Chapter 13
Origin, Spread and Biology of the Invasive Plague Skink (*Lampropholis delicata*) in New Zealand

David G. Chapple, James T. Reardon, and Joanne E. Peace

Abstract The plague skink (*Lampropholis delicata*) is the only reptile species that has established, and subsequently become invasive, in New Zealand. Native to eastern Australia, the plague skink was first detected in south Auckland in the mid-1960s. A molecular study has identified the source population for the introduction as inland northern New South Wales, near Tenterfield. The plague skink has now spread across the majority of the North Island via human-assisted jump dispersal. It has the potential to extend its distribution to the entire North Island, apart from the Central Plateau region, and also to the Nelson-Marlborough and Canterbury regions of the South Island. Sexual dimorphism exists in plague skink populations in New Zealand, with females having larger body size and interlimb lengths and males having longer and broader heads. Population density appears to influence body size in males. Plague skinks in New Zealand lay eggs, often communally, in sheltered microhabitats, with the eggs hatching in February and March. The mean clutch size varies among populations, and clutch size is positively related to female body size. Plague skinks utilise a wide variety of habitats, both natural and modified, are diurnal and are opportunistic insectivores. The evidence for the impact of the plague skink on the native New Zealand biota is currently equivocal. The plague skink has recently spread to conservation-sensitive offshore islands in the Hauraki Gulf, including Great Barrier Island, promoting additional research into eradicating or mitigating the spread of the species within New Zealand.

Keywords Biosecurity • Delicate skink • Invasive species • New Zealand • Plague skink

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13.1 Introduction

Invasive lizards have the potential to impose a broad range of ecological and evolutionary impacts in their introduced range (Lever 2003; Kraus 2009, 2015). Exotic lizard species are primarily moved around the globe via human-mediated transportation via the pet trade (deliberate introductions, escape/release from captivity) or as stowaways in freight and cargo (Kraus 2009; Chapple et al. 2016). Increasing globalization over the last few decades, and the associated expansion of international trade, has resulted in a sharp rise in the number of exotic lizard species being introduced to non-native regions (Kraus 2009). Lizards possess several traits that enhance their ability to remain undetected in freight and cargo, including small body size, cryptic nature, desiccation-resistant eggs, the ability to withstand temperature fluctuations and low metabolic rate that allows them to survive long periods without food and water (Kraus 2009; Toy and Newfield 2010). Invasive lizards therefore represent a significant threat to New Zealand's diverse, endemic lizard fauna (~104 extant species: ~61 skink and ~43 gecko species; Tingley et al. 2013; Hitchmough et al. 2016a, b; Chapple and Hitchmough 2016; Towns et al. 2016).

Although 99 lizard species (across 13 different families) have been intercepted by biosecurity agencies entering New Zealand (Chapple et al. 2016), the plague skink (*Lampropholis delicata*) is the only lizard species that has successfully established and subsequently become invasive in the country (Lever 2003; Kraus 2009; Chapple et al. 2013a, b). The plague skink (known as the delicate skink in its native range and also as the rainbow skink in New Zealand parts of its invasive range) is a small-sized species (adult snout-vent length [SVL] 35–55 mm) that is native to eastern Australia. It occurs across 26° of latitude in its native Australian range from northern Queensland to Tasmania and extends as far west as south-eastern South Australia (Chapple et al. 2011a; Wilson and Swan 2013; Cogger 2014; Fig. 13.1). The plague skink occurs across a range of moist habitats in Australia but thrives in disturbed habitats and suburban gardens (Wilson and Swan 2013; Moule et al. 2016). It reaches sexual maturity in 1 year and has a life span of approximately 2–4 years (Greer 1989). It is oviparous and often produces large communal egg nests that are positioned under rocks, logs and vegetation (Greer 1989; Cheetham et al. 2011; Doody and Paull 2013). The plague skink is the only species of Australian lizard that is invasive overseas (Lever 2003; Kraus 2009) and, in addition to New Zealand, has established populations in the Hawaiian Islands (Baker 1979) and on Lord Howe Island (Hutchinson et al. 2005; Schulz 2009; Chapple et al. 2014; Moule et al. 2015).

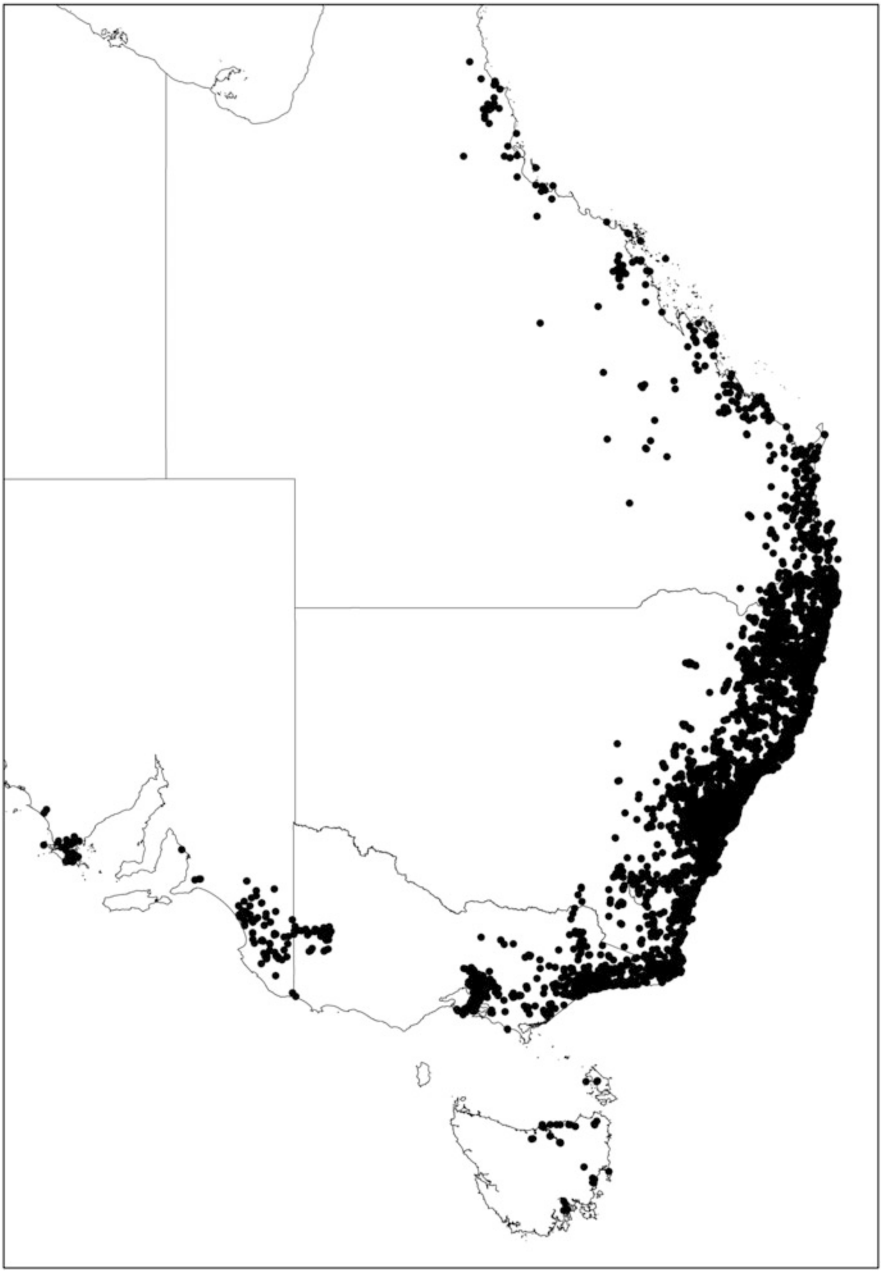

Fig. 13.1 Native Australian range of the plague skink (*Lampropholis delicata*). The distribution of the plague skink follows Tingley et al. (2016) and is based on the Atlas of Living Australia (www.ala.org.au) and the records of all major Australian museums

13.2 Introduction History and Post-establishment Spread in New Zealand

The plague skink has been present in New Zealand for at least 50 years. It was first detected in the country in the mid-1960s at the Otahuhu rail yards in south Auckland (A.H. Whitaker pers. comm. in Lever 2003), and it appears to have been accidentally introduced into New Zealand, possibly in a shipment of wooden railway sleepers from Australia (as eggs or juvenile/adult individuals; A.H. Whitaker pers. comm. in Lever 2003; Chapple et al. 2013a). The number of initial founders was likely small, as most lizard stowaways are transported individually or in small groups (Chapple et al. 2013b, 2016), and the incursion was restricted to the Auckland region for ~15 years (Lever 2003). However, its subsequent spread across the North Island was rapid, first into the Waikato [Hamilton, 1978; Paeroa, 1984], Bay of Plenty [Tauranga: 1978] and Coromandel Peninsula regions [Waikawau Bay: 1984] (West, 1979; Lever 2003; Fig. 13.2). Over the past two decades, the plague skink has spread southwards to the lower North Island [Wanganui, 1996; Palmerston North, 2009] and southern Bay of Plenty [Whakatane, 2003; Edgecumbe, 2007] and northwards into Northland [Whangarei, 2002; Dargaville, 2007; Kaitaia, 2008] (Peace 2004; Chapple et al. 2013a; New Zealand Herpetofauna database 2015; Fig. 13.2).

Although the source region for the initial introduction of the plague skink into New Zealand was initially thought to be Sydney (A.H. Whitaker pers. comm. in Lever 2003), recent molecular data (mitochondrial DNA sequence data; mtDNA) indicated that the founders originated from a forestry region of inland northern New South Wales, near Tenterfield (Chapple et al. 2013a). Substantial phylogeographic structure within the native Australian range (nine distinct genetic lineages and unique haplotypes in each locality sampled; Chapple et al. 2011a) enabled the seven haplotypes present in the introduced New Zealand populations to be traced back to a single Australian source region (Chapple et al. 2013a). Whilst it is possible that the plague skink was introduced from Australia on multiple occasions from the same source region, its ability to produce large communal nests (often involving 100+ eggs; Greer 1989; Chapple et al. 2014) means that all seven haplotypes could have been introduced in a single communal nest. Research is currently being conducted to determine whether the introduction of the plague skink into New Zealand was associated with a decrease in neutral genetic variation (i.e. microsatellite markers; Chapple and Thompson 2009; Chaplin 2013; DGC unpublished data).

The plague skink is particularly adept at dispersing via human-mediated transportation, especially compared to other widespread Australian species (e.g. *L. guichenoti*, Chapple et al. 2011a, b, c, 2013b; Cromie and Chapple 2012). Indeed, it is the fifth most intercepted lizard species (behind *Hemidactylus frenatus*, *Lepidodactylus lugubris*, *Gehyra oceanica* and *Hemidactylus platyurus*) by New Zealand biosecurity agencies (Chapple et al. 2016). The plague skink exhibits high levels of intraspecific behavioural variation (Michelangeli et al. 2016; Moule

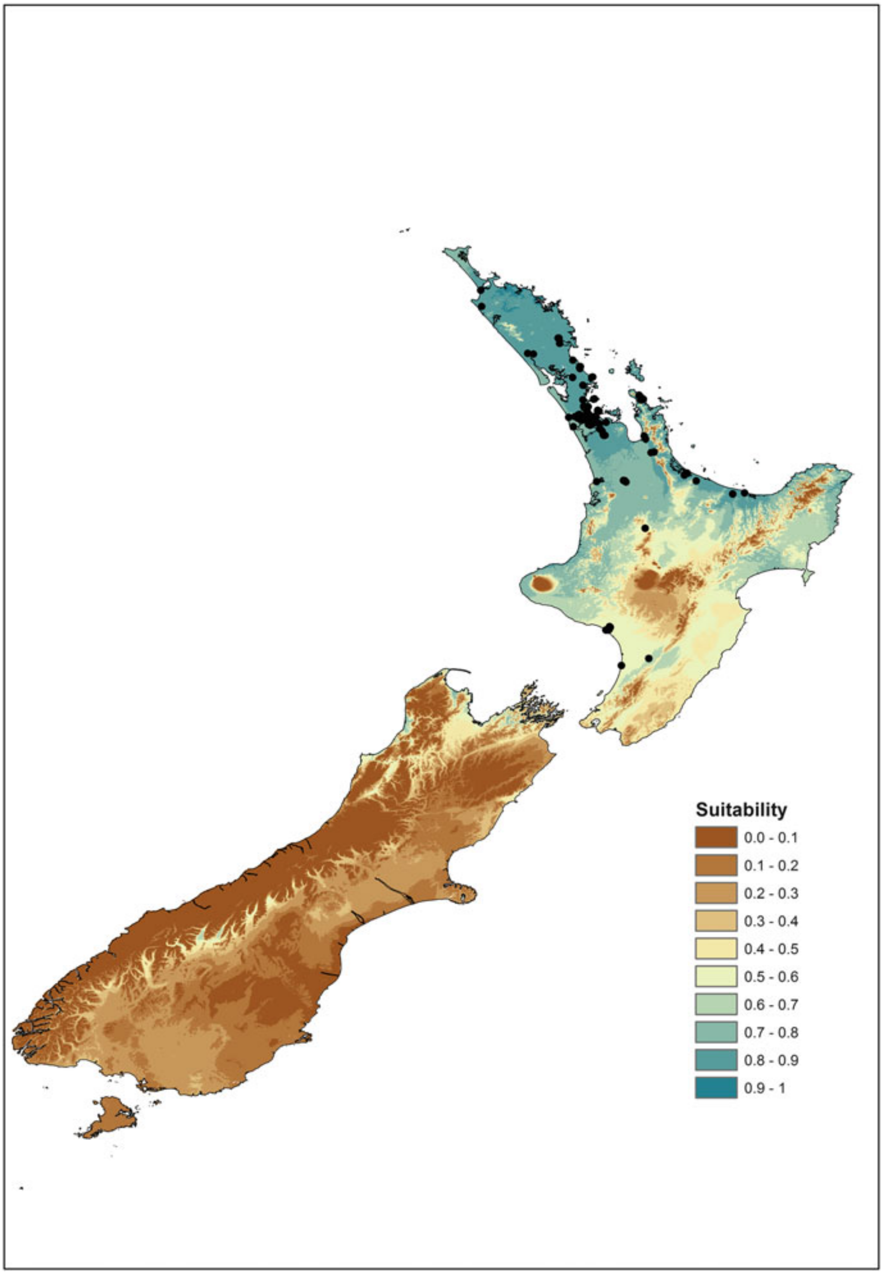

Fig. 13.2 Current distribution of the plague skink (*Lampropholis delicata*) in New Zealand (distributional data follows Tingley et al. 2016 and the New Zealand Herpetofauna database 2015). The potential distribution of the plague skink in New Zealand is indicated (adapted with permission from Tingley et al. 2016)

et al. 2016) and several behavioural traits that may increase its propensity for human-assisted dispersal (Chapple et al. 2011b, 2012; Cromie and Chapple 2012). For instance, the plague skink is highly exploratory, which may increase its likelihood of getting into freight and cargo but also has a tendency to actively hide and seek shelter, which could enhance its ability to remain undetected during transit (Chapple et al. 2011b; Cromie and Chapple 2012).

The spread of the plague skink throughout New Zealand appears to be driven primarily through human-assisted 'jump' dispersal (sensu Wilson et al. 2009), rather than natural range expansion (Chapple et al. 2013b). This has led to the 'spot fire' spread of the species across New Zealand, with human-assisted transportation of the species from the Auckland region to other locations in the country (as outlined above). Chapple et al. (2013b) conducted genetic analyses on tissue samples from the 79 plague skink specimens intercepted by the New Zealand biosecurity agency (Ministry for Primary Industries, MPI) between 2001 and 2009. Since the established New Zealand plague skink population has known mtDNA haplotypes, it was possible to assign biosecurity interceptions to either new arrivals into the country direct from Australia (and their specific point of origin) or post-border spread within New Zealand. The established New Zealand population is the major source of stowaways spreading across the country (84 % of interceptions), whereas only 16 % are new arrivals from Australia (generally originating from the region between Brisbane and Sydney; Chapple et al. 2013b; Table 13.1). Plague skinks arrive in New Zealand in freight and cargo via both air and sea transport routes (Table 13.1), but 30 % of interceptions involved the post-border spread of plague skinks (via road, rail and air transport) from the Auckland region to areas beyond the species' established New Zealand range (Chapple et al. 2013b; Table 13.2). Plague skink stowaways are typically solitary, adult individuals that are alive when detected and intercepted during the cooler months of the year (Chapple et al. 2013b; Tables 13.1 and 13.2).

Although the plague skink has been established in New Zealand for at least 50 years, it is still spreading across the country and is yet to fulfil its potential distribution (Chapple et al. 2013b; Tingley et al. 2016; Fig. 13.2). The species has not yet exhibited evidence of niche expansion following its introduction to New Zealand and has failed to colonise some environmental niches (16 %) in New Zealand that are equivalent to those occupied in its native Australian range (termed niche 'unfilling'; Tingley et al. 2016). Predictive environmental niche modelling indicates that the plague skink has the capacity to expand across the entire North Island, apart from the Central Plateau region (Tingley et al. 2016; Fig. 13.2). In addition, there is moderate potential for the plague skink to establish in parts of the South Island, most likely in the Nelson-Marlborough and Canterbury regions (Tingley et al. 2016; Fig. 13.2). Thus, conservation and biosecurity protocols should be developed to prevent, or limit, the continued spread of the plague skink throughout New Zealand (Chapple et al. 2013b, 2016; Wairepo 2015). Indeed, it would seem that over the past decade, the rate of spread of plague skinks across the islands of the Hauraki Gulf has accelerated, with the skinks now apparently established on Kawau and Rotoroa Islands. The more recent incursion

Table 13.1 Details of the plague skink (*Lampropholis delicata*) specimens intercepted entering New Zealand direct from Australia

Sample Code	Interception					Lizard			Origin	
	Location	Month	Transport method	Border or post-border	Cargo type	SVL (mm)	Adult?	Alive?	Predicted	Confirmed
LDN01	Wellington	Oct	Air	Post-border	Personal effects	28	N	Alive	Sydney	Sydney
LDN06	Auckland	March	Sea	Post-border	Shipping container (cosmetics, food)	30	N	Alive	Sydney	Sydney
LDN07	Auckland	June	Air	Border	Personal effects	39	Y	Alive	Brisbane	Gold Coast-Lamington NP
LDN23	Auckland	June	Sea	Post-border	Shipping container (light fittings)	30	N	Alive	Nth Sydney (Brookvale)	Nth NSW coast-Wyong
LDN26	Wellington	August	Sea	Post-border	Shipping container (household effects)	34	N	Alive	Gold Coast	Gold Coast-Lamington NP
LDN40	Auckland	Oct	Air	Border	Personal effects	35	Y	Alive	Sydney?	Brisbane (sth)
LDN47	Tauranga	April	Air	Post-border	Personal effects	26	N	Alive	Caboolture	Brisbane (nth)
LDN57	Christchurch	April	Air	Post-border	Personal effects	32	N	Alive	Brisbane	Brisbane (sth)
LDN62	Christchurch	August	Sea	Border	Shipping container (household effects)	40	Y	Dead	Brisbane (Kingston)	Gold Coast-Lamington NP
LDN64	Christchurch	Oct	Sea	Border	Shipping container (household effects)	37	Y	Alive	Brisbane (Samford)	Brisbane (nth)
LDN218	Auckland	Dec	Air	Post-border	Personal effects	36	Y	Alive	Unknown	Sydney
LDN230	Wellington	May	Sea	Border	Shipping container (mixed freight)	36	Y	Alive	Sydney	Sydney
LDN231	Invercargill	June	Air	Post-border	Personal effects	35	Y	Alive	Sydney	Nth NSW coast-Port Macquarie

The inferred Australian origin of each specimen from the molecular data is compared to the predicted origin recorded in the Ministry for Primary Industries interception database. All intercepted lizards were found alone rather than in groups. Reproduced with permission from Chapple et al. (2013b)

Table 13.2 Details of the plague skink (*Lampropholis delicata*) specimens intercepted being accidentally transported within New Zealand to regions beyond the established range

	Interception					Lizard			
Sample code	Location	Month	Transport method	Cargo type	Cargo contents	SVL	Adult?	Alive?	Predicted origin
LDN05	Palmerston North	Feb	Truck	Freight	Pet food	40	Y	Dead	Auckland
LDN11	Havelock North	Aug	Truck	Freight	Building materials	39	Y	Dead	Auckland
LDN12	Dunedin	Aug	Truck or trail	Freight	Timber	35	Y	Alive	Auckland
LDN16	Palmerston North	Oct	Truck	Freight	Machinery	40	Y	Alive	Unknown
LDN17	Christchurch	Oct	Truck or trail	Freight	Steel	49	Y	Alive	Auckland
LDN18	Christchurch	Dec	Truck	Freight	Decorations	28	N	Dead	Waihi Beach
LDN22	Christchurch	May	Rail	Container	Mixed freight	33	N	Alive	Auckland
LDN24	Nelson	June	Sea	Shipping container	Household effects	44	Y	Alive	Auckland
LDN29	Palmerston North	Oct	Truck	Courier	Computer	37	Y	Alive	Auckland
LDN30	Palmerston Nth	Oct	Truck	Freight	Engine parts	30	N	Alive	Auckland
LDN33	Christchurch	May	Sea	Shipping container	Beverages	40	Y	Alive	Auckland
LDN37	Christchurch	July	Truck	Freight	Electrical fittings	39	Y	Alive	Auckland
LDN45	Palmerston North	Feb	Truck	Freight	Building materials	38	Y	Alive	Auckland
LDN49	Palmerston North	May	Truck	Freight	Pipe fittings	36	Y	Alive	Auckland
LDN51	Porirua	July	Truck	Freight	Vegetables	22	N	Alive	Auckland
LDN58	New Plymouth	May	Truck	Freight	New car	37	Y	Alive	Auckland
LDN61	Christchurch	June	Rail or sea	Container	Unknown	38	Y	Alive	Auckland
LDN68	Napier	March	Truck	Freight	Plasticware	14	N	Dead	Auckland
LDN217	Dunedin	Nov	Truck	Freight	Mail	30	N	Alive	Unknown
LDN219	Napier	Dec	Truck	Freight	Mail	27	N	Alive	Auckland
LDN223	Palmerston North	Oct	Unknown	Unknown	Unknown	34	N	Alive	Unknown
LDN224	Stratford	Oct	Truck	Freight	Ceramics	26	N	Alive	Auckland

LDN225	Rotorua	Nov	Truck	Freight	Beverages	39	Y	Dead	Auckland
LDN232	New Plymouth	July	Truck	Freight	Steel	40	Y	Alive	Auckland

All intercepted lizards were found alone rather than in groups. Note that the plague skink did not establish in Palmerston North until ~2007. Reproduced with permission from Chapple et al. (2013b) on Great Barrier Island (GBI) is currently the focus of containment, with a view to eradicate plague skinks from the island altogether (Wairepo 2015).

13.3 Ecology, Life History and Reproduction in New Zealand

Previous species introductions to New Zealand indicate that even the basic ecology of a species may change markedly outside its native environment (e.g. Fitzgerald 1984; Green 1984). However, there are no striking differences in the life history of plague skinks in New Zealand compared to other regions across their native and introduced range (Table 13.3), although Lord Howe Island females tend to have a larger body size, and Sydney males are smaller than those from New Zealand.

There is marked sexual dimorphism in the plague skink, both in New Zealand and in its native Australian range, with females having larger SVL and interlimb length (ILL) and males having longer and broader heads (DGC unpublished data). Sexual dimorphism in these traits has also been documented on Lord Howe Island (Chapple et al. 2014). Similarly, in Massey, Auckland, female body size is larger than that of males (JEP unpublished data). Male body size also varies between populations, with the densest populations consisting of the smallest individuals (Peace 2004; JEP unpublished data; Table 13.3).

Plague skinks have tail lengths that average 155 % of the mean adult SVL. Overall, 59 % of plague skinks around Auckland have broken or regenerating tails, and whilst no differences are evident between populations or sexes, the proportion of individuals with tail loss varies among age groups. Juveniles have the lowest percentage of tail loss (22 %), an intermediate level of tail loss occurs in subadults (49 %), and adults display the highest incidence of tail loss (72 %) (Peace 2004; JEP unpublished data). Plague skinks also frequently lose their toes, with Peace (2004) reporting toe loss in 31 % of plague skinks. The proportion of individuals missing toes differed significantly between populations, and there was a positive trend towards toe loss in larger individuals (Peace 2004). No significant sexual differences in toe loss were evident (Peace 2004). Tail and toe loss in lizards is frequently attributed to predation (e.g. Whitaker 1968; Qualls and Shine 1998; Hare and Miller 2010); the observed trends may be due to the higher conspicuousness of adults to predators as a result of body size or longer movements, or could be a function of time, with older individuals exposed to predation and intraspecific aggression for a greater period of time (Peace 2004). Additionally, toe loss may occur due to dysecdysis (incomplete sloughing) (Frye 1981; Gartrell 2016). Percentages of tail and toe loss are comparable to those recorded for native New Zealand lizard populations and for plague skink populations in Australia and Lord Howe Island (Forsman and Shine 1995; Hare and Miller 2010; Chapple et al. 2014).

Plague skinks are oviparous, and eggs of New Zealand populations hatch in February and March (Gill and Whitaker 2001). Nests occur in a range of sheltered

Table 13.3 Comparative life history of the plague skink (*Lampropholis delicata*) across its native Australian range and introduced range (Hawaiian Islands, New Zealand, Lord Howe Island [LHI])

Country	Location (Latitude)	Female body size (mm)		Male body size (mm)		Clutch size		Size at maturity (mm)	Hatchling size (mm)
		Mean ± SE (*n*)	Range	Mean ± SE (*n*)	Range	Mean ± SE (*n*)	Range		
Australia	Townsville (20 °S)[a]	37.8 ± 2.35 (44)	NA	36.9 ± 1.86 (44)	NA	3.0 ± 0.84 (21)	1–4	35	21
	Brisbane (27 °S)[a]	38.8 ± 2.96 (39)	NA	38.7 ± 2.65 (67)	NA	3.1 ± 0.88 (22)	2–5	35	16
	Coffs Harbour (31 °S)[a]	37.5 ± 4.11 (64)	NA	36.5 ± 3.64 (53)	NA	3.7 ± 1.31 (22)	2–8	31	15
	Sydney (34 °S)[a]	37.0 ± 2.99 (69)	NA	36.1 ± 2.39 (102)	NA	3.1 ± 1.07 (14)	2–6	32	16
	Melbourne (37 °S)[a]	39.6 ± 3.78 (73)	NA	39.9 ± 3.84 (48)	NA	4.4 ± 2.03 (19)	1–8	33	17
	Tasmania (41 °S)[a]	39.6 ± 3.78 (73)	NA	39.9 ± 3.84 (48)	NA	4.4 ± 2.03 (19)	1–8	33	17
Hawaii	Oahu (21 °N)[a]	38.7 ± 1.59 (26)	NA	38.3 ± 1.72 (26)	NA	3.1 ± 1.22 (23)	1–5	36	17
	Oahu (21 °N)[b]	38.6 ± 1.7 (45)[c]	NA	NA	NA	3.5 ± 1.8 (45)	1–5	NA	NA
	Kauai (22 °N)[b]	41.8 ± 3.5 (9)[c]	NA	NA	NA	4.1 ± 1.0 (9)	3–6	NA	NA
	Hawaii (19 °N)[b]	41.2 ± 2.8 (10)[c]	NA	NA	NA	4.7 ± 1.3 (10)	3–7	NA	NA
	All islands (19–22 °N)[d]	40.6 ± 0.3 (143)[c]	35–47	39.5 ± 0.2 (159)[c]	35–46	4.0 ± 0.13 (106)	1–7	31	NA
LHI	Lord Howe Island (31 °S)[e]	44.4 ± 0.25 (349)[c]	35–57	42.8 ± 0.20 (367)[c]	35–55	3.4 ± 0.13 (63)	1–7	33–35	NA

(continued)

Table 13.3 (continued)

Country	Location (Latitude)	Female body size (mm)		Male body size (mm)		Clutch size		Size at maturity (mm)	Hatchling size (mm)
		Mean ± SE (*n*)	Range	Mean ± SE (*n*)	Range	Mean ± SE (*n*)	Range		
New Zealand	North Island (36–37 °S)[d]	40.8 ± 0.60 (39)[c]	35–51	40.0 ± 0.38 (52)[c]	35–46	4.1 ± 0.40 (7)	3–6	41	NA
	Great Barrier Island (36 °S)[f]	41.5 ± 3.9 (31)[c]	NA	NA	NA	3.6 ± 1.1 (31)	NA	NA	NA
	Motutapu Island (36 °S)[g]	41.9 ± 1.17 (9)[c]	36–46	38.4 ± 1.04 (7)[c]	36–44	NA	NA	35	17
	Rangitoto Island (36 °S)[g]	39.5 ± 0.46 (31)[c]	36–46	39.6 ± 0.55 (15)[c]	37–43	NA	NA	34	12
	Massey, Auckland (36 °S)[g]	40.2 ± 0.82 (55)[c]	36–46	38.7 ± 0.79 (51)[c]	36–42	4.7 ± 1.37 (3)	4–5	32	16
	Avondale, Auckland (36 °S)[g]	40.6 ± 1.16 (37)[c]	36–46	40.2 ± 1.36 (41)[c]	36–44	5.0 ± 2.16 (2)	4–6	31	15
	Otara, Auckland (36 °S)[g]	40.3 ± 0.81 (58)[c]	36–48	40.3 ± 1.00 (42)[c]	36–44	4.7 ± 0.52 (7)	3–7	30	17

[a]Forsman and Shine (1995)
[b]Baker (1979)
[c]Restricted analysis to adults
[d]DGC unpublished data
[e]Chapple et al. (2014)
[f]Wairepo (2015)
[g]Peace (2004), JEP unpublished data

microhabitats including cavities in banks, under rocks and in leaf litter (Peace 2004). This type of egg placement has often been observed in species that do not burrow well (Shine 1985). In the Auckland region, the mean clutch size is 4.75 (±0.33, $n = 12$, range 3–7), which is slightly greater than for the Great Barrier and Lord Howe Island populations (GB: 3.58 ± 1.1, $n = 31$; LH 3.4, range 1–7) (Peace 2004; Chapple et al. 2014; Wairepo 2015). Larger females tend to have larger clutch sizes (Baker 1979; Shine 1983; Peace 2004; Chapple et al. 2014). Eggs are laid in communal nests around Auckland from December to April (3–30+ eggs), with communal nesting also observed on the Coromandel Peninsula, on Rangitoto Island (40+ eggs) (Peace 2004; Peace 2011; DGC pers obs) and also on Lord Howe Island (11–200+ eggs; Chapple et al. 2014).

Auckland populations display an equal sex ratio, and testis and ovary volumes track the same seasonal fluctuations among sites (Peace 2004). Testis volume is low during September and October, increasing in November, reaching maximum volume in February and then decreasing through March and April. Enlarged ova are present from September onwards with the earliest yolked ova detected in February and the latest in March. Egg follicles are smallest from February to April and markedly larger in diameter between September and October (Peace 2004). In comparison, Lord Howe Island populations are reproductively active from September to February (Chapple et al. 2014). Most aspects of the reproductive biology of plague skinks in New Zealand (mean clutch size and general testis and ovary condition) are very similar to those in Australia and Hawaii (Baker 1979; Shine 1983; Joss and Minard 1985; Forsman and Shine 1995).

In New Zealand, plague skinks utilise a variety of habitats, ranging from highly modified environments (glasshouses, nurseries and well-maintained gardens) to shrubland (irregularly maintained, revegetated sites) and rank vegetation (weedy areas beside roadsides, railway sidings and industrial sites). On Rangitoto Island, they occupy lava formations from the supralittoral zone to the summit (Gill and Whitaker 2001; Peace 2004, 2011). A variety of refuges, including leaf litter, fallen logs, shade cloth and glass bottles, are used by most individuals (88 %), with these often occurring under a canopy (56 %) (Peace 2004). Plague skinks are diurnal, and in New Zealand, the peak in seasonal activity occurs from November to December (Peace 2004). Captive individuals are most often observed basking, although foraging activity is also frequent (Peace 2004). Plague skinks feed opportunistically on invertebrates (Wilson and Swan 2013; Cogger 2014), although there have been no detailed investigations of their diet in New Zealand. Vision and olfaction are used to search for prey items in leaf litter and refuges. Prey items are rapidly pursued when disturbed and are often caught with a quick lunge. Foraging lizards crowd around each other and attempt to catch invertebrates disturbed by other animals. Those that have captured prey are often pursued and bitten by conspecifics in an attempt to take prey from their mouths, both in the wild and captivity (Peace 2004).

13.4 Potential Impact of the Plague Skink in New Zealand

When plague skinks initially established in New Zealand, they were regarded as a protected species under the New Zealand Wildlife Act 1953; this status lasted until 2010, when they were included in Schedule 5 (‘wildlife not protected’) of the Wildlife Act and simultaneously listed as an ‘unwanted organism’ under the Biosecurity Act 1993. Plague skinks and native New Zealand lizards overlap widely in terms of geographic distribution and habitat use (Chapple and Hitchmough 2016), occurring sympatrically in many locations. When compared with native species, the more delicate form of plague skinks would confer considerable advantages in the introduced species; it would allow smaller refuges to be utilised and assist tail shedding and predator escape, thereby increasing its survival relative to native species in the presence of introduced predators, such as rodents (Peace 2004). Plague skinks arriving into New Zealand from Australia may also introduce parasites since exotic lizards intercepted entering New Zealand carry a range of ectoparasites, mostly mites (Heath and Whitaker 2015; Gartrell 2016). Mites hosted by plague skinks could impact the native herpetofauna directly or through vectoring diseases (e.g. Goka et al. 2013; Gartrell 2016).

Plague skinks occur in sympatry with native New Zealand lizards throughout large parts of their range. They are generalist feeders that forage for the same invertebrate prey (size and type) as the native New Zealand copper skink (*Oligosoma aeneum*) using similar foraging tactics (Peace 2004), suggesting that the two species compete for prey resources. Nonetheless, in captive populations, body condition indices for copper and plague skinks housed communally and, separately, do not differ within species over time (Peace 2004), though plague skinks are always more abundant in areas of sympatry with native lizard species in the Auckland region (e.g. three copper skinks versus 194 plague skinks; Peace 2004). No interspecific interactions have been observed in the field or captivity, and individuals of each species do not appear to avoid each other spatially (Peace 2004). Plague skinks have a larger clutch size than copper skinks and therefore have a higher potential annual reproductive output (Shine 1983; Joss and Minard 1985; Forsman and Shine 1995; Peace 2004; Cree and Hare 2016; Table 13.3). The difference in abundance observed for sympatric Auckland populations may reflect the hardiness of plague skinks to predation and habitat disturbance, as well as their greater reproductive output. This apparent increase in plague skink numbers may artificially elevate the abundance of predatory species, which in turn may result in greater predation pressure on native lizards (Norbury 2001).

Moth skinks (*Lipinia noctua*) and *Emoia impar* appear to have been replaced by the rapidly expanding populations of plague skinks in the Hawaiian Islands (Hunsaker and Breese 1967; Baker 1979), but the evidence for this is currently circumstantial (Fisher and Ineich 2012). On Lord Howe Island, the plague skink has the potential to impact the island’s endemic invertebrate fauna (Chapple et al. 2014), although, again, the evidence is anecdotal. Thus, at present, there is no conclusive data for the negative impact of plague skink in New Zealand or elsewhere in its invasive range.

13.5 Stopping the Spread of the Plague Skink in New Zealand

Whilst the plague skink has spread across much of New Zealand's North Island, during the past five decades, their establishment on inshore and offshore islands has been limited to Rangitoto-Motutapu and Waiheke Islands in the Hauraki Gulf. In recent years, however, they have expanded their range. They have colonised and established on Rotorua and Kawau Islands, all inshore islands in the Hauraki Gulf, continue to be occasionally intercepted in the South Island and have been detected in a timber shipment arriving on Raoul Island in the Kermadec island group, which lacks any indigenous terrestrial reptiles (Fisher 2011). Plague skinks were first detected on GBI in April 2013 during a presence/absence survey conducted by Auckland Council, and their establishment on GBI represents the first incursion of a breeding population of plague skinks on a New Zealand offshore island (Wairepo 2013). The discovery elicited a biosecurity response led by Auckland Council. GBI is a valuable ecological asset since it is free of mustelids, hedgehogs (*Erinaceus europaeus*), Norway rats (*Rattus norvegicus*), deer (Cervidae) and brush-tailed possums (*Trichosurus vulpecula*). Of equal concern was for the potential for plague skinks to reach other, more pristine and important conservation islands in the outer Gulf and beyond.

The response to this incursion highlighted the paucity of knowledge and tools to attempt either containment or eradication for small lizards. Whilst the skinks remained restricted to the vicinity of the Tryphena Wharf, ascertained using tracking tunnel monitoring at potential incursion sites across the island (Wairepo 2013), a programme of trapping was instigated using insect sticky traps (Wairepo 2015; see Lettink and Hare 2016). Insect sticky traps were used in place of conventional methods, such as pitfall trapping, due to perceived logistical challenges of establishing pitfall trapping grids and the ability to rapidly set up sticky traps (see Lettink and Hare 2016). These were deployed in an area greater than the incursion area and at higher densities than standard traps. Funnel trapping (see Lettink and Hare 2016) was attempted as a supporting technique on steep terrain. Whilst initial insect sticky traps capture rates looked promising, lizard removal rates did not result in a declining capture rate over the period of the study, and it was not possible to identify differences in capture probabilities between insect sticky traps and funnel traps (Wairepo 2015). Drift fencing was also recommended for the delimitation of the incursion, but these were only placed along small sections due to financial constraints.

These results suggest that plague skinks cannot be easily eradicated with modest density trapping of the incursion area and further support the recommendation that the efficacy of a number of interception methods need to be evaluated at a range of device and skink densities in order to determine their potential role as eradication tools. Without this research, it remains likely that plague skinks will continue to expand, both through natural dispersion and via human-mediated incursion pathways, to new habitats that can sustain them.

Research into the toxicant, acetaminophen, as a potential control or eradication tool for the plague skink has also been conducted (Wairepo 2015). Whilst acetaminophen is acutely toxic to plague skinks at an appropriate dosage, non-target risks and the need to develop effective means for field delivery currently prevent its development for operational use.

In the absence of eradication methods, containing the spread of plague skinks relies entirely on biosecurity measures. The Auckland Council, in partnership with other government and conservation agencies, has established a 'Treasure Island' initiative, which aims to increase awareness of invasion pathways and the role of biosecurity to minimise the risks of pest species being transported on vessels or in freight (http://treasureislands.co.nz/). This work includes the use of detector dogs (see Lettink and Hare 2016), which, together with their handlers, are able to communicate the biosecurity message whilst also detecting plague skinks. There is still a serious shortage of biosecurity tools to assist in the effective quarantining of materials originating from mainland locations occupied by plague skinks. A recent biosecurity advancement that may contribute to quarantine measures for plague skinks is the use of thermal fumigants. These involve the application of hot air (48–52 °C) at 3.4 m^3/min and have been used to prompt the invasive brown tree snake (*Boiga irregularis*) to become active so that they are more easily detected (Kraus et al. 2015). Such a treatment of cargo is easily achieved using conventional heaters and containment measures and, if adapted for small skinks, might provide a valuable tool to improve detection of plague skinks. However, the primary constraint of biosecurity measures for plague skinks remains the detection and destruction of their eggs. Plague skinks frequently deposit their eggs in disturbed surface soils, including the soil of potted plants, making the movement of horticultural products a high-risk invasion pathway (Baker 1979; see above). Currently the only robust measure to combat this risk is to de-soil plant roots prior to transport.

Plague skinks have, as yet, failed to establish on the South Island of New Zealand (see Sect. 13.2), despite the potential suitability of the climate and habitat through the northeast of the South Island and the lack of biosecurity barriers to freight, transport and trade between the islands. Given the failure to contain and eradicate the plague skink incursion on GBI and the high conservation values of the offshore island reserves of New Zealand's South Island, the development of effective detection and removal methods for this invasive species is a biosecurity research priority. Eradication of a recent incursion of this species is likely to depend equally on available eradication tools and the sensitivity of monitoring to detect an incursion early in their establishment phase. This challenge is complicated by the nature of human-mediated 'jump dispersal', which is the common mode of spread in plague skinks within New Zealand (Chapple et al. 2013b).

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