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Accurate identification of individual geckos (*Naultinus gemmeus*) through dorsal pattern differentiation

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Abstract: Mark–recapture methods are frequently used to obtain the data needed to inform conservation management of vulnerable species. This typically involves animals being captured, individually marked, then released and later detected by capture or resighting. This may be stressful for individual animals and can be resource-intensive. Photo-identification has emerged as an effective, and potentially less intrusive, alternative to traditional mark–recapture methods. Photo-identification can be used when animals have stable and individually identifiable natural markings that can be photographed in the field and used for long-term identification. A database of photographs and associated capture-history data can be used for robust estimation of demographic parameters such as population size and survival if an appropriate sampling regime is used. In addition, aspects of behavioural ecology, habitat use, movement patterns and home range can be examined. We outline the creation of a photographic database for jewelled geckos (*Naultinus gemmeus*) from Otago Peninsula and test the accuracy and speed with which human observers can use this database to differentiate between individual jewelled geckos. Jewelled geckos found during visual searches were captured, photographed and their photographs incorporated into a database. Volunteers then had to match 15 photos of randomly selected geckos to different photographs of the same animals, which were contained within a database of 855 individuals. All users correctly matched all 15 randomly selected geckos. Experience appeared to increase the speed of correct identifications. Our results show that photo-identification can provide an effective alternative to potentially more intrusive techniques such as toe-clipping or pit-tagging for jewelled geckos on the Otago Peninsula.

Keywords: mark–recapture; photo-identification; individual recognition; jewelled gecko

Introduction

Wildlife managers require precise and unbiased estimates of population parameters to inform effective conservation strategies for threatened species (Lettink & Armstrong 2003; Gamble et al. 2008). In addition, an understanding of an animal's behaviour, habitat use, movement patterns and home range can considerably improve management practices and enhance our understanding of ecological interactions. To acquire this information, studies typically require methods such as mark–recapture, where animals are captured, individually marked, then released and detected later by capture or resighting.

Mark–recapture methods are useful for estimating population parameters and typically provide more accurate and precise estimates than alternative methods (e.g. distance sampling), as long as underlying assumptions are met (Rodgers et al. 1992; Thompson et al. 1998; Schauster et al. 2002). However, mark–recapture studies have several limitations. Generally, they are resource-intensive and require animals to be caught, restrained, and then individually identified with markings or tags applied by the researcher(s) (Williams et al. 2002). This can be stressful for the individual animals involved (Langkilde & Shine 2006) and may affect their subsequent fate or behaviour, thereby compromising the reliability of the results (Powell & Proulx 2003; McCarthy & Parris 2004). Furthermore, capturing, marking or tagging individuals of some species may present significant challenges, and some animals may not retain marks or tags long enough to be of use (Davis & Ovaska 2001).

To overcome some of these problems, photo-identification has been developed as an effective, low-disturbance method for identifying individuals (see Arzoumanian et al. 2005; Karlsson et al. 2005; Gamble et al. 2008). This method is applicable where animals have individually identifiable natural features that can be photographed in the field and used for identification through visual matching of photographs from previous surveys. A database of photographs clearly depicting individually identifiable features can be created for a site or region through visual matching of photographs from previous surveys, either by eye (manual matching) or by using pattern-recognition software. Such a database and associated capture-history data may be used for robust estimation of population size if an appropriate sampling regime is used. In addition, longevity, survival, recruitment, population size trends, and patterns of dispersal can be explored. If the database is accessible to future researchers, it allows for the quantification of longer-term parameters and trends.

Here, we detail the creation, application and efficacy of a photographic database for jewelled geckos (*Naultinus gemmeus* McCann, 1955), a moderate-sized (total length up to 160 mm), cryptic, diurnal lizard, found only in south-eastern New Zealand (Jewell & McQueen 2007). This arboreal gecko is one of nine species of the endemic genus *Naultinus* and is classified as 'at risk, declining' by the threat classification system of the New Zealand Department of Conservation (DOC) (Hitchmough et al. 2010). Like other *Naultinus* species, jewelled geckos are long-lived and may live for several decades (e.g. there are individuals of the closely related *N. rudis* that are still alive in captivity and are at least 35 years old) (D. Keall, New Zealand Financial Planning, Wellington, pers. comm.). They are viviparous geckos with a maximum clutch size of two (Cree 1994). The major threats to jewelled geckos are predation by introduced mammals and possibly birds, habitat loss or fragmentation, and illegal collection for the international black market (Jewell & McQueen 2007).

Before the development of the photo-identification method, toe-clipping was the only method used to permanently mark and distinguish between individual jewelled geckos (Shaw 1994; Schneyer 2001; Wilson & Cree 2003). For temporarily recognising individuals without the need for recapture, both non-toxic ink (Shaw 1994; Schneyer 2001) and natural markings (Wilson & Cree 2003) have been used; however, all of these studies relied on toe-clips for long-term identification, and as a safeguard in case temporary marks were lost. Recently, a need for a permanent (but non-intrusive) method for long-term monitoring of individual jewelled geckos has arisen. This need arose because of concerns over animal welfare due to geckos being toe-clipped and repeatedly handled to identify individuals over time, the large number of geckos being monitored, and interest from landowners in monitoring geckos on their own land. Furthermore, toe-clipping is often regarded as unacceptable by iwi (indigenous Māori people's tribal organisations), and this means that in most instances DOC is unable to issue permits for toe-clipping of native lizards (Hitchmough et al. in press).

Shaw (1994) was the first to suggest that the appearance of jewelled geckos may be sufficiently variable to differentiate between individuals. In recent years, members of the local Otago community, landowners and researchers have learned to recognise individual jewelled geckos by their patterns and have used photographs to keep track of specific individuals (CDK pers. obs.). Most recently, photo-identification was used to compare the densities of jewelled geckos across 21 sites on Otago Peninsula, South Island, New Zealand (Knox et al. 2012).

As the photo-identification method has by default become more widely used for monitoring jewelled geckos, its accuracy needed to be assessed so that error rates could be determined. Error rates need to be taken into account when interpreting any demographic data calculated using the capture-histories derived from photo-identification. Thus, we wanted to test the accuracy to which human observers could use photographs of jewelled geckos to differentiate between individuals. In addition, we wanted to assess whether an experienced observer would be quicker at making correct matches than inexperienced observers. The time taken to make correct identifications is important because databases become impractical if the time taken to make a match becomes excessive. The objectives of this study were: (1) to create a regional photographic database for jewelled geckos that can be used to estimate population size and other demographic parameters; (2) to test whether clear photographs of the dorsal patterns of individual jewelled geckos can be used to reliably distinguish between individuals; (3) to determine whether observer experience in matching photographs of jewelled geckos is needed to identify individuals accurately; (4) to assess how experience in using the database may affect the speed of correct identifications; and (5) to assess the advantages and limitations of photo-identification relative to alternative identification methods.

Materials and methods

Study sites

Fieldwork was conducted on the Otago Peninsula (c. 45°50' S, 170°35' E and elevations of 0–300 m a.s.l.) in south-eastern South Island, New Zealand. Forty-one sites containing jewelled geckos (representing the majority of the known jewelled gecko sites on Otago Peninsula) were visited between November 2008 and March 2011. The number of searches per site varied between one and 41 (average 6.6 per site, total 270 across all sites). Adjacent sites containing jewelled geckos were considered as independent only if they were separated by 50 m or more of pasture. Jewelled geckos are sedentary lizards and movement of individuals between sites separated by these distances is unlikely (Salmon 2002). Site borders were also determined by property boundaries and changes in vegetation composition.

Jewelled gecko sites on Otago Peninsula generally consisted of fragmented *Coprosma* spp. shrubland or regenerating coastal forest dominated by kānuka (*Kunzea ericoides*). Jewelled geckos were most frequently sighted in divaricating native shrubs and trees, as well as in overlaying vines; particularly *Coprosma propinqua*, *C. crassifolia*, kānuka, mānuka (*Leptospermum scoparium*), *Muehlenbeckia australis*, *Helichrysum lanceolotum, Corokia cotoneaster* and tōtara (*Podocarpus* sp.). The vast majority of jewelled geckos were sighted on the vegetation surface, or partially buried in vegetation, between 0.1 and 3 m above ground level. Jewelled geckos were rarely sighted on the ground (<1% of sightings), and only appear to use the ground when in transit between bushes or trees in fragmented habitat (Salmon 2002; Knox 2010).

Visual searches and formulation of the photographic database

Visual searches (n = 270) of habitat at each site took place in an attempt to capture and photograph as many geckos as possible. All habitat potentially containing jewelled geckos was surveyed during the day, in weather conditions when jewelled geckos are most likely to be emerged (Duggan 1991). Areas of tall (>3 m), dense or impenetrable vegetation and steep terrain were excluded from visual searches, because even if individuals were sighted they could not be captured and photographed for identification. During searches, all accessible vegetation was thoroughly scanned with the naked eye for geckos. A Fujifilm finepix S2000HD digital camera was used to take photographs of the dorsal surface of jewelled geckos, using the macro function from approximately 40 cm directly above the gecko (which was placed on a flat surface).

Variation in the appearance of jewelled geckos, particularly the presence of stripes and diamond patterns, can enable differentiation of individuals (Schneyer 2001; Wilson & Cree 2003; Fig. 1). The first time each gecko was sighted it was captured and photographed. Individuals that had previously been photographed could sometimes be identified and recorded as resighted without the need for recapture. This was done while the gecko was basking on the vegetation surface, by matching the dorsal patterns on each gecko to the collection of individual photographs from the site (digital photographs from each site were stored on an Apple iPod touch (version 5.0.1), which we took on searches). Using this method, geckos often only had to be captured once, i.e. to obtain the initial reference photograph. We found this method to be feasible

Figure 1. Examples of variation in the dorsal patterns of jewelled geckos (*Naultinus gemmeus*) on Otago Peninsula.

when <50 geckos had been photographed at a site (n = 30 sites); however, when >50 geckos had been photographed (n = 11 sites), the time taken to identify the geckos using the iPod was too great to be practicable. When applied, identity of a previously photographed individual could be confirmed using the iPod approximately half the time. When the method did not work it was usually because the gecko was found partially emerged or retreated into vegetation before it could be identified (in this case, we attempted to catch the gecko by hand and then photograph it).

From the 270 searches (taking 596 person hours), 855 individual geckos were captured and photographed across the 41 sites (average number of geckos seen per search = 10.0; range = 0–46 individuals). The photograph of each jewelled gecko that best showed the dorsal pattern was added to the database. Digital photographs of geckos were organised in 41 folders (one per site) on a computer, each containing one photograph of every jewelled gecko recorded at the site. Sites were given code names and each gecko was allocated an identification number based on the order of photography, i.e. the first gecko recorded at a site was recorded as '1'. Therefore, each of the 855 geckos had a unique code.

In addition to surveys undertaken in the wild, we collated and compared photographs to determine whether or not the dorsal patterns of three adult jewelled geckos (two males and one female) in captivity changed over time. We also compared photographs to determine whether, and if so how, the dorsal patterns of a captive-born gecko changed as the gecko reached maturity.

Statistical methods

The accuracy and speed at which human observers could use a photographic database to correctly differentiate between jewelled geckos was investigated using a photo-matching exercise undertaken on a computer by eight volunteers. Only one of the participants was experienced in matching photographs of jewelled geckos. The proportion of correct identifications of jewelled geckos and the time taken to identify individuals correctly were compared among the participants.

Fifteen geckos were randomly selected from the database (by an individual not involved in the exercise) and the code name recorded for each gecko. Different digital photographs of these 15 geckos (i.e. photographs taken from a different angle or on a different surface, and not stored in the database) were given to the participants so that rather than matching the photo given to them to an identical photo in the database they would have to rely on their own ability at pattern recognition. The two photographs of the same individual were taken in quick succession on the same day; however, time and date information were not made available to the participants as these could potentially assist identification.

All participants recorded how long it took them to identify their match and afterwards all 15 matches were examined to determine whether they were correct or not. For all participants, when making a match, the photographs in the database were checked in the same order (i.e. the coded sites were examined in alphabetical order and the individual geckos at each site in numerical order) so that the times taken to make a correct match would be comparable between participants. The total time taken to match all individuals that were correctly matched was compared between the experienced user and the inexperienced users by determining whether or not the time taken by the experienced user was within the 95% confidence interval (CI) for the mean time taken by inexperienced users.

Results

All users, regardless of experience, correctly matched all 15 of the randomly selected geckos. The experienced user was, however, faster than the inexperienced users at correctly matching the individuals. The experienced user took 101 min to correctly match all 15 geckos, whereas the inexperienced users took between 183 and 587 min (mean plus 95% CI = 309 (182–437) min). As the experienced user's time of 101 min did not lie within the 95% CI for the inexperienced users, it is reasonable to conclude that the speed at which correct identifications can be made is likely to increase with experience.

By examining photographs of three adult captive jewelled geckos (two males and one female) taken through time we found no evidence to suggest that the dorsal patterns of adult geckos change with age (Fig. 2a, b). In addition, the shapes of the dorsal patterns on a jewelled gecko born in captivity did not change as the gecko grew to sexual maturity, despite changes in colouration (Fig. 2c, d).

Discussion

Our results show that photo-identification can provide an effective alternative to potentially more intrusive techniques (e.g. toe-clipping) for identifying individual jewelled geckos. We found that human observers could successfully use the database to identify individual geckos, regardless of the user's experience in viewing photographs of geckos. This suggests that error rates in the photo-identification of jewelled geckos are likely to be very low or non-existent. Hence, any researcher calculating population parameters (e.g. abundance) from capture-histories derived from the photographs can expect to have a high degree of confidence in their results.

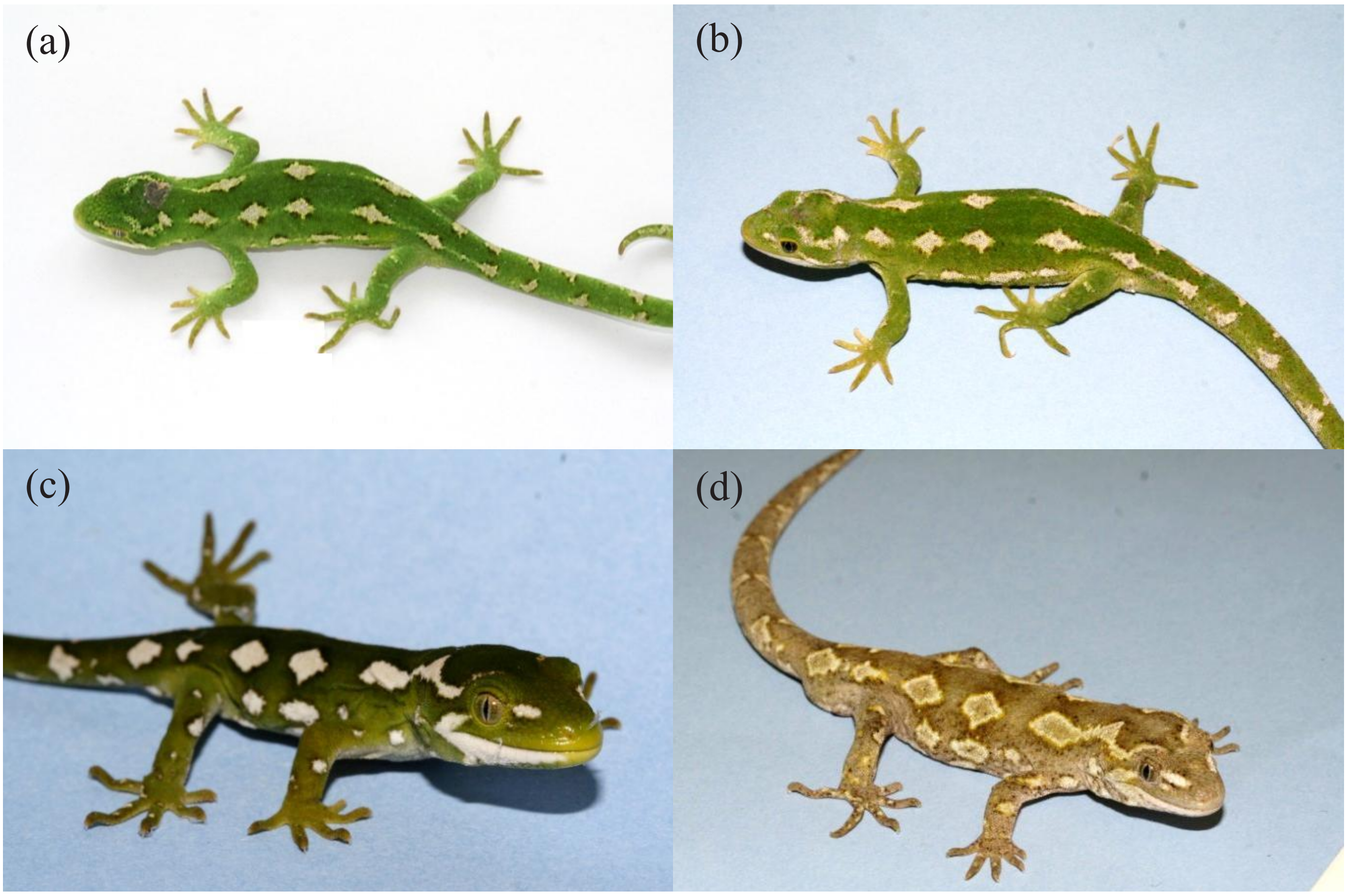

Figure 2. Evidence for the maintenance of dorsal pattern shapes over time in captive jewelled geckos (*Naultinus gemmeus*) of Banks Peninsula origin in (a) a captive adult female photographed on 6 March 2007, (b) the same female photographed more than 4 years later on 10 August 2011, (c) a male gecko photographed soon after birth in captivity on 12 December 2008, and (d) the same male photographed as a mature gecko almost 3 years later on 10 August 2011.

We found that an experienced participant in our trial could make identifications more quickly than inexperienced ones. Manual matching approaches are best suited for studies where sample sizes are low, or in cases where individual pattern markings are able to be split into different categories (e.g. Gill 1978). For large populations that cannot be coded into separate groups, computer pattern recognition programs may be needed as the time required for manual matching may be excessive. Approaches using computers to identify individuals based on pattern recognition software may increase the speed of correct identifications (relative to manual matching) regardless of the user's experience (e.g. Kelly 2001; Arzoumanian et al. 2005; Gamble et al. 2008). However, computer-based methods vary in their degree of accuracy and all require some additional visual confirmation that the correct match has been identified by the program. For example, Gamble et al. (2008) used a computer algorithm to test a database of 1008 images of salamanders with the algorithm identifying 95% of 101 known matches in the top 10 ranks (i.e. the top 1% of all images) and 70% were returned as the top-ranked image. Time spent on manual elements of the matching process was estimated at 1 min per image (Gamble et al. 2008). Developing similar software programs to identify individual jewelled geckos could substantially speed up the matching process. However, it would not necessarily increase the proportion of correct identifications. The desirable method for individual recognition will depend on the study organism, constraints of the study, and the population size and structure. Manual matching is adequate for animals living in small and fragmented populations such as jewelled geckos on Otago Peninsula, but would be more difficult for animals living in one large meta-population.

There are some limitations to the photo-identification method. The most notable is that many species lack individually identifiable features or patterns. Also, patterns can change over time or with age (e.g. Reaser (1995) found that spot patterns of adult California tiger salamanders, *Ambystoma californiense*, held in captivity changed over time). Therefore, the success and usefulness of the technique will largely be determined by how stable, individual, and easily distinguishable each gecko's patterns are, and how many animals are involved. Where there are strong similarities among individuals and high pattern complexity, the risk of misidentification increases (Friday et al. 2000). This can result in false-positive and false-negative identifications, and as a consequence, faulty estimates of population parameters (Gebauer 2009). Thus, to determine its usefulness, the method needs to be tested on individual populations and species. For example, the photo-identification method appears to work well for jewelled geckos on Otago Peninsula and Banks Peninsula, near Christchurch (M. Lettink, Fauna Finders, Christchurch, pers. comm.); however, populations from Codfish Island / Whenua Hou, Southland (T. Whitaker, Whitaker Consultants, Motueka, pers. comm.) and some animals from south-eastern Canterbury do not appear to have sufficiently variable markings for photo-identification to be 100% accurate (M. Lettink, pers. comm.).

Photo-identification is more feasible for the non-expert (e.g. a private landowner) to perform (i.e. it does not require the assignment of unique codes in advance) and avoids public misgivings about toe-clipping. Another advantage of the photo-identification method is the ability to identify individual animals without marking or attaching tags that could potentially influence the behaviour or fate of the study species. Although the photo-identification method we used here for jewelled geckos does not avoid the need for initial capture (and sometimes subsequent capture/s), individuals can be photographed in seconds and released quickly, which intuitively minimises stress, relative to methods that require frequent or prolonged handling. However, any method used for individual identification may have subtle effects on behaviour or survival of the marked animals, and this should be considered when generating and interpreting estimated population parameters (Lemckert 1996; Willson et al. 2011).

Alternative techniques to photo-identification for identifying individual lizards include toe-clipping, pit-tagging and micro-branding; however, all these techniques have disadvantages. First, toe-clipping may reduce locomotor ability for arboreal species. For example, a dramatic decrease in clinging ability was demonstrated for the arboreal lizard *Anolis carolinensis* following toe-clipping (Bloch & Irschick 2005). Natural toe-loss may also result in toe combinations being lost (i.e. tag loss). Second, pit-tagging is costly, necessitates the scanning of animals, is less feasible to use on small-bodied species, and may have biological consequences (e.g. the hormonal stress response noted for a lizard that was pit-tagged; Langkilde & Shine 2006). Last, due to brands fading over time and ethical concerns, micro-branding is considered inappropriate for robust monitoring of New Zealand lizard populations (Hitchmough et al. in press). Notably, unlike most alternative marking techniques, tag-loss is irrelevant when using photo-identification.

Photographic databases, such as the one used for jewelled geckos in this study, can have many important uses. If an appropriate sampling regime is used, population size can be estimated from the associated capture-histories for each individual, using both open and closed population models in programs such as MARK. Several other demographic parameters can also be calculated. If databases are made accessible to future researchers, the exploration of long-term population parameters and trends (e.g. site fidelity, dispersal, survival and longevity) may be encouraged. Photo-identification can also assist studies of behavioural ecology, habitat-use and home-range. Furthermore, in recent years photo-identification has been used to identify individual jewelled geckos recovered from wildlife smugglers. This can potentially allow geckos to be returned to their home ranges. Illegal collection of New Zealand lizards is an ongoing threat and repeat situations can be anticipated.

Photo-identification has been used to identify individual animals based on natural patterns or features in a large number of species within several taxonomic groups, including amphibians (Gill 1978; Kurashina et al. 2003; Gamble et al. 2008), reptiles (Perera & Perez-Mellado 2004) and mammals (Whitehouse & Hall-Martin 2000; Arzoumanian et al. 2005; Karlsson et al. 2005). In recent years, photo-identification has grown in prominence in New Zealand and is currently being used to assist monitoring of several reptile and amphibian species, including jewelled geckos, small-scaled skink (*Oligosoma microlepis*) (Gebauer 2009), grand and Otago skinks (*O. grande* and *O. otagense*, respectively) (Reardon et al. 2012) and Archey's frog (*Leiopelma archeyi*) (Bradfield 2004).

In a recent review of marking and individual-recognition techniques for amphibians and reptiles, Ferner (2007) described an ideal mark or tag as one that: (1) does not affect the animal's survivorship or behaviour, (2) allows the animal to be as free from stress or pain as possible, (3) identifies the animal as a particular individual, (4) lasts indefinitely, (5) is easily read or observable, (6) is adaptable to organisms of different sizes, (7) is easy to use in both laboratory and field conditions, and (8) is constructed of easily obtained materials at minimal cost (see also Lewke & Stroud 1974). No mark or tag will completely satisfy all these requirements (Ferner 2007); however, we believe that clear dorsal photographs from most populations of jewelled geckos come close. Photographic identification is an effective alternative to more intrusive techniques such as toe-clipping or pit-tagging. Given that it minimises stress to individual animals and allows for long-term identification of individuals, photo-identification is likely to play an increasingly important role in monitoring and conservation of native lizards.

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