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To cite this article: KM Hare , G Norbury , LM Judd & A Cree (2012) Survival of captive-bred skinks following reintroduction to the wild is not explained by variation in speed or body condition index, New Zealand Journal of Zoology, 39:4, 319-328, DOI: [10.1080/03014223.2012.662160](https://doi.org/10.1080/03014223.2012.662160)

To link to this article: <https://doi.org/10.1080/03014223.2012.662160>



Published online: 02 Jul 2012.



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Survival of captive-bred skinks following reintroduction to the wild is not explained by variation in speed or body condition index

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(Received 10 October 2011; final version received 21 December 2011)

Translocation is a common conservation tool and often involves founders that are reared in captivity. Why some translocations succeed and others fail is not well understood, but may be related to phenotypic changes brought about by captivity. We found that variation in speed and body condition index among a small group of captive-reared Otago skinks (*Oligosoma otagense*) did not influence their survival after release to the wild. In the first 12 months, 75% of skinks persisted, and this reduced to 58% by 18 months. After combining our results with data for other *Oligosoma* species, we found that captive-reared skinks pre-release have a higher body condition index and are about 50% slower than wild lizards; however, slower speeds are not consistently associated with higher body condition indices. We suggest that reduced speeds of captive lizards are a function of physiological and behavioural changes associated with captivity, but not necessarily obesity.

Keywords: body condition; New Zealand; *Oligosoma otagense*; performance; skink; sprint speed

Introduction

Translocation of animals is commonly used in conservation management, and often involves captive-reared founders (Fischer & Lindenmayer 2000; Santos et al. 2009). In New Zealand, translocations of bats, birds, reptiles and invertebrates has generally been successful (especially when to areas where the agents of decline have been removed or mitigated), but some have failed (Sherley et al. 2010) in that they have failed to establish self-sustaining populations (Griffith et al. 1989). Success is most likely when habitat is of high quality, sufficient founders are released and founders stay in the translocation site and/or have high survival rates (Griffith et al. 1989). The quality of founders has a strong influence on their survival post-release, and changes in phenotype of captive-held or reared individuals, including

reduced locomotor performance (Snyder et al. 1996; Huntingford 2004; Connolly & Cree 2008) may directly influence their survival. Sprint speed, for example, has a direct effect on lifetime fitness of reptiles by enabling them to successfully evade predators (Husak 2006a), capture prey (Greenwald 1974), win social interactions (Garland et al. 1990) and have greater reproductive success (Husak et al. 2006). There is evidence that captive-reared lizards are slower than their wild counterparts (Garland 1985; Connolly & Cree 2008), and this raises concerns about whether captive-born individuals are suitable for release to the wild as founders.

New Zealand's tussock grassland regions of Otago have experienced some of the most dramatic declines in abundance and distribution of indigenous lizards (Patterson 1984;

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Towns & Daugherty 1994; Whitaker & Loh 1995). Of particular concern are the large Otago (*Oligosoma ottagense* McCann, 1955) and grand skinks (*Oligosoma grande* Gray, 1845), which now occupy less than 10% of their estimated former range (Whitaker 1996; Patterson 2002). Some sites are now intensively managed by the New Zealand Department of Conservation (Tocher 2009). Otago and grand skinks are also maintained in captivity as an 'insurance policy' and for reintroduction to protected sites (Connolly & Cree 2008; Hutchison et al. 2011), and some wild-wild reintroductions have also occurred (Whitmore et al. 2011). However, the restricted genetic origins of most of the captive skinks, small living spaces, benign housing conditions and the fact that nearly all of the captive population is housed well outside the native environmental range may produce poor-quality founder animals (Connolly & Cree 2008).

In general, captive-bred skinks appear to be of lower quality than their wild counterparts. For example, captive-bred Otago skinks have slower sprint speeds compared with their wild conspecifics, and higher body condition indices that could be interpreted as obesity (Garland 1985; Connolly & Cree 2008). An animal with higher body condition index has heavier mass for its size, but this does not necessarily equate to greater or reduced fitness. Locomotor performance of reptiles is in general a useful predictor of subsequent survival (e.g. Husak 2006a, b), although not in all cases (e.g. Bennett & Huey 1990; Clobert et al. 2000). Because Otago skinks that are released into new environments have to compete with other native lizards for food, basking and retreat sites, and avoid predation, captive individuals may be poor candidates for translocations (Connolly & Cree 2008).

We took advantage of a community initiative that reintroduced a small number ($n = 12$) of captive-reared Otago skinks to an area protected from introduced predators by exclusion fencing in the wild (www.coet.org.nz). Although we were unable to compare the

persistence of our captive-reared skinks with that of translocated wild skinks, we are able to report on within-population variation in pre-release phenotype (age, sex, size, body condition index and/or locomotor performance) and its relationship with persistence of captive-reared skinks after release. We also combined our results with data for other species of *Oligosoma* skinks to explore whether individual captive-held/reared skinks are generally slower and have higher body condition indices than their wild counterparts.

Otago skinks are viviparous, diurnal lizards found predominantly on rocky outcrops in sub-alpine native tussock grassland (Whitaker & Loh 1995). Since 1996, they have been classified by the IUCN red list as vulnerable (IUCN 2008), and in 2003 they were ranked by the New Zealand Department of Conservation as Nationally Critical, which is the highest category of concern (Hitchmough et al. 2010). Their vulnerability to extinction is exacerbated by several features including: late sexual maturity (at >107 mm snout-vent length; SVL), low productivity (2.34 offspring/female/year), moderately large body size (max. 169 mm SVL), highly specific habitat requirements, and small and isolated populations (Cree 1994; Whitaker 1996; Tocher & Norbury 2005; Tocher 2009). Translocations are now used as one of the conservation management tools to help safeguard their populations.

Methods

We studied 12 captive-reared Otago skinks that were descendents of wild stock originally sourced from the Middlemarch/Macraes area in eastern Otago. All skinks were born in captivity and were at least third-generation captive-born, with at least one parent, grandparent or great-grandparent in common. Some individuals were also siblings. This population is managed by a captive manager working with the Single Population Analysis and Record Keeping System (SPARKS), developed by the International Species Information Systems

(ISIS), to negate the potential for inbreeding. The average age of the animals at release was 5.3 ± 0.4 years (range = 2.8–8.8 years). In captivity, the animals were housed in enclosures of approximately $0.5 \times 0.5 \times 0.5$ m. Enclosure size and substrates varied between the four private holders, but all contained live vegetation and at least one refuge. Diets were varied and included pureed fruit, live insects, and some egg and meat products.

The skinks were released into the wild on 28 November 2009 within the Mokomoko Dryland Sanctuary near Alexandra, New Zealand, about 600 km south of their captive facilities, and about 65 km south-east from their predecessors' source site. The 0.3-ha Sanctuary is surrounded by a 1.9-m-high mammal-proof fence and has been free of all mammals since July 2009. It is expected that carrying capacity of Otago skinks will be reached at 50–60 individuals. As the Sanctuary is open-topped, avian predation is still possible. The enclosure consists of schist rock outcrops surrounded by shrubland (*Coprosma propinqua*, *Melicytus alpinus*, *Discaria toumatou*). The Sanctuary is outside the current range of Otago skinks, but within their historic distribution (Whitaker & Loh 1995). Alexandra experiences a continental climate and has much colder winters than both the source location and captive facilities (Rock et al. 2000). However, winter temperatures within rock cracks in the Sanctuary are similar to those experienced at the source location (minimum = 3 °C; G. Norbury unpub. data).

Skink morphology, reproductive status and sprint speeds were measured in an indoor quarantine facility 12 days prior to release in the Sanctuary. We measured mass (± 1 mg), SVL, tail length (± 0.5 mm) and hind-leg length (± 0.1 mm) of each skink. The reproductive condition and (if relevant) number of embryos of females were assessed using abdominal palpation (see Holmes & Cree 2006 for accuracy of palpation in other *Oligosoma* species).

As locomotor performance can be influenced by many factors, including morphology, sex, age, temperature, time of day and repro-

ductive status (Bennett 1982), we took care to provide standard experimental conditions for all animals. Skinks were fasted for 48 h prior to measuring sprint speed. Speed was measured for males ($n = 5$) and non-pregnant females only ($n = 3$). All individuals had complete tails. Individuals were sprinted at air temperatures of 18.5 °C, which is the air temperature at which high emergence would be expected in field conditions (Coddington & Cree 1997); the body temperature of the skinks was confirmed as 18.5 °C using a cloacal temperature probe. Three sprint measurements were taken between 1300 and 1400 h (NZDST), and skinks were rested for at least 15 min between each measurement.

Sprint speeds of eight skinks were measured along a plastic racetrack (length 1 m, width 0.15 m). Five paired infrared lights (0.25 m apart and 5 mm above the surface of the track) transmitted and received an infrared beam horizontally across the track. The interruption of each successive infrared beam stopped one of the timers. A paintbrush was used to encourage sprinting by touching the skinks' tails. We used the fastest speed recorded over 0.25 m as burst speed is a more ecologically relevant measure for Otago skinks. Their general confinement to rock outcrops in the wild means that long sprints are unnecessary to reach cover. Some individuals paused while running, and we recorded the number of pauses over each 0.25-m section.

Post-release monitoring was undertaken on 43 occasions between one and five times a month (except for June 2010) from 28 November 2009 to 21 May 2011. Monitoring involved an observer (the same observer on 81% of occasions) visually searching the rock tors for about 2 h during conditions that favoured emergence (i.e. warm and sunny with light wind; Coddington & Cree 1997). Skinks were photographed on the lateral sides from the nose to the foreleg from a distance of about 2 m, and identified by their unique markings (see Gebauer 2009 for photo-resight method for other *Oligosoma* skinks). We assumed that an

individual had not survived when after at least 15 consecutive occasions of optimal skink-sighting conditions (Coddington & Cree 1997) no additional sightings were recorded; all other individuals were generally sighted at least once every 10 occasions, but usually more frequently. The probability of re-sighting any given skink on a given occasion is 0.33 (G. Norbury unpub. data); thus after 15 surveys, one can be more than 99% sure that an animal that has not been seen is not present. Therefore, the small search area coupled with high detectability of Otago skinks gave us high confidence in our estimates of persistence. We had two levels of survival: (1) survived and (2) assumed dead (individual not sighted for at least 15 consecutive occasions).

Data were analysed using version 2.5.1 of the statistical program R (R-Development-Core-Team 2008). Statistical significance was assumed at $P < 0.05$. The small samples sizes meant that most factors were treated separately within models, but SVL was included as a covariate in all sprint speed analyses. Data are expressed as mean \pm 1 SEM unless otherwise stated. The sprint speed data from the eight Otago skinks were log-transformed to meet assumptions of normality. Body condition indices for the 12 Otago skinks were calculated using the residuals from fitted data using a linear regression of $\log(\text{mass})$ on $\log(\text{SVL})$. Log of maximum sprint speed was analysed using linear mixed-effects models, in relation to body condition index. We also tested the effects of other factors that are known to influence speed of lizards, namely body size variables (SVL, tail length and mass), age, number of generations in captivity, and number of pauses while running. Individuals from within a litter are not independent, so we included known parents as a random grouping variable within all analyses. We acknowledge that all individuals were related to some extent, but the structure of the pedigrees and small sample sizes meant no further level of relatedness could be added to the analyses. Sex was not included in the sprint speed analyses because of the small numbers of

females ($n = 3$), but for other *Oligosoma* species sex does not influence their speed, although pregnancy status does (e.g. Miller et al. 2010). The pause data were analysed in a similar manner, but using generalised linear mixed-effects models. We used generalised linear models to test whether phenotype prior to release (speed, body condition index, sex, SVL, tail length and mass) or age and number of generations in captivity was associated with survival.

We compared our sprint speed data with those of four other *Oligosoma* skink species from New Zealand, as well as data from a previous study on Otago skinks. We obtained the original datasets from authors (Connolly & Cree 2008; Miller et al. 2010; Gaby et al. 2011; K. Miller unpub. data) and selected only data from adult males and/or non-pregnant females at body temperatures within a 5 °C range (18–23 °C) to reduce potential variation in speeds related to body temperature (Gaby et al. 2011). This means that our sample sizes are in some cases smaller than the original sample sizes stated in various papers and therefore our averages of speed and body size may vary slightly (Table 1; Fig. 1). The conditions of captivity, sample sizes, body temperatures, sexes and references for the data are outlined in Table 1. Using the original data sets, we calculated a body condition index (as above) for all individuals. We then tested whether maximum speeds differed with body condition index and/or whether individuals were housed in captivity or wild-caught; species was included as a random factor.

Results

Average maximum sprint speeds of the eight Otago skinks prior to release was 0.59 ± 0.22 m/s (range = 0.26–2.08 m/s) and individuals on average paused 2.9 ± 0.6 times (range = 0–5 times). Speed was not associated with any of the factors measured, including age, number of generations in captivity, size measurements (SVL, tail length and body condition index),

Table 1 Details for five species of New Zealand *Oligosoma* skinks for which data on mean maximum sprint speeds of captive-held/reared and wild individuals were obtained from published and unpublished sources.

Species	Captive or wild	<i>n</i>	<i>T_b</i> (°C)	Sex	Reference
<i>O. maccanni</i>	Captive held	8	20	Female	Gaby et al. 2011
<i>O. otagense</i>	Captive-reared	8	19	Mixed	This study
<i>O. otagense</i>	Captive-reared	13	23	Mixed	Connolly and Cree 2008
<i>O. alani</i>	Wild	8	18	Mixed	Miller unpub. data
<i>O. otagense</i>	Wild	8	23	Mixed	Connolly & Cree 2008
<i>O. smithi</i>	Wild	31	18	Mixed	Hare & Miller unpub. data
<i>O. suteri</i>	Wild	46	18	Mixed	Miller et al. 2010

Data are from adult non-pregnant females and males with mean body temperatures (*T_b*) of 18–23°C. The wild species were measured within three days of capture, and the captive-reared/held lizards were in captivity for at least 8 months prior to measurement of sprint speed.

or number of pauses ($P > 0.05$ in all cases, Table 2).

The 12 Otago skinks released included five males and seven females. Their SVL averaged 98.5 ± 2.5 mm (range = 83–108 mm), mass averaged 23.9 ± 1.6 g (range = 17.1–29.7 g) and body condition index ranged from 1.7 to 1.4 standard residuals. Four females were pregnant at release (three with one embryo and one with three embryos), but no young from the first summer (January–February 2010) were ever sighted. Two pregnant females were seen during spring (September) 2010, and three newborn young were recorded in summer (January–February) 2011.

Of the 12 individuals translocated in November 2009, three females (two pregnant and one not pregnant) immediately disappeared, leaving nine individuals (75%) present 12 months later. A further two males disappeared over the summer of 2011, leaving seven individuals (58%) still present by May 2011. Survival was not related to age, number of generations in captivity, size measures (SVL, tail length and body condition index) or sprint speed before release ($P > 0.05$ in all cases; Table 2).

The body condition index of captive-reared skinks was on average about 60% higher than that of wild lizards at 0.25 ± 0.08 standard residuals and 0.81 ± 0.21 standard residuals,

respectively ($F_{1,116} = 65.584$, $P < 0.001$). However, speed of *Oligosoma* skinks was not related to body condition index ($F_{1,115} = 1.144$, $P = 0.287$), but was instead related to whether individuals were captive-held/reared or wild caught ($F_{1,115} = 84.067$, $P < 0.001$; Fig. 1A,B). The mean maximum sprint speed of captive-held/reared *Oligosoma* skinks was on average about 50% slower (0.53 ± 0.07 m/s; range = 0.24–2.08 m/s) than wild *Oligosoma* species (1.08 ± 0.04 m/s; range = 0.54–2.7 m/s).

Discussion

Like Connolly & Cree (2008), we found no evidence that body condition index influenced sprint speed within a captive-reared cohort of Otago skinks. The same has been observed for juveniles of other captive-bred *Oligosoma* skinks (e.g. *O. maccanni*, Hare & Cree 2010; *O. suteri*, Hare et al. 2008). However, data on multiple *Oligosoma* species (Fig. 1) indicate that among species, skinks that are captive-reared/held are on average 50% slower than wild individuals and that these differences in speed are not explained by differences in body condition index alone. These data are in contrast to other single-species studies where 'obese' and gravid/pregnant lizards are slower than their slim and non-gravid/pregnant counterparts (e.g. Garland 1985; Shine 2003; Connolly & Cree 2008). We suggest that, coupled with body

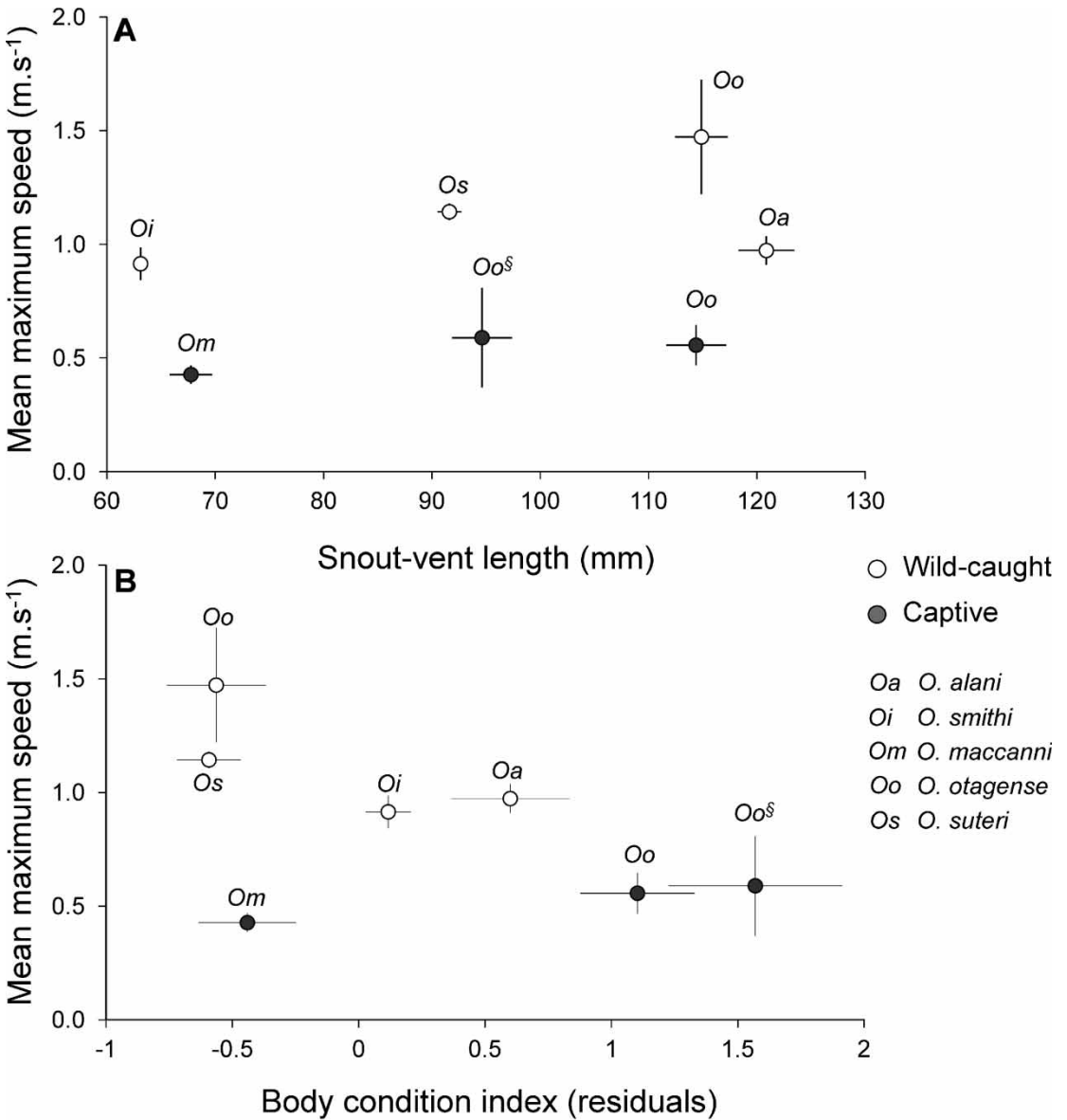


Figure 1 Mean maximum sprint speeds of captive-reared *Oligosoma* skinks in relationship to snout-vent length and body condition index. **A**, Snout-vent length (SVL). **B**, Body condition index (note that the y-axis does not pass through the x-axis at zero). Body condition index is calculated using the residuals from fitted data using a linear regression of log(mass) on log(SVL) for all individuals (i.e. all species combined). Data are from adult males and non-pregnant females with mean body temperatures of 18–23 C. The *O. ottagense* from this study are indicated by §. Error bars are 1 SEM. For data sources and sample sizes, see Table 1.

condition index for some species, captive-reared/held individuals have slower speeds because of reduced fear of humans, and/or phy-

siological changes (e.g. wasting muscle mass and reduced aerobic scope) brought about by small living spaces and benign conditions experienced

Table 2 Relationship between various traits and maximum sprint speed and survival among captive-reared Otago skinks (*Oligosoma otagensense*) based on analyses of covariance using linear mixed effects models (speed analyses) and generalized linear models (survival analyses).

Model independent variable		<i>F</i> or <i>z</i> -value	<i>P</i> -value
Sprint speed (<i>n</i> = 8)	Age	−0.491	0.644
	Body condition	0.872	0.447
	Captive generations	0.067	0.949
	Mass	1.169	0.363
	Pauses	−1.196	0.354
	Snout–vent length	−1.348	0.310
	Tail length	−0.101	0.929
Survival to 18 months (<i>n</i> = 12)	Age	−0.460	0.646
	Body condition	−0.312	0.755
	Captive generations	0.004	0.997
	Mass	−0.542	0.588
	Sex	−0.322	0.747
	Snout–vent length	−0.543	0.587
	Speed	−0.623	0.533
	Tail length	0.339	0.735

Interactions are not shown.

in captivity. However, these differences in speed amongst species may also be related to species-specific differences. For example, McCann's skink (*O. maccanni*) may be a particularly slow species for its size, although individuals do not appear to be any slower in field conditions, being as difficult to capture as other wild *Oligosoma* species (K. Hare pers. obs). It is important that future studies explore the factors that reduce the locomotor performance of captive animals, how long an animal is held in captivity before these changes manifest themselves, how to limit the reduction in locomotor performance and how quickly individuals recover after release into the field.

We also found little evidence that speed or body condition index (and additional factors) within a captive-reared cohort of Otago skinks influenced their survival after release in the wild. This is despite a range of speeds and body condition in the skinks studied here. Perhaps skinks with high body condition act much like heavily gravid lizards and alter their behaviour so they are not impaired by slower speeds (e.g.

Bauwens & Thoen 1981). However, our study was opportunistic and thus constrained by other considerations, resulting in low sample sizes and a lack of a wild–wild translocation to act as a control. We recommend further research in this area.

Seventy-five per cent of the captive-bred Otago skinks survived 12 months after release to the mammal-free field enclosure. These data are within the range of annual apparent survival estimates for wild Otago skinks at Macraes Flat, where populations experienced various levels of mammal control (A. Hutcheon, Department of Conservation, pers. comm.), and where individuals are able to emigrate from survey sites (range = 33–100%; Tocher 2009). It is encouraging that the captive-bred Otago skinks survived a cold winter (much colder than where they were reared), have mated and successfully had offspring. However, it is unlikely that the rate of survival is high enough to enable population persistence, and supplementation will be required. For translocations of New Zealand reptiles with low reproductive

rates and high mortality rates after release (amongst other variables not relevant here), founder groups should minimally include 30 individuals of mixed sex (Miller 2009). Furthermore, as the founding stock is small and all individuals are related to some degree, future supplementation using genetically distinct individuals may reduce the potential for inbreeding depression as well as increasing the chance of population persistence and growth (Miller 2009). Introducing novel genetic stock into new translocated populations of *Oligosoma* skinks have the greatest effect during the initial period of population growth, as new animals assist in limiting the impact of genetic drift (Miller 2009).

Our data indicate that, for Otago skinks, apparently negative changes in phenotype brought about by captive conditions (e.g. potential obesity and reduced speed) are not critical for their short-term survival, or ability to reproduce, where exotic predators are controlled. Furthermore, when comparing data among multiple species, it instead appears that the reduced speeds of captive lizards are potentially a function of physiological and behavioural changes associated with captivity, not necessarily obesity.

Acknowledgements

Thanks to Nicola Nelson for loaning us her sprint speed equipment, and Barry Baxter, Murray McKenzie and Riki Mules for technical support. We also thank the Central Otago Ecological Trust for access to Otago skinks prior to release in the field, and numerous field assistants for their help in collecting field data. Our gratitude to Joanne Connolly, Mya Gaby and Kimberly Miller for access to their original data, including unpublished data on two *Oligosoma* species, for our analyses among species, Andy Hutcheon for his personal communication, and Jo Hoare and Nathan Whitmore for discussion about statistical tests and useful comments on drafts of the manuscript. Thanks also to two anonymous reviewers for their useful comments on a draft. Financial support was provided by a Foundation for Research, Science and Technology,

New Zealand Science and Technology Postdoctoral Fellowship and Central Lakes Trust and Otago Community Trust. Research was carried out following consultation with Ngāi Tahu, including Kāti Huirapa Rūnaka ki Puketeraki, and approval from the New Zealand Department of Conservation and University of Otago Animal Ethics Committee.

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