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Value and impacts of collecting vertebrate voucher specimens, with guidelines for ethical collection

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Abstract

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Museum collections of preserved faunal specimens are immensely valuable resources for understanding the natural world, and such understanding has a crucial role to play during the current biodiversity extinction crisis. Collections of specimens, and the benefits accrued by collections, are not static; new and fresh specimens, or specimens from uncollected localities or of differing demographics, are always needed. Despite this, resistance to collecting specimens is mounting, as is an erroneous belief that modern techniques (such as molecular analyses) and technologies (such as digital cameras and tracking devices) negate the need to collect specimens. Contemporary technology sometimes facilitates a reduction in the number of voucher specimens that need to be collected, but it does not eliminate the need to collect. Concerns about animal rights have and will continue to play a crucial and desirable role in rectifying unnecessarily poor treatment of fauna, but we believe that judicious collection of specimens is at times a higher priority than preserving the life of every possible individual. We argue that museum collections provide essential verifiable evidence of species' occurrence over time and space, and thus permit rigorous taxonomic, biological and ecological investigations. The value of specimen data for these studies today and for the decades and centuries that follow, justifies the judicious collecting of specimens. Using local examples, we demonstrate the benefits provided by specimens, the need for continued collecting in Victoria, and a framework with which to guide the decision-making process for the collection of vertebrate specimens.

Keywords voucher specimen, fauna, museum, Victoria, natural history collections

Introduction

"*At this point I wish to emphasize what I believe will ultimately prove to be the greatest value of our museum. This value will not, however, be realized until the lapse of many years, possibly a century, assuming that our material is safely preserved. And this is that the student of the future will have access to the original record of faunal conditions in California and the west, wherever we now work.*" (Grinnell 1910, p. 166).

Collections of voucher specimens that are catalogued and curated in museums provide a critical foundation for taxonomy, evolutionary biology, biodiversity research, conservation biology, and public health and safety (Suarez and Tsutsui, 2004). Voucher specimens provide verifiable and permanent records of wildlife and environmental conditions. In contrast to many forms of botanical collection where only parts of a plant are collected, faunal voucher specimens require the sacrificing of an individual animal. Understandably, that loss of an animal's life results in concerns about animal welfare and conservation (Lunney, 2012), particularly for vertebrates (there is generally far less concern voiced about the welfare of invertebrates). Thus the decision to collect an animal is not made lightly or without substantial independent permitting and review. However, increasing resistance to the collecting of specimens (e.g., Minteer *et al.*, 2014) threatens to undermine the imperative to record today's dynamic faunal conditions for future generations to reference and study.

The Australian state of Victoria's *Flora & Fauna Guarantee Act* (1988) requires that all of Victoria's native flora and fauna can survive, flourish and retain potential for evolutionary development. This legislative requirement cannot be met without a clear understanding of the taxa that make up Victoria's biota - an understanding that cannot be achieved without comprehensive specimen collections. Furthermore, the *Museums Act* (1983) states that the functions of Museum Victoria are, 'to develop and maintain the State collections of natural sciences, …[and] to promote the use of those collections for scientific research.'

In this paper, we first argue that the maintenance and scientific value of faunal collections require continued collection of voucher specimens, using vertebrate specimen collection in Victoria as a focus. Second, we present a framework with which researchers can evaluate the need for and guide the collection of vertebrate specimens.

What are voucher specimens?

Voucher specimens are verifiable and permanent records, because they preserve as much of the physical remains of an organism as possible (Gans, 1993). Traditional voucher specimens include taxidermied study skins, cleaned skeletal material, and spirit specimens (Table 1). The latter represent whole or partial animals fixed in a preservative (e.g., formalin or ethanol). Each of these preparation methods preserves different aspects of an organism, requiring multiple specimens to document as complete a record as possible.

The formal taxonomic description of every non-fossil species is based on traditional voucher specimens, and the type specimens upon which the names of species are defined must be voucher specimens. Voucher specimens are extremely valuable because they preserve the characters by which species can be distinguished. In many instances, these are very small, requiring microscopy (e.g., reptile scale counts, pre-anal and femoral pores, and subdigital lamellae), or are not present or visible on the external anatomy (e.g., skull characteristics), so a whole voucher specimen is critical to their definition.

Current methods of specimen preparation and collection retain more data than ever (Table 1) and can be used in a multitude of ways (Vuilleumier, 1998). Modern specimens are often coupled with photographs, audio recordings (e.g., frog calls), and GPS-based localities that improve the documentation of their condition and provenance. The greatest shift in modern voucher specimens has been the proliferation of genetic samples coupled with traditional whole animal vouchers. These genetic samples are collected from multiple tissue types (e.g., muscle, heart, liver), and preserved cryogenically or in a fixative that slows degradation (e.g., ethanol, RNALater). Increasingly over the last decade, these tissue samples have been accessed for uses other than just DNA, including messenger RNA (the expressed form of DNA in cells), proteins, parasites, venoms, toxins and odorant compounds (e.g., Perkins *et al*., 1998; Nishimura *et al*., 2012).

The value of genetic samples to museum research has led to an increasingly common perspective that non-destructive genetic samples collected directly (e.g., blood, tail tip) or indirectly (e.g., scat, hair, feathers) from the animal are adequate replacements for physical specimens (Minteer *et al*. 2014; Table 1). These non-destructive genetic samples are valuable because they can provide a larger population genetic sample size than would otherwise be prudent if collected as vouchers from a single locality. In some species, where genetic variation has been previously characterised, non-destructive genetic samples can also provide documentation of an individual's identity. However, genetic samples lack many other sources of information preserved in voucher specimens (Rocha *et al*., 2014). Non-destructive genetic samples are typically small in size / volume, and often provide sufficient material for only limited analyses or just a single research project. Thus, they have restricted utility for documenting a species permanently. They also lack relevant RNA and other molecular information that is preserved in the tissues of entire voucher specimens. Finally, genetic samples without voucher specimens do not retain phenotypic morphological information that could be associated with genetic variation (for a practical example of why this is important, see Adams *et al*. 2014).

Victorian species' records also come in the form of photographs, videos, and audio recordings. For some species, these can be sufficient to identify currently recognised species, and they provide a low impact and efficient way to document species' occurrences. These records can preserve various aspects of an organism that otherwise are not preserved in voucher specimens (e.g., calls, behaviour). However, the value of these records is limited when taxonomy redefines species' limits, or for species that are difficult to distinguish from gross external morphology. Many small and complex characters that define species are not apparent on photographs. Images captured by remotely-triggered camera systems are often of low resolution; these enable identification of well-known species, but can be of limited value for small or similar species. In contrast, voucher specimens provide a range of data that cannot be quantified from photographs, such as colour, morphology, internal structures, diet, sex, and reproductive data.

Purely observational records, where there is no substantiated record of the species except the notes of an astute observer, reduces the long-term value of the data because questionable records are unverifiable (Rocha *et al*., 2014). The validity of an observation as a permanent record is dependent on both the expertise of the observer and the degree to which the expertise of the observer is known by the end user. These records also lose value with changes in taxonomy where it can be impossible to assign the original identification to a currently recognised species. Observational records that are coupled with representative voucher specimens are the most valuable because they demonstrate the expertise and accuracy of the observer, and can be assigned to species even after taxonomic revision.

Why are voucher specimens so valuable?

The immense value of specimen collections for research and reference underpins our understanding of biodiversity, and these collections are critical for conservation assessments now and in the centuries that follow. Voucher specimens serve a variety of purposes, including providing the foundation for understanding taxonomy and biodiversity, and are a verifiable record of faunal conditions over time and space that can be referred to repeatedly into the future. Museum collections are used in many ways, including contributing to public health and safety by permitting an examination of the history of infectious diseases and their sources or reservoirs (e.g., Suarez and Tsutsui, 2004). Perhaps the greatest value of specimens is that they provide opportunities for future study. Here we highlight some of the more common uses of voucher specimens within Victoria's vertebrate collections.

Table 1. Types of vertebrate records, their uses and drawbacks, and the direct impact of these records on individual fauna.

Record Type	**Examples**	**Information content / uses**	**Example of uses**	**Drawbacks**	**Direct impact to individual**
Voucher specimen (non-DNA)	Skins, skeletons, spirit specimens	Complete record of species' morphological phenotype (internal and external) Lasting record	Taxonomy, species identification; dietary analysis, morphological adaptation and acclimation, reproductive biology, ontogenetic studies, biogeography, demographic studies (e.g., sex ratios), global change and phenotypes, isotopic analysis, disease and public health research, ecotoxicology, phenology	Removes individual from the population; time- and cost-intensive; requires specialised skills	Death
Voucher specimen (DNA)	Tissues	Complete genome of individuals, tissue-specific RNA expression, proteins, parasites and disease	Phylogenetics, species delimitation, population genetics, phylogeography, kinship, proteomics, transcriptomics, public health and disease, genotype-phenotype association studies	Removes individual from the population, time- and cost-intensive, requires specialised skills	Death
Direct DNA specimens	Ear snip; toe / tail / fin clip; blood sample	Complete genome of individual. Value greatly increased by subsamples of voucher specimens from same locality	Phylogenetics, population genetics, phylogeography, kinship, species delimitation (if coupled with vouchers from same locality)	No record of the individual's phenotype; difficult to assign to new taxa when described. Often limited in quantity allowing relatively few studies. Does not preserve RNA	Minimal
Indirect DNA specimens	Scat, hair, feather sample, shed skin, scale, skin and buccal swabs	Some genetic approaches, testing for pathogens (e.g., the amphibian chytrid fungus in frogs)	Predator dietary analysis, species identification (where species are readily distinguishable by limited DNA alone), population genetics, phylogeography	Contamination issues relating to mis-identifications. Poor quality DNA for most genetic techniques	None
Image and audio recordings	Camera traps, photographs, video, audio recordings	Captures an image or audio recording of fauna, including its colouration. Provides species record that can be evaluated by multiple people, can 'ride out' inappropriate survey weather, allows for 24 hour site surveying	Broad-scale surveys and monitoring particularly for species with large ranges, rare encounters, or in difficult to sample habitats	Not suitable to detect some species; characters required for identification may be obscured or missed. Sex, age, and other phenotypes not preserved	None
Observation	Visual or auditory observation reported by individual	Potential species record at a locality	Phenology (e.g., Bird migrations), distribution records, citizen science (e.g., iNaturalist, BowerBird, eBird)	Unverifiable record; relies on expertise of observer and knowledge of observer's expertise by end user	None

1. Taxonomy, recognition of biodiversity, and conservation

Species are the fundamental unit of biodiversity. Therefore, responding to the modern biodiversity crisis (Pimm and Raven, 2009) requires a robust taxonomic and geographic understanding of species' limits. Delineation and description of species require the definition of physical characters that can be measured or observed on specimens. For every species, a designated holotype (and usually a series of associated type specimens) provides the physical evidence that justifies the application of a specific name. Any changes in taxonomy require comparison to relevant type specimens preserved in museum collections. Thus, taxonomy without specimens does not exist.

Properly prepared and curated voucher specimens last indefinitely, and thus provide a unique historical record of the fauna of a given area (Gans, 1993). Taxonomic revisions, even those using modern molecular techniques, that result in the 'splitting' of a nominal species into two or more taxa may not only require the collection of new specimens, but also the re-examination of existing specimens in order to determine the identity of taxa that occur (or once occurred) in an area. For example, morphological and genetic analyses demonstrated that the lizard *Rhynchoedura ornata* consists of five species (Pepper *et al*., 2011); however, specimens from Museum Victoria were not included in this analysis, and assignation of Victorian lizards previously referred to as *R. ornata* will necessitate examination of existing preserved specimens from Victoria, and perhaps collection of further specimens (P. Robertson pers. comm.). The revision of the dasyurid marsupial *Antechinus stuartii* revealed that southern populations were a distinct species, *Antechinus agilis,* requiring re-examination of voucher specimens from across the range of the two species to determine distributional limits (Dickman *et al*., 1998). Descriptions of new species of Australian mammals demonstrate the need for effective collecting (e.g., Kemper *et al*., 2011; Baker *et al*., 2012). Similarly, taxonomic revisions in fishes are common; for example, *Galaxias olidus* has recently been divided into 15 species (Raadik, 2011; Adams *et al*. 2014), necessitating a re-examination of museum specimens from across Victoria and south-eastern Australia to determine their identification and distribution. In addition to providing the basis for naming and describing species, voucher specimens are necessary for the identification of morphologically similar taxa, such as the freshwater fish *Craterocephalus stercusmuscarum fulvus* and *Craterocephalus fluviatilis* (Ivantsoff and Crowley, 1996).

The conservation of species is increasingly concerned with preserving evolutionary potential (Moritz, 2002), including local adaptation and variation within species, which are population-level phenomena, and dynamic over time. Subspecific taxa and / or local variation are the drivers of evolution (Schodde and Mason, 1999); only a comprehensive series of specimens from across the geographic range of a species allows an appreciation of variation within the species - an understanding that is essential to the conservation of the diversity contained within that species, and hence its evolutionary potential. In the words of Joseph (2011), collections are 'repositories of the evidence for and results of evolution' (p. i).

2. Ecology and the environment

Museum collections that include a variety of preparations, life stages, geographic locations, and time series provide unique opportunities to explore species' ecologies and the status of their environment (Pyke and Ehrlich, 2010). Specimens form a primary resource for studying topics as diverse as reproduction, morphology, skeletochronology, diet, habitat use and preferences, and geographic distribution and variation (e.g., Shine, 1980a; 1980b; 1981; 1989; 1991). For example, fish otoliths provide researchers with information on growth rates and aging, general biology, habitat occupancy, recruitment, movement and migration, as well as the diet of other species (Campana, 2005; Furlani *et al*., 2007). This may be particularly important for threatened, endangered and declining species, for which these data are necessary to develop effective conservation plans (e.g., Clemann *et al*., 2004). Specimen collection that targets communities, such as marine surveys or general collecting trips, can provide additional information, not only on individual species present at a given location, but also give an indication of community composition (Grinnell, 1910).

Understanding species' distributions requires vouchers for reliable and verifiable identification of the species, in addition to locality data. The presence of a vouchered record from a region helps to substantiate less verifiable records (such as catch-and-release records, sightings, acoustic records, nests, burrows and tracks) from that region. Significant records, such as range extensions or first records of a species from a jurisdiction (e.g., Raadik and Harrington, 1996; Clemann *et al*., 2007; Gillespie and Chang-Kum; 2011; Kemper *et al*., 2011), are best substantiated with a voucher specimen to eliminate ambiguity in identification. Conversely, a lack of vouchers can render published results unverifiable (Wheeler, 2003), and supposed records of some significance that are not substantiated with sufficient evidence (e.g., Urlus and Marr, 2011) can be open to criticism (e.g., Clemann and Gillespie, 2012). Distributional data (preferably substantiated by voucher specimens), when combined with other spatially- and temporally-explicit data (e.g., temperature, precipitation, land use) can be used to predict the presence of species in areas that have not been sampled (species distributional modelling; e.g., Kearney and Porter, 2004), or project likely distributions into the future (e.g., Kearney *et al*., 2008).

In a dynamic world, collections have both a temporal and spatial element (Gans, 1993; Feeley and Silman, 2011); changes in geographic distribution, size class representation, disease status over time (e.g., Cheng *et al*., 2011; Richards-Hrdlicka, 2012) and even physical changes in species over time (Gardner *et al*., 2008; Eastman *et al*., 2012) necessitate specimen time-series of varying duration. Newly emerging techniques can be applied across historical samples to investigate temporal changes in species' distribution (see Smith *et al*., 2013). Natural systems are dynamic, and processes such as climate change mean that the value of specimens from a particular region is not static; the faunal situation at any point in time provides a data point for comparison with conditions before and after that point in time. Shifts in distribution, age structure, timing of breeding and migration (Green and Scharlemann, 2003), and trophic level (Becker and Beissinger, 2006) can all be assessed using long-term collections of specimens. Specimen series also provide evidence of movement of taxa due to seasonal changes, such as the transition or replacement of migratory species across different seasons.

3. Future opportunities and value

Voucher specimens provide the most complete record of an organism and the greatest opportunity for repeated and future biological study, especially for unexpected uses (Rocha *et al*., 2014). Failure to collect specimens can render some studies unreliable because the identity of the study species cannot be verified (Krell and Wheeler, 2014). The unexpected value of museum specimens for future research is best exemplified by the environmental disaster created by the pesticide DDT (dichlorodiphenyltrichloroethane) in the middle of the 20th century. Comparison of eggshells in museum collections from before and after 1946 (the onset of DDT use) demonstrated a dramatic decrease in eggshell mass (Ratcliffe, 1967; Peakall and Walker, 1994). This examination of museum specimens, collected for entirely different purposes, was the first indication of the devastating impacts of DDT on wildlife, and ultimately led to legislative control of DDT use, and the subsequent recovery of wildlife.

In 1857, when Wilhelm Blandowski, the first state zoologist of Victoria, set out to chart the natural history of the arid interior near the confluence of the Murray and Darling Rivers, he presumably had no conception of a looming biodiversity crisis and could not know that 11 of the mammal species he collected would be extinct or extirpated from the region within 100 years (Menkhorst, 2009). Blandowski's specimens, preserved in the collections of Museum Victoria, provide a critical record of species' prior to their extinction or decline. For example, the Lesser Stick-nest Rat *Leporillus apicalis* was extinct by the 1930s, but on Blandowski's expedition it was one of the most common species collected, with 27 individuals still in the collection of Museum Victoria. These specimens provide a verifiable record that *L. apicalis* was a common component of Victoria's semi-arid ecosystem prior to its extinction. Similarly, there are Victorian species that have not been verifiably recorded in the state for more than 40 years, such as the Eastern Quoll *Dasyurus viverrinus*, the Grassland Earless Dragon *Tympanocryptis pinguicolla* and the Southern Barred Frog *Mixophyes balbus*; it is plausible that these species no longer occur in Victoria, and specimens of these species held by Museum Victoria may represent the only material evidence from their former occurrences in the State.

At the time of Blandowski's expedition, the discovery of DNA was about 100 years into the future, and, unknown to Blandowski, the skins and skeletons he collected also preserved fragments of DNA that can be extracted and analysed today (Rowe *et al*., 2011; Bi *et al*., 2013). Stable isotope analysis, in which slight changes in the atomic mass of elements preserved in voucher specimens can be informative about the diet, environment and movements of an organism, is another emerging field that highlights the unexpected information that can be obtained from voucher specimens with new technology (Kelly, 2000; Newsome *et al*., 2007; Inger and Bearhop, 2008; Hobson, 2011). The value of voucher specimens and the depth of information that they preserve will only increase as new technologies emerge.

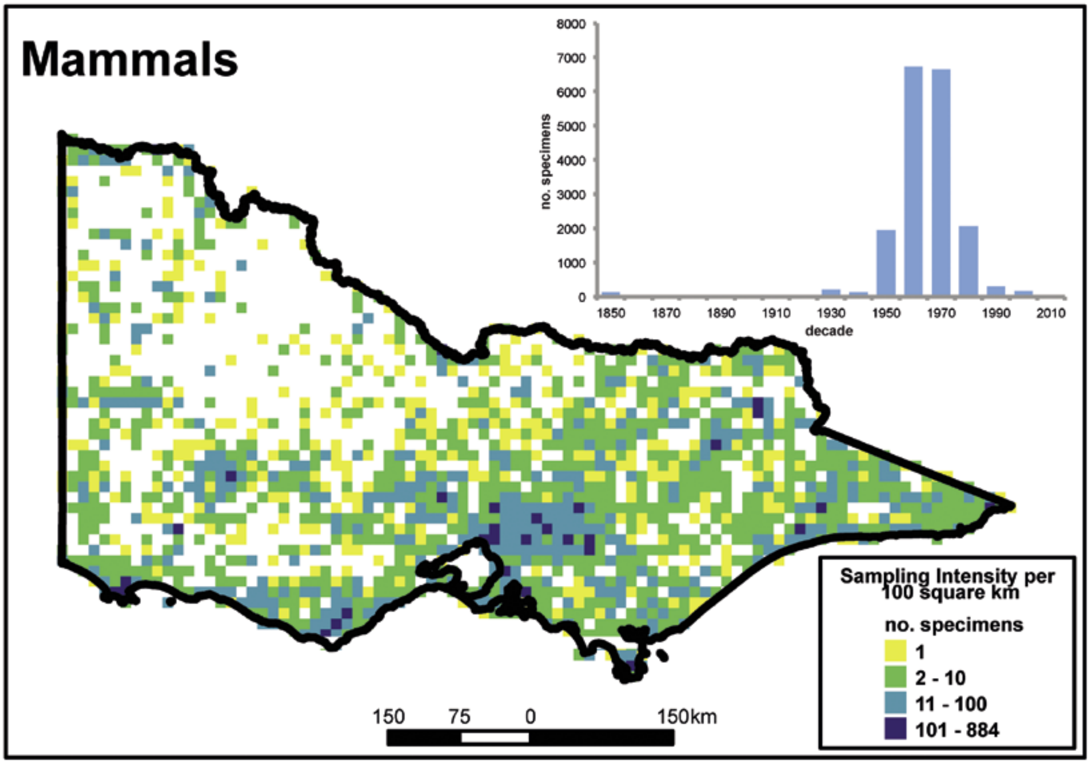
Impact of voucher specimen collection on wild populations

The impact on wild populations of scientific collecting of specimens is usually infinitesimally small, especially compared with other causes of mortality, including predation, disease, weather events, hunting, collision (e.g., road kill), and habitat loss or alteration (Erickson *et al*., 2005; Skerratt *et al*., 2007; Collins and Kays, 2011; Rocha *et al*., 2014). For example, the entire vertebrate specimen collection of Museum Victoria, compiled over more than 150 years from localities all over the world, totals less than 640,000 specimens. Of these, fewer than 200,000 individuals have been collected within Victoria (Figure 1). These amount to fewer than one vertebrate specimen (fish, amphibian, reptile, bird or mammal) per square kilometre of Victoria over the last 150 years. Of course, sampling is not evenly distributed across the state - the greatest concentration of collecting has occurred in the Melbourne metropolitan area (Figure 1). In many cases, specimens were collected from localities where subsequent urban development has eradicated the habitat and the populations of fauna that occupied it. Key elements of the biology and the ecology of those populations are now preserved as voucher specimens at Museum Victoria.

Roads present a major source of mortality for wild populations of native vertebrates. An estimated 377,000 to 1,500,000 vertebrates are killed along Tasmanian roads each year (Hobday and Minstrell, 2008). Other studies have estimated single species rates of road kill ranging from 2.1 to 78.8 individuals km^{-1} y^{-1} (Freeman, 2010 and references therein; Quintero-Ángel *et al.,* 2012). Vehicles kill an estimated five million Australian reptiles and frogs annually (Ehmann and Cogger, 1985).

Exotic predators such as foxes and feral and domestic cats also are a cause of significant mortality for small vertebrates in Australia (Read and Bowen, 2001; Spencer and Thompson, 2005). Studies looking at predation by domestic cats have suggested upwards of 85 million vertebrates were killed across Great Britain within a 5-month period (Woods *et al*., 2003), between 39 to 730 million animals are killed annually within the state of Wisconsin in the USA (Coleman and Temple, 1996), and suburban cats in Canberra kill between 10.2 and 23.3 animals per cat annually (Barratt 1998). Similarly, in freshwater environments, salmonids (trout) and other introduced predatory fish species prey extensively on smaller native fish (McDowall, 2006; Raadik, 2011; Harris, 2013) and frog species (Gillespie, 2001), eliminating populations and driving some species close to extinction.

Hunting and fishing, both of which are regulated for sustainability in Victoria under the authority of the *Wildlife Act* (1975) and *Fisheries Act* (1995), are also significant sources of animal mortality within Victoria. In 2012, duck and quail hunters are estimated to have killed 638,000 native birds (Moloney and Turnbull, 2012). Likewise, commercial and sport fishing around the world results in many times as many fish



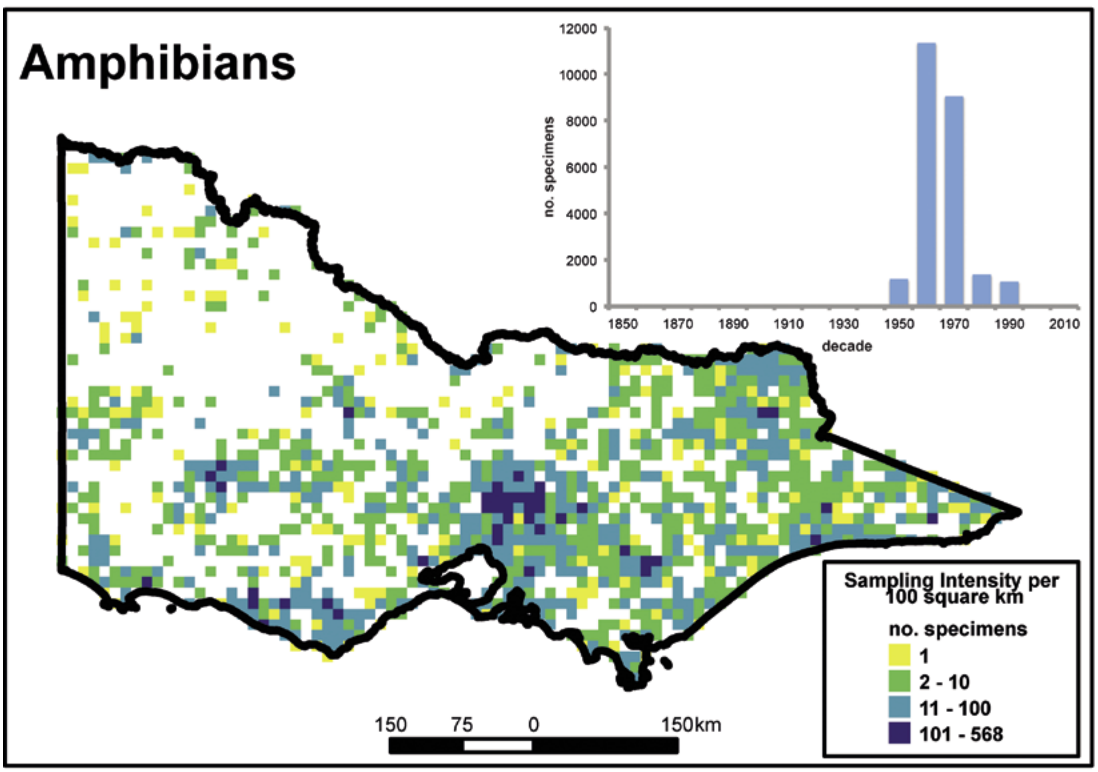
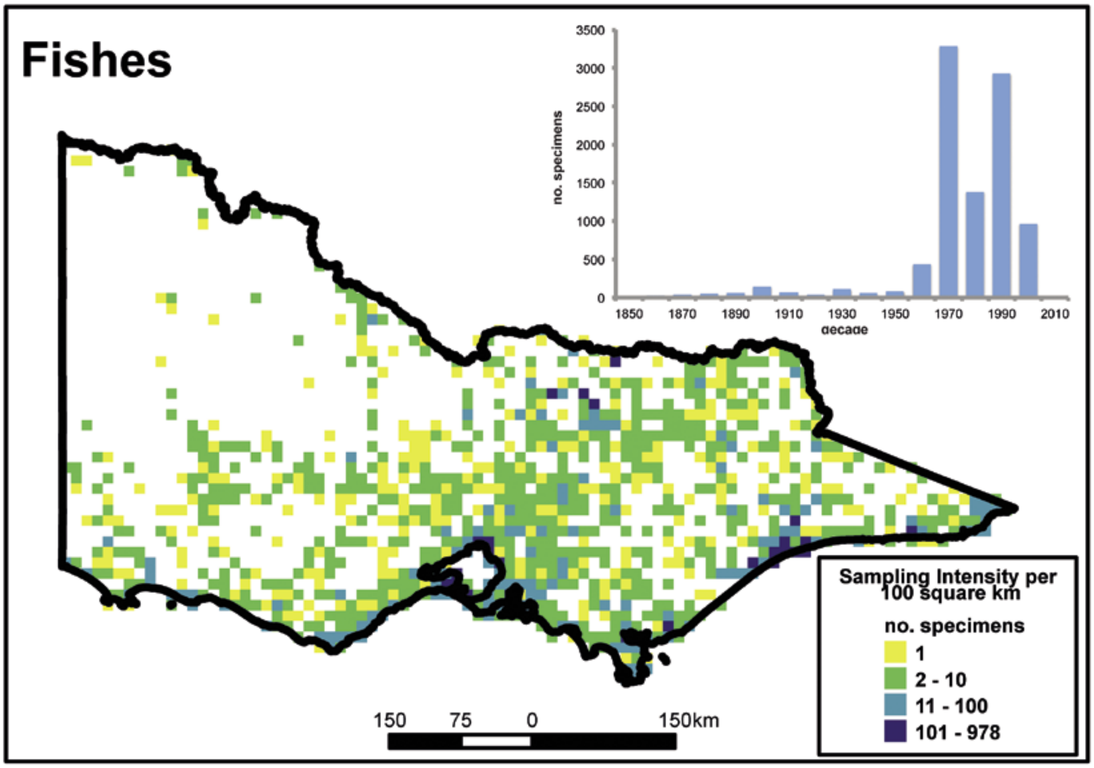
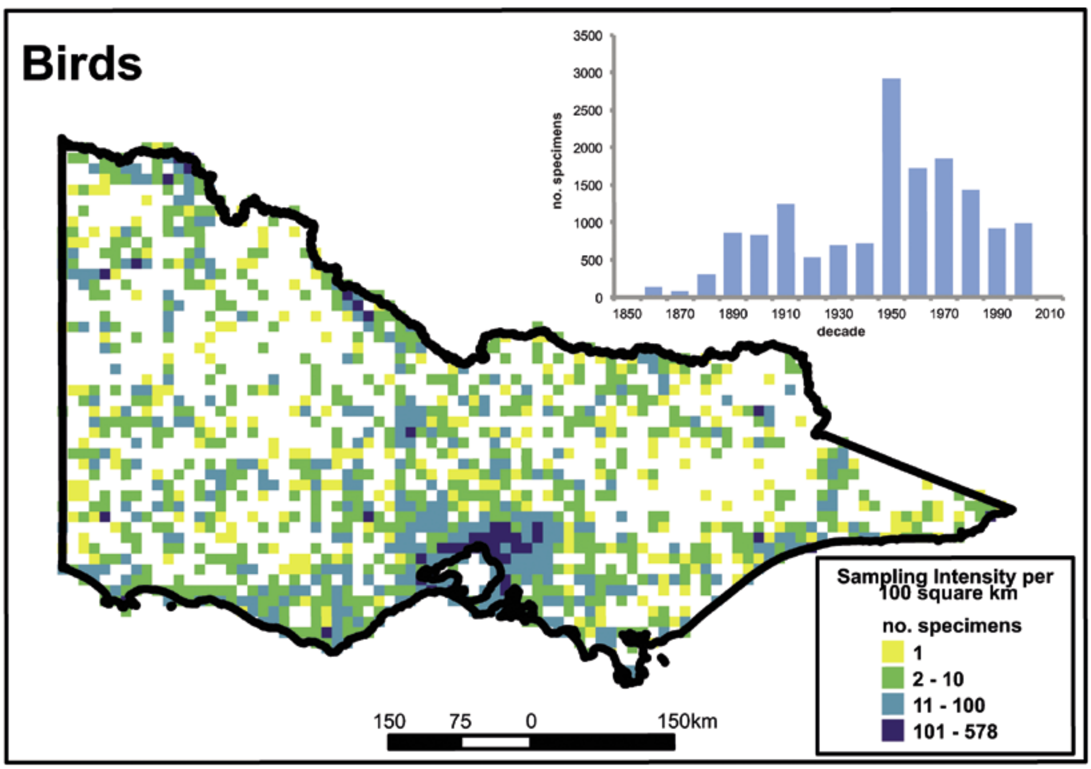
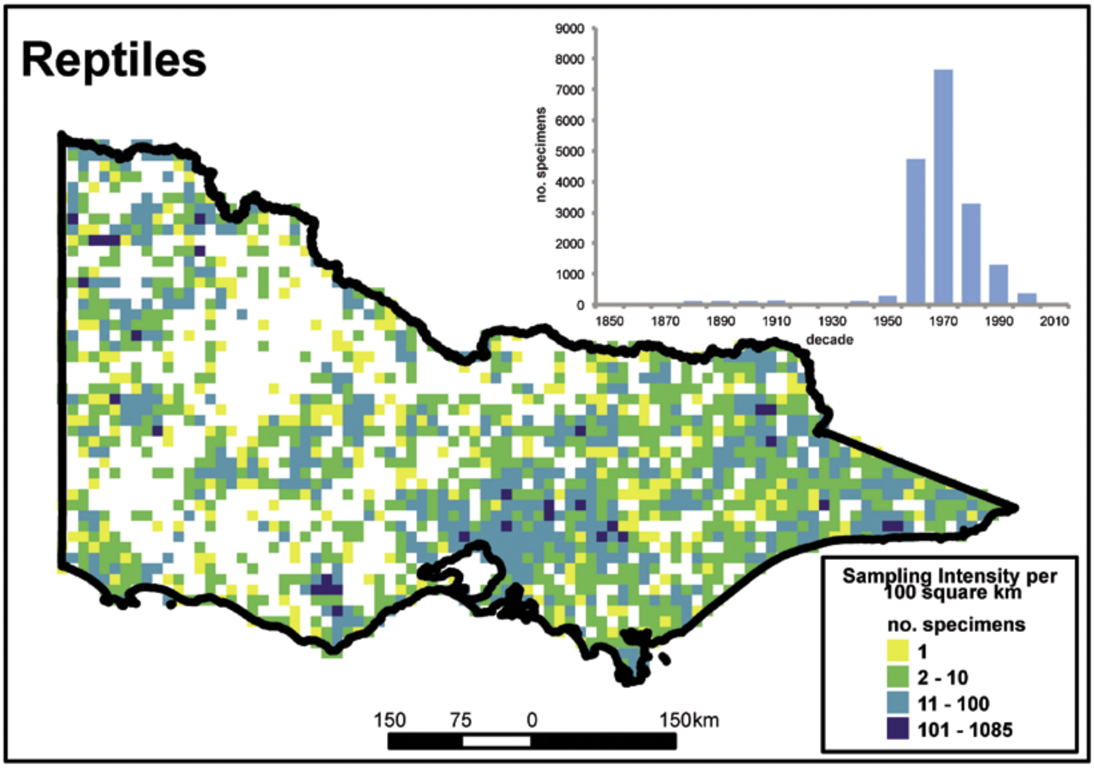
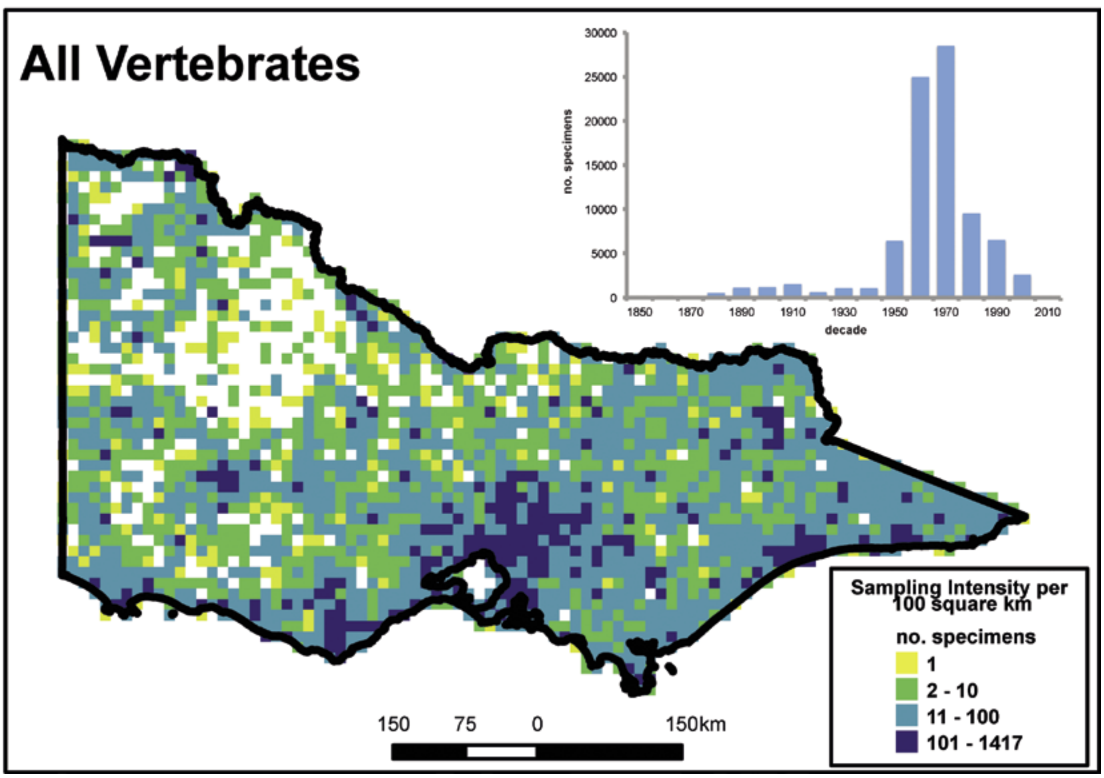


Figure 1. Geographic distribution of Museum Victoria's non-marine Victorian vertebrate specimens. Each pixel represents the number of specimens collected within a 100 km^2 grid (10 x 10 km square) from the earliest georeferenced specimen (collected in 1858) to 2012, spanning 154 years. Yellow, green, light blue, and dark blue pixels represent single (1), low (2 – 10), moderate (11 – 100), and high (> 100) numbers of specimens, respectively. White pixels represent areas with no specimens. Histograms represent the number of specimens by decade.


Fishes
3500
3000
2500
2000
1500
1000
500
0
no. specimens
1850 1870 1890 1910 1930 1950 1970 1990 2010
decade
150 75 0 150km
Sampling Intensity per 100 square km
no. specimens
1
2 - 10
11 - 100
101 - 978


Birds
3500
3000
2500
2000
1500
1000
500
0
no. specimens
1850 1870 1890 1910 1930 1950 1970 1990 2010
decade
150 75 0 150km
Sampling Intensity per 100 square km
no. specimens
1
2 - 10
11 - 100
101 - 578


Reptiles
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
no. specimens
1850
1870
1890
1910
1930
1950
1970
1990
2010
decade
Sampling Intensity per 100 square km
no. specimens
1
2 - 10
11 - 100
101 - 1085
150
75
0
150km


All Vertebrates
30000
25000
20000
15000
10000
5000
0
no. specimens
1850
1870
1890
1910
1930
1950
1970
1990
2010
decade
Sampling Intensity per 100 square km
no. specimens
1
2 - 10
11 - 100
101 - 1417
150
75
0
150km

mortalities each year than all the fish ever collected for scientific collections (Pauly *et al*., 1998; Allan *et al*., 2005). In Victoria alone, there are approximately 720,000 fishers in the Victorian recreational fishing sector, 290,000 of whom annually target freshwater species (VAGO, 2013), including native species.

Loss of habitat is often the single greatest immediate threat to fauna populations (e.g., Wilcove *et al*., 1998). Voucher specimens can be the primary source of information on populations prior to habitat loss (or even the only source, in cases where species have been entirely extirpated, such as is likely for the lizard *T. pinguicolla* around Melbourne). Healthy habitats often harbour locally abundant populations of otherwise rare taxa that are resilient to targeted collecting, for as long as the habitat is secured. For example, although restricted to a few alpine plateaux in south-eastern Australia, the nationally threatened Alpine She-oak Skink *Cyclodomorphus praealtus* and Guthega Skink *Liopholis guthega* can be locally abundant where they occur (N. Clemann unpublished data), and judicious collecting does not pose a threat to these populations. A legislative preoccupation with protecting individuals of Australian animal species, instead of habitat and populations, has been strongly criticised (Rawlinson 1980; Ehmann and Cogger, 1985). Judicious collection of specimens of these individuals for research has been shown to be a negligible component of overall mortality from both natural and human-induced sources (Ehmann and Cogger, 1985). Furthermore, once an organism is included on a threatened species list, resistance to collecting is often greatly magnified (Gans, 1993), despite an often urgent need to gather information to promote the persistence of these species. There is concern about the impact of collecting on small and vulnerable populations (Minteer *et al*. 2014), although it is likely that, if judicious collecting resulted in the total loss of a population or species, that population or species had little chance of persisting for much longer whether or not collecting occurred (Rocha *et al*. 2014), and there may be immense value in securing specimens prior to the final loss.

Considered collecting: a framework to guide the collection of voucher specimens

Despite their value and importance, careful consideration should be made when deciding whether or not to collect voucher specimens and, if the decision is made to collect, how to do so. In this section, we propose a framework to guide the decision-making process for the collection of vertebrate specimens within Victoria and elsewhere.

Decisions regarding the collection of vertebrate voucher specimens should focus on four main issues (Fig. 2): 1) are there knowledge gaps for the target species?; 2) do sufficient voucher specimens exist to address knowledge gaps?; 3) will collection have detrimental impacts on the targeted population?; and 4) can the target species be collected ethically? These considerations should include both species- and population-specific aspects, rather than individual-based criteria.

As discussed above, there are many reasons to collect voucher specimens. For example, are there taxonomic, phenotypic or genetic questions that cannot be answered with existing specimens? If there are such questions, which populations and how many individuals would be needed to address the current research objectives? If there is a demonstrated need for voucher specimens additional to those currently available, the collection may be warranted. In this case, targeted collection from populations that could provide unique insight should be prioritised. Where species are known to be in decline, or where habitat that is known or likely to be occupied by a threatened species will be destroyed, the need to collect representative specimens is urgent. For example, expansion of Melbourne's urban areas is resulting in the removal of grassland habitat occupied by the federally endangered Striped Legless Lizard *Delma impar*. Before this habitat is cleared it is imperative that representative specimens are collected from this area so that we have some record of what has been lost. Habitat currently earmarked for clearing includes areas where no collection had occurred, but samples were required for molecular analyses aimed at defining Evolutionarily Significant Units in this species (Maldonado *et al*., 2012). Consequently, there is an urgent need to collect this material prior to the loss of these habitats and populations. Collection of specimens during a decline can even help to highlight the processes driving losses (e.g., Green, 2008), with the potential to aid in population or species recovery.

Deciding from which populations to sample and how many vouchers to collect should be firstly based on ecological and population considerations, and will likely vary between species. For example, both the global and local distribution of the species should set the context for targeting populations for collecting. Geographic gaps, populations at the species' range limit, or isolated populations may be particularly informative. Alternatively, repeated sampling at known localities can inform change or stasis of a species through time.

Secondly, local abundance should be considered – is the species widely distributed and generally uncommon, but locally abundant in the focal population? In this case, targeted collection within the locally abundant population could be particularly informative with minimal impact on the species as a whole. At times there is considerable resistance to collecting specimens, especially threatened species, from certain land tenures, such as the parks system or land covenanted for conservation purposes (Gans, 1993). However, we believe that more biologically relevant criteria than land tenure alone should form the basis for prioritising areas for collection. Being prevented from collecting in reserved areas where a species may be most abundant, and therefore being forced to collect in non-reserved areas where the species is less common, can result in strain on non-reserved populations that would not be evident on those in reserves.

Thirdly, the reproductive biology of the species should guide numbers and timing of collection. Different consideration should be made for species that are long-lived with slow reproductive rates, versus those that are short-lived with high reproductive rates. The reproductive stage of the population should also be considered. Individuals considered less valuable (according to biological criteria) than other individuals to a vulnerable wild population may be preferentially chosen for collection; for example, Clemann and Beardsell (1999)

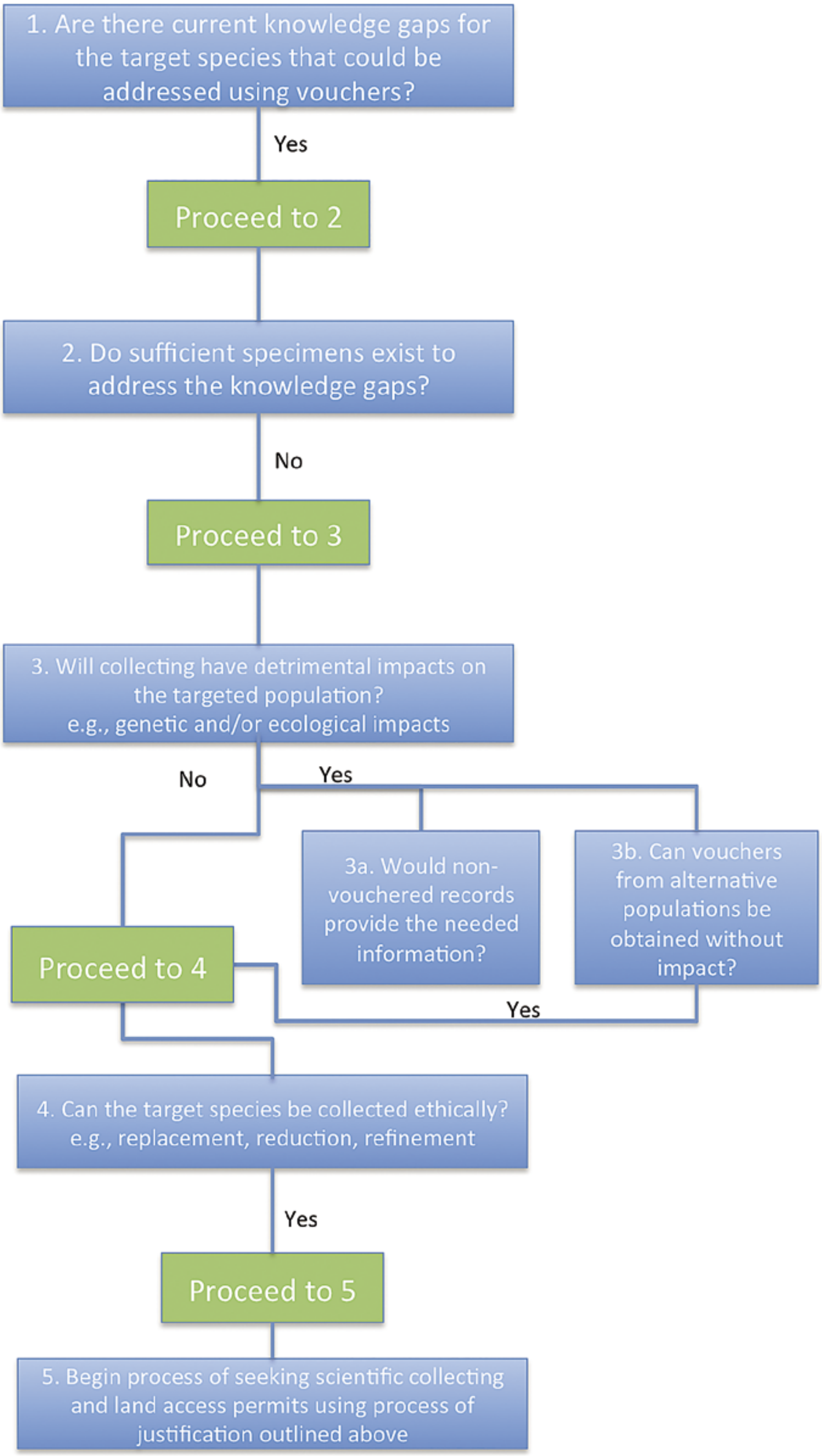


Figure 2. Decision process when considering collecting voucher specimens. Questions to consider are given in blue, with responses to each question given in black. Directions on how to proceed through the process are given in green. Further details and examples are provided in the text

captured a gravid female of the threatened Swamp Skink *Lissolepis coventryi*, and chose to release the female and all but one of the resulting offspring – the remaining neonate forming the voucher specimen to confirm this significant record. Similarly, excess bachelor males could be sampled for a species where few dominant males control territories and access to reproductive females, as in fur seals (Kirkwood and Goldsworthy, 2013). However, for some purposes one specific sex is needed, such as taxonomic studies of some bats where penis morphology is diagnostic (Reardon *et al*. 2014.).

Fourthly, researchers should identify if there are any existing local impacts on the focal population and consider how collecting will compare to those impacts. All populations are regulated by mortality rates, natural and human-induced; in almost all situations where judicious collecting of specimens occur, such collection represents a negligible fraction of mortality rates. If current threats outweigh the collection of limited numbers of vouchers, and collection could provide valuable information about the current status of the population, then collection of vouchers may be warranted. In addition, population-specific factors, such as local abundance, should guide numbers of vouchers (although collected numbers should not exceed the minimum to achieve all objectives).

Ethical considerations for the collection of vouchers are an important part of the process. Procedures for the collection of fauna in the wild are guided by established standards and upheld by animal ethics committees. Limits on the numbers of specimens that may be collected are regulated through federal and state agencies, under advice from scientists and wildlife managers. Collection of specimens should be judicious, with only the numbers needed collected. But, equally, it is folly to 'under' collect, as the cost of returning to the field to collect more specimens may be high; and in worst-case scenarios for declining species, future collection may not be possible due to scarcity or a total loss of a taxon from an area. Finally, the proper preparation and curation of specimens, along with accompanying data, should be mandatory to maximise the value of the specimen to future researchers.

Increasing resistance to returning research animals to the wild (e.g., Clemann, 2013) can create another source of specimens when research animals are retained at the conclusion of a project. Specimens collected for research purposes should be (and often are) required by permit regulations to be deposited in curated museums. These specimens should be accompanied by at least a minimum amount of collection information (e.g., collector name and affiliation, date, and accurate location details) in order to facilitate future research.

Conclusion

We acknowledge the role that advances in technology and increasing animal rights and welfare concerns play in the protection of individuals and populations of wildlife. However, judicious collecting of faunal specimens has underpinned most avenues of zoological investigation, and we argue that targeted collection of vertebrate voucher specimens will continue to provide a crucial component of our understanding of the natural world. Now and into the future, collections that are refreshed and expanded will provide the basis for advances in understanding of native animal zoology and conservation management.

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