the role of mainland sanctuaries for lizard conservation has focused on skinks, with comparatively little data available for geckos.

Only one species of exotic lizard, the plague skink (*Lampropholis delicata*), has successfully established and become invasive in New Zealand. Chapple and colleagues (2016b) outlined the first arrival in the mid-1960s, from a single source region in northern New South Wales in eastern Australia. Its subsequent spread across the North Island has been characterised by human-assisted jump dispersal. Bioclimatic modelling indicates that the species has the potential to spread across the majority of the North Island and into the Nelson-Marlborough and Canterbury regions of the South Island. Within New Zealand, the plague skink is a habitat generalist, exhibits sexual dimorphism, lays its eggs communally, and exhibits similar reproductive patterns to its native Australian conspecifics. Recently, the plague skink has spread to several conservation-sensitive offshore islands, and it has the potential to spread to others. Thus, effective management strategies are urgently needed to eradicate and/or mitigate the spread of the species within New Zealand.

14.2 A Critical Assessment of New Zealand Lizard Research

I have been involved with New Zealand herpetology for 12 years and have had numerous conversations with friends and colleagues about how lizard research is conducted in New Zealand. However, as I have been based in Australia for the majority of this time (since mid-2007), I have also had an opportunity to view it from afar (well, at least from across the ditch) and gain a perspective of how lizard research is done in New Zealand relative to elsewhere in the world. Here I outline my opinions about the strengths and weaknesses of New Zealand lizard research. The primary aim of this exercise is to spark constructive discussion among New Zealand lizard researchers and, ultimately, facilitate a reassessment of the way in which herpetological research is conducted in the country.

14.2.1 Strengths

Whilst there are several groups with strong and internationally recognised research programmes in physiology (e.g. Alison Cree, University of Otago) and conservation translocations (Dave Towns, Department of Conservation/Auckland University of Technology; Nicola Nelson, Victoria University of Wellington), here I focus on three areas that represent broader strengths within New Zealand herpetology.

1. Conservation New Zealand lizard researchers have a strong conservation ethos and awareness, a trait that is not as widespread elsewhere in the world. (Indeed, I developed my research interest in conservation biology during my 3 years in New Zealand.) Although the native lizard fauna was only awarded full legislative protection in the 1980s (Towns et al. 2016a), New Zealand has pioneered, and is rightly seen as a world leader in, conservation translocations (reviewed in Towns et al. 2016b) and the use of mainland sanctuaries (reviewed in Nelson et al. 2016). These approaches have supported and enhanced intensive in situ conservation efforts on native lizard species (reviewed in Nelson et al. 2014; Hitchmough et al. 2016b; Towns et al. 2016a). Additionally, an awareness of the factors that drive extinction risk in New Zealand lizards (reviewed in Tingley et al. 2013), coupled with comprehensive and regularly updated threat lists for lizards in New Zealand, by the Department of Conservation (Hitchmough et al. 2016c), is used to prioritise lizard conservation efforts. Importantly, these conservation approaches often involve collaborations with community groups and other conservation organisations.

2. Development of Sampling and Monitoring Methods Given the low abundances of lizards in several locations (e.g. mainland locations with high densities of mammalian predators), as well as their cryptic nature, New Zealand lizard species may be difficult to detect or sample. Thus, researchers in New Zealand have spent considerable time developing new lizard sampling techniques, or modifying existing methods to suit the local species and environment (reviewed in Lettink and Monks 2016; Lettink and Hare 2016). This has provided the techniques required to effectively sample and monitor lizard species across a broad range of habitats and environments.

3. Pioneering Ecological Studies The early ecological studies (e.g. Barwick 1959; Whitaker 1968, 1973; Towns 1975) generated a treasure trove of data and information on the ecology, life history, behaviour, reproduction, and conservation of New Zealand lizards (Bartle 2016). The success of these studies stemmed from their establishment of long-term monitoring sites, allowing them to examine, among other things, seasonal and annual trends, mating behaviour (Barwick 1959), diet (Barwick 1959; Towns 1975), and the impact of invasive mammals (Whitaker 1973). Sadly, such studies are now rare in New Zealand (see Sect. 14.2.2).

14.2.2 Weaknesses

1. Failure to Publish Research 'If it's not published, it hasn't been done' (Scott Keogh, pers. comm.). This was the adage that was drummed into me by my PhD supervisor. Research that has not been published not only withholds potentially useful information from the scientific community, but also leads to situations where the same (or similar) research is conducted on multiple occasions. However, a large amount of our knowledge of New Zealand lizards is held in unpublished works and is therefore not readily accessible (Chapple 2016). This may be a consequence of the relatively high proportion of New Zealand researchers that are based in government departments or environmental consulting agencies, where publication expectations, pressure, and/or time available to publish their research findings in scientific journals is lower than for university researchers. However, recent years have seen a proliferation in the number of biological sciences journals, thereby increasing the number of options for publishing research on New Zealand lizards. Whilst the abundance of unpublished student theses is an issue worldwide, it acts to accentuate the situation in New Zealand. The formation of online thesis repositories by New Zealand universities has acted to increase the broader accessibility of more recently completed student theses, but inclusion in these repositories requires approval by students, and their studies have not been through the peer-review process.

2. Conservation Focus at the Expense of High-Quality Ecological, Evolutionary, and Physiological Research Given that 83 % of the diverse, native lizard species are listed as threatened or at risk (Towns et al. 2016a; Hitchmough et al. 2016c), it is understandable that New Zealand research has a strong conservation focus. For instance, ~50 % of talks on lizard research at recent Society for Research on Amphibians and Reptiles in New Zealand (SRARNZ; 2011, 2013,

2015) conferences have conservation as their primary focus (compared to ~10 % at recent Australian Society of Herpetologists conferences; 2014–2016). It appears that a widely held attitude exists in New Zealand that if a research project does not have a 'direct' conservation benefit, then it should not be conducted, or at least that it represents lower priority research. This warrants consideration of what exactly 'direct conservation benefit' actually means. As highlighted throughout this book, without a proper understanding of the key aspects of a species' biology, we cannot fully understand the species, thereby restricting our ability to conduct effective conservation-focused research. For example, there needs to be a greater appreciation of the nexus that exists among thermal physiology, endocrinology, reproduction, response to climate change, and conservation.

Increasing our understanding of the ecology, life history, reproduction, and physiology of New Zealand lizards will require the completion of rigorous (i.e. sufficient sample sizes, appropriate controls, standardised survey techniques), well-designed, long-term field studies. In addition, greater emphasis needs to be placed on getting the full benefit out of those lizards that are caught or sampled during these studies, even when the study has a conservation focus. This includes determining the sex of individuals, taking a range of morphometric measurements, collecting a tissue sample for genetic and/or taxonomic studies (see below), documenting the presence of ectoparasites, and marking individuals for subsequent identification (see Lettink and Hare 2016). If such an approach was part of the standard fieldwork protocol for New Zealand studies, it would help to address the numerous knowledge gaps identified by the contributing authors throughout this book and ultimately contribute to conservation efforts.

3. Slow Rate of Species Description and a Departure from the Linnaean System Taxonomy underpins all aspects of biological research as it provides names, diagnoses, and distributions for all species. The published descriptions provide the scientific community with the rationale and supporting data for the recognition of the species. Thus, undescribed species are generally not formally recognised by government agencies and international conservation organisations. For instance, undescribed species are ineligible for conservation listing by the IUCN (2016) and therefore have been excluded from recent global analyses of the conservation status of reptiles (Böhm et al. 2013, 2016; Meiri and Chapple 2016). So, it is unfortunate that 45 % of New Zealand lizard species are still undescribed.

The New Zealand Threat Classification System (NZTCS) that exists in New Zealand (Townsend et al. 2008) could inadvertently contribute to the situation. Unlike the IUCN Red List classification system, the NZTCS permits the inclusion of undescribed species. This has many advantages for lizards, as it allows putative newly discovered species to be assigned a conservation ranking (e.g. Hitchmough et al. 2016c) and resources to be rapidly directed towards its conservation management. But conversely, it may have the unintended consequence of alleviating the pressure to describe the species, as it is already formally recognised for conservation purposes within New Zealand. In adopting this approach, a proliferation of tag names is used (e.g. *Mokopirirakau* 'Cupola') to refer to species, some of which have been in use for more than 30 years without the formal description of the species (Hitchmough et al. 2016a), and a deviation from the Linnaean taxonomic system follows.

Another factor is that there have been no full-time lizard taxonomists in New Zealand since McCann's (1955) revision of the native lizard fauna (Hitchmough et al. 2016a). Although 21 lizard species (18 skinks, 3 geckos) have been described since 1980, species descriptions have failed to keep up with the additional 66 extant species/taxa recognised over the same period (Hitchmough et al. 2016a). Lizard taxonomy in New Zealand has seemingly been relegated to something that interested researchers pursue in their spare time. For instance, over the past 30 years, Geoff Patterson has described 18 species (Patterson and Daugherty 1990, 1994; Patterson 1997; Chapple and Patterson 2007; Chapple et al. 2008a, b, 2011; Bell and Patterson 2008; Patterson and Bell 2009; Patterson et al. 2013), elevated two subspecies to species status (Patterson 1997), and reinstated the genus *Oligosoma* (Patterson and Daugherty 1995). What is even more remarkable about this achievement is that most of this has been accomplished whilst working full time at a bank!

A broader cross section of New Zealand herpetologists need to become involved in lizard taxonomic research in order to overcome the taxonomic impediment. After all, since the 1960s, it has taken an average of 16.5 years between the discovery of novel taxa until their formal description (data from Table 4.4, with undescribed species right-censored; Hitchmough et al. 2016a). Given that an average of 0.58 species has been described each year since 1980, if this rate continues, it will take a further ~80 years to describe the remaining 47 undescribed taxa that we are aware of (not to mention additional species that might be discovered during this time). However, there are promising signs these species descriptions may be published more quickly, as several major taxonomic works on geckos (R.A. Hitchmough, S.V. Neilsen, A. Bauer, unpublished data) and skinks (*O. infrapunctatum* and *O. lineoocellatum*-*O. chloronoton* species complexes: G.B. Patterson and S. Melzer, unpublished data; *O.* 'Whirinaki': B. Barr, D.G. Chapple, R.A. Hitchmough, unpublished data) are currently in advanced stages of preparation (Hitchmough et al. 2016a).

4. Limited Awareness of the Value of Natural History Collections Aside from Charles McCann, museum-based researchers have failed to play a major role in New Zealand lizard research (Chapple 2016). This has impacted the size and scope of the natural history collections for lizards, and the two major specimen collections in New Zealand (Te Papa Tongewara, Museum of New Zealand, Wellington; Auckland Museum, Auckland) are small relative to the diversity of the lizard fauna. Indeed, the situation could be worse if it was not for the fact that the Te Papa collection also incorporates the extensive specimen collection of the former Ecology Division (Department of Scientific and Industrial Research) and 1250 specimens from the collection of Charles Daugherty (Victoria University of Wellington). Despite this, these museum collections represent one of the most valuable resources available to New Zealand herpetologists, though they are surprisingly undervalued and underutilised.

The value of natural history collections extends beyond simply providing lizard species that can be used for species descriptions. They contribute to our knowledge of species distributions (and temporal changes in distribution), life history, reproduction, diet, and parasite ecology (e.g. Pettitt 1991; Kemp 2015). Yet, it is becoming increasingly difficult for researchers to collect tissue samples, or voucher specimens, of New Zealand lizard species. This may stem from the reluctance of the permitting agency (Department of Conservation) to permit specimen collection, or the failure of researchers to consult properly with iwi (Māori groups) about such research (it is often seen by researchers as a hurdle, rather than an opportunity to excite tangata whenua about the importance of their research and what they can do to help protect their taonga). This often applies even when researchers encounter unusual specimens or suspected new species, leading to attempts to subsequently identify these individuals based on photographs. Some of these taxa are unable to be found on subsequent field trips (e.g. *Oligosoma* 'Whirinaki' in Whirinaki Forest) and remain taxonomic enigmas today. Researchers are sometimes even denied permission to collect the voucher specimens that are required to formally describe new species (called type specimens). This represents another factor that has inhibited the rate of species description in New Zealand.

14.3 New Zealand Lizards: The Way Forward

As highlighted in this book, the New Zealand lizard fauna represents a fascinating study system. Because of its size, diversity, and ecological oddities, the New Zealand lizard fauna enables us to address a range of ecological, evolutionary, and physiological questions. Here I outline, in no particular order, the priority areas for future research on New Zealand lizards.

1. Comparative Osteological Studies of Extant New Zealand Lizard Species As highlighted by Worthy (2016), our interpretation of the lizard fossil record in New Zealand is constrained by limited comparative material from extant species, as well as by a lack of analyses of the intra- and interspecific variation in skeletal structures. It is therefore difficult to assign fossil material to extant species, which would provide an indication of the pre-human distribution of each lizard species, or whether it is from a distinct, now extinct species. This knowledge would not only improve our understanding of the biogeography and evolutionary history of New Zealand lizards but would also enable us to better quantify the post-human declines of the fauna. In a conservation context, it would allow potential mainland translocation or reintroduction sites to be identified. This field of study also represents one of the underappreciated potential uses of natural history collections in New Zealand (see Sect. 14.2).

2. Taxonomic Research and the Description of All Undescribed Lizard Species As highlighted throughout the book (Chapple 2016; Hitchmough et al. 2016a; Sect. 14.2), the large proportion (45 %) of undescribed lizard species in New Zealand has been an impediment to our understanding of the fauna. Conservation-focused researchers and government agencies need to better appreciate the urgent need for taxonomic work and the formal description of all remaining undescribed species. The completion of this work may require the specific allocation of funds (e.g. government grants) and other resources, along with greater support from permitting agencies to facilitate the collection of tissue samples and type species required for thorough and robust species descriptions.

3. Biogeographic Studies of New Zealand Lizards As emphasised by Chapple and Hitchmough (2016), the foundations have been laid for a golden age of New Zealand lizard biogeography. We now have a better grasp on the true diversity of lizard species in New Zealand (Hitchmough et al. 2016a) as well as of the current distribution of each species. If this was eventually combined with a better understanding of the pre-human distributions of each species, it would enable a broad range of biogeographic, and conservation biogeographic, studies to be completed. To date, most studies on the biogeography of New Zealand lizards have used a broad-brush, qualitative approach. Future studies now have an opportunity to adopt quantitative approaches to address fundamental biogeographic patterns and processes (e.g. Di Virgilio et al. 2014), or focus in on fine-scale or regional patterns (e.g. comparative studies on the impact of specific biogeographic barriers and studies of secondary contact among species or distinct genetic lineages). These investigations would increase our understanding of species-isolating mechanisms in New Zealand lizards, the process of reinforcement, and the drivers of speciation within this diverse fauna.

4. Detailed Studies on the Ecology, Reproduction, Life History, and Physiology of New Zealand Lizards Several chapters highlighted the large knowledge gaps that we have on the ecology (Hare et al. 2016), reproduction and life history (Cree and Hare 2016), and physiology (Hare and Cree 2016) of New Zealand lizard species. To rectify this situation, researchers should conduct well-designed, long-term field studies, specifically targeting poorly known species (see Sect. 14.2). Detailed studies are also required to address specific issues or questions, such as (1) vocalisations in geckos, (2) mating system and sociality (including investigation of hybridisation in both wild and captive populations), (3) how lizard species manage to persist in extreme alpine habitats (e.g. *O. pikitanga*, *O. judgei*, *Mokopirirakau kahutarae*), and (4) the potential impact of climate change on native lizard species. Some high-quality studies have already been conducted in this area (e.g. Penniket and Cree 2015), but further research is required on each topic.

5. Investigation of How Species Persist, Without Being Detected, in Mainland Locations with Mammalian Predators The recent discovery of a remnant Duvaucel's gecko (*Hoplodactylus duvaucelii*) individual within Maungatautari, a fenced mountain sanctuary in the Waikato region, North Island (Morgan-Richards et al. 2016; Nelson et al. 2016), indicates that some species have the ability to persist, undetected, in the presence of mammalian predators (e.g. Hoare et al. 2007). Research from an ecological and evolutionary perspective should be conducted into this issue, as it may generate knowledge that could facilitate the discovery of additional remnant populations on the main islands, as well as detect such 'stealth' populations on the offshore islands occupied by mammalian predators.

6. Quantitative Studies on the Value of Mainland Sanctuaries for Lizard Conservation Nelson et al. (2016) identified that there is a lack of quantitative data on the conservation benefit of mainland sanctuaries to lizards. Long-term field studies, using appropriate sampling and marking techniques (see Lettink and Hare 2016), are therefore required to compare lizard populations within, and outside of, the mainland reserves (and if possible, multiple sites of each should be used) and monitoring of predator populations. As outlined by Nelson et al. (2016), a rigorous, consistent trapping grid should be employed and a range of morphometric, behavioural, body condition, and physiological measurements taken to better quantify the potential sublethal impacts of mammalian predators. Although mainland sanctuaries have great potential for lizard conservation, such studies are essential in order to justify the conservation resources and efforts currently being devoted to them.

7. Quantify the Potential Impact of the Plague Skink on the New Zealand Biota Chapple et al. (2016b) highlighted that there have been no documented negative impacts of the plague skink. However, it is important to note that our ability to detect any impact has been limited as there has never been any dedicated research programme that aims to address this issue, either in New Zealand or elsewhere in its invasive range (Lord Howe Island, Hawaiian Islands; Chapple et al. 2013, 2014). Without this evidence, it becomes harder to justify to government and conservation managers why mitigation and/or eradication of the plague skink may be required. Current efforts to eradicate or mitigate the effects of plague skinks on Great Barrier Island represent an ideal opportunity to rectify this; it provides the perfect study system in which to investigate the lethal and sublethal (e.g. impacts on behaviour, life history, and/or body condition) effects of the plague skink on native skinks. This could be achieved by investigating and comparing native skink populations (or other faunal groups such as invertebrates) where they are sympatric, and allopatric, with plague skinks. Indeed, due to the wide distribution of the plague skink and the lower abundance of native lizard species, there are very few places in mainland locations on the North Island where there is this access to paired sites within the same region.

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