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Killing them softly: a review on snake translocation and an Australian case study

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Human-wildlife conflicts with 'nuisance' snakes are becoming more frequent around the world as urbanisation continues to encroach on remaining habitats. In an attempt to mitigate this issue, snakes are often translocated in an uncontrolled fashion, with little to no conservation value. To determine the most appropriate methods of translocation we reviewed the available primary literature on studies performing translocations of snakes. We found two types of translocation: long and short-distance. Based on the welfare of the animals involved and difficulty of achieving success with long-distance translocations, we deduced that short-distance translocations are the most favourable. We also reviewed the literature on a third method - repatriating wild populations of snakes with captive-bred or captive-reared individuals, the results of which were very similar to those of long-distance translocations. In conjunction with a mark recapture study carried out by snake catchers in Darwin, Australia, we use our findings to make suggestions on the most appropriate course of action for the mitigation-based snake catching activities in Australia. The difficulty of ensuring successful outcomes for long distance translocations along with a high mortality rate meant we cannot suggest this as an appropriate method for managing 'nuisance' snakes. Instead, we argue that short distance translocations are the most suitable for the welfare of the snakes involved. Nevertheless, no outcome will be more favourable for the snakes than to be simply released within their home range accompanied by a change in attitude of the general public towards a willingness to coexist. Although we focus primarily on Australia our suggested framework can be applied in any country where there is conflict with snakes. Furthermore, should our suggestions be implemented, they are merely a temporary solution to an ongoing problem and we are in desperate need for further research to devise a long-term management plan.

Keywords: serpentes, translocation, relocation, repatriation, human-wildlife conflict

INTRODUCTION

Globally, there is a fear of snakes. Often this fear is somewhat warranted considering that in many parts of the world, snakes are a significant cause of mortality to humans: up to 80,000 deaths per year, mainly occurring in the world's more remote, and less developed tropical areas (Kingsbury et al., 2019; Williams et al., 2019). This fear often results in people killing snakes that they encounter (Narayanan & Bindumadhav, 2019; Whitaker & Shine, 2000). Even in Australia, home to some of the most venomous snakes in the world (Mirtschin et al., 2017), where the number of deaths attributed to snake bites is extremely low (average two deaths per year; Johnston et al., 2017), the attitude that "the only good snake is a dead snake" is a widespread view held by many Australians (Whitaker & Shine, 2000). As urbanisation continues to encroach on remaining habitats around the world, human encounters with snakes are on the rise, especially since many snakes exploit urban or suburban environments (Schlauch, 1978; Zappalorti & Mitchell, 2008; French et al., 2018). In an attempt to mitigate these conflicts, thousands of 'nuisance' snakes are translocated every year (Craven et al., 1998; Shine & Koenig, 2001; Brown et al., 2009). A few generalist snake species are good examples of this, such as carpet pythons (*Morelia spilota*) in Australia and water snakes (*Nerodia sipedon*) in the USA which have successfully exploited the abundant new shelter and prey opportunities available in urban areas (Fearn et al., 2001; Pattishall & Cundall, 2009). At the same time, habitat destruction due to urbanisation is a major cause of species decline for many of the world's taxa and this holds true for reptiles, a severely understudied taxonomic group of which 20 % is at risk of extinction (Wilcove et al., 1998; Sala et al., 2000; Todd et al., 2010; Böhm et al., 2013).

Translocation can be considered either as conservation translocation or mitigation translocation. Conservation translocation, focused on particular species of concern (Armstrong & Seddon, 2008), is often followed by

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monitoring of the translocated population. Mitigation translocation, however, tends to be targeted at human-wildlife conflict, with the aim of reducing wildlife mortality and danger or nuisance to people (Sullivan et al., 2015), and is rarely followed by monitoring (Massei et al., 2010). Mitigation translocation has a history of high failure rates (Sullivan et al., 2015), and this is likely to be particularly true for reptiles and amphibians where translocation of all types has resulted in successful outcomes in only 41 % of attempts (Germano & Bishop, 2009). Translocated reptiles appear to suffer high mortality rates relative to resident individuals, and this is often attributed to aberrant movement patterns, stress, disease, and inability to survive winters for species where finding adequate hibernacula is a priority (Nowak et al., 2002; Brown et al., 2008; Massei et al., 2010; Harvey et al., 2014; Sullivan et al., 2015).

While much data for conservation translocation is available in the primary literature, the data for mitigation-based reptile translocations, which are often ad hoc, either simply does not exist or is largely inaccessible (Germano et al., 2015). In Australia, a huge number of largely uncontrolled, mitigation translocations take place every year with the intent to reduce human-wildlife conflicts. For example, one voluntary organisation in New South Wales Australia, 'rescued' over 22,000 squamate reptiles during a ten year period, with the majority of snakes translocated to another locality (Shine & Koenig, 2001). However, with the evidence from scientific articles indicating that snakes and other reptiles react poorly to being translocated, and with mitigation-based relocations occurring globally and serving little to no conservation purpose, it has been suggested that regulations should be changed to match conservation outcomes (Germano et al., 2015).

The aim of this review is to evaluate from the literature the viability of different methods for translocating snakes. There have been some recent reviews on translocation for mitigation purposes and translocation of herpetofauna but we deemed it important to focus on snakes due to the large scale mitigation translocations happening around the world (Germano & Bishop, 2009; Germano et al., 2015). For the purposes of this review, translocation of snakes, whether for conservation or mitigation, is defined as the movement of animals, either individually or as groups, by humans, from one part of their range to another (Brown et al., 2008). We also include studies of repatriating wild populations of snakes from captivity. Finally, we present data from a two year mark-recapture study collected by snake catchers in Darwin, Australia, and in conjunction with the results from the literature review provide suggestions on how snake relocation efforts should be carried out. Although these suggestions are aimed specifically at Australia, they have the potential for global application.

Review of the literature on snake translocation

We reviewed scientific literature on snake translocation and repatriation projects. We searched the first 10 pages of Google Scholar and the Curtin University library database using the following search terms: "snake translocation", "snake long distance translocation", "snake short distance translocation", "snake repatriation", "snake headstarting", "snake mitigation translocation" and "snake conservation translocation". We also used reference lists and personal contacts to find articles. This resulted in a database of 65 publications. We then removed non-empirical (e.g. literature reviews), duplicate publications (e.g. university theses and their subsequent publications) and non-peer reviewed case studies or pre-prints. Finally, we screened for methodologies that aimed to evaluate the viability of short-distance translocation (SDT), long-distance translocation (LDT), or repatriation for their study species or what impact these processes would have on the species biology (e.g. space use). Following this, we were left with 34 publications comprising 38 studies (publications that included, for example, both LDT and SDT were treated as two separate studies) on 24 snake taxa, across 9 countries (Table 1). For each project we recorded the taxa studied, type of translocation (mitigation or conservation), whether the donor population was wild or from captivity, and the success of the project. Translocation success is hard to determine and it has been suggested that a translocation can only be considered successful if it results in a self-sustaining population (Dodd & Seigel, 1991; Griffith et al., 1989). However, it can require several years of monitoring to make such an observation which is beyond the remit of many of the studies we have compiled. Hence, for studies that did not fit this criterion, we considered the translocation a success if 70 % or more of the translocated individuals survived for the duration of the study, or if the survival probability of the translocated individuals was not significantly lower than that of the resident population. Studies that did not estimate survival or did not monitor appropriately to estimate survival were classed as uncertain.

We reviewed 34 projects comprising 19 long distance translocation studies, 11 short distance translocation studies, and eight studies releasing captive-born or reared snakes into the wild. Of the 19 LDT studies 37 % were successful, 47 % failed, and 16 % had uncertain outcomes (Fig. 1). 73 % of SDTs (11 studies) had successful outcomes while 19 % failed and 8 % had uncertain outcomes (Fig. 1). There were only a small number of studies on repatriation or releasing captive-reared snakes into the wild (eight studies) of which 40 % succeeded, 50 % failed, and 10 % were uncertain (Fig. 1). The most commonly reported causes of failure were attributed to aberrant movement behaviour and reduced overwinter survival (Table 1). The majority of studies were conducted in the USA predominantly on rattlesnakes

Long and short distance translocation

Long distance translocation studies were generally driven by conservation goals; the primary goal of short distance translocation studies was to mitigate human-wildlife conflict although this still has a conservation function. LDT is defined as the transport of an animal beyond its home range (Hardy et al., 2001), or at least

Table 1. Snake translocation studies with summarised aims and outcomes

Country	Species	Aim of study	Outcome	Reference
Antigua and Barbuda	Antiguan racer (*Alsophis antiguae*)	Describe the methods of the successful reintroduction of the critically endangered species to several offshore islands	The efforts increased the population size from 51 individuals on one island to >1100 on four islands	(Daltry et al., 2017)
Australia	Woma python (*Aspidites ramsayi*)	Test the efficacy of reintroducing captive bred woma pythons	All individuals were predated by mulga snakes (Pseudechis australis)	(Read et al., 2011)
	Tiger snake (*Notechis scutatus*)	Determine the effects of translocation on the spatial ecology of tiger snakes	Translocated snakes had much larger home ranges and travelled greater distances	(Butler et al., 2005a; Butler et al., 2005b)
	Dugite (*Pseudonaja affinis*)	Assess the impact of translocation to resolve human-wildlife conflict for dugites	All translocated snakes died and travelled great distances before doing so.	(Wolfe et al., 2018)
China	White-lipped pit vipers (*Trimeresurus albolabris*)	To determine if LDT is viable conservation option	Aberrant movement patterns of females, reduced reproduction. High mortality when compared to residents.	(Devan-Song et al., 2016)
India	King cobra (*Ophiophagus hannah*)	Study the effects of translocation on king cobras.	The translocated king cobra moved a lot more, ate less frequently and did not reproduce.	(Barve et al., 2013)
Jamaica	Jamaican boa (*Chilabothrus subflavus*)	Determine the suitability of Jamaican boa for SDT	Female boas appeared to be able to establish new home ranges following SDT	(Newman et al., 2019)
South Korea	Amur ratsnake (*Elaphe schrenckii*)	Investigate spatial ecology of resident and translocated individuals to design translocation projects	Translocated snakes had higher mortality, aberrant movements, and used different habitat structures compared to resident snakes.	(Lee & Park, 2011)
Sweden	Grass snake (*Natrix natrix*)	Evaluate movement and habitat use during egg laying period and if translocated snakes have different movement behaviour compared to resident snakes	Translocated snakes moved more than residents but used same habitats	(Elmberg et al., 2019)
		Evaluate the adaptability of potentially gravid female grass snakes	Translocated snakes had larger home ranges and remained close to familiar habitat types	(Pettersson, 2014)
UK	European adder (*Vipera berus*)	Ascertain the effects of translocation on the spatial ecology of adders	Translocated males on average moved more every day than resident males. Males also exhibited uni-directional movements away from release site, and one male even displayed homing behaviour. Females tended to stay within 50m of release site.	(Nash & Griffiths, 2018)
	Barred grass snake (*Natrix helvetica*)	Establish what proportion of translocated reptiles remained within receptor sites	Negligible recapture rate.	(Nash et al., 2020)
USA		Examine the utility of LDT for managing eastern diamond-backed rattlesnakes	High survival rate, limited aberrant movements because the source population had small home ranges	(Jungen, 2018)
		Examine the effectiveness of LDT on eastern diamond-backed rattlesnakes.	Translocated snakes had larger home ranges but second year survival probability was not significantly different from non-translocated individuals	(Kelley, 2020)

Country	Species	Aim of study	Outcome	Reference
	Western diamond-backed rattlesnake (*Crotalus atrox*)	Evaluate the effects of nuisance rattlesnake relocation	Translocated snakes moved considerable distances and experienced 50 % mortality. Homing behaviour was also observed.	(Nowak et al., 2002)
	Timber rattlesnake (*Crotalus horridus*)	Assess whether SDTs resolve the human-wildlife conflict as well as LDTs do	SDTs were successful in easing the fears of the public and the translocated snakes quickly resumed normal behaviours.	(Sealy, 1997)
		Locate critical habitats, determine causes of decline and study reproductive and spatial ecology	SDT had a 100% success rate with adults quickly resuming normal behaviours and breeding successfully	(Sealy, 2002)
		Assess the impact of translocation on timber rattlesnakes	Translocated snakes had higher mortality and aberrant movements compared to resident snakes	(Reinert & Rupert, 1999)
		Test whether relocating an entire population to suitable habitat post winter emergence would allow for establishment in a new home range	Snakes regained normal activity and foraging patterns after the second full activity season	(Walker et al., 2009)
	Western rattlesnake (*Crotalus oreganus*)	Effects of LDT on stress levels in male rattlesnakes	Increased testosterone and corticosterone	(Heiken et al., 2016)
		Use radiotelemetry to determine effectiveness of SDT	Multiple SDT did not affect survivability but did influence activity patterns and snakes often returned to point of capture	(Brown et al., 2009)
	Northern pacific rattlesnakes (*Crotalus oreganus*)	Test if repeated SDT and handling represent thermal stressors	SDT and repeated handling does not have major adverse effects on the thermal ecology	(Holding et al., 2014)
	Red diamond rattlesnake (*Crotalus ruber*)	Study the effects of translocation on movement and survivorship	If excluding deaths from complications with surgery there was a low mortality rate in both SDT and LDT	(Brown et al., 2008)
	Eastern indigo snake (*Drymarchon couperi*)	Establish a viable population in Conecuh National Forest and test most suitable release method	High mortality rate in the first year but survivability increased in the second year post release. Hard release had a higher survivability than soft release.	(Godwin et al., 2011)
	Hognose snake (*Heterodon platirhinos*)	Assess viability of translocation for conservation	Translocated snakes had higher mortality and aberrant movements compared to resident snakes	(Plummer & Mills, 2000)
	Northern water snake (*Nerodia sipedon*)	Compare individuals translocated from wild population with individuals translocated from captive populations	Both showed low survivorship with captive reared snakes showing aberrant behaviours and both cohorts had low overwinter survival	(Roe et al., 2010)
		Test if enrichment during captivity improves the success of captive reared snakes in the wild	Elaborate enclosures may not have affected survival of captive reared snakes but brumation in captivity may have	(Roe et al., 2015)
	Ratsnake (*Pantherophis obsoletus*)	Test if enrichment offsets negative effects of captivity prior to translocation	Captivity negatively affected survival and enrichment did not offset this. Wild translocates temporarily had aberrant movement patterns but did not affect survival	(DeGregorio et al., 2017)

Country	Species	Aim of study	Outcome	Reference
	Burmese python (*Python molurus*)	Study the movement and activity patterns of pythons in Florida	Burmese pythons are capable of homing after being displaced at an incredibly large scale	(Pittman et al., 2014)
		Repatriate an area where massasaugas used to exist from a captive population and carry out short distance translocations to assess how this species responds to SDT	All captive born snakes did not survive the winter. SDT snakes moved more than resident snakes but were not negatively affected by SDT.	(Harvey et al., 2014)
	Eastern massasauga rattlesnake (*Sistrurus catenatus*)	Test if soft release improves survival rates for mitigation translocation	No difference in survival between soft release and hard release but had significantly lower survival than resident snakes	(Josimovich, 2018)
		Evaluate translocation of wild snakes versus repatriation with captive snakes	Snakes released in summer had a higher survival rate.	(King et al.,2004)
	Plains gartersnake (*Thamnophis radix*)	Evaluate the effectiveness of headstarting versus releasing neonates	Some offspring born in captivity succeeded in reproducing either when released as newborns or following headstarting	(King & Stanford, 2006)

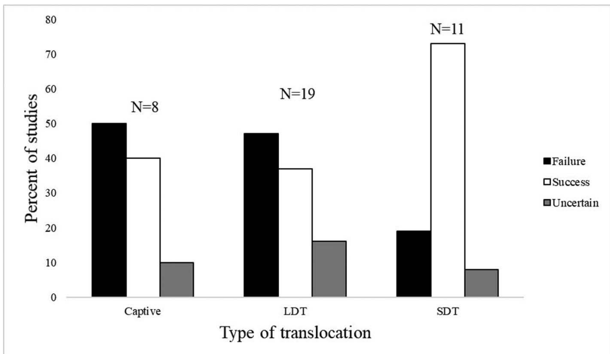

Figure 1. Outcomes of translocation and repatriation projects for 37 studies. The number above each category indicates the number of studies.

twice the distance the animal could cover in a straight line over the course of one year (Nowak et al., 2002), but extensive translocation distances (e.g. 50 km) have been reported (Clemann et al., 2004; Holding et al., 2014). SDT is defined as the relocation of an animal within or near its home range (Hardy et al., 2001; Brown et al., 2009). For LDT studies, we found a trend of high mortality reported across a wide range of species including hognose snakes (*Heterodon platirhinos*; Plummer & Mills, 2000), Amur ratsnakes (*Elaphe schrenckii*; Lee & Park, 2011), white-lipped pit vipers (*Trimeresurus albolabris*; Devan-Song et al., 2016), dugites (*Pseudonaja affinis*; Wolfe et al., 2018) and many others (Table 1). These species include a wide range of ecological types - active hunters, ambush hunters - but they all experienced high mortality, sometimes within days of translocation. Many factors are likely to influence this observed increased rate of mortality; however, increased predation is probably the most common cause of snake mortality in LDT (Sullivan et al., 2015; Teixeira et al., 2007) which can be attributed to the aberrant movement behaviour (Devan-Song et al., 2016) displayed in almost every study. Snakes subjected to LDT moved more frequently and covered greater distances (Jungen, 2018; Nowak et al., 2002), explored different habitat features (Lee & Park, 2011), and, in some cases, males and females displayed different movement behaviours (Brown et al., 2008; Devan-Song et al., 2016). Road mortality was also a common cause of mortality and is almost certainly related to aberrant movement after translocation (Sealy, 2002; Wolfe et al., 2018)

LDT comes with other problems: snakes distributed in temperate zones of higher latitudes require hibernacula to survive the winter (Shine & Mason, 2004) and when snakes are relocated to a completely unfamiliar area finding a suitable place to overwinter can be a limiting factor to their survival (Reinert & Rupert, 1999; Lee & Park, 2011; Shonfield et al., 2019). Disease is also likely to be an important consideration when translocating snakes outside of their home range as the introduction of a diseased animal to an area that already supports a population could be detrimental to many more individuals than just the ones being translocated (Nowak et al., 2002; Brown et al., 2008; Suarez et al., 2017). Introducing animals into an area with an existing population might also push the number of individuals in the already established population above their ecological carrying capacity (Germano et al., 2015). When translocating individuals from a disjunct population into an existing one there is the potential for introducing deleterious genetic effects and causing outbreeding depression if the two populations are genetically divergent (Whiting, 1997). Similarly, if translocating individuals into an area of suitable habitat but without an existing population, this new population may undergo a genetic bottleneck or inbreeding depression from a loss of genetic diversity (Gautschi et al., 2002; Újvári et al., 2002; Daltry et al., 2017).

Despite all these issues, LDT is the favoured option both for conservation, if managed appropriately post-translocation (Daltry et al., 2017), and for mitigating human-wildlife conflict because the possibility of future conflict with humans is greatly reduced (Brown et al., 2009). Despite the high proportion of failed attempts with LDT's there are success stories from species such as eastern diamondback rattlesnakes (*Crotalus adamanteus*; Jungen, 2018) and timber rattlesnakes (*Crotalus horridus*; Walker et al., 2009) where the practitioners went to great lengths to understand the phenology and ecological requirements of the species and relocated them to suitable habitat absent of conspecifics. Western rattlesnakes (*Crotalus ruber*) also managed to locate dens, forage, mate, and establish new home ranges (Brown et al., 2008). Another example of a successful LDT is the reintroduction of the Antiguan racer (*Alsophis antiguae*) to offshore islands where the practitioners had removed all predators and the populations were continuously monitored (Daltry et al., 2017).

In comparison, at first glance SDT seems to be a much more favourable option than LDT when considering ecological, genetic and disease transmission concerns (Dodd & Seigel, 1991; Reinert, 1991; Sealy, 2002). However, snakes that undergo SDT still demonstrate an increase in movement and activity patterns which can, in part, be attributed to exploratory behaviour, but is often associated with snakes attempting to return to the point of capture (Brown et al., 2009; Germano & Bishop, 2009). This homing behaviour occurs in many species regardless of their ecology; e.g. European adder (*Vipera berus*; Nash & Griffiths, 2018), western rattlesnake (*Crotalus oreganus*; Brown et al., 2009), and tiger snake (*Notechis scutatus*; Butler et al., 2005a), all three of which appear to have otherwise relatively small home ranges. It has been demonstrated through LDT that some snakes will travel extreme distances in an attempt to return to their home range (Pittman et al., 2014). Homing behaviour is a problem in the context of SDT because it does not resolve the human-wildlife conflict when snakes have been translocated for mitigation purposes and return to the area of conflict (Germano et al., 2015; Sullivan et al., 2015). Even if the translocation itself did not negatively affect the survival of the snakes (Brown et al., 2009) the common lack of post-release monitoring for SDT does not allow us to draw robust conclusions on the long-term effectiveness in helping snakes. However, though SDT does disrupt the normal behaviour of snakes, some species have been shown to be capable of habituating to a new home range, e.g. Jamaican boas (*Chilabothrus subflavus*; Newman et al., 2019) and massasauga rattlesnakes (*Sistrurus catenatus*; Harvey et al., 2014) while timber rattlesnakes (*Crotalus horridus*) actively avoid contact with humans within their chosen habitats post-translocation (Sealy, 1997). SDT for many species could be a viable management strategy, at least in the short-term, but it requires extensive knowledge of species' requirements and the efforts put into successful release in a suitable area needs to be combined with a willingness of communities and the public to coexist with snakes (Sealy, 2002).

Reintroduction from captive population

Capturing wild snakes and breeding them in captivity to reintroduce a population into the wild is of growing interest in conservation (Germano & Bishop, 2009). The primary aim of these studies is to use captive reared snakes to re-establish populations where they have been extirpated or to bolster existing populations (King et al., 2004; Roe et al., 2010). Several studies have attempted releasing snakes born in captivity after 'headstarting' - raising them to a certain age so they are less vulnerable than are neonates prior to release. Studies on woma python (*Aspidites ramsayi*; Read et al., 2011), eastern indigo snakes (*Drymarchon couperi*; Godwin et al., 2011), and massasauga rattlesnakes (Harvey et al., 2014; Josimovich, 2018) have even included soft-release techniques where snakes were released in temporary outdoor fenced areas to assist the captive-reared snakes. Interestingly, all the woma pythons were depredated and soft-released eastern indigo snakes and massasauga rattlesnakes fared worse than or the same as hard-released individuals. A lack of prior experience in captive-born and headstarted eastern water snakes impacts their behaviour as such snakes were incapable of thermoregulating or selecting adequate hibernacula to survive winter, had limited movements, and uncharacteristically spent the majority of their time in terrestrial environments (Roe et al., 2010). It has been suggested that the deleterious effects imposed on snakes during their time in captivity such as aberrant behaviour could potentially be mitigated by providing enrichment with naturalistic enclosures during the headstarting process (Roe et al., 2010) but this has proven to be ineffective, at least in the relatively short period enrichment was provided (Roe et al., 2015). Similar studies on ratsnakes (*Elaphe obsoleta*) showed that adult snakes captured in the wild and then held in captivity had a reduction in their ability to detect and react to prey after extended periods of time in captivity (DeGregorio et al., 2013) and that this deleterious effect was not mitigated with enrichment during captivity either (DeGregorio et al., 2017). Simulating an overwintering period in captivity may have contributed to improved overwinter survival for headstarted eastern water snakes in the wild; although the death of several snakes during this brumation process could have resulted in the eventual release of only individuals better suited to survive the winter (Roe et al., 2015).

Moderate success has been recorded in studies releasing headstarted individual tiger snakes (Aubret et al., 2004; Shine & Bonnet, 2009), massasauga rattlesnakes (King et al., 2004) and both neonate and headstarted plains gartersnake (*Thamnophis radix*) (King & Stanford, 2006), all of which had a relatively high survival rate. Releasing captive-born snakes while they are still neonates may be a better option as it is time and cost effective. Releasing neonates allows for natal habitat preference induction (NHPI; Davis & Stamps, 2004) where the released neonate snakes gain experience in selecting shelters, foraging for food and avoiding predators (Roe et al., 2010). Few studies have assessed the survival rate of neonates released immediately back into the wild after birth in captivity, but, this has been shown to be a successful tactic with royal pythons (*Python regius*) where gravid females are caught in the wild and the eggs are collected in captivity; the females are then released and when the eggs hatch 10 % of the offspring are released to maintain the local population while the rest go into the wildlife trade (Aubret et al., 2003; Shine, 2009). Several studies conducting headstarting programs agree that when retaining young for captive rearing a proportion of neonates is to be returned to the capture site to minimise the effects on donor populations (King et al., 2004; Roe et al., 2010).

Australian case study

Australia is home to a plethora of snake species, some of which occur in high abundance in urban areas. As a consequence, human-snake conflicts are commonplace throughout Australia (Clemann et al., 2004; Shine & Koenig, 2001). Conflicts are generally mitigated by private snake catchers who obtain permits from their relevant state wildlife departments. These permits allow individuals to translocate 'nuisance' snakes at the request of the public on a fee for service basis (New South Wales Government, 2019). Such a license can be obtained with ease across most of the country; in most cases a person simply needs to be trained in first aid and complete a venomous snake handling course (Queensland Government, 2019), which is often a single day event using captive snakes that often do not reflect the behaviour of wild conspecifics (J.C., pers. obs.). In some cases, as per the recent amendment of the regulations in the Biodiversity Conservation Act, a permit is no longer required to take reptiles in certain situations in Western Australia (Western Australia Government, 2018).

In the Northern Territory (NT), snake catching services are jointly managed by the Parks & Wildlife Commission of the NT (PWCNT) and private contractors. For the NT's three main population centres (Darwin, Alice Springs and Katherine), snake catchers are employed under contract agreements with the PWCNT. These contracts are advertised to the private sector on a three-year basis with a suitable applicant chosen based on their experience, capability and the competitiveness of their quote (T.P., pers. obs.). This system is highly valued by the community because snake removal services are reliable, available at all hours and free of charge to local residents and businesses.

Darwin is the capital city of the Northern Territory, situated in the wet-dry tropics (Fig. 2). It is Australia's least populated capital city (132,054 people; ABS 2016) and boasts the highest diversity of snake species (35 species; Zozaya & Macdonald, 2017). The greater Darwin area covers a sprawling urban-rural gradient of approximately 550 km^2, and is bordered by a number of conservation reserves and crown land estates. Human-snake conflicts here are common: between 2011 and 2017, contract snake catchers attended between 631 and 851 callouts per year (Parkin et al., 2020). The vast majority (98 %) of snakes caught in Darwin are not considered dangerous to humans, with dangerously venomous species such as northern brown snakes (*Pseudonaja nuchalis*) accounting for only a small proportion of total callouts (2 %; Parkin et al., 2020). Venomous snakes captured in urban areas were translocated outside of town boundaries due to concerns about public safety, and as per the stipulations of snake catching permits (PWCNT, 2017). For most harmless snakes, translocations were often deemed unnecessary. Once a snake was identified as non-venomous and posing no threat, the public were usually content to leave it alone. However, translocations did occur if the snake was, a) threatening domestic pets or poultry, b) found living inside a home or building, or c) injured or in immediate danger of being killed (i.e. from a dog, cat, or human). Non-venomous snakes were usually translocated to the closest uninhabited parcel of crown land or conservation reserve (typically under 1 – 2 km). Release sites were chosen based on suitability of the habitat, and the presence of immediate sheltering opportunities. Between September 2016 and December 2017, Darwin Snake Catchers, a business contracted by the NT Government, undertook a mark-recapture study to assess rates of recapture for translocated snakes. Data from this preliminary study is presented herein.

During the mark recapture study, 464 snakes of five predominant species were individually marked with ventral scale clips, weighed, measured and sexed. The coordinates of the snake's original capture site, translocation site, and recapture site were recorded using Sightings (Macdonald, 2013), an ecological data-collection app for iPhone. To determine whether a translocation was SDT (within the species expected home range) or LDT, we examined previous radio-telemetry studies on the same or similar species to estimate expected home range sizes. Unfortunately, no data was available on the home range size of Children's pythons (*Antaresia childreni*), olive pythons (*Liasis olivaceus*) or common tree snakes (*Dendrelaphis punctulatus*). Some species of pythons e.g. water pythons (*Liasis fuscus*) and carpet pythons, have been found to undergo a seasonal shift in home range size associated with mate searching activity and migrations of their prey, while black-headed pythons (*Aspidites melanocephalus*) can move considerable distances (>500 m) in a single day (Heard et al., 2004; Johnson et al., 1975; Madsen & Shine, 1998; Slip & Shine, 1988). Slaty-grey snakes (*Stegonotus cucullatus*) at Fogg Dam on the outskirts of Darwin have been found to retain a relatively small home range throughout the year, despite their habitats becoming seasonally inundated in the monsoon season (Brown et al., 2005). Given the limited published data available on home range sizes for our focus species, we broadly defined translocations <1500 m as SDT and translocations of a greater distance as LDT. This method has clear limitations because home range sizes may vary intraspecifically (Madsen & Shine, 1998), and the available data was also collected from individuals living in natural rather than urban environments. Snakes living in urban areas may behave differently to conspecifics living in natural environments (Pattishall & Cundall, 2008) and therefore we must acknowledge that our

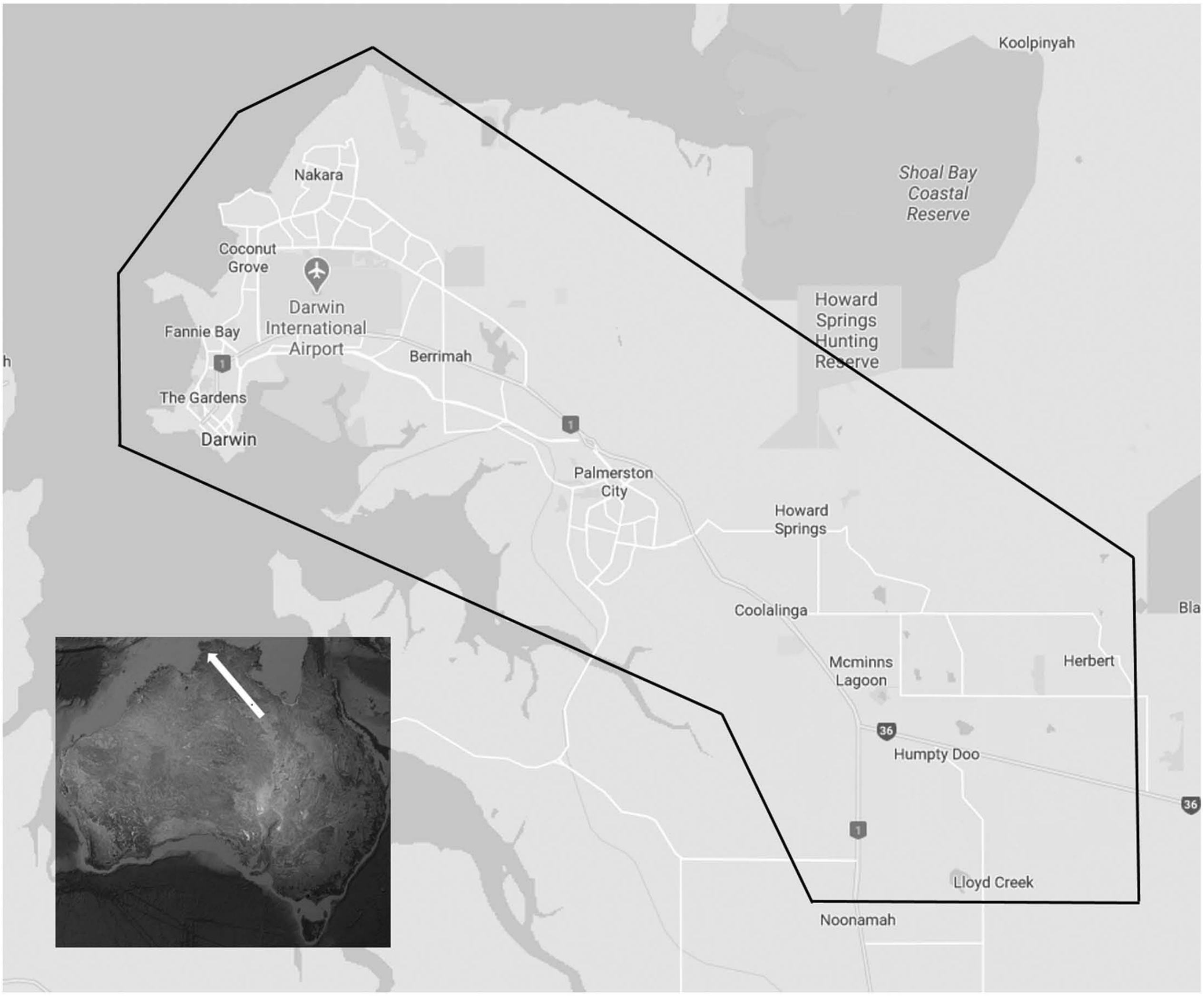

Figure 2. Map of Darwin with black lines indicating boundary of contracted snake call-out services (PWCNT, 2016).

Table 2. Number of snakes marked and recaptured

Species	Marked	Recaptured
Antaresia childreni	57	3
Aspidites melanocephalus	3	1
Boiga irregularis	2	0
Dendrelaphis punctulatus	79	2
Furina ornata	1	0
Liasis fuscus	94	8
Liasis olivaceus	27	5
Morelia spilota	119	17
Stegonotus cucullatus	78	2
Tropidonophis mairii	4	0

definition of what constitutes a 'short distance' is merely an assumption.

Of 464 marked snakes, only 8 % were recaptured (Table 2) either during call-outs for snake relocations or opportunistically while driving around Darwin. This included a total of 44 recapture events of 7 species and 38 individual snakes. The majority of the recaptured snakes had been subjected to SDT (92 %) of which a few were released on site within their home range (8 %). Very few recaptured snakes had been subjected to a LDT (8 %). 15 % of the recaptured snakes were either found dead or had to be euthanised and in one case, the snake was observed being killed by a member of the public (Table 3). All of the deceased snakes except for one had been subjected to SDT and all of them had been killed as a result of human activity, either run over by a car, attacked by dogs, or directly killed by a person. Considering all of these records were incidental, as none of the snakes were radio-tracked, the mortality rate of 15 % should be viewed as a conservative minimum and may indeed be much higher. 52 % of the recaptured snakes had displayed some kind of homing behaviour, defined as either heading away from their translocation point in the direction of the original point of capture or by being recaptured at the original point of capture (Table 3). All recaptured snakes that were translocated to nearby bushland subsequently returned to urban areas, with at least seven individual snakes returning to exploit anthropogenic prey sources such as domestic chickens or caged birds. One individual olive python was recaptured three times in the same suburb preying on caged birds. When examining homing behaviour by species it appears that primarily nocturnal, ambush hunting pythons (Children's python, water python, olive python, and carpet python) were likely to home when translocated (Fig. 3). Due to the small sample size of the remaining snake species (black-headed python, common tree snake, and slaty-grey snake) it is difficult to draw any conclusions concerning homing behaviour without speculating (Fig. 3), although it is unsurprising that the single specimen of black-headed python did not home considering this species can move large distances and are thought to be active foragers (Bedford, 1996; Johnson et al., 1975; Swan & Harvey, 2019). The low number of recaptured slaty-grey snakes also does not let us draw any conclusions on their tendency to home; however, due to their small home ranges at Fogg Dam, without a seasonal shift in range size, homing behaviour is probable. Furthermore, we did not omit the accidental release of a slaty-grey snake and the two potentially translocated carpet pythons where the identifying marks may not have been noticed; if we had removed them from the data, the trend of homing behaviour would have been even greater (Table 3, Fig. 3). The high proportion of snakes that displayed homing behaviour reflects the findings of many translocation studies around the world (Germano & Bishop, 2009) and is a strong indication that more information is required on the management of 'nuisance' snakes in Australia, and globally. The interspecific variation in homing behaviour also shows that regulations on translocated snakes need to be tailored to the ecological requirements of species. Although our sample size is small and conclusions broadly speculative, we would like at least to bring attention to the fact that the three recaptured snakes that were released within their home range had moved 100 m or less at the time of recapture, while all snakes that were translocated a 'short distance' still moved several hundred meters (Table 3). The data collected by snake catchers in Darwin has proven useful for examining patterns of human-snake conflict, as well as revealing information about the urban ecology of snakes. Their study could be used as an example to set the standard for other snake catching activities around Australia.

Summary and suggestions for the future

Globally, wildlife agencies have been largely unsuccessful at documenting the success or otherwise of mitigation translocations and consequently managing these activities with appropriate conservation outcomes

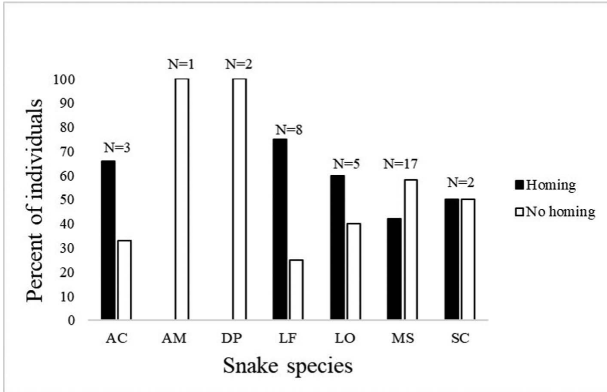

Figure 3. Percent of recaptured individuals that did or did not display homing behaviour. AC = *Antaresia childreni*, AM = *Aspidites melanocephalus*, DP = *Dendrelaphis punctulatus*, LF = *Liasis fuscus*, LO = *Liasis olivaceus*, MS = *Morelia spilota*, SC = *Stegonotus cuculatus*. Number above each category indicates sample size.

(Germano et al., 2015). In Arizona, USA, for example, thousands of rattlesnakes are translocated to the urban edge every year without surveying for habitat suitability, resident population viability, or post release monitoring (Sullivan et al., 2015), a situation which is mirrored with other species around the world. Mitigation translocations have been criticised for lacking robust evidence to support their use as an effective conservation management tool (Germano et al., 2015; Sullivan et al., 2015; Bradley et al., 2020), this can be attributed to the lack of published data on unsuccessful translocations (Berger-Tal et al., 2020) or the lack of appropriate data being collected in the first place (Nash et al., 2020). Human-snake conflict is also common issue in Africa, Asia and South America and the associated management tactics are broadly similar to those of Australia. The removal of nuisance snakes in these parts of the world are carried out by various actors, including non-profit organisations (Deshmukh et al., 2015; Hauptfleisch et al., 2020), independent snake catchers or 'rescuers' (Yue et al., 2019), dedicated government agencies (Teixeira et al., 2015) or combinations thereof. Unfortunately, a lack of training, equipment, staff, policy guidelines (Roshnath & Jayaprasad, 2017) or adequate pre and post-release monitoring (Teixeira et al., 2015) to carry out these mitigation services effectively is of major concern. Wildlife agencies in Australia are in a position to take a step in the right direction by collecting high quality data on regional human-snake conflict that could be reviewed and implemented in improved management practices, revised policies and permit conditions. By doing so these agencies can evaluate whether the current state of affairs is appropriately protecting the species they are responsible for and in turn any advancements made in management practices may be applied elsewhere. Based on some of the practices incorporated by snake catchers in Darwin, we have devised a framework that would address some of these issues:

1. If translocated snakes are marked, age is determined (juvenile, sub-adult, adult), sexed, coordinates

recorded for point of capture, release and recapture, and all of this data was compiled in a database, we would be able to develop better management practices tailored to the ecological needs of species.

2. The accuracy of data collected by snake catchers could be greatly improved with the use of simple smartphone-based data collecting apps such as Sightings (Macdonald, 2013), which records an accurate GPS location of capture and translocation site, date and time the snakes were caught, and allows records to be easily uploaded to wildlife authorities. This would streamline the reporting requirements of snake catchers, allow state wildlife departments the ability to examine temporal and spatial patterns of human-snake conflict in regional areas, and monitor these mitigation translocations.
3. Likewise, state governments or local councils could take more responsibility for human-snake conflict as being a community and urban conservation issue. The situation may be improved by providing guidelines to snake catchers on appropriate translocation methods, improving reporting requirements and data management, making permit acquisition more competitive, and relieving the burden on the general public who pay for snake catching services by subsidising the role of professional snake catchers, such as in Darwin.
4. Together with a transition to a framework such as this, research institutions would ideally also conduct radio-telemetry studies on the most commonly translocated snakes such that we gain proper insight to the movement patterns and mortality rates of individuals that are released within their home range or undergo translocations and whether they are capable of establishing new home ranges.

Researchers attempting to determine whether LDT is a viable option for snakes need to have a comprehensive understanding of the candidate species before translocations take place. Practitioners of successful conservation LDT studies have gone to great lengths to ensure the survival of the species they were studying by understanding their ecological requirements and taking great care in selecting suitable release sites (Jungen, 2018); creating artificial shelter sites, baiting them to attract prey and only releasing snakes at the appropriate time of year to aid in overwinter survival (Walker et al., 2009). Once the animals were translocated they were monitored for extended periods of time and possible predators were managed (Daltry et al., 2017). With LDT it is almost impossible to choose an area that looks appropriate, release the snakes and simply expect them to survive without such research. Therefore, we cannot recommend LDT for mitigation purposes. If it became clear that translocation of any kind is not appropriate for managing certain species, taking these animals into captivity for breeding purposes and releasing neonates into the wild to maintain the population could be considered (Aubret et al., 2003; King et al., 2004; Shine, 2009). Despite the probable high mortality rates, which is what would likely occur naturally, it would allow the surviving snakes to gain experience in their environment (Davis & Stamps, 2004). We suggest that in terms of the welfare of the animals being translocated, SDT is the most favourable option to mitigate human-wildlife conflict, although some authors of previous studies argue the contrary because of homing behaviour. Even so SDT should be considered as a last resort to be used only for snakes that are potentially dangerous. Evidently, snakes found within a residence or building, or those threatening domestic pets and livestock, should be removed to reduce conflict but we advocate that for species that pose no threat to humans, release should be within the immediate vicinity of where they were caught (e.g. at the back of the garden). For snakes that are deemed too dangerous to be left in the garden and are translocated, even if it is only a short distance, great care should be taken in selecting an area where the snakes do not need to cross any major roads should they attempt to return to their home range. We acknowledge that homing behaviour is an issue but snakes can be incredibly hard to find, even by trained and experienced herpetologists (Boback et al., 2020). If a high standard of snake relocation service were to exist that does not incur a cost to the public, relocating the same snake multiple times should not have a negative impact on the public or the snakes involved. Given the low number of recaptured snakes in Darwin, even if the majority of translocated snakes did return to the original conflict area, they appeared to remain out of sight and out of mind. The general public could further reduce the likelihood of encountering a snake by maintaining their garden and ensuring that their outdoor bird enclosures, should they have them, are snake proof (Bush et al., 2007).

Ultimately, public education and community engagement are probably the most effective tools to resolve the conflict between humans and snakes (Sealy, 1997), particularly for places like urban Australia where the risk of snake bite is relatively low, and the public are naïve or uninformed about snakes in their area (Wolfe et al., 2020). People need to be willing to accept that even though they live in an urban world “nature is not a separate domain hiding away in the wilderness” (Low, 2002) and animals live around them and don’t need to be removed simply because their presence is unwelcome (Shine & Koenig, 2001). Easing this discomfort appears to be the main objective of the mitigation translocations snakes are subjected to, and very little attention has been given to the ecology, behaviour, and habitat requirements to ensure survival of translocated individuals (Sullivan et al., 2015). Although the success rate of reptile conservation translocations has improved (Germano & Bishop, 2009), translocations for mitigation purposes have received far less scientific scrutiny and few advancements have been made in their application (Germano et al., 2015). A significant improvement would be to uphold mitigation translocations to the same guidelines described by the IUCN for conservation (IUCN/SSC, 2013; Sullivan et al., 2015).

Although we have focused heavily on Australia, as this

Table 3. Distance travelled by recaptured snakes. Distance was calculated as a straight line between translocation and recapture points. † Deceased snakes, ‡ snakes displayed homing behaviour, § snakes were recaptured at original capture point, ♦ snakes potentially relocated by park rangers without noticing marks. (HR=released in home range, SDT=short distance translocation, LDT=long distance translocation)

Species	ID	Translocations	Distance travelled (m)
Antaresia childreni	AC117a†§	1 SDT	350
A. childreni	AC127†	1 SDT	323
A. childreni	AC215‡	1 SDT	318
Aspidites melanocephalus	AM111	1 SDT	4817
Dendrelaphis punctulatus	DP114	1 SDT	430
D. punctulatus	DP117	1 SDT	399
Liasis fuscus	LM121§	1 SDT	466
L. fuscus	LM124 ‡	1 SDT	802
L. fuscus	LM146§	1 HR	74
L. fuscus	LM152	1 SDT	560
L. fuscus	LM167a‡	1 SDT	339
L. fuscus	LM219	1 SDT	1249
L. fuscus	LM224†§	1 SDT	1109
L. fuscus	LM80-30-4§	1 HR	0
Liasis olivaceus	LO112‡	2 SDT	850
L. olivaceus	LO118‡	2 SDT	737
L. olivaceus	LO124†	1 SDT	491
L. olivaceus	LO126	3 SDT	926
L. olivaceus	LO212§	1 SDT	1454
Morelia spilota	MS114♦	1 SDT	3802
M. spilota	MS128‡	1 SDT	380
M. spilota	MS129	1 SDT	168
M. spilota	MS137‡	1 LDT	1663
M. spilota	MS138‡	1 SDT	668
M. spilota	MS179	2 SDT	875
M. spilota	MS213§	1 LDT	1449
M. spilota	MS222	1 SDT	375
M. spilota	MS226♦	1 SDT	2465
M. spilota	MS228§	1 SDT	836
M. spilota	MS234‡	1 SDT	1068
M. spilota	MS235	1 SDT	356
M. spilota	MS236§	1 SDT	568
M. spilota	Ms237†	1 SDT	30
M. spilota	MS253	2 LDT	3000
M. spilota	MS254‡	1 SDT	837
M. spilota	MS268	1 LDT	625
Stegonotus cucullatus	SC123†	1 LDT	41
S. cucullatus	SC226§	1 HR	100

is where our case study was conducted, the framework we have suggested is not limited to Australian application; any country experiencing human-wildlife conflicts with snakes is in a position to benefit. Furthermore, should our suggestions be implemented, they are merely a temporary solution to an ongoing problem as urbanisation will further encroach on the habitat of wild reptiles. To ensure these animals' survival amidst the destruction of their habitat, it is critical for us to develop tools and management plans that can suitably deal with this issue.

Conflict of interest statement:
We have no conflict of interests to declare.

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