

Feather forensics: tracing Australian parrot trade with online trade analysis, stable isotopes, and citizen science

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Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

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Abstract

Native Australian parrots are some of the most globally traded pet birds, yet we currently lack the tools to monitor and manage their trade, detect unsustainable harvest, or prevent the establishment of new invasive species. In this thesis, I assessed novel applications of emerging forensic methods to assist in the conservation and biosecurity of the Australian pet parrot trade.

The emerging popularity of online commerce for wildlife trade provides a unique opportunity to create a snapshot of domestic pet bird trade. I investigated the species composition and relative abundances of parrots and passerines sold online, and identified the main correlates, which potentially drive a species' abundance in trade. Australian native parrots were the most frequently traded, yet the species composition in trade were predominantly non-natives. Additionally, high abundance in trade was correlated with species traits associated with higher invasion risk, including cheap prices.

Some of the most traded native parrots in Australia were cockatoos (Cacatuidae), which are potentially harvested illegally from the wild and laundered as captive bred. I assessed the application of stable isotope methods to identify differences in diets between cockatoos from captive and wild origins. I created a citizen science project to collect feathers in South Australia and investigated the effects of large geographic range sizes and individual variability on the accuracy of these methods. Stable carbon and nitrogen isotopes confidently classified Galahs (*Eolophus roseicapilla*); however, I identified that for three *Cacatua* spp., the diet of wild birds was similar to captive birds, resulting in high rates of misclassification.

Rainbow Lorikeets (*Trichoglossus moluccanus*) were the third most traded native species in online domestic pet trade, and consequently have established multiple invasive populations within Australia. I applied stable isotope methods to identify the isotopic niches of four populations of lorikeets at different stages of the pet-release pathway, to see if these methods could confidently differentiate between recently released pets and established wild populations. The invasive population showed a similar isotopic niche size to the native population, with large overlap with captive birds. In the smaller established and managed population, we were able to confidently identify two recent captive escapees; indicating these methods are applicable to contained established populations and can assist in identifying the most effective management decision-making method to prevent further establishment and spread.

These three novel applications of digital and wildlife forensic methods are effective at monitoring Australian parrot trade and managing its associated risks. However, these tools have caveats, and the potential sources of variation and their limitations need to be thoroughly investigated before widespread application. Nevertheless, new tools are important and welcome additions to the wildlife forensic toolbox for assisting in the conservation and biosecurity of trade in native Australian parrots.

1

Introduction

1.1 The risks of legal and illegal pet trade

Wildlife trade is a massive, and highly complex, transnational marketplace, which much of the world relies upon, yet its full scale and complexity is relatively unknown (Sinclair et al. 2021). The majority of wildlife trade is legal and is an important global market, worth up to US\$220 billion annually, providing a key source of income for many different communities (Andersson et al. 2021b). Alternately, the illegal wildlife trade is one of the largest black markets in the world, estimated to be worth US\$23 billion annually with complex trade routes and mechanisms to avoid detection (Nellemann et al. 2014). Both legal and illegal wildlife trade poses significant threats to environments and global economies, such as through unsustainable harvest to supply demand and the introduction of invasive species and their diseases (t Sas-Rolfes et al. 2019, Pyšek et al. 2020).

The harvest of wildlife (collecting live wildlife from the wild for sale) can be sustainable if it is appropriately managed to consider wildlife population demographic factors and human cultural factors (Challender et al. 2015, Roe et al. 2020). Specifically, data on a species' wild population size and abundance, and the trade volume and dynamics, can inform management tools such as harvest limits, seasonal hunting restrictions, and permits (Natusch et al. 2016, Hughes et al. 2023), while engaging with local communities can provide human welfare and conservation benefits (Cooney et al. 2017). However, harvesting policies and regulations are not always supported by evidence (Nijman et al. 2012), can only be determined in hindsight after ongoing harvest (Natusch et al. 2016), and have high rates of non-compliance (Challender et al. 2015). Consequently, there is often no assessment whether this legal trade is in fact sustainable (Hughes et al. 2023). The Convention on International Trade in Endangered Species (CITES) is the largest and one of the only international regulatory bodies of wildlife trade; however, only 10.5% of terrestrial vertebrates are protected under this framework (Watters et al. 2022), leaving the majority of the world's wildlife vulnerable to unsustainable harvest.

Wildlife trade presents many biosecurity risks, acting as a novel transport vector for invasive species which can cause significant damages to environments and economies (Hulme 2015, Lockwood et al. 2019, Bradshaw et al. 2021). The stages of invasion can be described in six steps according to the model developed by Blackburn et al. (2011; Figure 1-1). Wildlife trade first transports species outside of their native range to a new environment; often to a new country, but this can include areas within the same country but still outside its native range. Once transported, the animal may then be intentionally or unintentionally released from captivity

(Hulme 2009, Cassey and Hogg 2015). Intentional release may occur through cultural practices (Su et al. 2015), or when a pet is no longer desired (Reaser and Meyers 2007). Unintentional release may occur from an animal escaping captivity, due to negligence or poor-quality housing (Vall-Ilosera and Cassey 2017b). Not all releases result in an established population; the likelihood often depends on propagule pressure, which is defined as the number of release events and number of individuals per release (Lockwood et al. 2005, Cassey et al. 2018). Therefore, highly abundant species in pet trade, or species which are regularly released, are more likely to establish (Vall-Ilosera and Cassey 2017b, Stanley et al. 2023).

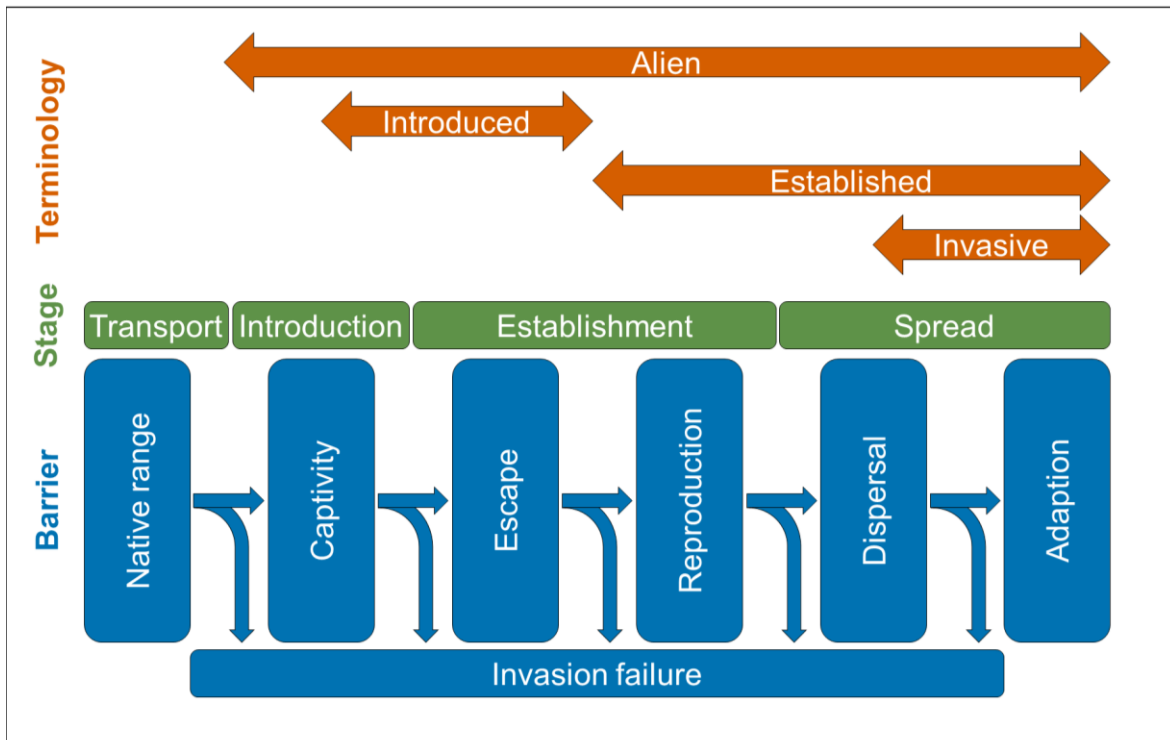


Figure 1-1: The process of a biological invasion of a species transported by pet trade, following the framework by Blackburn et al. (2011). The process of invasion is broadly described in six stages, and between each stage there is a number of barriers which can cause an invasion to fail. The terminology used throughout this thesis is shown in relation to the relevant stages of invasion.

Birds are one of the most traded terrestrial vertebrate taxa in the international pet trade, and consequently are both at risk unsustainable harvest, and are a risk for establishing as invasive species (Scheffers et al. 2019, Romero-Vidal et al. 2020, Gippet and Bertelsmeier 2021). Of all the avian orders, parrots (Psittaciformes) are the most frequently traded, primarily for use as companion pets, where the number of species are overrepresented in trade in comparison to global bird species diversity (Bush et al. 2014, Su et al. 2022). The trade of parrots as companion pets has a long history, and records of the pet trade of Rose-ringed Parakeet (*Psittacula krameri*), native to Asia and sub-Saharan Africa, date back to the first century B.C. when they became famous and highly-traded as pets in the Roman and Byzantine Empires (Kinzelbach 1986). In modern times, the Rose-ringed Parakeet is one of the most globally traded parrot species (Chan et al. 2021), and one of the most successful invasive species, where it has established in over 35 countries (Jackson et al. 2015).

Australia has high parrot species richness and endemism, and Australian parrots are some of the most globally traded (Kosman et al. 2019). In particular, Budgerigars (*Melopsittacus undulatus*) and Cockatiels (*Nymphicus hollandicus*) are two of the most traded species with Australia and internationally (Vall-Ilosera and Cassey 2017c, Shivambu et al. 2022, Stanley et al. 2023). Due to their popularity as companion pets, Australian parrots have been illegally harvested from the wild to supply the pet trade and have established invasive populations after release from captivity (Alacs and Georges 2008, White et al. 2012, Robinson et al. 2020, Stanley et al. 2023).

For my thesis, I focussed on the pet trade of native Australian parrots within Australia; some of the most globally traded and iconic companion species under a unique domestic regulatory landscape.

1.2 The unknown dynamics of Australian bird trade

1.2.1 The unique, “closed” domestic bird trade

The global trade of native Australian parrots, and other native Australian wildlife, is highly regulated, where almost all export from Australia is prohibited. Under the Environment Protection and Biodiversity (EPBC) Act 1999 (Australian Government 1999, Samuel 2020), the export of wildlife for commercial purposes, including pets, is prohibited. Consequently, almost all Australian species in international trade should be descendants of birds traded prior to this act (i.e., via captive breeding programs), and most Australian birds are exported from the Netherlands, Belgium, and South Africa (Vall-Ilosera and Cassey 2017a). This trade is further regulated as all Australian parrots are listed on CITES Appendix II, which is often given to species which are not yet known to be threatened by wildlife trade but could be at some point in the future. Therefore, international trade of Australian parrot species is only legally conducted with an appropriate permit, which also provides a detailed record of global movements (i.e., between countries) of native Australian species. However, despite the high level of restrictions of Australian parrot trade internationally, the trade within Australia occurring is relatively unknown.

Australia has some of the strictest biosecurity laws in the world, which has influenced the parrot species available domestically for trade and, therefore, their popularity (Vall-Ilosera and Cassey 2017c, Toomes et al. 2022). Unlike some international markets with less restrictive laws, which experience changes in the species available in pet trade (e.g., Stringham and Lockwood 2018, Vall-Ilosera and Su 2019), multiple levels of legislation and protection in Australia prevents new species legally entering the market; for example, through the restricted import of new non-native species and prevention of harvesting new native species. This has effectively created a unique “closed” system, whereby the species available are limited to those that were already in trade more than 25 years ago. Between 1990 and 1995, the import of approximately 4,800 non-native parrots from approved countries was permitted, essentially establishing captive breeding populations at the time (Australian Department of Agriculture Water and the Environment 2020). However, in 1995, the import was banned due the lack of evidence around the biosecurity risk of emerging exotic diseases and has remained extremely restricted ever since (Australian Department of Agriculture Water and the Environment 2020). The import of any parrot species is now restricted to pet birds from New Zealand belonging to permanent residents, and only for species already on the Live Import List (Department of Environment and Energy 2017). Furthermore, the harvest of

native Australian parrots is prohibited for most species, further limiting the trade to those that were harvested prior to these restrictions. Therefore, captive populations of native and non-native birds in domestic trade are predominantly descendants of birds either imported or harvested prior to restrictions.

1.2.2 The lack of effective legislation of domestic pet parrot trade

While Australia has strict biosecurity laws at a national level to prevent new species entering trade, laws surrounding pet ownership within the country are less strictly enforced. The Australian domestic trade of pet parrots is poorly regulated, and the full diversity of species in trade and their trade volumes is unknown. Australia implements a variety of permit systems for pet-keeping, which provides an insight to the diversity and abundances in trade (Toomes et al. 2022). However, as permits are not required for all species, there is no comprehensive list of non-native and native species in trade.

Australia has three levels of government: Federal (i.e., governs all of Australia), State or Territory (six States and two mainland Territories), and local councils (approximately 500, e.g., cities and suburbs). The biosecurity at Australia's borders which prevents new species entering trade is governed at Federal level, while domestic trade laws are generally at the State and Territory level. As the eight States and Territories all have their own governance and local laws, there are large inconsistencies in the laws relating to keeping native and non-native species; particularly which species are legal to keep freely, and which species require a specialist permit. Permit systems and laws surrounding pet-keeping differ between the States and Territories, where a species which requires a permit in one State or Territory might be traded freely in a bordering State or Territory (Toomes et al. 2023). For example, Sulphur-crested Cockatoos (*Cacatua galerita*) cannot legally be harvested in South Australia, while the harvest of Little Corellas (*C. sanguinea*) is legal but requires a permit (Government of South Australia 2021). However, in neighbouring Western Australia, these species are unprotected, declared pests (Blythman and Porter 2020). To standardise the Federal record keeping of non-native birds, the National Exotic Bird Registration Scheme (NEBRS) was introduced in 1996, which required all non-native birds to be registered in the national database (Commonwealth of Australia 2018). However, this scheme was discontinued, and in 2007 the Exotic Bird Record-Keeping Scheme (EBRKS) was introduced, where owners are encouraged to keep records of the origins and subsequent sales of their birds. To accompany this, the "Inventory of Exotic (non-native) Bird Species known to be in Australia" was created, which listed all non-native species in trade across all of Australia and classified them as high or low interest based on their pest and disease risk and the potential for illegal trade (2007). However, these lists did not capture native species, and did not include the quantity of all species in trade. Consequently, the dynamics of domestic trade are relatively unknown.

In August 2020, the Australian Government released the "Psittacine birds (household pet and aviary) import risk review draft", in which the report suggested removing the restriction on the import of parrots into Australia (Australian Department of Agriculture Water and the Environment 2020). This risk review was initiated after continued requests from private owners of parrots, as the literature of known diseases carried by non-native Psittacine birds has improved since the ban in 1995. The draft review investigated the risks of importing parrots as household pets and in large quantities for commercial trade and did not consider the increased invasion risks. Furthermore, while the draft review only explored the import of

species currently on the Live Import List, the authors expected the species on the List to be reviewed and more non-native species to be allowed in Australian trade. In response, I provided feedback during the public consultation of the Review, as I and my co-authors argued the risks of allowing the import of non-native species far outweighed the benefits for commercial breeders. See Chapter 6 of this thesis for the full response.

1.2.3 Understanding the dynamics of trade

To assist in the conservation of threatened species and prevent the establishment of new invasive species, it is important to understand which species are sold, where they are sold, and in what volumes. However, this lack of regulation on non-native bird keeping, and failure to record native birds in the trade, means that there is no comprehensive record of species composition or abundance. Without this knowledge, conservation and biosecurity practitioners lack reliable information on: (i) which native species have been introduced to the trade since the legislations; (ii) if any non-native species have been illegally introduced into the pet trade since the import restrictions; (iii) which species may be at risk of unsustainable harvest to supply trade (Stringham et al. 2021a); and (iv) which non-native species are sold in high abundances and may be a future invasion risk (Blackburn and Duncan 2001).

In addition to understanding the species composition and abundances in trade, it is important to understand the relationships between a species' characteristics and its relative popularity to aid in decision-making around future management of pet trade (Stringham and Lockwood 2018, Toomes et al. 2022). The abundance of a species in pet trade is often closely linked to its species characteristics, such as its appearance, behaviour, and availability (Chan et al. 2021, Jain et al. 2022). Understanding which species characteristics are related to abundance in trade may provide an insight into why certain species are traded in high volumes and may assist in predicting which species may enter the pet trade if the import of parrots into Australia is once again permitted (Blackburn and Duncan 2001, Toomes et al. 2020).

Furthermore, understanding the dynamics of trade can assist with predicting and preventing future invasion risks (Blackburn and Duncan 2001). Species traded in high abundances generally have higher propagule pressure (Lockwood et al. 2005), and there is likely a relationship between species traits and release probability, such as low prices and high intelligence (Vall-Ilosera and Cassey 2017b). Furthermore, traits which make a species abundant in trade are also associated with traits of successful invasive species (Gippet and Bertelsmeier 2021). Understanding these species trait correlations, in combination with species composition and abundance data, can assist in informing release and establishment risks from pet trade.

While wildlife trade has previously been difficult to monitor, the emergence of online wildlife trade markets has provided a unique opportunity to obtain a quantitative snapshot of domestic parrot trade (Siriwat and Nijman 2020, Stringham et al. 2021c). Surface web trade, such as classifieds sites, advertise large quantities of wildlife to the general public, providing information such as the species, the quantities, prices, and location. With this information, it is possible to create databases of online trade and investigate correlations with species traits to better explain and predict species composition and abundances in trade.

1.3 Tracing origins of birds for conservation and biosecurity

A key missing piece to the biosecurity and conservation wildlife forensics toolbox is the ability to identify the captive and wild origins of wildlife (Huffman and Wallace 2012). The ability to identify between origins has two key applications: (i) identifying illegal harvest (poaching) of vulnerable species; and (ii) detecting wild populations established by escaped pets.

1.3.1 Illegal harvest of vulnerable species

Australian parrots are some of the most desired species in international and domestic trade (Vall-Ilosera and Cassey 2017a, Chan et al. 2021), yet some species are difficult to breed in captivity and are therefore likely to be illegally harvested from the wild (Jupp 2000, White et al. 2012). While there is established captive breeding populations for some species, the low inherent risk and high potential return of harvest can create incentive to illegally harvest Australian cockatoos and launder them as “captive bred” (Bulte and Damania 2005, Lyons and Natusch 2011, Shepherd et al. 2012). Consequently, parrots and parrot eggs have been the second-most illegally exported wildlife in the past (Alacs and Georges 2008). This is particularly a problem for threatened species which did not have captive breeding populations prior to the export ban on Australian wildlife, such as the black cockatoos (*Calyptorhynchus* spp.); potentially selling for more than AUD\$12,500 per bird (White et al. 2012, Lee 2013). While the high levels of protection Australian species are provided likely reduces the frequency of harvest, compared to other countries with less regulation (Pain et al. 2006), the lack of enforcement and penalties, and increasing access to nest hollows after deforestation, mean chicks are can still be harvested from nests for aviary trade (Rowley and Chapman 1991, Vergara-Tabares et al. 2020).

Illegally harvested animals may be laundered as captive bred when demand for a species is higher than the captive breeding output, or for a greater financial gain (Lyons and Natusch 2011, Shepherd et al. 2012). For some highly traded species, such as budgerigars (*Melopsittacus undulatus*) and cockatiels (*Nymphicus hollandicus*), the cost of captive breeding is low and these species have high reproductive outputs, and therefore there is likely little incentive to illegally harvest wild animals (Pain et al. 2006, Vall-Ilosera and Cassey 2017c). However, some of the most popular species in trade, such as cockatoos (Cacatuidae), are difficult to breed as they form compatible, monogamous pairs, which only produce up to three eggs per clutch each year (Ambrose et al. 1990). These chicks require a high level of care for up to 20 weeks, often with low survival rates (Ambrose et al. 1990). For parrot species such as these, where the financial and time cost of raising captive bred animals is too high to make a desirable profit, they are more likely to be harvested as chicks from hollows and sold as pets (Rowley and Chapman 1991, Pain et al. 2006, White et al. 2012). Once poached, young birds can be hand-raised and sold, and potentially laundered to naïve buyers as captive-bred (Lyons and Natusch 2011, Shepherd et al. 2012).

Despite the likely illegal harvest of Australian species, including threatened and common species, there is currently no method to verify a bird’s captive or wild origin. Through the voluntary EBRKS, owners of non-native birds are encouraged to keep records of parentage and have a permanent marker such as a microchip or leg band.

However, this does not protect native species. Documents can be relatively easy to forge, and markers can be applied to poached juveniles. Therefore, it is unknown how many birds in domestic and international trade have been illegally harvested, and there is no method to detect unsustainable harvest of vulnerable species.

1.3.2 Pet trade as a vector for invasive species

The large, global trade network for birds as pets is an emerging source of new invasive species (Hulme 2009, Lockwood et al. 2019). The invasiveness of a bird species in trade is strongly associated with its abundance; where species found in pet trade are overrepresented amongst the approximately 500 bird species which have established invasive populations (Gippet and Bertelsmeier 2021). Within Australia, non-native parrots that are abundant in domestic pet trade are being increasingly observed escaping captivity (Vall-Ilosera and Cassey 2017b). For example, incursions of the Rose-ringed Parakeet, one of the most invasive species globally and highly abundant in pet trade, are increasing, and the species is believed to be highly likely to establish invasive populations in Australia (Vall-Ilosera et al. 2016).

While the spread of invasive species from the pet trade between different countries is a recognised issue, there is little research into species forming introduced populations within the same country as their native range, which I will call “domestic non-native” species (Lockwood et al. 2019, Nijman et al. 2022). These species are native to that country, but the invasive population is outside their native range. Consequently, domestic non-natives can “slip through the cracks” of invasive species management because biosecurity laws in some local government areas do not consider native to that country as a biosecurity threat.

Several Australian parrot species have established invasive populations within Australia (Blythman and Porter 2020, Robinson et al. 2020). For example, one of the most prolific Australian parrot species, the Rainbow Lorikeet (*Trichoglossus moluccanus*) native to the eastern coast, has established a wild population in Perth, Western Australia, after several intentional releases since the 1960s (Long and Tingay 1981, Coyle 1988; Figure 1-2). This population is so prolific, it is now the most observed bird species in the State (Birdlife Australia 2022). Additionally, Sulphur-crested Cockatoos, and Little and Long-billed Corellas (*C. sanguinea* and *C. tenuirostris*) have established in south-western Australia (Blythman and Porter 2020). Some populations have unconfirmed origins but were likely escaped from the pet trade; including the Eastern Rosella (*Platycercus eximius*) in Adelaide (Ambrose et al. 1990). These populations outcompete local natives for resources and tree hollows, particularly birds and mammals (Hingston 2019a), spread disease (Vaz et al. 2020), can hybridise with local species (Hingston 2019b), and can cause significant damage to agriculture (Bomford and Sinclair 2002).

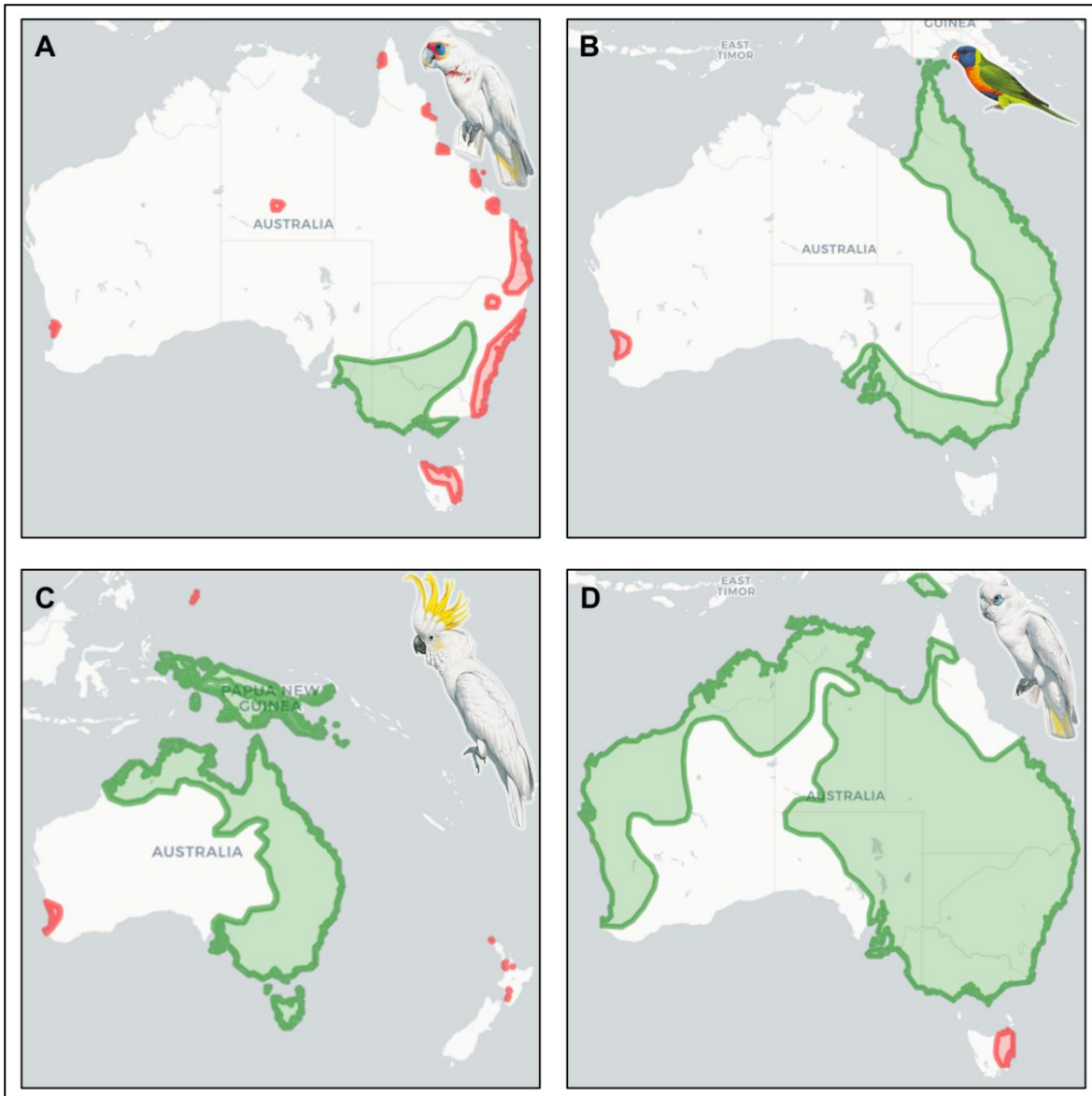


Figure 1-2: Native (green) and introduced (red) ranges of Australian parrots. For each of these species, these introduced populations were likely established by escapes from captivity. Species include: (A) Long-billed Corella (*Cacatua tenuirostris*), (B) Rainbow Lorikeet (*Trichoglossus moluccanus*), (C) Sulphur-crested Cockatoo (*Cacatua galerita*), and (D) Little Corella (*Cacatua sanguinea*). Bird images are reproduced with permission from Lynx Edicions, and species distribution maps from BirdLife International and Handbook of the Birds of the World (2019).

The key to effective invasive species management is prevention and early management (Mack et al. 2000, Keller et al. 2007, Henderson et al. 2011). In the case of escapes from the pet trade, the most cost-effective step is to prevent the initial introduction of a pet species, through schemes such as bans on highly invasive species, preventing further imports, and strict permit systems (Stringham et al. 2021c, Toomes et al. 2022). In cases where the trade of a species is allowed, which is the case for many domestic non-native species, the early identification of established populations can increase the likelihood of eradication (Keller et al. 2007, García-Díaz et al. 2017). Emerging applications technologies such as eDNA are highly effective at detecting incursions of non-native species (Rees et al. 2014, Bylemans et al. 2016). However, not all incursions lead to established populations.

Therefore, the ability to distinguish between a single incursion, such as a recently released pet compared with an individual in an established population, can assist with invasive species management and potentially improve the probability of eradicating established populations early.

Current methods to identify established populations often rely on passive methods, such as monitoring reports of incursions, ongoing surveillance, or citizen science programs (Larson et al. 2020). However, these programs can require a significant amount of time, and their success relies on the detectability of the species (García-Díaz et al. 2017, Cobden et al. 2021). In the time required to conduct these programs, or if a species is highly cryptic and difficult to observe, an introduced population may have grown to an unmanageable size, undetected, and can no longer be eradicated (Tingley et al. 2015). Therefore, an effective tool should be able to classify a single incursion as either a recent release or from an established wild population.

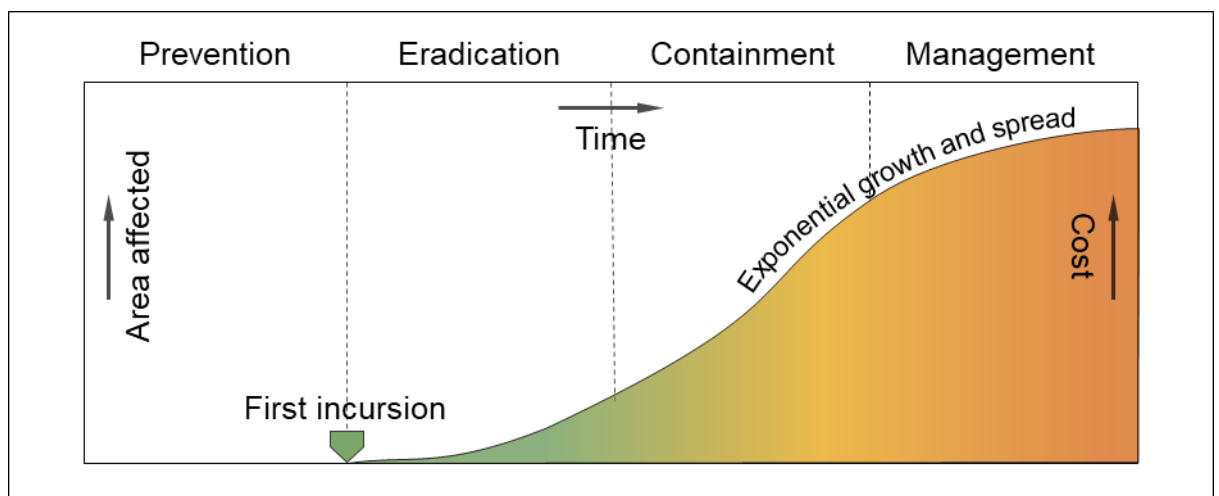


Figure 1-3: The invasion curve: the theoretical relationship between the population growth and geographic spread of an established invasive species population, and the economic cost of managing the population, redrawn from (Blackburn et al. 2011).

1.3.3 Current methods for tracing captive and wild origins

While molecular methods can potentially determine if an animal is bred in captivity or the wild, these methods do not always tell the full story. DNA methods are the most established in wildlife forensics, particularly where parentage or pedigree testing can identify birth origin (e.g., Jan and Fumagalli 2016, Hogg et al. 2018, Campbell et al. 2019, Willows-Munro and Kleinhans 2020). While this has proven to be successful in some species, research into applying these methods is decreasing over time, likely due to the difficulties of obtaining the genomes and reference databases required (Sánchez-Mercado et al. 2021). Additionally, DNA methods lose their effectiveness when a species' wild genetic diversity is already relatively low, or when a captive population is relatively new to trade and is still too similar to wild populations (Hogg et al. 2018). Finally, while knowing the birthplace origin is crucial for detecting cases of laundering, it is less effective for determining if a non-native bird is from an established wild population or is an escaped pet. This is particularly a problem in long-lived species such as parrots, where a bird may have been raised in captivity, but has since escaped and is free-living and reproducing as a wild bird. Therefore, wildlife forensics requires a tool which does not need specialist

knowledge, can be applied to species relatively new to trade with low genetic diversity, and is sensitive to changes in origin over an animal's lifespan.

1.3.4 Tracing wildlife origins with stable isotopes

Stable isotope analysis is an emerging forensics tool for identifying captive and wild origins of wildlife and has shown some success on tracing species in pet trade (e.g., Alexander et al. 2019, Andersson et al. 2021a). Stable isotopes are non-radioactive, alternate states of the same element, where their atomic mass is altered by a different number of neutrons, but their chemical behaviour remains relatively unchanged (Michener and Lajtha 2008). These differences in masses cause isotopes to behave differently in an environment, but in predictable ways. For example, ^{12}C is the most common isotope of carbon, while another isotope, ^{13}C , is less abundant and is heavier due to an additional neutron. The abundance is then expressed as a ratio to its heavier form (heavy-to-light), such as $^{13}\text{C}/^{12}\text{C}$ which is expressed as $\delta^{13}\text{C}$, and is reported relative to a standard in parts per thousand:

$$\delta(\text{‰}) = \left(\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right) \times 1000$$

where R is the ratio of heavy-to-light ratio of the sample and standard respectively. These abundances reflect the environmental processes of that environment, and therefore can act as an “environmental fingerprint”. In this thesis, I explore the use of stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotopes, which can provide information on an animal's diet, and therefore captive and wild origins.

Stable isotopes can provide information on where an animal has been and how it behaved in a certain time and location, as they are assimilated from the animal's environment and into the animal tissue depending on the animal's diet, behaviour, environment, and tissue synthesis (Kelly 2000). If an inert tissue is measured, where the tissue remains biologically unchanged since it is grown such as hair, claws, and feathers, it is possible to obtain a long-term snapshot of which environment the animal has been and where it has moved. Therefore, measuring feathers in parrots should provide a snapshot of the bird's diet when the feather was grown. Australian parrots undergo complete moult during summer, and while parrots take several months to complete a moult, individual feathers grow in up to three weeks (Ambrose et al. 1990). Once grown, feathers remain inert and stable isotope ratios remain unchanged. Therefore, measuring stable isotopes in Australian parrot feathers may provide information on the birds' diet, and therefore captive or wild origin, to assist in conservation and invasive species management.

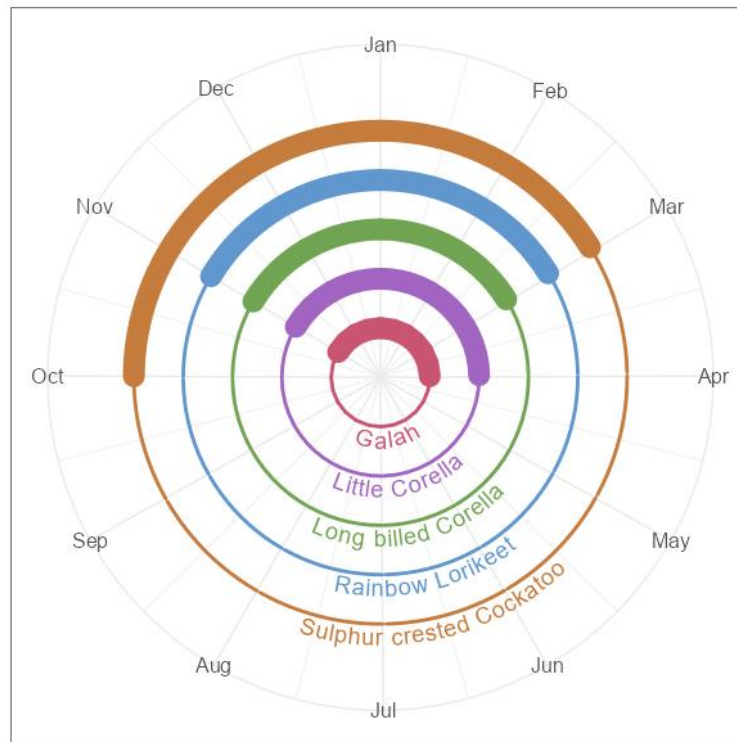


Figure 1-4: Moult timings for five Australian parrot species, according to Ambrose et al. (1990). Each species goes through a complete moult over these periods (thick lines), but each feather takes up to three weeks to grow. The stable isotope ratios of these feathers remain inert, and is moulted in the following year.

Between different species, the $\delta^{13}\text{C}$ in bird feathers is highly influenced by diet type. For example, granivores generally show significantly higher $\delta^{13}\text{C}$ than nectarivores, insectivores and omnivores (van Wijk et al. 2021). However, as Australian parrot species have generalist diets and access a variety of these food sources, the $\delta^{13}\text{C}$ is likely linked to the relative abundance of C_3 and C_4 plants in the bird's diet (Still et al. 2003, Hobson et al. 2012). C_3 plants are generally depleted in ^{13}C compared to the atmospheric CO_2 , as they preference the lighter ^{12}C to reduce the energetic costs of oxygen fixation. C_4 plants have further adaptations for hot and dry environments to reduce water loss during this process, which ultimately increases the concentration of $^{13}\text{CO}_2$ (O'Leary 1988, Kohn 2010). Within Australia, most agricultural crops are C_3 , such as wheat, barley, and rice, while C_4 plants, such as sorghum and maize (corn), make up only 2% of total cropland (Munroe et al. 2022). While unavailable to wild birds, these C_4 crops are common in commercial captive food such as birdseed mixes, which would potentially reflect in the $\delta^{13}\text{C}$ of parrot feathers. However, a number of environmental processes further impacts $\delta^{13}\text{C}$ in environments. For example, water stress in plants can cause an increased concentration of $^{13}\text{CO}_2$ in a plant, while $\delta^{13}\text{C}$ can differ between plant organs (such as stems, fruit, and flowers) (Michener and Lajtha 2008). Due to the high variability of $\delta^{13}\text{C}$ in environmental systems, combining this information with another isotope can improve inferences on an animal's diet, such as the addition of $\delta^{15}\text{N}$.

The nitrogen cycle is extremely complex, and $\delta^{15}\text{N}$ in an environment is influenced by a variety of mechanisms (refer to Szpak 2014). For example, $\delta^{15}\text{N}$ in marine systems is higher than in terrestrial and freshwater systems, while nitrogen fixation in plants such as legumes can reduce $\delta^{15}\text{N}$ in the plant tissue compared to non-

nitrogen-fixing plants (Rubenstein and Hobson 2004; Michener and Lajtha 2008). However, the major effects of the $\delta^{15}\text{N}$ in parrot feathers are the birds' trophic position and the use of nitrate-based agricultural fertilisers (Rubenstein and Hobson 2004, Szpak 2014, van Wijk et al. 2021). The $\delta^{15}\text{N}$ in animals is closely linked to their trophic position, as the amount of available, fixed N in an environment is extremely limited. Therefore, fixed ^{15}N generally increases with trophic position, where $\delta^{15}\text{N}$ increases with each trophic transfer (Kelly 2000, Post 2002). While wild parrots often consume low trophic position organisms such as invertebrates (Ambrose et al. 1990), captive parrots may have access to higher position food products in commercial pet food, such as meat products (Gillanders et al. 2017). A potentially more prominent factor affecting $\delta^{15}\text{N}$ in parrot feathers is the influence of agricultural fertilisers on the food products provided to captive birds. Agricultural fertilisers, particularly nitrate-based fertilisers, can significantly increase the available $\delta^{15}\text{N}$ in the soils, and therefore in the agricultural crops, in comparison to unfertilised plant material. In parrot diets, captive birds are likely to have a higher proportion of fertilised plant material in their diet in comparison to wild birds. However, while $\delta^{13}\text{C}$ closely reflects the values in their diet, $\delta^{15}\text{N}$ can be further influenced by nutritional stress (Hobson et al. 1993). Therefore, a multi-isotope approach can potentially improve the accuracy of captive and wild classification in Australian parrots.

1.4 Stable isotope analysis to trace origins of animals in wildlife trade

Stable isotopes have been used for a variety of applications for tracing wildlife; however, their use in identifying captive and wild origins is relatively new (Huffman and Wallace 2012, Sánchez-Mercado et al. 2021). Fields such as archaeology have used isotopes to identify domestication in animals found in archaeological sites (e.g. Balasse et al. 2016, Ehrlich et al. 2022). These applications generally assume that domesticated animals are provided food otherwise unavailable to wild animals, such as cultivated crops or meat products at much higher trophic levels. A similar assumption could be made for modern wildlife trade, where pets are more likely to be fed food that wild animals do not have access to. For example, captive parrots may be fed commercial bird seed, nutritional supplements, or non-native agricultural crops.

Here, I performed a systematic literature review to investigate how far the use of stable isotopes for tracing captive and wild origins has progressed. Due to the large differences in biological processes between animals, I limited this search to modern samples of tetrapods (amphibians, birds, mammals, and reptiles), with research that directly compared captive and wild populations. Using 47 search terms (Supplementary Information 1-1) I obtained all references from Web of Science (1,475), and the first 500 references from Google Scholar and excluded references following the PRISMA framework (Page et al. 2021).

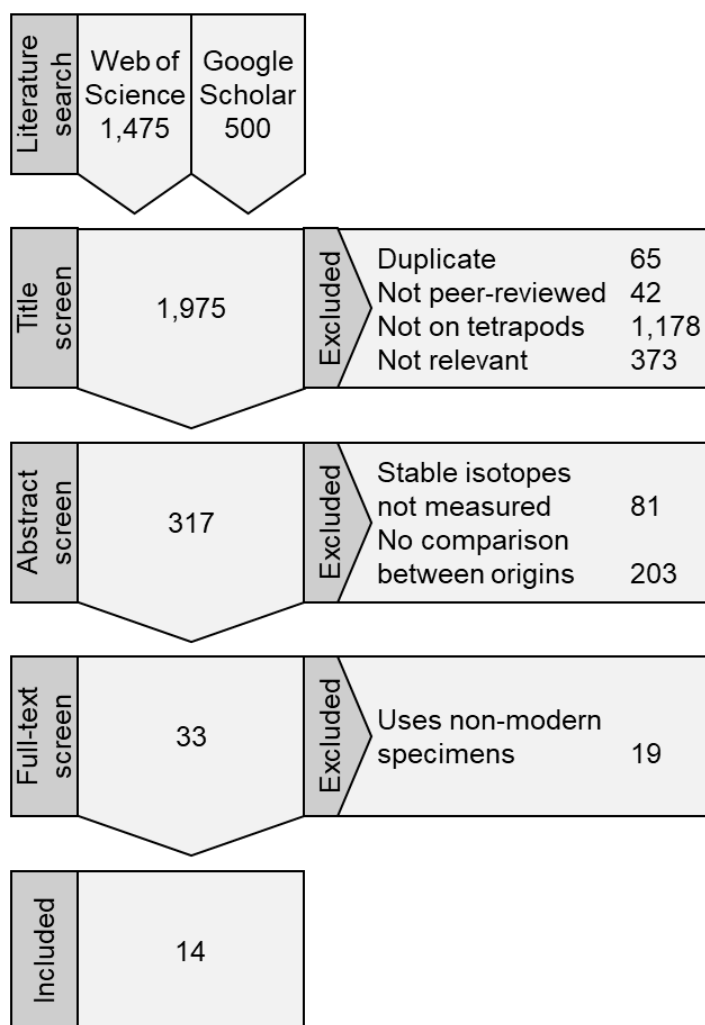


Figure 1-5: Flow diagram of references excluded during the systematic literature review following the PRISMA framework (Page et al. 2021). I collected all matches to 47 search terms from Web of Science, and the first 500 references from Google Scholar. References were excluded following pre-determined exclusion criteria, after screening different levels of the publication.

The main aim of this literature search was to identify some of the barriers behind the uptake of using stable isotope analysis to verify captive and wild origins. Stable isotopes have been used in wildlife forensics for tracing geographical origins and migrations (Bowen et al. 2005, Hobson and Wassenaar 2018); however, its use in verifying captive and wild origins is in its infancy (Huffman and Wallace 2012). I aimed to identify some of the sources of uncertainty of these analyses, which were identified by these authors, and which may impede on the accuracy and future uptake of these tools and require further investigation, particularly for application on native Australian parrots.

Table 1-1: Summaries of literature which compare stable isotope ratios between wild and captive origins of modern tetrapods in wildlife trade. The accuracy is the reported classification accuracy of separating the origin groups.

Authors		Year	Species	Common name	Isotopes	Accuracy (%)
Amphibians	Dittrich <i>et al.</i>	2016	<i>Hoplobatrachus rugulosus</i> , <i>Fejervarya cancrivora</i> , <i>Limnonectes macrodon</i>	Asian Rugose Bullfrog, Crab-eating Frog, Fanged River Frog	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$	-
Birds	Castelli and Reed	2017	<i>Colinus virginianus</i>	Northern Bobwhite	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^2\text{H}$, $\delta^{34}\text{S}$	100
	Alexander <i>et al.</i>	2019	<i>Psittacus erithacus</i>	African Grey Parrots	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^2\text{H}$	-
	Jiguet <i>et al.</i>	2019	<i>Emberiza hortulana</i>	Ortolan Bunting	$\delta^2\text{H}$	-
	Andersson <i>et al.</i>	2021	<i>Cacatua sulphurea</i>	Yellow-crested Cockatoo	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	91
Mammals	Kays and Feranec	2011	<i>Canis lupus</i> , <i>Canis latrans</i>	Wolf, Coyote	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	-
	He <i>et al.</i>	2018	<i>Moschus spp.</i>	Musk Deer	$\delta^{13}\text{C}$	-
	Brandis <i>et al.</i>	2018	<i>Tachyglossus aculeatus</i>	Short-beaked Echidna	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	91
	Hutchinson and Roberts	2020	<i>Panthera leo</i>	African Lion	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	70
Reptiles	Van Schingen <i>et al.</i>	2016	<i>Emberiza hortulana</i>	Crocodile Lizard	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	96
	Natusch <i>et al.</i>	2017	<i>Python reticulatus</i> , <i>Python bivittatus</i>	Reticulated Python, Burmese Python	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^2\text{H}$	41, 100
	Hill <i>et al.</i>	2020	<i>Trachemys scripta elegans</i>	Red-eared Slider Turtle	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	96
	Hopkins III <i>et al.</i>	2022	<i>Glyptemys insculpta</i>	Wood Turtle	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	97
	Gamboa-Delgado <i>et al.</i>	2022	<i>Crocodylus moreletii</i> , <i>Crocodylus acutus</i>	Morelet's Crocodile, American Crocodile	$\delta^{13}\text{C}$, $\delta^{15}\text{N}$	-

After the first study in 2011 tracing origins of captive and wild wolves and coyotes (*Canis spp.*), a small number of studies (n = 14) have further tested the methods on a variety of species. There was some bias towards taxonomic Class, with 4 of the studies on birds, 4 on mammals, 5 on reptiles, and only 1 on amphibians. The most used stable isotopes were those relating to diet; where 93% used $\delta^{13}\text{C}$, 86% used $\delta^{15}\text{N}$, 29% used $\delta^2\text{H}$, 7% on $\delta^{34}\text{S}$ and $\delta^{18}\text{O}$. For tissue type selection, most studies (85%) used inert tissues that could be taken from live animals (non-invasive), including claws, feathers, hair, and scutes, to provide longer-term snapshots of captive and wild origins.

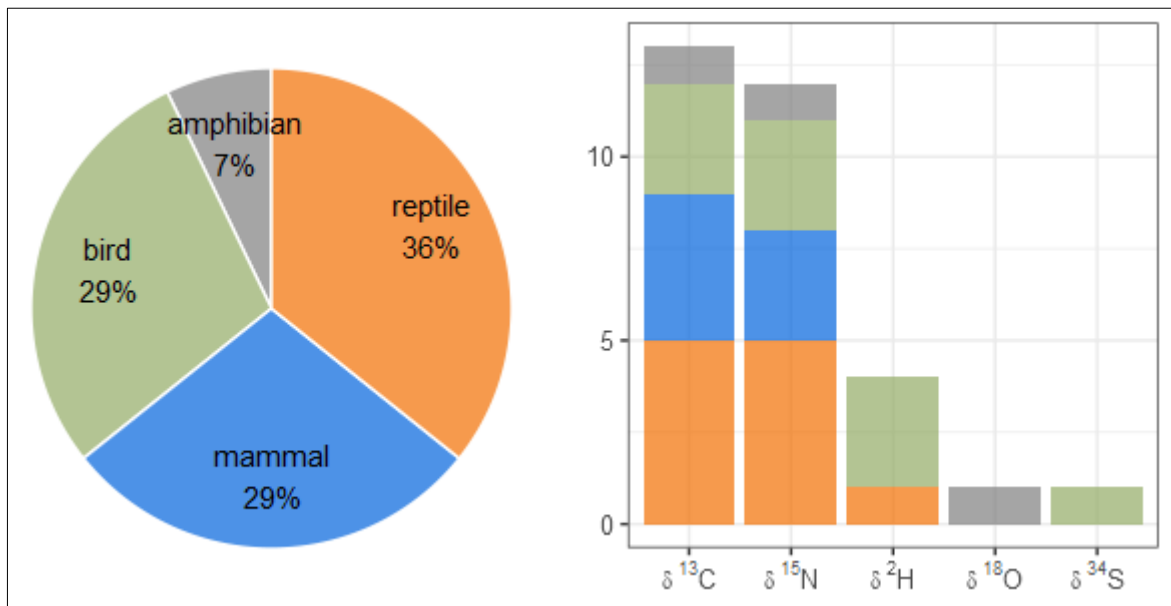


Figure 1-6: Summaries of the number of studies which compare stable isotope ratios between wild and captive origins of modern tetrapods in wildlife trade; (left) the number of publications per Class, and (right) the five stable isotopes used by the publications, by taxa. Most studies used a combination of multiple isotopes.

Of the studies that tested the accuracy of these methods, most of them were able to successfully separate wild and captive origin groups by their stable isotope ratios, showing great potential for the future applications in wildlife forensics. Each study used different statistical methods to identify the accuracy of their analysis, but generally followed the same principle: accuracy relates to how many individual captive animals had “wild” stable isotope values, and vice versa. In total, six of the 14 studies reported an accuracy above 90%, which is suitability high to develop into a forensic tool. However, six studies did not report the accuracy, and one study had an accuracy as low as 41%.

One of the main areas identified for further investigation was the effect of large geographic range sizes on the variation of stable isotope values in wild populations. Stable isotopes in an environment can vary significantly over a species’ geographic range, which can potentially cause overlap in values for captive and wild origins (Hobson 1999, Natusch et al. 2017). I found that current research was primarily focussed on species threatened by unsustainable harvest for wildlife trade, which limits the sample sizes of wild populations and the geographic range of the samples. Five species have an International Union for Conservation of Nature (IUCN) Red List of Threatened Species rating of Least Concern; however, four of these species have suspected illegal trade. The remaining species are at higher risk of extinction,

with four as Endangered and one as critically endangered. For example, Natusch et al. (2017) compared two python species, which are commonly traded for their skins: Burmese Pythons (*Python bivittatus*), which are listed as Vulnerable due to unsustainable harvest and habitat loss, and Reticulated Pythons (*P. reticulatus*), which are Least Concern. As the Burmese Pythons have a restricted range and smaller wild population size, the animals likely have relatively similar diets, and therefore show a smaller range in isotopic values and showed 100% classification accuracy. However, Reticulated Pythons with a much larger range and variety in diets resulted in only 41% accuracy. The authors identified that the lack of specimens from across the entirety of the species' range greatly limited the applicability of stable isotopes for origin classification. Therefore, it is currently unclear if stable isotopes are an appropriate forensic tool for species with large geographic range sizes.

A further area of investigation is the influence of within-individual variation, and the chance of misclassifying an individual based on the selected sample, such as the feather type. Within-individual variation may arise from a variety of factors, such as slight changes in diet between the growth of the tissues (e.g., between the growth of two body feathers), or differences in isotopic fractionation between different tissue types (e.g., between a primary wing or a breast feather) (Symes et al. 2017, Alexander et al. 2019). Most of these studies have focussed sampling on between-individual variation, but to develop best-practice methods, it is important to identify exactly which section of the tissue should be sampled to avoid potentially misclassifying individuals (Bontempo et al. 2014).

In summary, I identified two main points of variation, which I did not believe had been explored in sufficient depth: (i) the applicability of stable isotope analysis to species with large range sizes, and (ii) the influence of individual variation on classification accuracy. Furthermore, with the exception of my previous work (Hill et al. 2020), stable isotopes are yet to be applied to invasive species control. In this thesis, I explore the applicability and repeatability of stable isotopes on widespread species for two applications: (i) identifying laundering of wild-caught animals; and (ii) identifying captive escapes in established invasive populations.

1.5 Thesis structure

In this thesis, I aim to provide tools which can aid in the conservation and biosecurity of Australian native parrot pet trade.

Chapter 2: I investigated the dynamics of domestic online Australian pet bird trade and identified the species composition and abundances in trade, to predict potential invasive species risks based on their species characteristics. I collected novel online trade database of domestic online bird trade and quantified the species composition and abundances, and investigated which biological and economic species characteristics influenced a species' abundance. My specific focus was on the invasion risk introduced by bird trade, and the high number of non-native species sold in large abundances in pet trade.

Chapter 3: I explored the applicability and repeatability of using stable isotope methods to detect cases of laundering of illegally wild-caught parrots. Here, I focussed on Australian native cockatoos (Cacatuidae); species which are difficult to raise in captivity and are likely poached from the wild. I investigated the influence of

within-individual variation on the classification accuracy of captive and wild origins, using feathers collected through a citizen science program.

Chapter 4: I investigated the relatively unexplored application of stable isotopes to inform invasive species management. I investigated the size and overlap in isotopic niches between four populations at different stages of the pet-release pathway. To achieve this, I analysed feather samples from Rainbow Lorikeets (*T. moluccanus*), a domestic non-native species which has established invasive populations in Australia. Using these isotopic niches, I investigated the application of these methods to detect captive escapes within the established and invasive populations

2

Who's a pretty bird? Predicting the abundance of bird species in Australian online pet trade

2.1 Abstract

The increasing popularity of online commerce provides a new opportunity to investigate and quantify the dynamics of pet trade. Understanding these dynamics, including relationships between species characteristics and a species' relative abundance, can assist in informing trade regulation for conservation and biosecurity. We identified the leading correlates behind the abundance in the Australian pet trade of parrot (Psittaciformes) and passerine (Passeriformes) species. We examined 14,000 online sales of parrots and passerines collected from a popular online Australian marketplace in 2019 (representing 235 species) using an automated data collection method. We identified the characteristics that correlated with online species abundance; including (i) breeding and handling requirements; (ii) trade and availability; and (iii) appearance and behaviour. We found 55% of parrot species and 64% of passerine species traded online were non-native to Australia; of these, 81% and 85% respectively have an extreme risk of establishing invasive populations. Species abundance of both orders was correlated with cheaper prices, which is associated with a higher invasion risk. Trade in parrots was also correlated with attractive birdsongs, being easy to care for, and a preference for native Australian species. Passerine abundance was correlated with attractive plumage colour and, to a lesser extent, the availability of colour mutations and smaller geographic range sizes. These results, combined with an understanding of consumer behaviour and international trends, may help predict which species will become abundant in domestic trade in the future, and identify current and future invasion risks to assist in environmental biosecurity efforts.

2.2 Statement of Authorship

Title of paper	Who's a pretty bird? Predicting the popularity of birds in Australian online pet trade
Publication status	<input type="checkbox"/> Published <input checked="" type="checkbox"/> Accepted for publication <input type="checkbox"/> Submitted for publication <input type="checkbox"/> Unpublished and unsubmitted work written in manuscript style
Publication details	Hill KGW, Stringham OC, Moncayo S, Toomes A, Tyler JJ, Cassey P, Delean S (2023) Who's a pretty bird? Predicting the popularity of birds in Australian online pet trade. <i>Unpublished</i>

Principal Author

Name of principal author (candidate)	Katherine GW Hill		
Contribution to the paper	Web scraping data curation, species characteristics data curation, data analysis and interpretation, wrote manuscript, and corresponding author		
Overall percentage (%)	75%		
Certification	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its conclusion in this thesis. I am the primary author of this paper.		
Signature		Date	30/11/22

Co-author contributions

By signing the Statement of Authorship, each author certifies that:

- i. the candidate's stated contribution to the publication is accurate
- ii. permission is granted for the candidate to include the publication in the thesis
- iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of co-author	Oliver C Stringham		
Contribution to the paper	Lead web scraping code developer, web scraping data curation, supervision, and edited manuscript		
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Contribution to the paper	Supervision, edited manuscript		
Signature		Date	9/12/2022

Name of co-author	Phillip Cassey		
Contribution to the paper	Primary supervision, edited manuscript		
Signature		Date	01/12/2022

Name of co-author	Steven Delean		
Contribution to the paper	Methodology development, data analysis, and edited manuscript		
Signature		Date	02/12/22

2.3 Introduction

The global exotic pet trade threatens both biosecurity and biodiversity conservation, as the transport of species outside of their native ranges is a major pathway for new invasive alien species to establish and spread (Seebens et al. 2017, Lockwood et al. 2019). However, the dynamics of pet trade, including species composition and abundance, are relatively unknown (Andersson et al. 2021b). Understanding the major correlates behind species abundance in pet trade can help inform regulatory policy making and assist with improving conservation and biosecurity outcomes, such as predicting which new species may enter the market (Toomes et al. 2020, Stringham et al. 2021a) and may be a future invasion risk (Blackburn and Duncan 2001, Gippet and Bertelsmeier 2021).

We focus on the domestic trade of pet birds in Australia; one of the most traded taxa within a unique market (Su et al. 2022, Toomes et al. 2023), and an emerging source of new invasive species (Vall-Ilosera and Cassey 2017b). Australia implements a near complete ban on the import of live birds, while simultaneously leaving the domestic trade largely unregulated (Alacs and Georges 2008). This essentially creates a “closed” system, whereby the non-native species available in trade are predominantly limited to those that had established breeding populations prior to the implementation of this import ban. Consequently, new non-native bird species very rarely enter the domestic pet trade; however, they are increasingly escaping captivity (Vall-Ilosera and Cassey 2017b, Stanley et al. 2023), such as the highly invasive Rose-ringed Parakeet (*Psittacula krameri*) (Vall-Ilosera et al. 2016). Despite the increasing incursions, there is currently no quantitative record of the species composition of all native and non-native species in domestic Australian pet trade, or their relative abundances. Identifying species sold in high abundances, and the major correlates behind these abundances, may assist in understanding propagule pressures of non-native species and identify risks early in the invasion pathway (Blackburn and Duncan 2001).

While there is some insight into the major drivers behind global trade in pet birds (e.g., (Chan et al. 2021, Senior et al. 2022), factors such as trade restrictions and networks, and different pet-keeping practices and cultures, mean that the most desirable characteristics are likely to greatly vary between different marketplaces and regions (Su et al. 2022). For example, abundance in global parrot trade is associated with large wild population sizes, colour mutations, and intelligence (Chan et al. 2021, Jain et al. 2022). In these markets, native Australian species are common (Vall-Ilosera and Cassey 2017a), such as the Sulphur-crested Cockatoo (*Cacatua galerita*) and Rainbow Lorikeet (*Trichoglossus moluccanus*). Within the Australian market, the greater availability and diversity of Australian species and desire for non-native species would likely influence species abundance in trade (Toomes et al. 2020). While a previous study has investigated some dynamics of Australian bird trade using data collected from brick-and-mortar trade (Vall-Ilosera and Cassey 2017c), the authors used price to predict abundance, as actual abundance counts could not be quantified. However, the online trade of wildlife is becoming increasingly popular (Siriwat and Nijman 2020), providing a unique opportunity to investigate the trade dynamics of relatively unregulated domestic trade of native and non-native pet birds (Stringham et al. 2021c).

Here, we investigated which species characteristics are associated with species abundance in domestic Australian online parrot (Psittaciformes) and passerine

(Passeriformes) pet trade. To quantify species composition and abundance, we collected data from an internet marketplace, which provides unique opportunities to quantify and investigate the dynamics of the pet bird trade (Siriwat and Nijman 2020, Stringham et al. 2021c). We monitored a highly-used Australian bird trading website and determined the number of advertisements of each species traded. We fitted Generalized Linear Models (GLMs), using block cross-validation methods to account for the influence of phylogeny, to investigate species characteristics and trade variables, which we hypothesised to correlate with abundance. Finally, we used our unique online bird trade dataset to address two other secondary aims of potential biosecurity importance: (i) we compared the rate at which non-native and native species are traded; and (ii) investigated the use of price as a proxy measure for abundance.

2.4 Methods

2.4.1 Data collection

2.4.1.1 *Online trade data*

We monitored a popular surface-web Australian classifieds website where the Australian domestic bird trade is prolific (Stringham et al. 2021b). Using an established automated data collection method (Stringham et al. 2021c), we collected listings (i.e., advertisements) over five months from July to December 2019. Over this period, we collected unique listings from the ‘bird’ subsection of the website (Supplementary File 2-1 for list of species found). As this website used free text (i.e., traders type their listings individually), each listing needed information to be manually cleaned and extracted for species names and other attributes, such as price. This assumes advertisements resulted in a sale, but does not capture changes in price, such as through price negotiations in private messages. Due to the large number of listings, we chose to clean a random subset accounting for 25% of all listings over this time, resulting in 13,800 unique listings (Supplementary File 2-2). All data were collected according to established ethical recommendations for de-identifying e-commerce data (Stringham et al. 2021c). As we used automated collection methods on free-text advertisements, some may include the sellers’ personal data, such as images, contacts, or writing style (Thompson et al. 2021). To ensure the privacy of the website users, we de-identified data by analysing only the information relevant for this research (i.e., species name, quantity, and price). This research was conducted with ethics approval from the University of Adelaide (Semi-automated monitoring of international online wildlife trade; HREC no. H-2020-184).

From each listing, we used the listing text and photos (if provided) to identify the species traded to the most specific taxonomic rank possible, following BirdTree nomenclature (Jetz et al. 2012; www.BirdTree.org), and reported using the Clements taxonomy (Clements et al. 2022). We recorded the quantity of individuals sold and if the bird was a colour mutation. We also recorded cases where the advertiser stated the bird was wild caught; however, this is highly regulated in Australia and is illegal for the majority of native species. We also recorded advertisements where the bird was hand raised, which we assume to be the common practice where a juvenile bird is removed from the parents and fed and socialised by humans.

We only considered listings identified to species and subspecies, excluding hybrids between two species and listings only to genus or family level identifications. Our

focus was on the two most traded orders: Psittaciformes (parrots; 95 species, 9192 listings, 23121 individuals) and Passeriformes (passerines; 48 species, 1245 listings, 4077 individuals). We excluded orders which did not have sufficient species diversity for further analysis, including species from the following orders: Anseriformes (waterfowl; 9 species, 313 listings), Casuariiformes (Emu, *Dromaius novaehollandiae*, 4 listings), Charadriiformes (Painted Buttonquail, *Turnix varius*, 2 listings), and Columbiformes (pigeons and doves; 9 species, 86 listings) (Supplementary File 2-2). To identify potential biosecurity risk of non-native species, we compared the proportion of sales of native and exotic species and identified the threat categories of all non-native species using the Australian List of Threat Categories of Non-indigenous Vertebrates (Australian Intergovernmental Environment & Invasives Committee 2018). These threat categories incorporate the danger posed by an individual animal if it were to escape captivity, the likelihood of it establishing a wild population, and the consequences if it were to establish.

2.4.1.2 Species characteristics

To investigate correlates of species abundance in trade, we collected species characteristics that we predicted may contribute to a species' desirability. We grouped these characteristics into three categories: (i) breeding and handling; (ii) trade and availability; and (iii) appearance and behaviour (Table 2-1). Where characteristic data was missing for a species, we used the average for the genus for numerical characteristics, and the most common value in the genus for categorical characteristics. If this information unavailable, the species was excluded from the correlates of abundance analysis. We excluded 12 species where price was not advertised, and the median price could not be calculated (Supplementary File 2-2), and we excluded one species (Pictorella Mannikin, *Heteromunia pectoralis*) that was missing values for some of the below characteristics in Table 2-1, where genus-level data was unavailable. We checked for correlations between characteristics by assessing variance inflation factors (VIF), removing characteristics if they were highly correlated with another ($VIF > 5$) (Daoud 2017). We found no instances of high correlations between species characteristics, where the highest correlation for parrots was median price ($VIF = 5.13$) and for passerines was level of care ($VIF = 3.01$).

Table 2-1: Species characteristics we hypothesised are related to species abundant in online trade. These characteristics were identified in previous studies on different wildlife trade markets.

Character	Source	Unit	Description	Prediction
Breeding & handling				
Annual fecundity	Birdcare	total eggs	Average number of eggs produced each year in captivity, according to an online birdkeeping guide Birdcare.	Species with a higher reproductive output may have more individuals available for sale, increasing total abundance (Toomes et al. 2022).
Body mass	Myhrvold et al. (2015)	grams	Average mass of species for males and females.	Birds with higher body mass are often described as more attractive, suggesting they will be more abundant (Romero-Vidal et al. 2020, Siriwat and Nijman 2020).
Level of care	Birdcare	1 (beginner) to 4 (specialist)	Level of experience recommended for keeping species, according to the online birdkeeping guide.	Birds that require more experience to keep may be less accessible to the public, and therefore less abundant (Vall-llosera and Cassey 2017c).
Mutations	Birdcare	presence	If colour mutations are present in Australian trade, according to the online birdkeeping guide.	Species which can have colour mutations available may be viewed as “collectable”, making the species more abundant (Chan et al. 2021).
Hand-raised	Calculated	presence	If hand-raised birds were present in the dataset.	Species which can be hand-raised may be seen as more desirable companion animals, and more abundant.

Trade & availability				
Provenance	BirdLife Working List of Australian Birds	native or non-native	If the species has a native range within Australia.	Non-native species may be perceived as “rare” in trade and more abundant.
Range size	BirdLife International and Handbook of the Birds of the World (2019)	km ²	Total geographic range size for the species, including invasive populations.	Species with smaller range sizes may be perceived as “rarer” and more desirable and abundant (Toomes et al. 2022).
Median price	Calculated	\$AUD	Median price of all sales for each species in dataset.	Cheaper species may be more accessible to the public, and therefore more abundant. (Tella and Hiraldo 2014).
Appearance & behaviour				
Song complexity	Xeno-Canto	total unique birdsong recordings	Total number of unique recordings on birdsong repository (Blackburn et al. 2014).	Species with more complex songs may be more perceived as more attractive and, more abundant (Garnett et al. 2018).
Plumage colour	Dale et al. (2015) and (Carballo et al. 2020)	colour elaboration score	Colour elaboration scores of male birds.	More colourful birds may be more attractive, and therefore more abundant (Chan et al. 2021, Senior et al. 2022).
Intelligence	Tsuboi et al. (2018)	encephalization quotient (EQ)	The brain to body mass ratio can be used as a rough estimate for intelligence (Jerison 1955).	More intelligent birds, which have a greater ability to learn tricks and behaviours, may be more abundant (Chan et al. 2021, Jain et al. 2022).

2.4.2 Data analysis

Our analysis between abundance and species characteristics involved three steps. First, we identified candidate statistical models each containing various combinations of the species characteristics as explanatory variables. Second, we identified which models best predicted the data using a cross-validation method that accounted for phylogenetic autocorrelation. Finally, we ran the ‘best’ models on the full dataset using a model averaging approach and reported on covariates of interest and model performance metrics.

To identify the correlates of species abundance in trade, we used a model selection method with phylogenetic cross-validation to account for the non-independence caused by phylogenetic autocorrelation, investigating parrots and passerine trade separately. Due to the large number of characteristic covariates ($n = 11$) compared to the number of species in trade (83 parrots, 48 passerines), we constrained the complexity of individual models to avoid overfitting by limiting the number of covariates used in each model. To do so, we created univariate models containing each explanatory variable from Table 2-1, as well as models with one variable from each model grouping: (i) breeding & handling; (ii) trade & availability; (iii) appearance & behaviour. However, as there were no advertisements for hand-raised passerines, this character was removed from the passerine analysis. This resulted in 95 candidate models for parrots and 79 for passerines (Supplementary File 2-4). The dynamics of the trade in budgerigars (*Melopsittacus undulatus*) are very different to other parrots (e.g., often sold as a “starter bird” for children) (Valllosera and Cassey 2017a). Consequently, their abundance in online trade was four orders of magnitude larger than the next most abundant species. Due to the magnitude of the difference and specific characteristics of this species, they were not considered further in any statistical analysis.

We checked for phylogenetic correlations in the data and found a high correlation for parrot abundance (Pagel’s $\lambda = 0.99$, $p < 0.0001$), although not for passerines ($\lambda = 0$, $p = 1$). Therefore, the linear regression assumption of independence of the observations was violated for parrots, and we needed to correct for phylogenetic autocorrelation (Revell 2012). We used k-fold block cross-validation, which takes “blocks” of species (i.e., phylogenetic clades) based on their phylogenetic distance to create training and test datasets and assess model predictive performance (Harris et al. 2017, Roberts et al. 2017). The cross-validation procedure iterates over the phylogenetic blocks to build the model with training data and predict for the held-out test block of species (i.e., remaining species which were not in the “block”). Models were then ranked by their average predictive performance (i.e., root-mean-squared error: RMSE) to identify the highest ranked models for inference (Dormann et al. 2018). For consistency, we used this block method to evaluate candidate models for both parrots and passerines separately.

Using methods from Thompson et al. (2021), we ran negative binomial Generalised Linear Models (GLMs) for all candidate models. As the phylogenetic distance that would ensure independence among species was unknown, we repeated the model selection with increasing numbers of phylogenetic “blocks” (i.e., reducing the number of held-out species) to assess the sensitivity of the model chosen for inference under different amounts of phylogenetic relatedness (Yates et al. 2023). Using a phylogenetic consensus tree using 1000 trees from BirdTree (Rubolini et al. 2015), we estimated an ideal block size (i.e., number of blocks/clades) of five for

passerines and four for parrots (Supplementary File 2-4), from which we selected the best-performing models based on the lowest root-mean-square-error (RMSE).

To obtain final model estimates and to visualize relationships for count data with no zeros, we constructed negative binomial GLMs on the full dataset for all cross-validated models with $\Delta\text{RMSE} < 10$ and assessed model performance using marginal R^2 (Nakagawa et al. 2017). We used conditional model averaging, where models were weighted using RMSE, and the relative importance (RI) of each variable was calculated using the sum of model weights for models that included the variable. We used the results of model averaging to: (i) identify the average model estimates of each characteristic; (ii) identify which characteristics were most strongly correlated (i.e., greatest relative importance) with species abundance; and (iii) to interpret characteristics whose 95% confidence intervals do not overlap with zero.

2.4.3 Testing the use of price as a proxy

Finally, we tested price as a proxy for actual abundance in our database of Australian online trade, to investigate the validity of a common assumption made in previous wildlife trade studies (e.g., (Harris et al. 2017, Vall-Ilosera and Cassey 2017a). To do so, we compared the abundance (i.e., number of individuals traded online) per species to their median per-unit price and calculated the Pearson's correlation statistic to quantify the relationships between abundance and price. We performed this analysis separately for parrots and passerines.

All analysis was conducted using R 4.1.3 software for statistical and graphical computing (R Core Team 2022). Variance inflation factors and marginal R^2 values were calculated using package 'performance' (version 0.9.2, Lüdecke et al. 2021) and phylogenetic correlation was calculated using 'phytools' (version 1.2.0, Revell 2012). GLM models were fitted using 'glmmTMB' (version 1.1.4, Brooks 2017), and 'MuMIn' for model averaging (version 1.47.1, Barton 2022).

2.5 Results

2.5.1 Species composition and abundance

Native parrots were more abundant (15,962 individuals) than non-native parrots (6,197 individuals); however, most species were non-native (53 non-native species, 41 native; Figure 2-1). Three native species dominated trade: Budgerigar (*Melopsittacus undulatus*, 10,022 individuals), Cockatiels (*Nymphicus hollandicus*, 2,457 individuals), and Rainbow Lorikeets (*Trichoglossus moluccanus*; 1,889 individuals). Abundant non-native species included Rose-ringed Parakeets (*Psittacula krameri*, 1,971 individuals), Green-cheeked Parakeets (*Pyrrhura molinae*, 820 individuals), and Rosy-faced Lovebirds (*Agapornis roseicollis*, 805 individuals). Approximately 10% of all parrot advertisements were selling hand-raised birds. On the Australian List of Threat Categories of Non-indigenous Vertebrates, 43 non-native parrot species in the trade are listed as an extreme risk, two as a serious risk, five as a moderate risk, one as a low risk, and two species are not listed.

Passerine trade was predominantly non-native species in both composition (33 non-native species, 18 native) and abundance (2,413 non-native individuals, 1,674 native). The most abundant native species were Zebra Finches (*Taeniopygia guttata*, 698 individuals), Gouldian Finches (*Chloebia gouldiae*, 598 individuals), and Painted Finches (*Emblema pictum*, 94 individuals). Abundant non-native

species included Domestic Canaries (*Serinus canaria*, 1,667 individuals), Java Sparrows (*Padda oryzivora*, 130 individuals), and European Goldfinches (*Carduelis carduelis*, 86 individuals). We found no advertisements of hand-raised passerines. Of the non-native passerine species, 28 are listed as an extreme risk and five as a serious risk.

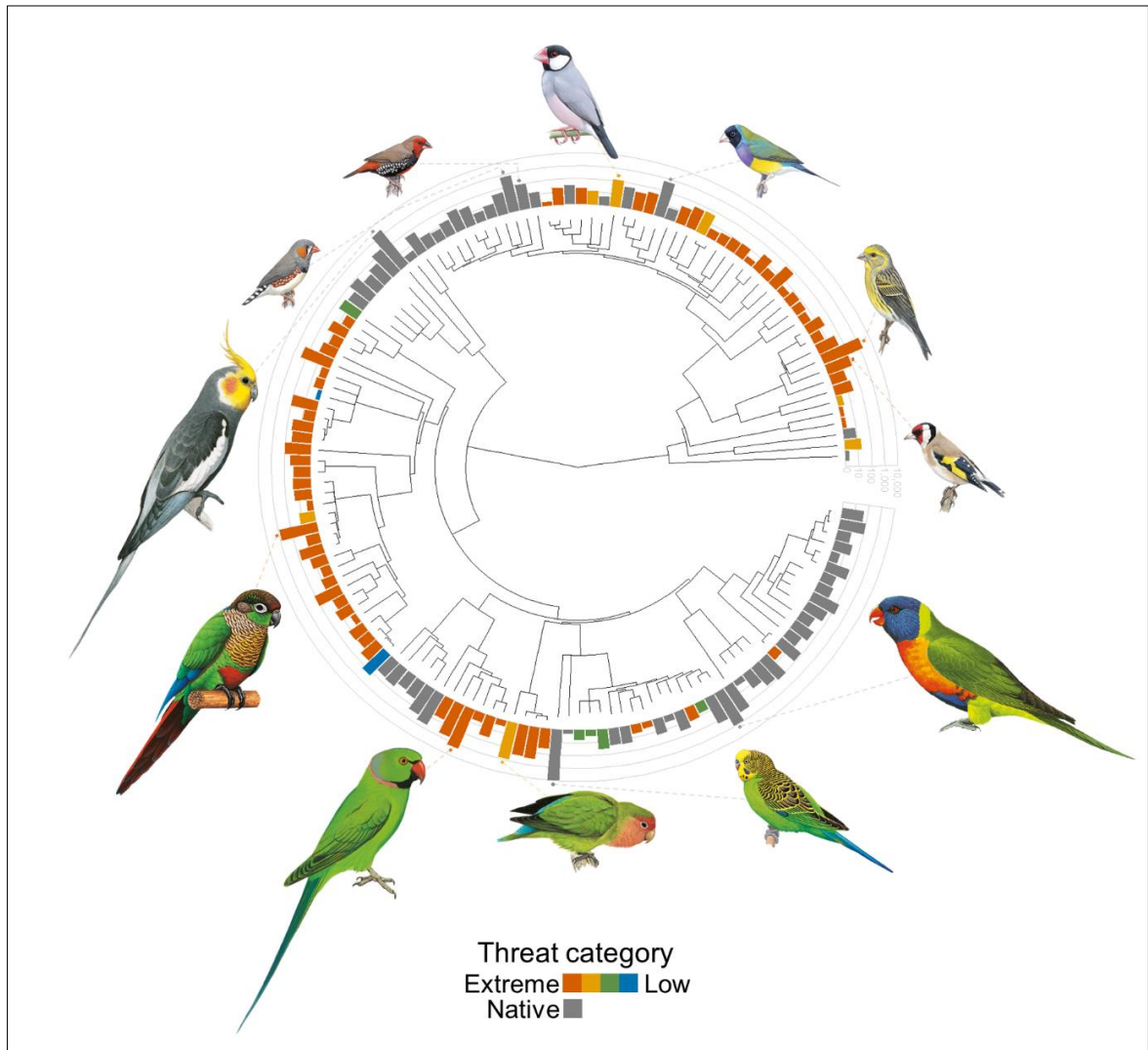


Figure 2-1: Abundances of species in Australian online tree, and their phylogenetic relationships using a consensus tree of 1000 trees from BirdTree (Rubolini et al. 2015). Bar height indicates the total abundance and are coloured by their risk of establishing wild populations according to the Australian List of Threat Categories of Non-indigenous Vertebrates (Australian Intergovernmental Environment & Invasives Committee 2018). The top three most abundant non-native and native species are shown for both parrots and passerines, with body size shown to scale. Clockwise from top: Java Sparrow (*Padda oryzivora*), Gouldian Finch (*Chloebia gouldiae*), Domestic Canary (*Serinus canaria*), European Goldfinch (*Carduelis carduelis*), Rainbow Lorikeet (*Trichoglossus moluccanus*), Budgerigar (*Melopsittacus undulatus*), Rosy-faced Lovebird (*Agapornis roseicollis*), Rose-ringed Parakeet (*Psittacula krameri*), Green-cheeked Parakeet (*Pyrrhura molinae*), Cockatiel (*Nymphicus hollandicus*), Zebra Finch (*Taeniopygia guttata*), and Painted Finch (*Emblema pictum*). Illustrations were produced with permission of Lynx Edicions.

2.5.2 Relationships between abundance and species characteristics

For parrot trade, four models were selected, with high marginal R^2 (0.62 to 0.66; Supplementary File 2-4). The most important correlate with species abundance was song complexity (i.e., the variety of songs and ability to mimic speech; Figure 2-2). This variable was in all top-performing models (relative importance (RI) = 1.00), with a positive correlation between more complex songs and abundance in trade (slope (M) and 95% confidence interval = 1.97 ± 0.57 ; Supplementary File 2-4). The level of care was the next most important characteristic (RI = 0.91), where higher levels of care were negatively correlated with abundance ($M = -0.91 \pm 0.32$). Provenance was an important characteristic (RI = 0.60), where native Australian species were positively correlated with abundance ($M = 0.48 \pm 0.53$); however, its confidence interval included zero. Median price had low relative importance (RI = 0.15) and a negative correlation with abundance in trade ($M = -1.29 \pm 0.77$), while the presence of colour mutations was the least important characteristic of those selected (RI = 0.09), with a positive correlation ($M = 0.96 \pm 0.68$) and preference towards species with mutations available in trade.

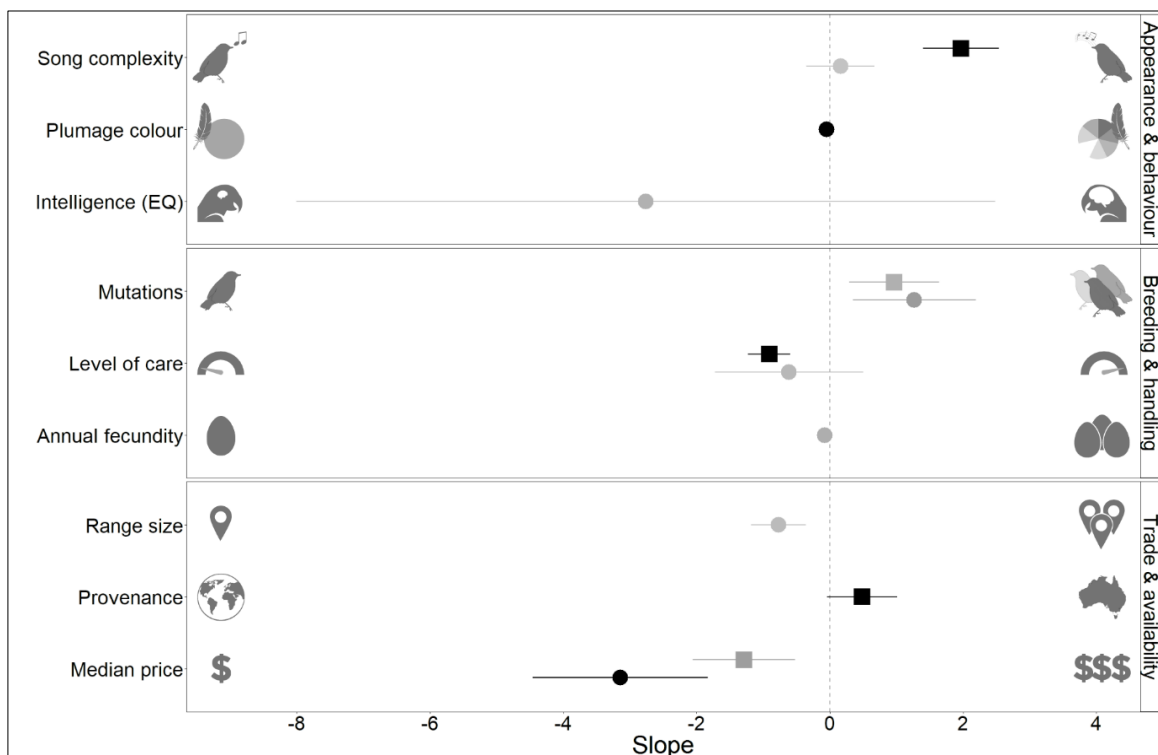


Figure 2-2: Slopes and 95% confidence intervals for the correlations of species characteristics with species abundance in online trade for parrots (squares) and passerines (circles). Characteristics are coloured by their relative importance (RI; 0 = light grey, 1 = black). The closer to 1, the stronger association the characteristic has on abundance.

For passerine trade, eight models were selected, with high marginal R^2 (0.60 to 0.74) the most important correlate with species abundance was the median price (RI = 0.96), where lower prices were correlated with higher abundances ($M = -3.15 \pm 1.32$). Plumage colour was the next most important characteristic (RI = 0.84); however, its small negative correlation ($M = -0.05 \pm 0.05$) included zero. The presence of colour mutations had low relative importance (RI = 0.17) a positive

correlation ($M = 1.26 \pm 0.92$) with preference towards birds with mutations available in trade. Range size had a low relative importance ($RI = 0.04$), with a negative correlation with abundance ($M = -0.77 \pm 0.41$). The remaining characteristics had confidence intervals overlapping zero, including annual fecundity ($RI = 0.09$; $M = -0.08 \pm 0.12$), intelligence ($RI = 0.08$; $M = -2.77 \pm 5.24$), level of care ($RI = 0.05$; $M = -0.61 \pm 1.11$), and song complexity ($RI = 0.01$; $M = 0.16 \pm 0.51$).

2.5.3 Testing price as a proxy for abundance

Median price has a very weak, although significant, negative relationship with total abundance of parrots ($R^2 = 0.14$, $F_{1,82} = 14.03$, $p < 0.001$) and passerines ($R^2 = 0.36$, $F_{1,47} = 28.47$, $p < 0.001$) (Supplementary File 2-5).

2.6 Discussion

As the bird trade in Australia continues to be an emerging source of new invasive species, continued monitoring of pet sales is crucial for early prevention and effective biosecurity (Vall-Ilosera and Cassey 2017b, Lockwood et al. 2019, Toomes et al. 2019). Here, we have found that a number of characteristics which correlate with species abundance in trade are also characteristics associated with successful invasive species.

In our study, the price of a given bird species was a correlate of abundance, where cheaper species were more abundant. This has implications for biosecurity, as price is also a major correlate for species escapes from captivity in Australia (Vall-Ilosera and Cassey 2017b). Simultaneously, cheaper species are also correlated with captive escapes which, combined with the higher abundances in trade identified here, increases the propagule pressure of non-native species in trade (Cassey et al. 2018). The two most commonly traded non-native parrots, the Rose-ringed Parakeet (*Psittacula krameri*) and the Green-cheeked Parakeet (*Pyrrhura molinae*), and two of the most commonly traded non-native passerines, the Domestic Canary (*Serinus canaria*) and European Goldfinches (*Carduelis carduelis*) are identified as extreme biosecurity risks (Australian Intergovernmental Environment & Invasives Committee 2018). In particular, wild incursions of Rose-ringed Parakeets are increasing in Australia due to increasing pet trade and are likely to establish as an invasive species without ongoing control (Vall-Ilosera et al. 2016). This species possesses the most important correlates with abundance for parrots: it is relatively cheap (approximately AUD\$120; median parrot price \$175 with a range of \$20 to \$8,000), is easy to care for (often sold for “beginners”), has a wide variety of songs, and is available in many colour mutations. This is consistent with other studies where the characteristics which make a species abundant in trade also makes them a successful invasive species (Gippet and Bertelsmeier 2021). Concerningly, 81% of non-native parrot species and 85% of non-native passerine species are listed as extreme biosecurity risks on the Australian List of Threat Categories of Non-indigenous Vertebrates (Australian Intergovernmental Environment & Invasives Committee 2018). This risk level suggests that these species should not be kept unless there is sufficient management to reduce the potential of these species to establish. With the current lack of regulation around bird-keeping in Australia, we recommend these extreme risk species be closely monitored by environmental agencies and birdkeeping societies to reduce their potential for establishing invasive populations.

Although there were more non-native species present in trade, native species were sold in far greater abundances. For native species, it is likely that many of these species are being sold outside of their native ranges, potentially in large numbers, which is an unexplored biosecurity risk. For example, the third most abundant native parrot species, the Rainbow Lorikeet (*Trichoglossus moluccanus*), is native to the eastern coast of Australia, but has established invasive populations in Western Australia and Tasmania due to their popularity in trade (Chapman 2005, Robinson et al. 2020). With the high number of native species sold, there is potential for another 'domestic non-native' species to establish, which has occurred in other international markets (e.g. Javan Myna, Nijman et al. 2022).

Most species characteristics we explored differed in their importance between parrot and passerine abundance. The characteristic with the strongest association with parrot abundance in trade was song complexity, the measure of how attractive people find the species' call measured by unique uploads to a birdcall website (Xeno-Canto.org). While this may be a traditionally desirable characteristic in parrots due to their association with repeating phrases, it may also be driven by modern media, as videos of parrots mimicking songs and speech are popular online (e.g. Siriwat et al. 2020, Moloney et al. 2021). We also found that species which are easy to care for (i.e., "beginner" species) were more abundant, which encapsulates species that are hardy, have generalist diets and do not need specialist housing or attention. Characteristics associated with easy care are also correlates of successful invasive species; where they are able to readily adapt to new environments (Valllosera and Sol 2009).

Alternately, passerine trade abundance is driven by characteristics more associated with aviary birds, where cheaper, more colourful species were more abundant. Plumage colour (here, for the "natural" colour, not colour mutations) was the next most important factor explaining abundance after median price; however, the direction of which is unclear. Similarly, the presence of colour mutations had some effect on species' abundance, where pet owners may wish to have unusual colours or forms, collect a variety of different mutations, or attempt to breed new mutations. However, this might not have a direct influence on abundance, as the more a species is captive bred, the higher the chance of a colour mutation arising (Chan et al. 2021). The most abundant native and non-native species, Zebra Finches (*Taeniopygia guttata*) and Domestic Canaries (*Serinus canaria*) respectively, have some of the most diverse colour mutations available, and are highly desired for use in birdkeeping competitions.

Interestingly, body mass was not identified as a significant correlate for either order, which has previously been identified as a major driver of species abundance in international bird trade (Romero-Vidal et al. 2020, Siriwat and Nijman 2020). Hand-raised parrots were common but did not influence the abundance of a species. We found no evidence of hand-raising in passerines. This may indicate a different bird-keeping cultures for these two orders, as hand-raised birds are usually sold as companion birds. Hand-raised birds are believed to "bond" more easily with the owners but are more difficult to breed. Annual fecundity did not correlate with species abundance for parrots, and very weakly for passerines, indicating that abundance in trade is not necessarily correlated with reproductive output (i.e., supply), but by consumer demand and other species characteristics.

Despite the high relative importance of median price on species abundance, it was not an appropriate proxy for abundance in Australian online trade. The correlation is far too weak and varied to make assumptions on the abundance of a single species. We recommend that median price on its own is not used as a proxy for predicting species abundance. However, the combination with other covariates, such as the species characteristics identified here, can potentially predict abundances of birds in domestic Australian online trade.

While we quantified biological and economic correlates driving the abundances of traded bird species, it is important that this information is combined with consumer behaviour research on the reasons why people purchase pet birds. Species characteristics do not affect trade on their own, and additional factors such as cultural preference or legislation may change the abundance of a species in trade. For example, while domestic bird trade in Australia is relatively unregulated, some jurisdictions require the pet owner to have a permit to keep or wild harvest a species, and others do not (Woolnough et al. 2020). This is likely to greatly influence the abundance of a species in trade, for both native and non-native species, as species which require a permit would be available to a smaller market (Toomes et al. 2022). Additionally, we found evidence of only two illegally wild caught individuals (Australian Ringneck: *Barnardius zonarius*; and Pink Cockatoo: *Lophochroa leadbeateri*), where the sellers stated the birds were harvested from the wild despite no wild permits allowing the harvest of these species. This may be an indication of laws sufficiently protecting wild populations, or sellers purposefully concealing their origins. More detail on the trade or cultural factors which make a bird more likely to be purchased and kept as a pet, such as using surveys or choice experiments, would assist in further explaining trends in the bird pet trade (Krishna et al. 2019, Marshall et al. 2020). These, in combination with our findings, may assist in identifying key species requiring greater regulation to manage biosecurity and conservation priorities.

While the domestic Australian trade has unique restrictions, these results may provide insights into the dynamics of other marketplaces. For example, some of the most popular native Australian species in this market, such as the Rainbow Lorikeet (*T. moluccanus*) and Galah (*Eolophus roseicapilla*) are also abundant in global trade (Vall-Ilosera and Cassey 2017a, Chan et al. 2021). Consequently, these species are potentially invasive species, such as in New Zealand where large numbers are escaping captivity (Stanley et al. 2023). It may be possible to use the online monitoring methods and correlations of species characteristics and abundances identified here to identify high-risk species and reduce their invasion risk such as greater restrictions to their trade.

In conclusion, characteristics that correlate with species abundance varied between passerines and parrots, differed from international markets, and were synonymous with characteristics that predict successful invasive species. By providing species abundances, and an improved understanding of drivers behind the online trade, our research will assist policy makers and birdkeeping societies to identify invasion risks of non-native species and further aid in biosecurity efforts.

3

Feather Forensics: tracing the origins of parrots in wildlife trade with stable isotopes and citizen science

3.1 Abstract

To supply the high demand for wildlife as exotic pets, animals may be illegally and unsustainably harvested from the wild and laundered as captive bred. Consequently, there is considerable interest in wildlife forensic tools that are capable of verifying captive breeding origins. Stable isotopes are an emerging tool for verifying captive and wild origins by identifying key differences in dietary intake. While previous studies have effectively classified origins by differences in their isotope ratios, these studies are often limited to species with small population sizes and geographic ranges, masking potential variation caused by different environments and diets. We tested the accuracy of stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope ratios to verify captive and wild origins using bird species that are common in pet trade, with widespread distributions, and have generalist diets. Through a citizen science project in South Australia, we collected naturally dropped feathers from four native Australian cockatoo (*Cacatuidae*) species: Galahs (*Eolophus roseicapilla*); and three *Cacatua* species, Sulphur-crested cockatoos (*Cacatua galerita*), Little Corellas (*C. sanguinea*), and Long-billed Corellas (*C. tenuirostris*). We compared isotope ratios of captive and wild birds and calculated the classification accuracy of using stable isotopes to determine origin. While $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values were significantly different between captive and wild birds and could differentiate *Eolophus* origins, they were less reliable for the *Cacatua* studied. Captive birds had significantly higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ than wild birds, and individual *Eolophus* could be classified with high accuracy (88%). However, *Cacatua* showed low repeatability and large overlaps between the origin groups, which reduced their classification accuracy (74%). Stable isotope analysis can be a potential classification tool in wildlife trade; however, before on-ground implementation, we recommend that variation from different diets across a species' geographical range be more thoroughly investigated to better understand and explain the full range of possible $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values.

3.2 Statement of Authorship

Title of paper	Feather Forensics: tracing the origins of parrots in wildlife trade with stable isotopes and citizen science
Publication status	<input type="checkbox"/> Published <input type="checkbox"/> Accepted for publication <input checked="" type="checkbox"/> Submitted for publication <input type="checkbox"/> Unpublished and unsubmitted work written in manuscript style
Publication details	Hill KGW, Delean S, Hall T, Tyler JJ, Stringham OC, Cassey P (2022) Feather forensics: tracing the origins of parrots in wildlife trade with stable isotopes and citizen science. <i>Unpublished</i>

Principal Author

Name of principal author (candidate)	Katherine GW Hill		
Contribution to the paper	Project conception, methodology design, creation of citizen science project, sample collection, sample preparation and analysis, data analysis, led writing of manuscript		
Overall percentage (%)	90%		
Certification	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its conclusion in this thesis. I am the primary author of this paper.		
Signature		Date	15/06/2023

Co-author contributions

By signing the Statement of Authorship, each author certifies that:

- i. the candidate's stated contribution to the publication is accurate
- ii. permission is granted for the candidate to include the publication in the thesis
- iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of co-author	Steven Delean		
Contribution to the paper	Data analysis, edited manuscript		
Signature		Date	15/06/2023

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Name of co-author	Oliver C Stringham		
Contribution to the paper	Supervision, edited manuscript		
Signature		Date	16/05/2023

Name of co-author	Phillip Cassey		
Contribution to the paper	Primary supervision, edited manuscript		
Signature		Date	16/05/2023

3.3 Introduction

Wildlife trade is a complex and lucrative transnational market that threatens global environments and economies (Gore et al. 2019); however, we currently lack key forensic tools to trace origins of wildlife in illegal trade chains. To supply high demand, animals may be illegally harvested from the wild and laundered as captive bred (Lyons and Natusch 2011, Shepherd et al. 2012). This is further incentivised by the low risk and high potential return of illegal wild harvesting versus the cost and infrastructure required for captive breeding (Bulte and Damania 2005). There is currently no forensically validated method to verify captive origins, preventing the detection of illegal and unsustainable wild harvest.

We explored the use of stable isotope analysis to identify captive and wild origins. Stable isotopes are a promising wildlife forensics tool to trace the origins of wildlife and wildlife products (e.g., Natusch et al. 2017, Jiguet et al. 2019, Hill et al. 2020). We investigated the use of stable carbon ($^{13}\text{C}/^{12}\text{C}$, reported as $\delta^{13}\text{C}$) and nitrogen ($^{15}\text{N}/^{14}\text{N}$, $\delta^{15}\text{N}$) isotope ratios, which are strongly related to an animal's diet and environment (Hoefs 2021). For example, $\delta^{13}\text{C}$ is influenced by the relative proportion of C_3 and C_4 plants in the animal's diet, as C_3 plants have significantly lower $\delta^{13}\text{C}$ (Hobson and Clark 1992a), and $\delta^{15}\text{N}$ is influenced by trophic position (Post 2002), where animals with higher trophic positions have higher $\delta^{15}\text{N}$.

Stable isotope analysis has been used to effectively discriminate between captive and wild populations of a variety of terrestrial vertebrate species including reptiles (van Schingen et al. 2016, Natusch et al. 2017, Gamboa-Delgado et al. 2022, Hill et al. 2022, Hopkins III et al. 2022), mammals (Kays and Feranec 2011, Brandis et al. 2018, He et al. 2018, Hutchinson and Roberts 2020) and birds (Castelli and Reed 2017, Alexander et al. 2019, Jiguet et al. 2019, Andersson et al. 2021a). While these studies have found relatively high success differentiating between origins, there remains a number of challenges which may prevent the future uptake of this technology for wildlife forensic science, including the unknown influence of large geographic range sizes. The $\delta^{13}\text{C}$ can vary greatly across a species' range, such as the proportion of C_3 and C_4 plants, water availability, and altitude (Michener and Lajtha 2008), while $\delta^{15}\text{N}$ is influenced by a large variety of mechanisms across a landscape and different land uses, such as through the use of nitrate-based agricultural fertilisers, and the presence of nitrogen-fixing plants (Rubenstein and Hobson 2004). Therefore, the larger a species' range size, the more varied the sources of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, which could potentially reduce the classification accuracy of stable isotope classification methods (Natusch et al. 2017; Symes et al. 2017). As this tool may be used in law enforcement and biosecurity management, it is crucial that stable isotope ratios across a broad range of potential environmental variability is investigated and quantified.

For this study, we focused on native South Australian cockatoos (Psittaciformes: Cacatuidae). Many of these cockatoos are widespread and common in the wild and frequently traded in domestic and international markets (Vall-Ilosera and Cassey 2017a, Hill et al. 2022). With the exception of Budgerigars (*Melopsittacus undulatus*) and Cockatiels (*Nymphicus hollandicus*), all native Australian parrot species are listed in the Convention on the International Trade in Endangered Species (CITES) Appendix II which limits international trade (CITES 2023), and there is a ban on the export of native wildlife from Australia for sale as pets (Australian Government 1999). Despite the high level of protection, chicks are harvested from nest hollows

(Rowley and Chapman 1991, Pain et al. 2006, White et al. 2012) and laundered as “captive bred” in international and domestic pet trade (Low 2014, Sy et al. 2022).

We investigated the use of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ to determine captive and wild origins using feathers from cockatoos from the Australian State of South Australia. We developed a citizen science project to collect feathers dropped from wild birds from a wide variety of environments, and captive bird feathers from private birdkeepers and aviaries. We tested the accuracy of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ to correctly classify the captive and wild origins of South Australian cockatoos. Finally, we quantified variation within individuals and across the geographic range of samples to test the repeatability of these methods.

3.4 Methods

3.4.1 Sample collection

The stable carbon and nitrogen isotope ratios in animal tissue provides a snapshot of an animal’s dietary history. Here, we use feathers, which grow quickly but their composition remains relatively the same even after moulting. Therefore, measuring naturally-shed feathers reflects a bird’s diet from when the feather was grown. Australian parrots moult annually over summer, taking a few months to complete the full moult (generally November to March;) while individual feathers regrow over a few days (Ambrose et al. 1990). Therefore, the stable isotope ratios in feathers reflect the dietary history of that bird during feather growth and remain unchanged even after moulting.

We created a citizen science project to collect naturally dropped feathers from captive and wild parrots. We asked participants to collect wild feathers they found on private property and send via post, labelled with the collection date and location, precise to postcode. Postcodes in Australia are closely related to population density; therefore, urban postcodes generally represent smaller geographical areas than rural postcodes. Similarly, we asked owners of captive parrots, aviaries, pet stores and zoos to collect naturally dropped or clipped feathers. We advertised this citizen science project through special interest social media groups, animal rescue organisations and local media (e.g., radio and newspaper), and interested participants were directed to our website (www.FeatherForensics.com). We ran the collection from December 2020 to March 2022. We only included feathers from birds which have been in captivity for at least one year (since the birds’ last moult) to ensure these birds were adults and truly captive. In total, we received feathers from 20 aviaries and private owners for captive birds, and 50 members of the public collecting wild bird feathers. We received ethics approval from the University of Adelaide (HREC no. H-2020-184).

We focused our analysis on the genus with the largest number of collected feathers: cockatoos (Cacatuidae; 57% of all feathers). This included species with similar diets: Galahs (*Eolophus roseicapilla*), Sulphur-crested Cockatoos (*Cacatua galerita*), Little Corellas (*C. sanguinea*), and Long-billed Corellas (*C. tenuirostris*). These species have generalist diets, consuming a variety of fruits, vegetables, grains, nuts, and invertebrates, and are abundant in wildlife trade (Vall-Ilosera and Cassey 2017c, Hill et al. 2022, Stanley et al. 2023). When selecting wild feathers for analysis, we prioritised sampling feathers from as many postcodes as possible to capture the largest geographic range possible with this dataset. A large proportion of white feathers from *Cacatua* could not be identified to species because they were not

visually distinguishable. Therefore, we combined all white feathers for analysis into one taxon (*Cacatua*), which we assumed to have similar diets and isotope ratios (Andersson et al. 2021a). In total, we measured 17 captive and 55 wild *Eolophus* individuals, and 13 captive and 34 wild *Cacatua* individuals. The *Cacatua* group included 6 captive and 6 wild Sulphur-crested Cockatoos, 5 captive and 13 wild Little Corellas, 2 captive and 1 wild Long-billed Corella, and 14 wild feathers which could not be identified to species (see Supplementary Information 3-1). While we could identify and remove juvenile *Eolophus* feathers, juvenile *Cacatua* feathers are not visually different from adults; therefore, juvenile *Cacatua* may be present in our analysis. Feathers were stored in sealed bags at room temperature prior to analysis.

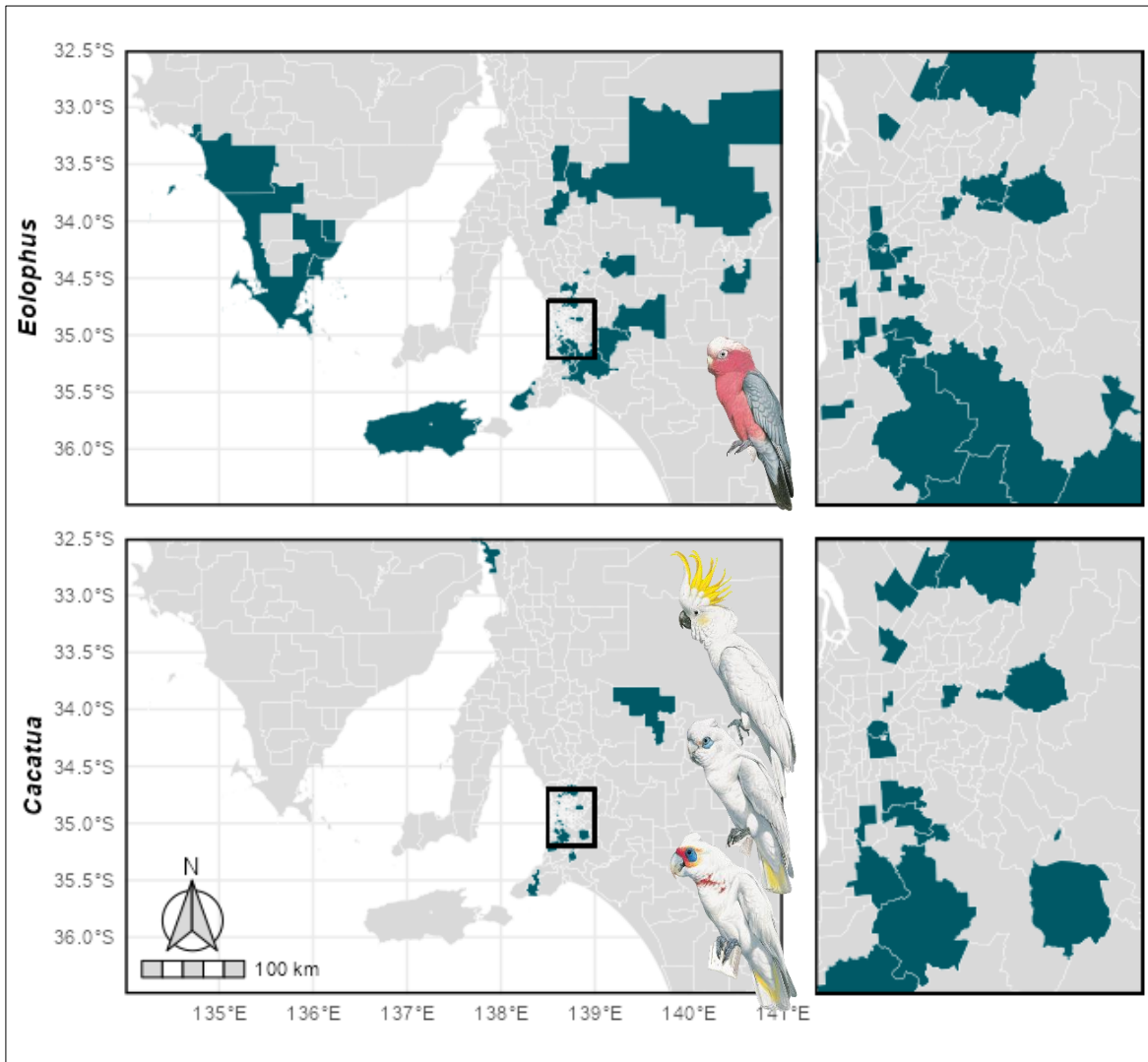


Figure 3-1: South Australian locations of wild feathers donated and analysed via the Feather Forensics citizen science project. Locations of feathers obtained were specific to postcode, shaded in green. Inset: City of Adelaide locations. Parrot illustrations were produced with permission of Lynx Edicions (Del Hoyo et al. 1992).

3.4.2 Isotope analyses

Feathers were cleaned by washing with scientific-grade detergent (Decon® 90) and water to remove surface contamination, and then repeatedly submerged in baths of 2:1 diethyl ether:methanol to remove lipids, following Bontempo et al. (2014). Feather vanes were separated from the rachis and cut into small sections with sterile dissecting scissors.

Approximately 0.4 mg of randomly selected vane sections were weighed into tin capsules and sealed ready for analysis. The samples were analysed for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ using a continuous flow isotope ratio mass spectrometer (Nu Horizon, Wrexham, UK) equipped with an elemental analyser (EA3000, EuroVector, Pavia, Italy). Stable isotope ratios are expressed in δ notation as deviations from a standard in parts per mil ($\delta X\text{‰}$):

$$\delta X\text{‰} = \left(\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right) \times 1000$$

Where R_{sample} is the atomic ratio of $^{13}\text{C}/^{12}\text{C}$ or $^{15}\text{N}/^{14}\text{N}$ in the sample, and R_{standard} is this ratio in the standard. $\delta^{13}\text{C}$ was reported relative to the standard Vienna Pee Dee Belemnite (VPDB) and $\delta^{15}\text{N}$ was reported relative to the atmosphere (AIR). All samples were corrected for instrument drift and normalized according to reference values using in-house standards ($n=19$); $\delta^{13}\text{C}$ = glycine -31.2‰ , glutamic acid -16.72‰ , and triphenylamine (TPA) -29.2‰ ; and $\delta^{15}\text{N}$ = glycine 1.32‰ , glutamic acid -6.18‰ , and triphenylamine (TPA) -0.54‰ . The in-house standards were calibrated against USGS and IAEA certified reference materials (USGS40, USGS 41, IAEA-2).

3.4.3 Quantifying within-individual variation

We quantified variation in isotope ratios within individual birds using hierarchical sampling across feather types and multiple samples within each feather. Variance along the growth of a feather and between feather types has been studied previously in other parrot species (e.g., (Grecian et al. 2015, Greer et al. 2015, Symes et al. 2017, Andersson et al. 2021a), where within-feather variation and differences between feather types were minimal. To ensure this was consistent in Australian cockatoos, we created a pilot dataset to test within-individual variation. We measured feathers from birds with multiple feathers available: nine *Eolophus* and five *Cacatua*. We compared $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for up to three of each feather type from each bird: body (breast) feathers ($n = 50$ *Eolophus* feathers and 23 *Cacatua* feathers), primary wing feathers (42 and 20), and “other” feathers (e.g., crest or tail; 39 and 18); with two measurements per feather from random sections of the vane (Supplementary Information 3-1). We therefore investigated the variance at four levels of within-individual hierarchical sampling: within-individual > between feather types > between feathers of the same type (between-feather) > within single feathers (within-feather).

We tested for significant differences in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of primary wing and “other” feathers in comparison to body feathers. To achieve this, we used linear mixed effects models for each isotope with and without feather type as a term, and with within-individual and between-feather as random effects in the R 4.2.2 software environment for statistical and graphical computing (R Core Team 2022) with the lme4 package (version 1.1-31) (Bates et al. 2015). We compared models with and without feather type as an independent variable using likelihood ratio tests, and specific differences using Holm-Bonferroni corrected contrasts between estimated marginal means (EMMs; emmeans package, version 1.8.2; Lenth 2022).

We identified the hierarchical scale of isotope variation to allow recommendations for targeting future sampling efforts (i.e., between-individual > within-individual > feather type > between-feather > within-feather) by investigating the components of variance in the linear mixed effects models. As this does not quantify the relative

variation among feather types, we also calculated the repeatability estimates (R) for each level of sampling. This measure is the chance of obtaining precise measurements of the stable isotope ratios for an individual bird, no matter which feather is sampled. We calculated the R for each level of sampling using parametric bootstrapping with the `rptr` package (version 0.9.22) (Stoffel et al. 2017), where each level ignored the other sampling levels to see how the relative size of between-feather variation increased. Estimates closer to 1 indicate high repeatability, which in this case is the likelihood that similar isotope values can be obtained from an individual each time it is sampled (i.e., low within-individual variation).

As we combined three *Cacatua* species, we tested if differences in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ was influenced by species. With a subset of feathers of all feather types where we were able to confidently verify the feather to species, we fit linear mixed effects models with and without species as a term and examined significance of dropping different independent variables using a Pearson's chi-squared test.

3.4.4 Spatial autocorrelation of isotope variables across large range sizes

To identify potential sources of between-individual variation, we investigated if the geographic location of wild feathers influenced isotope ratios; was there spatial autocorrelation such that feathers from birds in nearby regions had more similar isotope ratios than birds farther away. Using calculated individual $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ means for all wild feathers, we tested for spatial autocorrelation using Moran's I with the `ape` package (version 5.6-2) (Paradis and Schliep 2019).

3.4.5 Classifying captive and wild origins with stable isotopes

Due to the nature of collection through the citizen science program, we often only had single feathers per individual bird, as most donations were single feathers. To reduce the potential variation introduced by feather type, we subset the data to include only one feather type. Body feathers were selected for further analysis as they were the most frequently collected feather type (57%), are often dropped from birds during routine handling, and the loss of a single feather does not negatively affect a bird's function. Additionally, feathers from museum samples are generally body feathers to reduce destruction of specimens, which could be a limiting factor for species where wild individuals are difficult to source.

To test the accuracy of using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ to classify captive or wild origin of individual birds, we created classification models using a support vector machine (SVM). This is a supervised learning technique that identifies the optimised linear boundary line to split two classes (i.e., captive and wild) by isotope ratios in two dimensions ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$). As we had multiple samples from the same individual, and the hierarchical analyses described above showed repeatability within individuals, we first created subsets of data containing one randomly selected data point per individual so that classification accuracy was not inflated by non-independence of the sample data. Due to the uneven sample sizes of the two classes in both *Eolophus* (captive $n = 17$ and wild $n = 55$) and *Cacatua* ($n = 13$ and 34), SVM models fit to these data would overestimate the accuracy of classifying the larger class (wild). Therefore, we used Synthetic Minority Oversampling Technique (SMOTE) in the `DMwR2` package (version 0.0.2) (Torgo 2016), which creates synthetic data for the minority (captive) class (Chawla et al. 2002; Supplementary Information 3-4). With this subset, we fit linear SVM models using the `caret` package (version 6.0-93) (Kuhn 2022) with an internal (5-fold) cross-

validation to evaluate the accuracy. We extracted the boundary line estimates and evaluated performance measures, including accuracy, precision, recall and F-measure over the internal cross-validation. Accuracy is the total proportion of correct classifications to all classifications; precision is the number of captive classifications which were correct; recall is the proportion of correct captive classifications to the total number of captive birds in the dataset; and F-Measure (F1) is the harmonic mean of precision and recall. We then repeated this process using 1000 iterations of different subsets to identify the effect of individual variation on the boundary estimate. For the final predictions, we present the means and standard deviations of the boundary line estimates and the performance measures.

3.5 Results

3.5.1 Quantifying within-individual variation

We found statistical support for differences between *Eolophus* feather types for $\delta^{13}\text{C}$ ($\chi^2_3 = 11.1$, $p < 0.01$; Figure 3-2); where $\delta^{13}\text{C}$ was lower in primary wing feathers than body feathers ($t_{56.1} = -3.4$, $p < 0.01$). There were no clear differences between body and other feather types in $\delta^{13}\text{C}$ for *Cacatua* ($\chi^2_3 = 4.8$, $p = 0.09$), or in $\delta^{15}\text{N}$ for either *Eolophus* ($\chi^2_3 = 4.5$, $p = 0.10$) or *Cacatua* ($\chi^2_3 = 4.8$, $p = 0.09$).

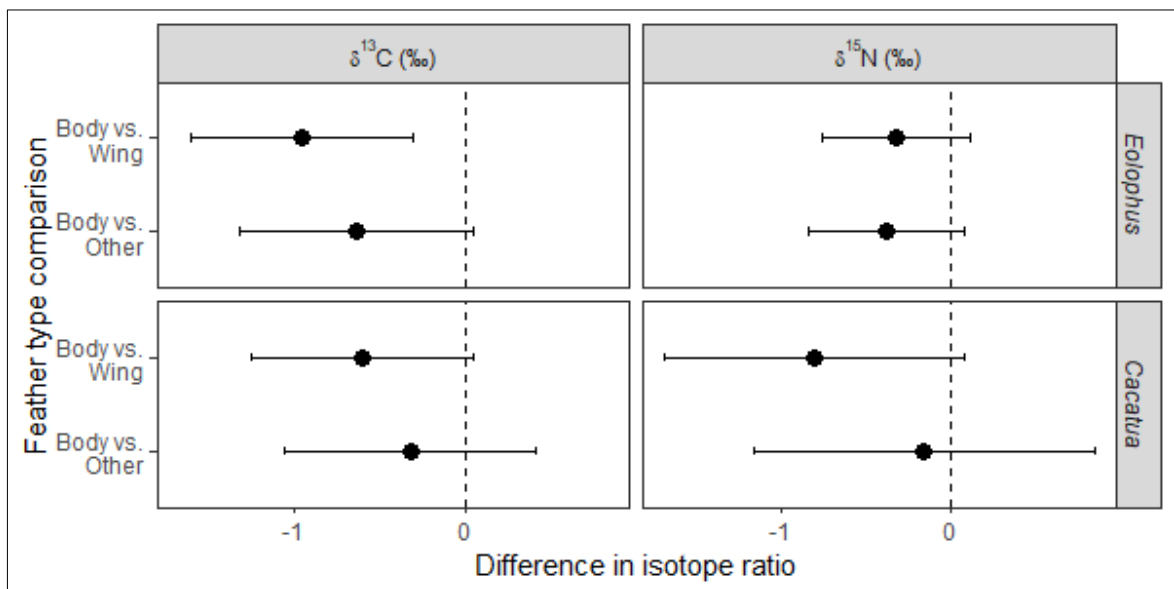


Figure 3-2: Pairwise contrasts of body (breast) feathers compared to primary wing and “other” (e.g., crest) feathers for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in *Eolophus* (*Eolophus roseicapilla*) and *Cacatua* spp. Statistical support for differences in isotope concentration between the feather types are where the confidence interval for a comparison does not overlap with zero.

After accounting for feather type differences (i.e., feather type as a fixed effect, leaving the hierarchical levels: between-individual > within-individual > between-feather > within-feather), between-individual differences explained most of the variation in *Eolophus* isotope ratios ($\delta^{13}\text{C}$: 92%, $\delta^{15}\text{N}$: 90% of see Supplementary Information 3-2). Within-individual repeatability was high for both $\delta^{13}\text{C}$ (R mean \pm standard error = 0.93 ± 0.05 , $p < 0.01$) and $\delta^{15}\text{N}$ (0.98 ± 0.01 , $p < 0.01$). Repeatability was also high between-feather ($\delta^{13}\text{C}$: 0.97 ± 0.01 , $p < 0.01$; $\delta^{15}\text{N}$: 0.92 ± 0.03 , $p < 0.01$) and within-feather ($\delta^{13}\text{C}$: 0.99 ± 0.01 , $p < 0.01$; $\delta^{15}\text{N}$: 0.98 ± 0.01 , $p < 0.01$).

In *Cacatua*, $\delta^{13}\text{C}$ was more influenced by within-individual variation (49%) than between-individual variation (35%), while $\delta^{15}\text{N}$ variation was predominantly explained by between-individual variation (77%). Consequently, repeatability for $\delta^{13}\text{C}$ was low for within-individual (0.42 ± 0.19 , $p < 0.01$) and between-feather (0.56 ± 0.14 , $p < 0.01$), but improved for within-feather (0.83 ± 0.06 , $p < 0.01$). $\delta^{15}\text{N}$ was reasonable for within-individual (0.79 ± 0.16 , $p < 0.01$) and between-feather (0.77 ± 0.11 , $p < 0.01$), and high for within-feather (0.95 ± 0.02 , $p < 0.01$).

We found no evidence of species affecting $\delta^{13}\text{C}$ ($\chi^2_2 = 2.4$, $p = 0.3$) or $\delta^{15}\text{N}$ ($\chi^2_3 = 3.4$, $p = 0.2$) when feathers from the three *Cacatua* species were combined.

3.5.2 Spatial autocorrelation of isotope variables across large range sizes

We found evidence for spatial autocorrelation for $\delta^{13}\text{C}$ in *Eolophus* (Moran's $I = 0.3$, $p < 0.01$), but not $\delta^{15}\text{N}$ ($I < 0.01$, $p = 0.8$; Supplementary Information 3-2). Conversely, spatial autocorrelation was present in *Cacatua* for $\delta^{15}\text{N}$ ($I = 0.3$, $p < 0.01$), but not $\delta^{13}\text{C}$ ($I = 0.2$, $p = 0.06$).

3.5.3 Classifying captive and wild origins with stable isotopes

As within-feather variation in the pilot analysis showed high repeatability for *Eolophus* and *Cacatua* in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, for the remaining analysis we took one replicate per feather per individual. To reduce variance introduced by feather type, and to improve repeatability within *Cacatua*, we used a subset of the data including only body feathers, with one sample per individual.

We found significant differences between captive and wild origin birds for both *Eolophus* and *Cacatua* groups. There were clear differences in $\delta^{13}\text{C}$ (*Eolophus*: $t_{61} = -3.4$, $p < 0.01$; *Cacatua*: $t_{45} = -3.1$, $p < 0.01$) and $\delta^{15}\text{N}$ (*Eolophus*: $t_{61} = -7.5$, $p < 0.01$; *Cacatua*: $t_{45} = -2.8$, $p < 0.01$). On average, individual captive *Eolophus* had higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ than wild *Eolophus* ($\delta^{13}\text{C}$ mean \pm SD: $-18.7 \pm 1.3\text{‰}$ and $-21.2 \pm 0.8\text{‰}$; $\delta^{15}\text{N}$ mean \pm SD: $8.7 \pm 0.6\text{‰}$ and $6.1 \pm 0.4\text{‰}$). *Cacatua* had similar $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ means, where individual captive bird feathers had higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ compared to wild populations ($\delta^{13}\text{C}$: $-19.9 \pm 0.9\text{‰}$ and $-21.3 \pm 0.6\text{‰}$; $\delta^{15}\text{N}$: $7.8 \pm 0.8\text{‰}$ and $6.5 \pm 0.5\text{‰}$).

The linear support vector machine successfully separated the captive and wild classes for both *Eolophus* and *Cacatua*. The linear boundary lines over the 1000 iterations for *Eolophus* had low variation in the slope (slope \pm standard deviation = -0.25 ± 0.06), which indicates a relatively low influence of within-individual variation. Overall accuracy was high (88%, Supplementary Information 3-4 for additional metrics); however, two captive and three wild individual birds were misclassified in all iterations (precision = 73%, recall = 85%). The boundary line for *Cacatua* was highly variable (-2.1 ± 1.4). Overall accuracy was lower (74%), where three captive and four wild individual birds were misclassified in all iterations (precision = 53%, recall = 73%).

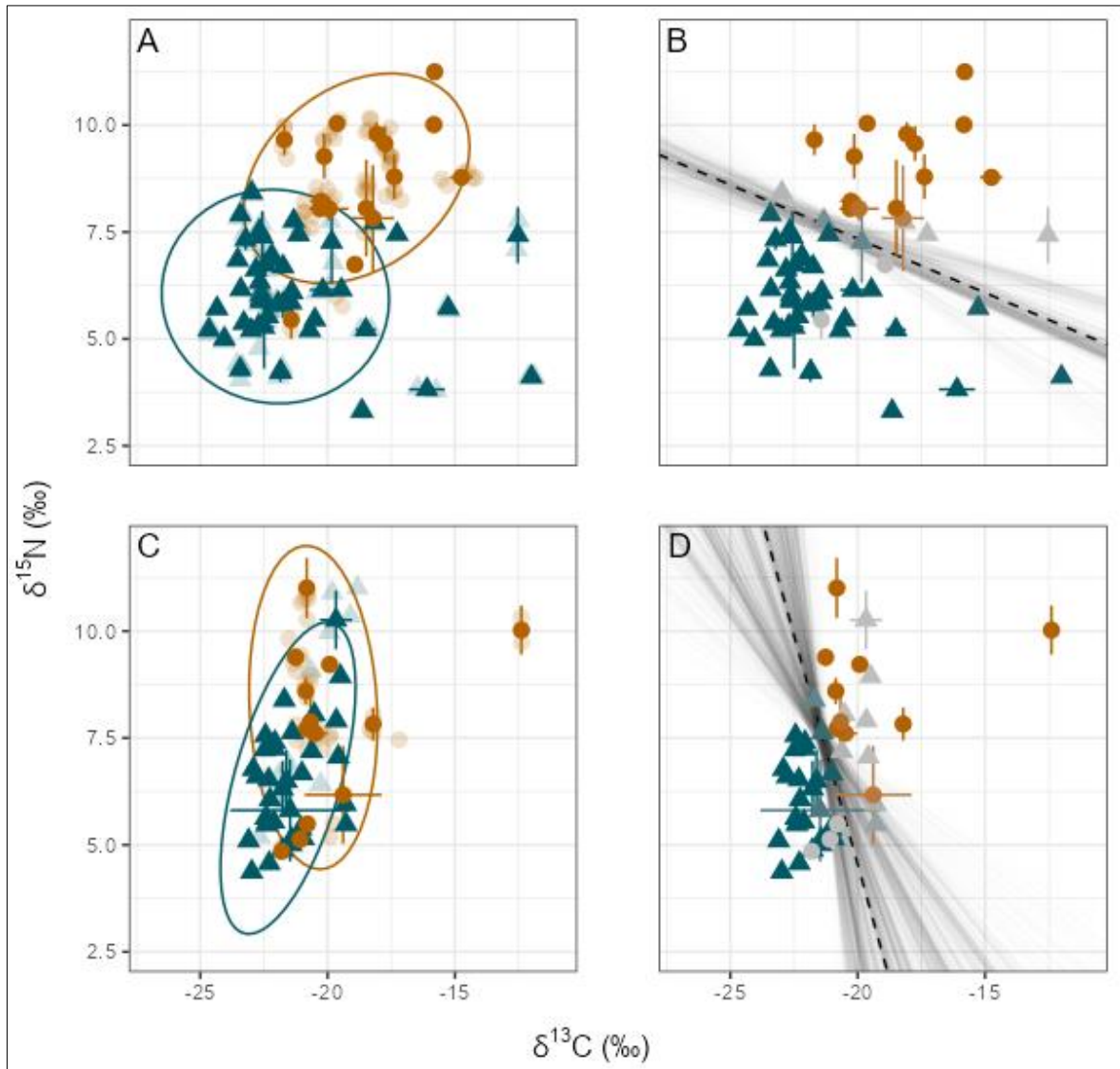


Figure 3-3: $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for body feathers from captive (orange circles) and wild (blue triangles) *Eolophus* (A&B) and *Cacatua* (C&D; Sulphur-crested Cockatoos, and Little and Long-billed Corellas). (A&C) All raw isotope values measured (transparent), overlaid with means for individuals (opaque). Individuals used in the pilot analysis, where within-individual variance was calculated, are shown with 95% confidence intervals. (C&D) Individual means and 95% confidence intervals, coloured by their classification accuracy using support vector machines (light grey points = 100% incorrectly classified). The mean optimised boundary line (dashed) and all optimised boundary estimates were calculated over 1000 iterations.

3.6 Discussion

Here we demonstrate that analysis of the dietary-influenced stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope ratios in feathers can discriminate between captive and wild populations of South Australian cockatoos, with higher values for both isotope ratios in captive birds. However, the accuracy of these methods for classification varied between the two genera of cockatoos. The classification accuracy was influenced by high variation within the captive and wild populations, and particularly high within-individual variation in *Cacatua*, which is likely a consequence of the species' large geographic range size and highly varied diets.

Stable carbon and nitrogen isotope analyses of body feathers provide a one-year snapshot of a bird's environment. The isotope composition of body feathers was found to be homogenous within an individual, indicating that the diet of these birds over the moult period was stable. However, *Eolophus* body feathers exhibited marginally higher $\delta^{13}\text{C}$ than primary wing feathers, which may relate to differences in isotope fractionation during the biosynthesis of these two feather types (Hobson and Clark 1992b, Grecian et al. 2015) or may indicate dietary or spatial changes during the growth of these feathers. Between-individual variation of wild birds appears to be partially influenced by their geographic location, as we found evidence of spatial autocorrelation in $\delta^{13}\text{C}$ for *Eolophus* and $\delta^{15}\text{N}$ for *Cacatua*. Therefore, the between-individual variation might be explained by the large geographic range of these species, encompassing a large variety of environments and diets.

Due to the number of individuals that were misclassified here, particularly for *Cacatua*, where a captive classification has a 50% chance of being incorrect, we recommend that stable carbon and nitrogen isotopes are not used in isolation for identifying the provenance of species with large population and geographic sizes. In these cases, these methods could be combined with other isotope analyses (e.g., hydrogen; Alexander et al. 2019), or with forensically validated methods such as DNA pedigree testing (e.g., Hogg et al. 2018) to provide more detailed insights into an animal's geographic origin and movements to aid in investigations. While stable carbon and nitrogen isotope analyses to identify origin may not have suitable accuracy to identify origin at an individual level, they may still provide useful information at population-levels; for example, identifying if an invasive species population is a recent escape from captivity, or a wild, breeding population (Hill et al. 2022).

For both *Eolophus* and *Cacatua*, captive birds were higher in $\delta^{13}\text{C}$, which partly inferred to reflect the proportion of C3 and C4 plants in their diets (Hobson and Clark 1992a). Captive birds are likely fed a high proportion of high- $\delta^{13}\text{C}$ C4 plant material, such as corn (maize) or sorghum as seeds and pellets. By contrast, wild birds have very limited access to C4 plants, as vegetation in Southern Australia is primarily C3 plants (Munroe et al. 2022). In agricultural regions, wild cockatoos are often observed consuming C3 crops such as wheat, oats, and sunflower (Blythman and Porter 2020). These crops are also common components of commercial bird seed; therefore, captive birds with low $\delta^{13}\text{C}$ may be fed higher proportions of these crops. Alternatively, there are several wild individuals which have very high $\delta^{13}\text{C}$ in their feathers. This could be explained by wild birds potentially adapting their diets to urban areas by consuming what would ordinarily be classified as "captive" food. For example, these birds may be fed by members of the public, while Sulphur-crested Cockatoos have learnt to open bins to access discarded food (Klump et al. 2021). These birds with access to "captive" foods may have a higher chance of being misclassified with these methods.

Captive *Eolophus* and *Cacatua* feathers were found to have higher $\delta^{15}\text{N}$ than wild bird feathers, which may be driven by agricultural fertilisers used in commercial food available to captive birds (Moller et al. 2018). Alternatively, commercial bird food often contains animal products, such as egg and fat, which may increase captive birds' trophic levels compared to the invertebrates that are common in wild diets (Del Hoyo et al. 1992). This may be further amplified by animal products from marine origins, such as omega 3 supplements and cuttlefish bone, which would result in higher $\delta^{13}\text{C}$ values (Hobson et al. 1994). Higher $\delta^{15}\text{N}$ values have been observed in

the feathers of nutritionally stressed birds, which may occur in the wild, but is particularly likely in captive birds kept in poor conditions or fed a low-quality diet (Hobson et al. 1993).

While all four species studied here have similar diets, slight differences in feeding behaviour and preferences may influence their carbon and nitrogen isotope composition. For example, $\delta^{13}\text{C}$ can vary depending on the plant organ consumed (e.g., bulbs, stems, or seeds; Hoefs 2021). *Eolophus* primarily feed on the ground surface, with a preference for available seeds and rarely dig for roots, bulbs, or other buried food (Noske et al. 1982). On the other hand, Long-billed Corellas primarily dig for underground storage organs of grasses (Ambrose et al. 1990), and Little Corellas also consume herbaceous plants, blossoms, and insects. Sulphur-crested Cockatoos show a preference for fruits but are often observed accessing the same food as the other three species (Noske et al. 1982). Further variation may be introduced depending on the age of the individuals, due to different foraging behaviours between juveniles and adults (McLean et al. 2023; Wehi et al. 2023). Consequently, while we found no evidence of species-specific differences, between-individual differences in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ may be influenced by different foraging behaviours and investigating the effect of these differences may improve classification accuracy.

The values reported here for $\delta^{13}\text{C}$ in South Australian parrots are similar to previously reported captive and wild populations of other parrot species, where $\delta^{13}\text{C}$ was higher in the captive populations for *Cacatua* in Hong Kong (Andersson et al. 2021a), and African Grey Parrots in central Africa (*Psittacus erithacus*; Alexander et al. 2019). However, $\delta^{15}\text{N}$ in South Australian cockatoos differ from these international parrot populations. For example, Andersson et al. (2021a) used feathers from several species of *Cacatua*, including Sulphur-crested Cockatoos and Yellow-crested Cockatoos (*C. Sulphurea*) in Hong Kong. These wild *Cacatua* had higher $\delta^{15}\text{N}$ than captive birds, a direct contrast to our South Australian cockatoo feathers. This further contrasts with a lack of difference in $\delta^{15}\text{N}$ between the captive and wild African grey parrots in central Africa (Alexander et al. 2019). Consequently, we suggest that differences in $\delta^{13}\text{C}$ means are more reproducible across different parrot species and locations and may be more robust as an indicator of captive and wild bird populations. However, the discrimination between captive and wild origins can be improved when $\delta^{15}\text{N}$ data are included, especially for populations with large range and population sizes.

Here, we have demonstrated that stable carbon and nitrogen isotopes in feathers can be used to discriminate captive and wild populations of South Australian cockatoos. However, while we found high classification accuracy for *Eolophus*, *Cacatua* show high within-individual variation and overlap between the origin groups, reducing the overall accuracy. For use in wildlife forensics, such as detecting illegal laundering of wild-harvested individuals, this method requires per-species forensic validation, and within and between-individual variation needs to be quantified. With adequate validation, carbon and nitrogen isotope analysis of bird feathers can be a valuable addition to the multi-faceted toolbox for detecting illegal wild harvesting of animals and may assist in efforts to monitor and manage wildlife trade.

4

Identifying recent captive escapes of Rainbow Lorikeets (*Trichoglossus moluccanus*) at different stages of the pet-release pathway

4.1 Abstract

Rainbow Lorikeets (*Trichoglossus moluccanus*) are a highly desirable bird in Australian pet trade, and consequently have established invasive populations outside their native range. These birds are highly aggressive, outcompete native species, and cause significant damage to agriculture. Invasive populations have not been curtailed by current management practices, and it is unclear if their persistence is due to their high fecundity, or from regular escapes from captivity.

We measured the isotopic niches of Rainbow Lorikeets in Australia to test if recent captive escapes could be distinguished from wild birds by their stable isotope ratios. We measured stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotopes in feathers from four populations: (i) captive birds; (ii) birds within their native distribution; (iii) a newly established population; and (iv) a large invasive population.

Captive birds were found to have higher $\delta^{13}\text{C}$ than the three wild populations, and also had the largest isotopic niche area. The invasive population showed a similar isotopic niche size to the native population, while the newly established population had the smallest niche size. We found evidence of two escaped captive birds in the newly established population due to the higher and more variable $\delta^{13}\text{C}$, which is likely driven by the consumption of nectar supplements. Stable isotopes can be a useful tool to identify recent captive escapes in contained wild populations with small isotopic niches which can inform management of invasive species incursions.

4.2 Statement of Authorship

Title of paper	Identifying recent captive escapees of Rainbow Lorikeets (<i>Trichoglossus moluccanus</i>) at different stages of the pet-release pathway
Publication status	<input type="checkbox"/> Published <input type="checkbox"/> Accepted for publication <input checked="" type="checkbox"/> Submitted for publication <input type="checkbox"/> Unpublished and unsubmitted work written in manuscript style
Publication details	Hill KGW, Delean S, Robinson, SA, Hall T, Tyler JJ, Stringham OC, Cassey P (2022) Feather forensics: tracing the origins of parrots in wildlife trade with stable isotopes and citizen science. Unpublished

Principal Author

Name of principal author (candidate)	Katherine GW Hill		
Contribution to the paper	Project conception, methodology design, creation of citizen science project, sample collection, sample preparation and analysis, data analysis, led writing of manuscript		
Overall percentage (%)	80%		
Certification	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its conclusion in this thesis. I am the primary author of this paper.		
Signature		Date	15/06/2023

Co-author contributions

By signing the Statement of Authorship, each author certifies that:

- i. the candidate's stated contribution to the publication is accurate
- ii. permission is granted for the candidate to include the publication in the thesis
- iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of co-author	Steven Delean		
Contribution to the paper	Methodology design, data analysis, edited manuscript		
Signature		Date	15/06/2023

Name of co-author	Sue Robinson		
Contribution to the paper	Project conception, sample collection, edited manuscript		
Signature		Date	25/05/2023

Name of co-author	Tony Hall		
Contribution to the paper	Technical support, edited manuscript		
Signature		Date	26/05/2023

Name of co-author	Jonathan J Tyler		
Contribution to the paper	Supervision, edited manuscript		
Signature		Date	15/06/2023

Name of co-author	Oliver C Stringham		
Contribution to the paper	Supervision, edited manuscript		
Signature		Date	25/05/2023

Name of co-author	Phillip Cassey		
Contribution to the paper	Primary supervision, edited manuscript		
Signature		Date	25/05/2023

4.3 Introduction

The exotic pet trade facilitates a novel introduction pathway for new invasive alien populations to establish, which can lead to significant damage to environments and economies (Hulme 2015, Lockwood et al. 2019, Bradshaw et al. 2021). Once an exotic pet is transported and sold outside its native range, it can be intentionally or unintentionally released from captivity, where they may survive and establish a wild population and spread (Cassey and Hogg 2015, Vall-llosera and Cassey 2017b, Toomes et al. 2022). Prevention and early management of potentially invasive species lowers the environmental and economic damages, while also increasing the likelihood and cost-effectiveness of eradication (Keller et al. 2007, Henderson et al. 2011).

Biosecurity efforts currently lack the technology to identify recent captive escapes from a 'true' wild animal, which can assist with detecting incursions in invasive populations. Detection and monitoring of established populations often relies on surveys, which may not identify an established population until it has grown to an unmanageable size (e.g., Robey et al. 2011, Tingley et al. 2015). Additionally, understanding the proportion of recent captive escapes in an already established population can inform where management can be most effective: by eradicating the wild population, or by preventing further captive escapes. While DNA methods such as pedigree testing may identify if an animal was bred in captivity (e.g., Frankham et al. 2015), this method is less effective for invasive populations which are recently descendant from captive escapes, such as Rainbow Lorikeets (*Trichoglossus moluccanus*).

The Rainbow Lorikeet is a parrot species native to the eastern and southern coasts of Australia, and one of the most common pet bird species within Australia (Vall-llosera and Cassey 2017a, Chan et al. 2021, Hill et al. 2022). In part because of their popularity, they have established invasive populations outside their native range in Australia and internationally. These birds are intentionally or accidentally released from captivity and have species characteristics correlated with higher probabilities of escape, as well as being abundant in captivity and affordable in trade (Vall-llosera and Cassey 2017a, Chan et al. 2021, Hill et al. 2022). Escapes are particularly prevalent in urban areas, where a higher density of pet birds are kept, and these are often environments where Rainbow Lorikeets can readily adapt (Shukuroglou and McCarthy 2006, Vall-llosera and Cassey 2017b, Stanley et al. 2023). Consequently, international pet trade has resulted in established populations of Rainbow Lorikeets in New Zealand (Polkanov and Greene 2000) and Singapore (Neo 2012), while domestic Australian trade has introduced populations outside their native range in Western Australia (Chapman 2005) and Tasmania (Robinson et al. 2020). In Australia, they compete with local species for hollows and food (Ambrose et al. 1990, Hingston 2019a), hybridise with other native lorikeets, such as the musk lorikeet (*Glossopsitta concinna*) (Hingston 2019b), and cause significant damage to agriculture, particularly fruit crops (Bomford and Sinclair 2002).

Tasmanian and Western Australian Rainbow Lorikeets represent two populations at different stages of the pet-release invasion pathway. In the invasive population in Tasmania, the first wild breeding pair was observed in 2007 (Robinson et al. 2020). Import of the species was banned in 2011; however, pet-keeping is still allowed for captive individuals imported before these restrictions (Department of Primary

Industries 2002). Despite early and ongoing management efforts (i.e., culling), there are now three self-sustaining populations, each with an estimated maximum population size of approximately 500 individuals (Robinson et al. 2020). The invasive Western Australian population likely originated from a small number of captive escapes and intentional releases around the capital city Perth in the 1960s (Long and Tingay 1981, Coyle 1988). This population rapidly expanded in size and range and is now the most observed bird in the State (Birdlife Australia 2022) with an estimated 40,000 birds in 2018 (Pickering 2018). While being a declared pest, they may still be kept as pets, providing opportunity for escapes to continue and contribute to their population growth (Department of Primary Industries and Regional Development 2018).

Despite the high risks of Rainbow Lorikeets to environments and economies, Rainbow Lorikeets are still legally traded in Australia in large numbers (Hill et al. 2022). Permits are required for pet-keeping in Western Australia and Tasmania (Department of Primary Industries 2002, Department of Primary Industries and Regional Development 2018), which may reduce the number of birds sold (Toomes et al. 2022). However, these regulations do not prevent captive birds from escaping which potentially create, or contribute to existing, invasive populations. For example, the removal of individuals from invasive Tasmanian populations has been ineffective in controlling their population size (Cobden et al. 2021). For this Tasmanian population of Rainbow Lorikeets, it is unclear if recovery from management is due to their high fecundity, or from regular immigration directly from captivity.

Here, we test if recent captive escapes could be identified by stable isotope analysis; an emerging tool in wildlife trade monitoring to determine captive and wild origins of wildlife (Natusch et al. 2017, Ziegler et al. 2018, Andersson et al. 2021a). However, its use in invasive species management is relatively unexplored (Hill et al. 2020). As the stable isotope ratios in an animal's tissue are strongly related to its diet, stable isotope analysis can provide a snapshot of an animal's dietary history, and thus its environmental origin (Kelly 2000); particularly as the diet of wild and captive birds can be dramatically different. Stable carbon isotope ratios ($^{13}\text{C}/^{12}\text{C}$, reported as $\delta^{13}\text{C}$) vary significantly in relation to the plant material an animal consumes (Hobson and Clark 1992a), such as the proportion of C_3 and C_4 plants, plant water stress, marine and freshwater origins, and horticultural fertilisers (Hoefs 2021). Nitrogen isotope ratios ($^{15}\text{N}/^{14}\text{N}$, $\delta^{15}\text{N}$) are partly influenced by an animal's trophic position (Post 2002). $\delta^{15}\text{N}$ varies due to a variety of processes related to nitrogen cycling between the atmosphere, soils, and water, and the subsequent assimilation by plants. These are likely to differ markedly between natural and agricultural plants, as well as between different plant types; notably N-fixing legumes and those that rely on the assimilation of nitrate. For captive Rainbow Lorikeets, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ is likely further influenced by consumption of unique food sources not available to wild birds, such as nectar supplements. Stable isotope analysis of feathers reflects the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ composition of the bird's diet over the course of its growth and remains inert until it moults, which for Rainbow Lorikeets is one year (Ambrose et al. 1990, Hobson and Wassenaar 2018).

While the use of stable isotope analysis to determine captive or wild origins has shown promise in parrot species (Alexander et al. 2019, Andersson et al. 2021a), its efficacy is potentially reduced in species with generalist diets and large range sizes (Chapter 3, this thesis). Generalist species, and species with large range sizes, occupy larger isotopic niches (i.e., the range of stable isotope ratios within a

population) (Bearhop et al. 2004), which may overlap with the diet of captive animals. This overlap in isotopic niche could be most pronounced when wild birds become urban adaptors and have access to food presumed to be only accessible to captive birds, such as household gardens or foraging in human food waste (Klump et al. 2021). Nonetheless, the analysis of carbon and nitrogen isotopes on well-adapted, large invasive populations has yet to be explored, and may assist in the management of relatively new invasive populations in restricted areas.

Here, we investigate the use of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analyses to differentiate three wild populations of Rainbow Lorikeets in Australia. We test the precision of this approach by measuring repeatability within an individual and identify the isotopic niches of Rainbow Lorikeets within its native range and at three different stages of an invasion pathway from pet trade: captive birds, a newly established population, and a large invasive population. Finally, we apply these methods to estimate the proportion of recent captive escapes in these populations.

4.4 Methods

4.4.1 Sample collection

We collected feathers from Rainbow Lorikeets from four distinct populations in Australia: (i) a native population in South Australia (natSA); (ii) birds kept in captivity (CAP); (iii) a recently established and actively managed population in Tasmania (estTAS); and (iv) a widespread invasive population in Western Australia (invWA) (Figure 4-1).

For the captive and native populations, we created a citizen science project to collect naturally dropped feathers. We asked owners of captive parrots, aviaries, pet stores and zoos to collect naturally dropped feathers from their birds. Owners also provided samples of nectar supplements often fed to their birds. Similarly, we asked participants to collect lorikeet feathers found in backyards from wild birds. These feathers were sent via post, and labelled with the collection date and location, precise to postcode. As Rainbow Lorikeets moult over summer, feathers were collected over two summers from December 2020 to March 2022. We received ethics approval from the University of Adelaide (HREC no. H-2020-184).

We received feathers from 18 captive individuals, predominantly from South Australia ($n = 16$), with additional samples from New South Wales ($n = 1$) and Queensland ($n = 1$). We also collected samples from three brands of nectar supplements provided by captive bird owners (3 replicates per brand) to measure $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$.

Furthermore, a total of 33 feathers from the native population were selected for analysis, which represented as wide a geographical area as possible within the State of South Australia. As we were unable to collect multiple feathers from the same wild individual, we also obtained feathers from two additional wild origin birds from the South Australian Museum collection to measure individual variation.

For the invasive Western Australia population, we measured feathers from 40 birds found in metropolitan Perth, which were sent to a wildlife rescue centre and euthanised, due to their declared pest status, between January and August 2022. For the established Tasmanian population, we measured feathers from 47 birds

euthanised in management efforts collected from Kingston Beach, the southernmost established population, in June 2021.

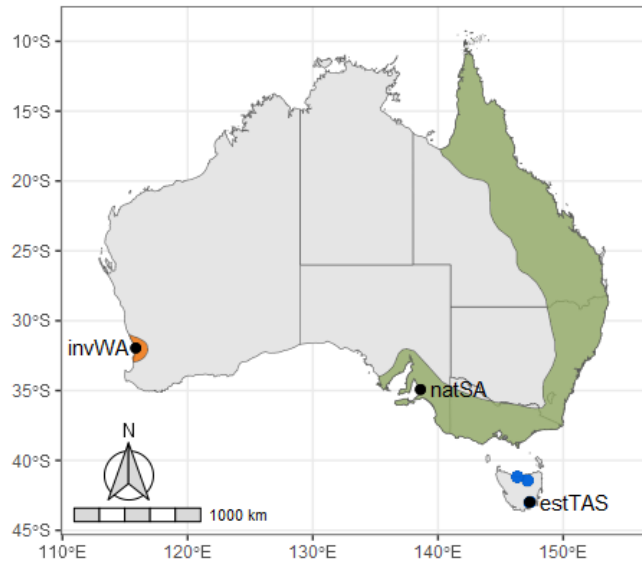


Figure 4-1: native (green), invasive (red), and the three newly established (blue) populations of the Rainbow Lorikeet in Australia, and the three sampling locations for the three wild populations: South Australia (natSA, $n = 33$); Tasmania (estTAS, $n = 47$); and Western Australia (invWA, $n = 40$).

4.4.2 Stable isotope analyses

Feathers were cleaned by washing with scientific-grade detergent (Decon® 90) and water to remove surface contamination, and then repeatedly submerged in baths of 2:1 diethyl ether:methanol to remove lipids, following Bontempo et al. (2014). Feather vanes were separated from the rachis with sterile dissecting scissors and cut into small sections.

Approximately 0.4 mg of random samples of each feather's vane and nectar supplements were weighed accurately into tin capsules and sealed for analysis. The samples were analysed for $^{13}\text{C}/^{12}\text{C}$ and $^{15}\text{N}/^{14}\text{N}$ using a continuous flow isotope ratio mass spectrometer (Nu Horizon, Wrexham, UK) equipped with an elemental analyser (EA3000, EuroVector, Pavia, Italy). Stable isotope ratios are expressed in δ notation as deviations from a standard in parts per mil ($\delta X\text{‰}$):

$$\delta X\text{‰} = \left(\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right) \times 1000$$

Where R_{sample} is the atomic ratio of $^{13}\text{C}/^{12}\text{C}$ or $^{15}\text{N}/^{14}\text{N}$ in the sample, and R_{standard} is this ratio in the standard. $\delta^{13}\text{C}$ was reported relative to the standard Vienna Pee Dee Belemnite (VPDB) and $\delta^{15}\text{N}$ was reported relative to atmospheric N_2 (AIR). All samples were corrected for instrument drift and normalized according to reference values using in-house standards ($n=19$); $\delta^{13}\text{C}$ = glycine -31.2‰ , glutamic acid -16.72‰ , and triphenylamine (TPA) -29.2‰ ; and $\delta^{15}\text{N}$ = glycine 1.32‰ , glutamic acid -6.18‰ , and triphenylamine (TPA) -0.54‰ . The in-house standards were calibrated against USGS and IAEA certified reference materials (USGS40, USGS 41, IAEA-2).

4.4.3 Investigating sources of variation

First, we aimed to investigate if the choice of feather influenced the stable isotope ratios, and if repeat sampling was necessary to obtain accurate measures for individual birds. Here, we had five hierarchical levels of sampling that could introduce variation: (i) between individuals (between-individual); (ii) within an individual (within-individual), (iii) between feather types (feather type); (iv) between feathers of the same type (between-feather); and (v) between replicates from the same feather (within-feather). While this has been investigated in some depth in other birds (e.g., Grecian et al. 2015, Greer et al. 2015, Symes et al. 2017), Rainbow Lorikeets have highly variable diets and are semi-nomadic, which may influence stable isotope ratios (Cannon 1984, Ambrose et al. 1990, Klump et al. 2021). To investigate the variation within each level of sampling, we created a pilot dataset of five individual birds (three CAP and two natSA). From each bird, we measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ at three sampling levels: three feather types (body, primary wing, and tail), three feathers per feather type, and two replicates per feather.

To investigate differences between feather types, we used linear mixed effects models with and without feather type as a term, with the other levels of sampling (between-individual and between-feather) as random effects. We compared these models with likelihood ratio tests and identified specific differences between feather types using Holm-Bonferroni corrected contrasts. We then identified which level of sampling introduced the greatest proportion of variation by investigating the components of variation in these linear mixed effects models. To investigate the relative variability within each level of sampling, we calculated repeatability estimates (R) (Choudhary and Nagaraja 2017). Using the pilot dataset, we calculated R for each level using parametric bootstrapping, where linear model ignored the other levels of sampling to see how the relative variation changed (Stoffel et al. 2017). Estimates closer to 1 indicate higher repeatability, or low variation at that level.

Finally, we compared mean stable isotope values of all four populations (one captive and three wild) using separate linear mixed effects models for each of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, with between-individual and within-feather as random intercepts and identified specific differences with Tukey HSD. We included the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ means and standard deviations of the three captive nectar supplements to inspect the potential influence of different brands on the captive bird values visually.

4.4.4 Comparing isotopic niches

To investigate variability in diets between the four populations, we quantified sizes of isotopic niches: the range of values each population occupies in bivariate space (i.e., $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) using ellipses (estimated with the SIBER package in R; Jackson et al. 2011). To account for the potential variation introduced by multiple hierarchical levels of sampling, we aggregated the data to the mean stable isotope ratio per bird (i.e., mean of 2 feather replicates per individual bird; see Supplementary Information 4-2 and 4-3 for non-aggregated analyses).

Estimation of the variance-covariance matrix of the relationship between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for calculation of the Standard Ellipse Area (SEA) assumes that the isotope ratios are multivariate normal (Jackson et al. 2011). We examined the assumption that the data conformed to a multivariate normal distribution with tests of Mardia's multivariate skewness and kurtosis coefficients (Mardia 1970). Where there was evidence of departure from multivariate normality, we extended the SIBER analysis

to assume a multivariate Student's t-distribution for the $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ variance-covariance relationship providing robust posterior estimates of the model parameters. We also examined whether the data conformed to a multivariate t-distribution using Mardia's kurtosis coefficient and quantile-quantile plots against a theoretical multivariate t-distribution.

To quantify isotopic niches, we used SIBER to fit multiple Bayesian standard ellipses for each population that allow between population comparisons in the presence of uncertainty (Jackson et al. 2011). Posterior distributions of the isotope mean values and the covariance matrix parameters were calculated using Markov chain Monte Carlo (MCMC) by fitting a multivariate normal distribution to each of the populations independently with JAGS via the R package rjags (Plummer 2022). Uninformative priors were used for the means of each isotope ratio ($\mu = 0$ and $\sigma^2 = 10^6$) and a Wishart prior was used for the covariance matrix ($\rho = 2$; 2×2 scale matrix V with value two on the diagonal and zero on the off-diagonal). We also generated robust estimates of the parameters using a multivariate t-distribution for each population by constructing the t-distribution from underlying normal and Gamma random variables (Plummer 2017). We used the same uninformative priors as for the multivariate normal distribution described above with an additional prior for the degrees of freedom parameter of the t-distribution sampled from an exponential distribution with mean approximately equal to 30 (i.e., with degrees of freedom of 30 or greater the multivariate t-distribution converges to the multivariate normal). The sampled degree of freedom value was used to specify the shape and rate parameters of the Gamma distribution (which in turn scales draws from the multivariate normal to produce a distribution with wider tails commensurate with lower degrees of freedom). Isotope values were z-score transformed prior to the analysis. We ran two MCMC chains for 40000 iterations each, discarded the first 1000 draws as burn-in, and thinned the resulting chains to retain every 10th iteration to remove autocorrelation (Supplementary Information 4-2).

To compare sizes of isotopic niches, we calculated SEA corrected for small sample sizes (SEA_c), which contains approximately 40% of the data, and identified the proportion of posterior distributions of one population which were larger than the other. The resulting metrics are the permille square area (‰^2), and pairwise comparisons of the number of ellipses of one population which are larger than the other. We investigated the overlap in isotopic niches, to test if recent captive escapes could be identified by their stable isotope ratios, by calculating means and standard deviations of Bayesian estimates for ellipse overlaps over 1000 draws.

In addition to examining the isotope niche area to measure overlap among populations, we examined whether the populations could be classified in bivariate space using kernel discriminant analysis (Simonoff 2012). This nonparametric classification method does not require the underlying distributions to be multivariate normal and allows for nonlinear classification boundaries (Mika et al. 1999). The misclassification rate (overall and within populations) was used to summarise model performance.

All analyses were conducted in the R 4.2.2 software environment for statistical and graphical computing (R Core Team 2022). We calculated repeatability with rptR (version 0.9.22; Stoffel et al. 2017), linear mixed effects models with lme4 (version 1.1-31; Bates et al. 2015), model coefficients with emmeans (version 1.8.2; Lenth 2022), isotopic niche ellipses with SIBER (version 2.1.6; Jackson et al. 2011),

variance components with mixedup (version 0.4.0; Clark 2023), Mardia's multivariate skewness and kurtosis coefficients with MVT (version 0.3-8; Osorio 2023), and kernel discriminant analysis with ks (version 1.13.5; Duong 2022).

4.5 Results

4.5.1 Investigating sources of variation

In the subset of five individual birds (3 CAP and 2 natSA), there were clear differences in $\delta^{13}\text{C}$ between feather types ($\chi^2_2 = 15.2$, $p < 0.01$; Supplementary Information 4-1). Specifically, tail feathers had lower $\delta^{13}\text{C}$ than body feathers ($t_{28.4} = 3.6$, $p < 0.01$), and wing feathers ($t_{27.7} = 3.9$, $p < 0.01$). There was no difference in $\delta^{15}\text{N}$ between feathers ($\chi^2_2 = 5.5$, $p = 0.06$). As inclusion of tail feathers may increase individual variation, we excluded them from further analyses.

Once tail feathers were excluded from analysis, within-individual repeatability was very high for $\delta^{13}\text{C}$ ($R = 0.94$, $p < 0.01$), but low for $\delta^{15}\text{N}$ ($R = 0.75$, $p < 0.01$). Feather type ($R = 0.95$, $p < 0.05$; $R = 0.83$, $p < 0.01$) and feather replicate ($R = 0.96$, $p < 0.01$; $R = 0.90$, $p < 0.01$) repeatability were similarly high. Most of this variation was explained by between-individual differences (94% total variation in $\delta^{13}\text{C}$, 74% in $\delta^{15}\text{N}$), followed by between-feather differences (3% and 17%). Therefore, we determined that repeated sampling within each feather was not necessary, and body and primary wing feathers could be combined for analysis. However, for the estTAS and invWA populations, only body feathers were available, so the remaining analysis for these populations includes two body feathers per bird (i.e., two measures of each $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ per bird). Due to the nature of the citizen science collection of the CAP and natSA populations, most birds only had single feathers available, so only include one feather per bird.

4.5.2 Comparing isotopic niches

The CAP population's body and wing feathers exhibited significantly higher $\delta^{13}\text{C}$ values (mean \pm SD: $-21.8 \pm 2.1\text{‰}$) than all three wild populations: natSA ($-23.2 \pm 1.6\text{‰}$; $t_{133} = 9.2$, $p < 0.01$), estTAS ($-23.5 \pm 1.3\text{‰}$; $t_{124} = 11.6$, $p < 0.01$), and invWA ($-22.5 \pm 1.4\text{‰}$; $t_{125} = 4.7$, $p < 0.01$; Figure 4-2). While the CAP population also exhibited higher $\delta^{15}\text{N}$ values ($7.5 \pm 5.8\text{‰}$) than invWA ($5.6 \pm 3.9\text{‰}$; $t_{131} = 11.6$, $p < 0.01$), the values were similar to the natSA ($8.3 \pm 4.4\text{‰}$; $t_{131} = -1.8$, $p = 0.3$) and estTAS populations ($7.3 \pm 3.6\text{‰}$; $t_{131} = 0.4$, $p = 1$). The three nectar supplements showed large variability between brands, where two brands showed high $\delta^{13}\text{C}$ in comparison to all lorikeet population means ($-17.8 \pm 0.6\text{‰}$ and $-20.6 \pm 0.5\text{‰}$), while one brand was very low ($-24.6 \pm 0.2\text{‰}$). $\delta^{15}\text{N}$ values were similarly varied between brands ($5.2 \pm 0.7\text{‰}$, $1.5 \pm 0.3\text{‰}$ and $3.2 \pm 0.4\text{‰}$, respectively).

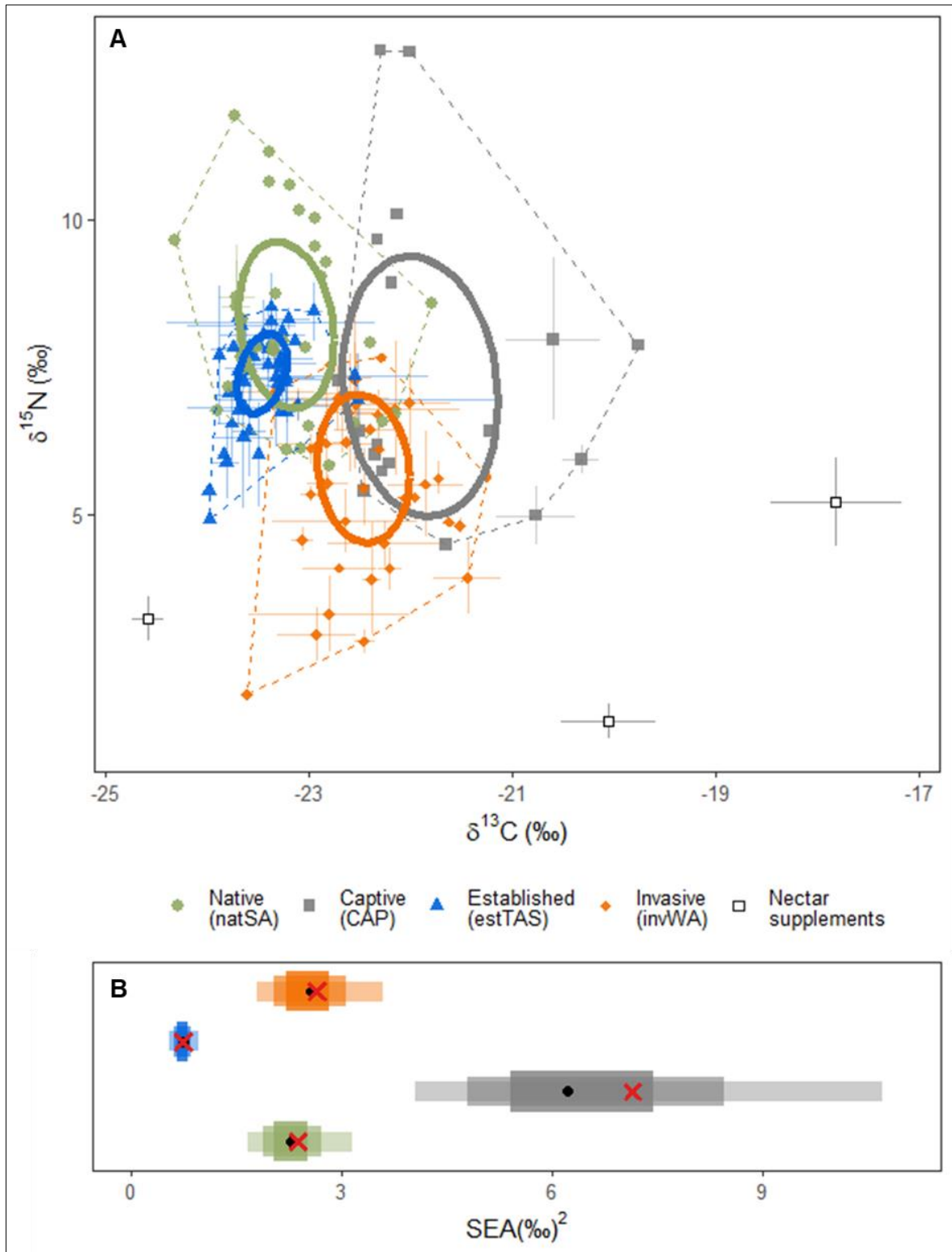


Figure 4-2: (A) individual means and standard deviations of stable isotope ratios of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of four populations of Rainbow Lorikeets: South Australia (native, green circles), captive (grey squares), Western Australia (invasive population, orange diamonds), and Tasmania (newly established population, blue triangles), and the means and standard deviations of three brands of nectar supplements for captive birds (open black squares). Dotted lines indicate convex hull areas, and solid lines are standard ellipse areas. (B) Boxplot of calculated Standard Ellipse Area (SEA) for each population with maximum likelihood of the posterior mode (black point) and SEA_c (red cross), and 55, 75, and 95% confidence intervals.

The CAP population had the largest isotopic niche ($SEAc = 7.1\text{‰}^2$) of all populations, where 100% of posterior distributions were larger than those for the three wild populations. The natSA and invWA populations had similar isotopic niche sizes ($SEAc = 2.4\text{‰}^2$ and 2.6‰^2 respectively, where 69% of natSA posterior distributions were larger than invWA), and estTAS population was significantly smaller than all other populations ($SEAc = 0.8\text{‰}^2$, 0%). The captive population's isotopic niche overlapped with a large proportion of the natSA ($74 \pm 17\%$ of total natSA area), estTAS (73%), and invWA populations (88%). The majority of the estTAS population was contained within the natSA population (92% of estTAS area, 26% of natSA area) and partly with the invWA (50% and 16%). Approximately half of the invWA isotopic niche area overlapped with natSA (47% and 42%).

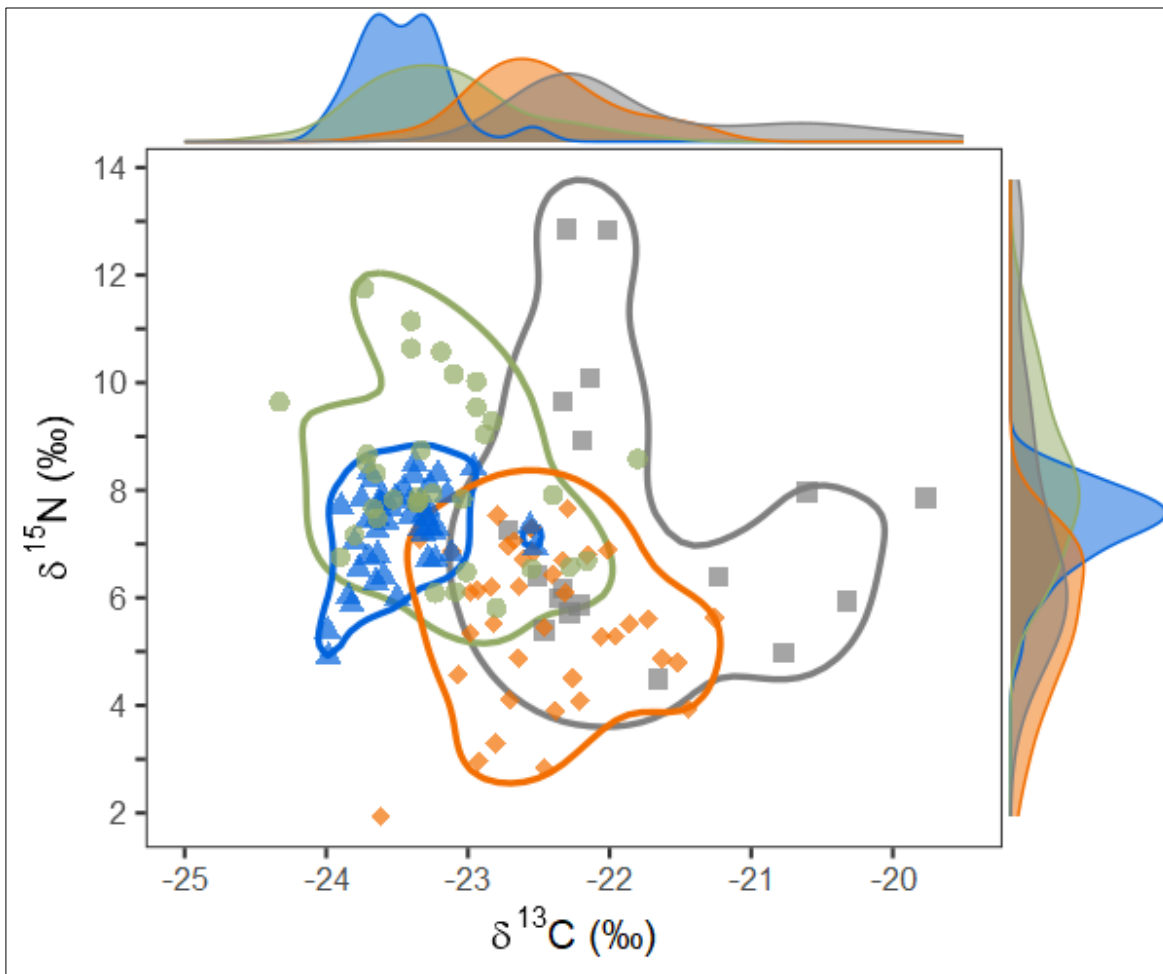


Figure 4-3: Individual means of stable isotope ratios of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of four populations of Rainbow Lorikeets: South Australia (native, green circles), captive (grey squares), Western Australia (invasive population, orange diamonds), and Tasmania (newly established population, blue triangles). Solid lines show boundaries of the discriminant analysis to classify individuals to their respective populations. Axes show density plots for each isotope and population.

We found that the estTAS showed high discriminant success, with 96% classified correctly (Table 1), but two individuals were incorrectly classified as invWA due to their significantly higher $\delta^{13}\text{C}$ values compared to the remaining population (Figure 3). The invWA population also showed high success (95%), while the CAP and natSA populations showed low success (50% and 36% respectively; see Supplementary Information 3 for analysis with non-averaged analyses). While the

decision boundaries partitioned the natSA, CAP, and invWA populations into their respective groups, two individuals in the estTAS group were significantly different to the remaining population and were separated into a separate cluster.

Table 4-1: Results of the discriminant analysis, using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ to classify individuals to their respective populations. Misclassified individuals are marked with an asterisk.

		Classification				Total	Correct predictions
		CAP	natSA	estTAS	invWA		
Population	CAP	9	0	0	9*	18	50%
	natSA	0	12	13*	8*	33	36%
	estTAS	0	0	45	2*	47	96%
	invWA	0	0	2*	38	40	95%
Total		9	12	60	57	138	75%

4.6 Discussion

Stable isotope analysis is a potential tool for managing invasive populations that have originated from the pet trade; however, our results suggest their use is limited to relatively new populations with small population and geographical range sizes. Due to the large isotopic niche of the captive Rainbow Lorikeet population, it is likely not possible to create a reference database of “wild” and “captive” populations; however, it may be possible to use $\delta^{13}\text{C}$ to classify outliers in small, established populations, such as in Tasmania.

In the Tasmanian population, which is still relatively well managed and contained, stable carbon and nitrogen isotopes in the body and primary wing feathers may still be an effective tool to identify recent captive escapes. Here we found that two of the 47 birds from the Tasmanian population were misclassified due to their higher $\delta^{13}\text{C}$ values, and also sit within the captive isotopic niche. While the other two wild populations had misclassified individuals, the probability of capturing multiple recent captive escapes in their comparatively much larger population sizes is low, and the larger isotopic niches which overlaps with other wild populations means their misclassification is inherently higher. The small Tasmanian isotopic niche is very restricted in comparison, and such dramatic differences in $\delta^{13}\text{C}$ suggest these two misclassified birds consume a significantly different diet and are potential recent captive escapes. However, these two misclassified birds also have some of the highest individual variation. As the birds in the pilot analysis showed little variation between feathers of the same body type, this variation may be due to a large change in diet between the growth of the two feathers, such as a spatial change or a recent immigration from captivity into the wild. The population we sampled is the newest and most isolated of the three populations, and so has little migration from the other wild populations (Cobden et al. 2021). Therefore, these outliers are more likely to be recent captive escapes. We therefore have relatively high confidence that two of the 47 Tasmanian birds we sampled are recent escapes from captivity.

The captive birds exhibited a large range of $\delta^{13}\text{C}$ values, which may be influenced by access to different nectar sources, which is a factor that needs to be considered if these methods are used to detect recent captive escapes. Wild lorikeets rely on nectar and pollen from flowering plants, particularly C_3 eucalypts and cultivated non-native plants, which can contribute up to 95% of a bird's total diet (Waterhouse 1997, Smith and Lill 2008). Nectar and pollen are a key source of protein and carbohydrates in Rainbow Lorikeet diets (Frankel and Avram 2001). However, such high volumes of nectar are difficult to provide in captive environments, so commercial nectar supplements are commonly used. Here, we found that two of the three brands of nectar supplements had relatively high $\delta^{13}\text{C}$. The main ingredients in these brands are sugars sourced from refined sugar, sugar cane, a C_4 plant, which would result in higher $\delta^{13}\text{C}$ in bird tissue compared to other, C_3 nectar sources (Padovan et al. 2003). The last nectar supplement had low $\delta^{13}\text{C}$, as the main ingredients were C_3 plants including wheat and oats. These nectar supplements could be used to bait wild Rainbow Lorikeets for trapping efforts. Therefore, we recommend that, if practitioners aim to use stable isotope methods to detect recent captive escapes, any feed tables used in baiting should use a C_3 -based supplement to avoid masking the $\delta^{13}\text{C}$ values of recent escapes.

Due to the large isotopic niche of South Australian and Western Australian populations, and large overlap with the captive population, our results suggest that stable carbon and nitrogen isotopes alone are not an effective tool to identify recent captive escapes in widespread invasive populations of Rainbow Lorikeets. While it may be possible to identify a recent captive escape with a high $\delta^{13}\text{C}$ value (above -21‰), almost the entirety of the South Australian and Western Australian populations of Rainbow Lorikeet feathers had isotopic niches that are within the captive niche (74% and 88% overlap, respectively). In these cases, the misclassification rates would be too great for effective management of these populations. Here we focussed on $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ to complement previous work (e.g., Natusch et al. 2017, Ziegler et al. 2018, Hill et al. 2020, Andersson et al. 2021a) and reduce sampling costs. To further improve the classification accuracy of stable isotope analysis to determine captive and wild origins, other isotopes could be included. For example, migratory research often includes stable oxygen ($\delta^{18}\text{O}$) and hydrogen ($\delta^2\text{H}$) isotopes which are influenced by precipitation (Hobson et al. 2012), and stable sulphur isotopes ($\delta^{34}\text{S}$), which are influenced by anthropogenic sources such as pollution, have previously improved the success of classifying captive and wild origins of animals (Castelli and Reed 2017, Natusch et al. 2017, Alexander et al. 2019).

To further improve the confidence of using $\delta^{13}\text{C}$ to identify recent captive escapes in invasive populations, including potentially broadening the application to well-established populations with large isotopic niches, captive feeding trials may be useful to identify the sources of variability in $\delta^{13}\text{C}$. Here, we found that tail feathers showed lower $\delta^{13}\text{C}$ than body and wing feathers, which is likely driven by different diet-tissue discrimination or growth rate between the feather types (Becker et al. 2007; Smith et al. 2008). Different feather types from the same individual could be used to standardise values, to allow practitioners to take any feather sample from a suspected recent captive escape (Alexander et al. 2019). Captive trials may also assist in quantifying the assimilation of $\delta^{13}\text{C}$ from nectar supplements and other captive food into the tissues to explore the large variation seen in the captive isotopic niche (Symes et al. 2017). Similarly, the assimilation of stable carbon isotopes into

tissues with longer time frames, such as bone, could be calculated to provide longer snapshots of the animals' captive or wild origin (Kays and Feranec 2011).

Our results indicate that stable carbon and nitrogen isotopes in bird feathers can be an effective tool in the management of invasive species in populations early in the pet-release invasion pathway. Rainbow Lorikeets are a highly adaptable species where their behaviour in the wild, including their isotopic niches, can closely reflect diets in captivity. To improve the classification confidence for detecting recent captive escapes in established populations, a captive feeding trial could identify reasons for the high variability in captive individuals and quantify the influence of nectar supplements on $\delta^{13}\text{C}$ in bird feathers to assist in the ongoing management of these highly invasive species.

5

Discussion

5.1 The decline of native parrots available in domestic pet trade

The domestic pet trade in Australia poses a significant threat to Australian environments through the introduction of alien and domestic non-native species, and the unsustainable harvest of wild animals (Lyons and Natusch 2011, Shepherd et al. 2012, Lockwood et al. 2019). However, these risks are often unquantified, poorly managed, and do not protect vulnerable species (Hughes et al. 2023). As a consequence, the current management of the Australian pet trade is unlikely to suitably protect threatened native parrot species from extinction.

Over the duration of this thesis, five Australian parrot species were added to the List of Threatened Fauna.

All five species are in domestic pet trade.

When a species is listed on the Environment Protection and Biodiversity Conservation (EPBC) Act List of Threatened Fauna, it often means a species is likely to go extinct without substantial changes to their environmental protection (Australian Government 1999). Since 2019, five native parrot species were added to this list due to increasing anthropogenic threats and loss of habitat, such as the 2019-20 bushfires (Garnett et al. 2023). I found that all five species are present, or are subspecies of a species present, in the domestic online pet trade (Chapter 2). This includes the Gang-Gang Cockatoo (*Callocephalon fimbriatum*, Endangered), Pink Cockatoo (*Lophochroa leadbeateri leadbeateri*, Endangered), and Blue-winged Parrot (*Neophema chrysostoma*, Vulnerable). Two other species, the South-eastern Glossy Black-Cockatoo (*Calyptorhynchus lathami lathami*, Vulnerable), and Kangaroo Island Crimson Rosella (*Platycercus elegans melanopterus*, Vulnerable), are subspecies which are not currently in trade, but another subspecies is. While these two subspecies may not be in trade, from my research we know that very similar species possess desirable traits, and these threatened subspecies may eventually enter the pet trade. While wildlife trade is not a leading threat to these five species added to the List of Threatened Fauna, activities such as illegal poaching from nests would hinder their conservation efforts (Symes et al. 2018). Furthermore, if the wild populations of these species continue to decline, the newly perceived rarity of the species may make them even more desirable (Courchamp et al. 2006, Krishna et al. 2019). Captive populations of threatened birds can assist with the long-term viability of a species, such as the reintroduction of Orange-bellied

Parrots (*Neophema chrysogaster*) (Smales et al. 2000). However, these programs are only successful when highly managed by a limited number of expert organisations, and only acts as a last resort in species recovery (Harley et al. 2018). Therefore, captive populations of threatened species in public pet trade are highly unlikely to aid in the long-term protection of these species.

I found that native Australian parrots were more abundant in domestic online trade than non-native parrots (Chapter 2); however, through discussions with citizen scientists and aviculturists (engaged through my Feather Forensics project,) it became anecdotally evident that the harvest of native species for pet trade is relatively frequent; particularly for “common” species such as Galahs, Corellas, and Sulphur-crested Cockatoos (e.g., BirdCare). The harvest of wild birds is legal and commonplace for Galahs and Corellas in South Australia under permit (BirdCare, Government of South Australia 2021), but is illegal for all other parrots in South Australia. I identified two cases of native parrots, which were explicitly stated by the seller to have been harvested from the wild, including the newly listed, endangered Pink Cockatoo (*L. leadbeateri*). It is likely that other advertisements included wild-caught birds; however, their wild origin may not have been explicitly stated in the advertisement text and was not captured in my analysis. Unlike in international markets (Ribeiro et al. 2019), there does not appear to be a clear desire for wild-caught birds, so there is little incentive for a seller to list a bird’s origin. Therefore, I highly recommend this as an area for further investigation, to identify which species are harvested from the wild, both legally under permit and illegally, to better understand the scale of this issue.

With no comprehensive record of all native species currently in trade, and no forensically validated tool to detect cases of illegal harvest, native parrot species could potentially be at further risk of extinction through competition with invasive species released from the pet trade and illegal harvest (White et al. 2012, Vall-llosera and Cassey 2017b). From the research outcomes of my thesis, I have three recommendations: (i) continued monitoring of domestic trade to create an inventory list for *all* native and non-native species present in trade; (ii) incorporating citizen science and public knowledge into wildlife trade management; and (iii) further developing stable isotopes to identify captive and wild origins. I will expand on these recommendations below.

5.2 Improved monitoring and management of pet bird trade

The parrot trade is an emerging source of new invasive species in Australia (Vall-llosera et al. 2016, Vall-llosera and Cassey 2017b), yet the current level of monitoring and management of the trade is insufficient to prevent new invasive populations from establishing. For example, a number of highly invasive Alexandrine Parakeets (*Psittacula eupatria*) have been sighted in South Australia, with one pair confirmed as breeding in the wild (Green Adelaide 2021). I found that, while native parrots were more abundant, the species composition of Australian online pet bird trade was predominantly non-native parrot and passerine species, most of which have an extreme threat of establishing as invasive species. This included the two most common non-native parrots; the Rose-ringed Parakeet (*Psittacula krameri*, 1971 individuals in the 25% subset over 5 months of trade) and the Green-cheeked Parakeet (*Pyrrhura molinae*, 820 individuals), and the two most common

passerines; Domestic Canary (*Serinus canaria*, 1667 individuals), and Java Finch (*Lonchura oryzivora*, 130 individuals). Each of these species were traded in high enough numbers to potentially form established populations, if they are intentionally or accidentally released in suitable climates. However, this snapshot is for all of Australian trade; the birds need to be released in relatively close proximity to establish. A first key step to improving the management bird trade would be through improved monitoring systems, such as systematic online monitoring methods, to create an updated list of all species in trade, native and non-native, and their predicted abundances (e.g., Lavourga et al. 2020).

The most abundant species in trade possess species characteristics associated with successful invasive species. With this information, in combination with research such as Toomes et al. (2020), it may be possible to predict which species may be requested for addition to the Live Import List, if the live import of Psittacine birds is reconsidered, or species which may illegally enter the domestic market. Therefore, I strongly recommend that the import of parrots remains prohibited, particularly without a more detailed, quantitative understanding of the species composition and abundances currently in online and physical trade, their establishment risk, and economic threat. However, if it is allowed, this ability to predict which species may be highly desired may assist in identifying which species would require greater regulation to prevent the risk of invasion.

While I investigated a large number of species traits which are correlated with species abundance in wildlife trade, to understand consumer behaviour I recommend future work incorporates social science methods, such as choice experiments or surveys. I identified some traits which were influential (i.e., explained variance in the model); however, it was unclear if these traits were positively or negatively correlated with abundance. For example, plumage colour was a significant trait for passerines and provenance for parrots; however, the slopes were small and included zero. It may also be possible to investigate the differences in pet-keeping cultures between parrots and passerines, as evidenced by the different key traits identified in Chapter 2. Choice experiments for identifying trends in wildlife trade often involves participants selecting between two theoretical species with different species traits, while surveys can directly involve traders, breeders, and consumers of wildlife trade (Krishna et al. 2019, Marshall et al. 2020). For example, a useful resource would be to incorporate the results from the “iratebirds” project by Haukka et al. (2023), where participants rated the visual attractiveness of birds in photographs. Furthermore, social science projects may identify traits which could not be explored here, such as the impact of social media (e.g., videos of species). The incorporation of social science projects could therefore aid in identifying the impact of traits which influence the purchase of birds in pet trade, and potentially identify traits which were not included here.

5.3 Incorporating citizen science into wildlife trade management

I utilised public information to gain insights into wildlife trade dynamics, and this project would not have been possible without the unique knowledge and capabilities of citizen scientists. A key to effective management of threats from domestic pet trade is the engagement of the public and aviculturists. This project was only possible due to the assistance and unique knowledge provided by these groups. In

particular, the collection of feathers by the public and aviculturists provided samples from a wide variety of environments in South Australia, which otherwise would have been extremely difficult as a single researcher. Research into captive birds, including their diets, was only possible due to their involvement. In total, I had 20 private birdkeepers and organisations collect captive feathers, and 50 participants collecting wild feathers. They contributed 3,300 feathers from 18 parrot species, with the most commonly collected being Galahs (1,167), Rainbow Lorikeets (440), Sulphur-crested Cockatoos (419), and Crimson Rosellas (312). I was not able to analyse all feathers due to budgetary and time constraints; however, these feathers can contribute to future research such as the creation of a Crimson Rosella database, or for new applications.



Figure 5-1: Infographic of feathers collected through the Feather Forensics citizen science program, created as a social media post for participants (see Supplementary information 5-1 for more social media advertisements). From this citizen science project, I used a subset of 72 galah feathers, 47 white cockatoo feathers, and 57 rainbow lorikeet feathers in this thesis.

The largest task for running the Feather Forensics citizen science program was advertising to the public and engaging with participants. To initially advertise the project, I used graphical advertisements (Supplementary Information 5-1) on social media through my personal channels, and through special interest groups, such as groups for owners of particular parrot species. I also directly contacted animal rescue groups, who passed on the information to their members. Through these advertisements, I was contacted by journalists to advertise on two radio programs based in South Australia, and an online magazine. This magazine gained the largest outreach and is likely the reason behind the unprecedented engagement in this program. For the participants who provided contact information, I sent an update six months after the launch of the project (Supplementary Information 5-1), and participants were directed to the Feather Forensics website for updates. Final updates will be sent to participants when Chapters 3 and 4 are published. As the engagement was far greater than anticipated, which included a large number of feathers to catalogue, my engagement with participants was a weakness of this

project, and participants would have gained more from this project if I had a team of other researchers to assist with engagement. I highly recommend that researchers that intend to incorporate citizen science into their work has a team member to focus on engagement with participants, to ensure that participants are rewarded for their assistance with the program.

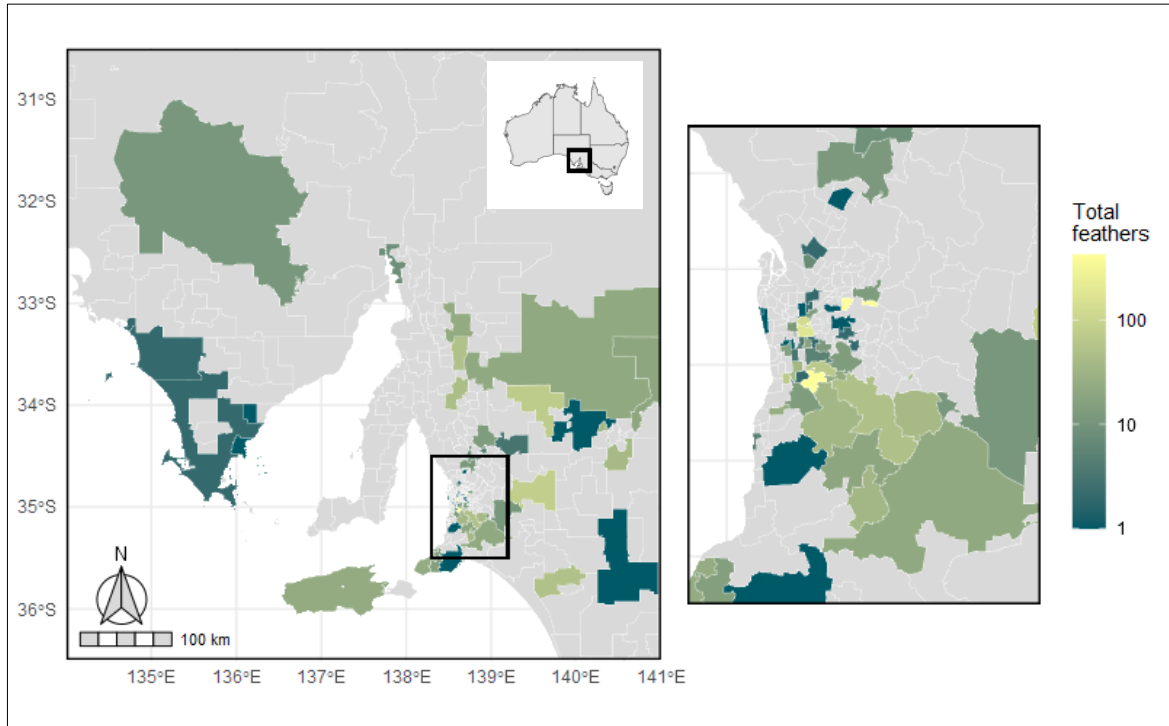


Figure 5-2: Postcode locations of all wild feathers collected in South Australia (left), and within the city of Adelaide (right), through the Feather Forensics citizen science program.

In reflection, the Feather Forensics project I developed would have benefited greatly from having a larger team of researchers, particularly to improve interactions with the citizen scientists. While I anticipated this project to be small (<10 participants), I released the project during the 2020-21 pandemic lockdowns in Australia. As people could participate in this project from home, I had an unprecedented number of participants for the wild collection (50), which I had not properly planned for. Conversely, due to the same limitations, I was unable to include more organisations with captive birds, which limited the captive sample sizes. Interactions with citizen scientists is crucial to keep engagement but requires diverse skills and is highly time-consuming. Future projects should consider having researchers fully committed to public communication for the duration of the project, in order to connect and involve citizen scientists further with the project. While the concept of citizen science is not new to invasive species and wildlife trade management (Ribeiro et al. 2019, Fricke and Olden 2023), I recommend this expert public knowledge continues to be incorporated into management and policy.

5.4 Tracing captive and wild origins with stable isotopes

I demonstrated that stable isotopes can be used for two different applications: (i) detecting harvest of wild animals; and (ii) detecting captive escapes in a wild population. I found that these applications were possible for Australian parrots; however, there are sources of variation which need to be explored in further depth before this tool is adapted into criminal investigations and environmental biosecurity.

While the use of a citizen science project for sample collection allowed for a larger sample size of feathers than I could have personally collected, it did introduce some unavoidable caveats. Primarily, I assumed that all feathers reported as collected from wild environments were from wild animals, and reported captive animals were in fact captive bred. The wild population sizes of the parrot species I studied are likely large enough that the chance of having a captive escape is relatively low; however, there is a possibility that some of the captive birds were in fact harvested from the wild, as Galahs and Corellas can be legally harvested from the wild in South Australia (Government of South Australia 2021).

As most wild feathers were collected after they had been shed, there was no way to verify the species and age of the bird. For Galahs, this was not particularly an issue as their pink feathers are unique. However, it was not possible to visually identify all *Cacatua* feathers to species, as most feathers are similar in size, shape, and colour between the species. While I found no evidence of differences between species in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, it may be possible to improve the classification confidence by verifying species and creating separate reference databases for each. Furthermore, feathers from juvenile *Cacatua* spp. and Rainbow Lorikeets are almost identical to those from adults, so it is possible that there were juveniles present in these analyses and may have impacted the isotope ratios (Meehan et al. 2003, Langin et al. 2007). To further develop these tools, the addition of feathers from known adults and juveniles to these databases would be beneficial. For the invasive Rainbow Lorikeet populations in Tasmania and Western Australia, as the birds themselves were captured and euthanised, it was confirmed that these birds were the correct species and were adults. For similar invasive species control applications, juveniles may be collected during trapping, and potential differences in stable isotope ratios could be explored. However, this is not possible for feathers collected by citizen scientists, particularly as identifying juvenile from adult feathers can be difficult. A subset of the *Cacatua* feathers were collected from Little Corellas as part of a wider research project, where the species and age were verified. Therefore, I recommend that, for species which are suspected to be illegally harvested, dropped feathers are collected during routine management, such as bird-banding, to develop stable isotope reference databases.

One of the largest barriers to understanding the variation of stable isotope values within a species was not knowing the species' actual diets and foraging behaviours in urban areas. Dietary studies for Galahs, *Cacatua* spp. and Rainbow Lorikeets are often at least 20 years old, and generally focus where the species are agricultural "pests" in rural areas (Noske et al. 1982, Rowley 1990, Hoyo et al. 1992). As these species have highly varied diets, the full range of food sources across all environments in Australia is unknown (Ambrose et al. 1990, Smith and Lill 2008). Other behavioural adaptations to access food, other than the bin-opening by Sulphur-

Crested Cockatoos (Klump et al. 2021), may be present in urban species, which would have significant impacts on the isotopic niches of these species. While this research is not crucial to the initial development of stable isotopes techniques, it has the potential to explain some of the unknown within-species variation I observed and, therefore, may assist in developing these tools further.

A significant confounding effect on this research is wild birds having access to generally “captive” food items, such as commercial bird seed in birdfeeders. When provided with a permanent food source, local Rainbow Lorikeets revisit feeding sites consistently, and recent releases can join the local flock at this food source (Cannon 1984). While this is likely to make their diets more closely reflect fully captive birds, these permanent food sources are unlikely to make up the full diet of wild birds. However, this could potentially hinder the use of stable isotopes to detect captive escapes if “captive” food is used as bait to manage the wild population. I recommend the stable isotope ratios of these bait food items are investigated, and practitioners potentially use food that more closely reflects wild-type food.

5.5 Improving the accuracy of stable isotope analysis

I explored the use of stable carbon and nitrogen isotopes in feathers to build on existing work tracing origins, but also because I expected these isotopes to reflect differences in captive and wild diets (Hill et al. 2020, Andersson et al. 2021a). Almost all previous studies differentiating captive and wild origins in vertebrates also used these isotopes; however, I found that large wild population sizes shown in *Cacatua*, and highly varied captive diets shown in Rainbow Lorikeets can reduce the classification accuracy of these methods. The addition of other isotopes and tissue types may improve the accuracy of these methods.

The addition of stable oxygen ($\delta^{18}\text{O}$) and hydrogen ($\delta^2\text{H}$, deuterium) isotopes may indicate the water source of the animal, and potentially the captive or wild origin (Bowen et al. 2005, West et al. 2014). Hydrogen has been used in previous work using stable isotopes to identify origin and may improve the accuracy of classification for Australian parrots (Castelli and Reed 2017, Natusch et al. 2017, Alexander et al. 2019). Oxygen has not been included in any of the previous work but could be a powerful addition. Using stable oxygen and hydrogen isotopes relies on the theory that captive birds have access to tap or treated water, while wild birds drink rain or groundwater; both of which may be identifiable through stable oxygen isotopes (West et al. 2014). Similarly, the oxygen and hydrogen isoscapes for Australia might assist in identifying the geographic origin of the bird (Hollins et al. 2018). For example, it might be possible to identify cases where a species was wild-harvested in one Australian State where the harvest is illegal but might be legal in other areas of Australia. However, it is likely that it would not be applicable to Australian parrots. The range expansion of many Australian parrot species, particularly in Galahs and *Cacatua* is partly attributed to the introduction of permanent water sources from agriculture (Rowley 1990, Black et al. 2018). In rural environments, wild parrots often consume water from water troughs – which can be filled with tap or treated water. Similarly, many captive birds may be provided water from rainwater tanks, which are common in Australian households. Therefore, there may be large overlap between captive and wild birds. Furthermore, while we have an established isoscape for $\delta^2\text{H}$ and $\delta^{18}\text{O}$ in Australia (Hollins et al. 2018), Australia

has a limited number of weather stations (15 stations) which collect rainfall data across a large geographical area, meaning the resolution of these isoscapes may not yet be suitable for wildlife forensic applications. Nevertheless, this isotope could potentially be a powerful addition to the stable isotope toolbox but may not be applicable for Australian parrots.

Stable sulphur isotopes ($\delta^{34}\text{S}$) could potentially be a powerful addition to the wildlife forensics toolbox. It was not included in this research due to budgetary constraints; however, when combined with stable carbon and nitrogen isotopes, Castelli and Reed (2017) could discriminate between captive and wild groups of Northern Bobwhite with 100% accuracy. Stable sulphur isotopes are influenced by a large number of environmental processes. For example, in animal tissue, $\delta^{34}\text{S}$ can show marine and freshwater origins of the food chain (Richards et al. 2003), is correlated with distance from marine coastlines (Zazzo et al. 2011), and is influenced by increased anthropogenic activity (e.g., atmospheric pollution). The addition of stable sulphur isotopes may assist in improving classification accuracy between captive and wild origins through differences in the marine and freshwater origins in the diet. For example, captive birds may have access to commercial pet food containing marine origin food, which wild birds would not access.

Here I explored stable isotopes in feathers, but a potentially powerful addition to the toolbox would be using other tissues to obtain different timeframes. As parrot feathers are moulted every summer (Ambrose et al. 1990), these methods can only provide the origin for up to one year prior to collection. Tissues which are retained on the body for longer periods, such as claw or bone, may provide insights on if a bird which has been in trade for many years was originally illegally harvested from the wild (Kays and Feranec 2011, Hopkins III et al. 2022). While these methods could be useful for invasive species management, these methods are likely not suitable for detecting cases of illegal laundering as they are difficult to collect and can potentially cause harm to the pet bird.

5.6 The future for stable isotopes in wildlife forensics

Stable isotopes can potentially be used by biosecurity and management officials to detect captive escapes in wild populations. However, the within-population variance (e.g., the wide variety of captive diets) needs to be carefully explored before adapting this technology further (Natusch et al. 2017, Symes et al. 2017).

I recommend that in its current research state, stable isotope methods are ready to be used as an early detection tool for biosecurity. Stable isotopes are also likely ready to be adapted for invasive species control (Fricke and Olden 2023) and can inform where management is best focussed: stricter management of captive pet trade or managing the existing wild populations through trapping and eradication efforts. However, I recommend these stable isotope forensic methods undergo more research before they are adapted for use in wildlife forensic science; particularly for investigating illegal wild harvest, as the chance of misclassification is relatively high. Misclassification for invasive species management would simply lead to less effective management; while misclassification in wildlife forensics to detect illegal harvest could lead to a miscarriage of justice (Huffman and Wallace 2012). From this thesis, and from previous work in this space, it is evident that the best-practice

methods to capture potential sources of variance, potentially for each species of interest, needs to be further explored (Natusch et al. 2017, Symes et al. 2017).

Stable isotopes techniques still need to go through more development before they are acceptable for wildlife forensics in criminal investigations. Once the methods are developed in a “proof of concept” work schedule, such as the research in this thesis, the tools will need to be forensically validated (Huffman and Wallace 2012). Some taxa such as *Cacatua* may require separate reference databases for each species. I recommend further research works closely with wildlife forensic practitioners to adapt these methods to assist in the detection and prevention of wildlife crime.

This thesis builds on the evidence that stable isotope methods to determine captive and wild origins does work, but with caveats; has the *potential* to become a forensic tool. But, in combination with forensically validated techniques, can be a useful tool in the wildlife forensics toolbox to manage wild poaching and captive escapes associated with pet trade.

6

Import Risk Review for Psittacine Birds from All Countries

6.1 Preface

In 1995, the import of all parrot species into Australia was banned due the lack of evidence around the biosecurity risk of emerging exotic diseases and has remained extremely restricted ever since. However, in August 2020, the Australian Government released the “Psittacine birds (household pet and aviary) import risk review draft”, which suggested removing the import restriction. This risk review was initiated after requests from private birdkeepers, as the literature of known diseases carried by non-native Psittacine birds has improved since the ban. During the public consultation period, I provided the following response as I do not support the proposed changes to the import of parrots into Australia, as this review did not consider the risk of new invasive species. Since this public consultation, the publication of the final review was delayed.

In June 2023, the Department of Climate Change, Energy, the Environment and Water released the “Proposal to delete unassessed psittacines from the Live Import List”. In this proposal, parrot species which have not undergone an environmental risk assessment would be removed from the Live Import List. Of the thirty parrot species on the Live Import List, only three species have approved environmental risk assessments: the Red-fronted Macaw (*Ara rubrogenys*), African Grey Parrot (*Psittacus erithacus*), and Maroon-bellied Conure (*Pyrrhura frontalis*). Therefore, to import a new parrot species, potential importers must apply to amend the Live Import List, which would trigger an environmental risk assessment. Provided that these assessments use methods in line with international standards and take a cautious approach to assessing the potential risks, I approve this amendment as it now recognises the biosecurity risk of the introduction of new invasive species.



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Friday, 18 September 2020

Import risk review for psittacine birds from all countries

We welcome the opportunity to provide comments to The Department of Agriculture, Water and the Environment (hereafter referred to as “the Department”) on the ‘*Import risk review for psittacine birds from all countries*’ draft report (hereafter referred to as the “risk review”).

Our comments are largely framed around the Biosecurity Act 2015, as applied to “diseases and pests that may cause harm to human, animal or plant health or the environment”. Key to the Biosecurity Act 2015 is preventing the introduction, establishment and spread of invasive pest species. In our comments below, we emphasise that the risk review has omitted the risks of invasive species, which undermines the quality and scope of the Assessment. We have identified two key concerns which put Australia’s economies and environments at risk by following the recommendations listed in the risk review, regardless of them being “*subject to a range of biosecurity risk management measures*”:

1. Introduction of new invasive psittacine species

Several psittacine species on the Live Import List are declared pests as they cause extensive damage to industry (particularly agriculture), and environments globally, and have a high potential of establishing in Australia (Vall-Ilosera et al. 2016, Lockwood et al. 2019). Allowing the import of alien parrots would greatly increase the potential of new invasive pests to establish and spread, causing significant economic and environmental damage, and requiring costly and intensive management (Hoffmann and Broadhurst 2016).

2. Lack of an evidence-based cost-benefit analysis

The identifiable benefits of the proposed changes are minimal, private, and for a very small section of society; however, consequences of invasive species establishment and disease outbreak are community-based, widely dispersed, and ongoing. It is extremely unlikely that the benefits of allowing the import of psittacine birds outweighs the risks to Australian biosecurity, economy, and environments.

Due to these serious key omissions, ***we do not support the import of psittacine birds based on the evidence provided in the risk review.***

The report does not provide sufficient transparency, nor evidence-based assessments of all benefits, risks, or associated costs, of allowing the import of psittacine birds. If the Department wishes to pursue this assessment, then future risk reviews must include the associated costs of facilitating new invasive species and provide justification on the broader societal benefits of allowing import of psittacine birds.

It is our professional scientific opinion that the benefits of importing psittacine birds are outweighed by the significant damages caused by the potential introduction of new invasive species.

Key concern 1: Introduction of new invasive psittacine species

The risk review undermines current Australian biosecurity policies, which prioritise preventing the entry of new pests and diseases, including new invasive species. Despite current regulation of exotic pet trade and ban on imports, the domestic live pet trade is one of the main sources of new invasive birds in Australia, through accidental escapes or intentional releases of alien species (Vall-Ilosera and Cassey 2017b). Many invasive parrots are known to cause extensive crop damages and outcompete native birds for resources (Menchetti and Mori 2014). By allowing the legal private import of psittacine birds, the number of alien species incursions would increase, as will the potential for new invasive species to establish and spread (Cassey and Hogg 2015, Cassey et al. 2018).

The risk review contains several management strategies of concern, which may assist regulation of disease, but do not address invasive species biosecurity nor management.

The risk review does not limit the number of imported aviary birds, which will cause inexpensive psittacine birds to be imported in potentially large numbers. Furthermore, there is no estimate on the number of psittacine birds which will be imported, and the capacity of (or the availability and pressure that this will place on) quarantine facilities. The potential risk of new invasive species scales with the number of species traded (propagule pressure), thus, as more individuals are imported, the risk of establishment and invasion increases (Cassey et al. 2018, Lockwood et al. 2019).

The risk review recognises “aviary birds”, which we assume to be predominantly used for commercial breeding, pose a higher risk to Australian biosecurity than “household” birds. However, the identified management strategies are far more relaxed for aviary birds and are likely insufficient to prevent escapes and incursions. The risk review does not consider how the differentiation between “household” and “aviary” birds will be regulated. Depending on a given species, a bird may be considered as both, depending on the preference of the owner.

Key concern 2: Lack of transparency around costs and benefits of imports

As stated in the risk review, successive Australian Governments have maintained a conservative, but non-zero risk, approach to managing biosecurity risks. This position recognises that there are trade-offs associated with import policies, which are typically measured through a cost benefit analysis. It is a requirement for changes in Australian Government regulation to undergo a Regulation Impact Statement, including a cost benefit analysis, to transparently quantify the trade-offs between the risks and benefits. While we understand that this is not a requirement under the Biosecurity Bill, it is a necessary component of good policy decision-making.

By not providing a cost benefit analysis, the decisions outlined in this risk review do not provide the same transparency and evidence-based assessment as other

reviews developed by the Department. Furthermore, this risk review does not consider the management steps and costs required in the event of disease outbreaks or alien species incursions. As described in the risk review, the majority of risks outlined do not have formal response arrangements in Australia.

The consequences of a biosecurity incursion due to these imports would be significant. The impacts would include the costs:

- associated with mitigating pathogen outbreaks
- to communities, industries, and native ecosystems in the event of pathogen outbreak
- associated with damages by, and management of, alien species incursions
- associated with managing the risks of imports (e.g. quarantine)

It is equally important to consider the distributional consequences from the proposed imports of psittacine birds. The benefits of imports are private and shared amongst those who import, trade, and keep birds, whereas the associated costs are shared across the general population and the environment. We do not believe that these distributional consequences have been reasonably calculated or communicated. We urge the Department to reject the proposal of the Review and to not permit the importation of live household pet and aviary psittacine birds to Australia.

The Director
Live Import List and CITES Policy Section
Department of Climate Change, Energy, the Environment and Water
GPO Box 3090
Canberra ACT 2601

30 June 2023

Proposal to delete unassessed psittacines from the Live Import List

We welcome the opportunity to provide comments to the Department of Climate Change, Energy, the Environment and Water on the '*Proposal to delete unassessed psittacines from the Live Import List*' (hereafter referred to as the "proposal").

In 2020, we provided a response to the '*Import risk review for psittacine birds from all countries*' draft report, in which we did not support the proposed changes due to the risk of introduction of new invasive psittacine species. Several psittacine species on the Live Import List have established invasive and highly damaging populations globally and continue to have a high chance of establishing invasive alien populations in Australia (Vall-Ilosera et al. 2017; Lockwood *et al.* 2019⁽²⁾). Despite current regulations, domestic pet trade is one of the main sources of new invasive birds in Australia, through accidental escapes, or intentional release of alien species (Vall-Ilosera et al. 2017b). By allowing the legal private import of psittacine birds, the number of alien species incursions would increase, as will the potential for new invasive species to establish and spread (Cassey and Hogg 2015; Cassey et al. 2018).

Due to the establishment risk of highly invasive psittacine species, ***we support the proposal to delete unassessed psittacines from the Live Import List.***

We believe that the removal of unassessed psittacines is the most appropriate measure to reduce the risk of new invasive bird species in Australia. While we support this proposal, we emphasise that the subsequent environmental risk assessments need to be conducted by independent experts and follow the current, best-practice methods. Importantly, they should not simply rely on existing rankings or historical vertebrate risk-assessment approaches (Henderson et al. 2011

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Supplementary Information

Supplementary Information 1-1

Table SI1-1.1: List of search terms used as part of the systematic literature review for literature that compared stable isotope ratios between wild and captive origins of modern tetrapods in wildlife trade. The search was formatted as (captive1 OR captive2 OR ... captivei) AND (wild1 OR wild2 OR ... wildi) AND (isotopes1 OR isotopes 2 OR ... isotopesi), and input into Web of Science and Google Scholar.

Captive	Wild	Isotopes	
Captive	wild	Isotope	hydrogen
captive-bred	feral	stable-isotope	$\delta^2\text{H}$
Farm	unmanaged	Carbon	^2H
Pet		$\delta^{13}\text{C}$	delta- ^2H
Caged		^{13}C	delta ^2H
laboratory		delta- ^{13}C	δD
laboratory-reared		delta ^{13}C	deuterium
laboratory-grown		nitrogen	Sulphur
domestic		$\delta^{15}\text{N}$	$\delta^{34}\text{S}$
		^{15}N	^{34}S
		delta- ^{15}N	delta- ^{34}S
		delta ^{15}N	delta ^{34}S
		Oxygen	Sulfur
		$\delta^{18}\text{O}$	strontium
		^{18}O	$\delta^{87}\text{Sr}$
		delta- ^{18}O	^{87}Sr
		delta ^{18}O	delta- ^{87}Sr
			delta ^{87}Sr

Supplementary Information 2-1

Table SI2-1.1: Full list of species for sale online. An asterisk (*) indicates the species is non-native to Australia.

Order	Common Name	Species Birdtree	Species Clements	Abundance	Adverts	Median price \$AUD
Anseriformes	Domestic Duck*	<i>Anas platyrhynchos domesticus</i>	<i>Anas platyrhynchos domesticus</i>	550	152	15
	Muscovy Duck*	<i>Cairina moschata</i>	<i>Cairina moschata</i>	288	85	11
	Domestic Goose*	<i>Anser anser domesticus</i>	<i>Anser anser domesticus</i>	238	66	25
	Brown Chinese Goose*	<i>Anser cygnoides</i>	<i>Anser cygnoides</i>	9	2	80
	Egyptian Goose*	<i>Alopochen aegyptiaca</i>	<i>Alopochen aegyptiaca</i>	4	2	238
	Black Swan	<i>Cygnus atratus</i>	<i>Cygnus atratus</i>	3	2	300
	Cape Barren Goose	<i>Cereopsis novaehollandiae</i>	<i>Cereopsis novaehollandiae</i>	3	2	175
	Chestnut Teal	<i>Anas castanea</i>	<i>Anas castanea</i>	2	1	38
Grey Teal	<i>Anas gracilis</i>	<i>Anas gracilis</i>	2	1	38	
Casuariiformes	Emu	<i>Dromaius novaehollandiae</i>	<i>Dromaius novaehollandiae</i>	13	4	180
Charadriiformes	Painted Buttonquail	<i>Turnix varius</i>	<i>Turnix varius</i>	6	2	29
Columbiformes	Diamond Dove	<i>Geopelia cuneata</i>	<i>Geopelia cuneata</i>	72	26	10
	Ring-Necked Dove*	<i>Streptopelia roseogrisea</i>	<i>Streptopelia roseogrisea</i>	71	22	10
	Peaceful Dove	<i>Geopelia placida</i>	<i>Geopelia placida</i>	32	16	15
	Pigeon*	<i>Columba livia domestica</i>	<i>Columba livia domestica</i>	26	6	10
	Namaqua Dove*	<i>Oena capensis</i>	<i>Oena capensis</i>	10	5	25
	Ruddy Ground Dove*	<i>Columbina talpacoti</i>	<i>Columbina talpacoti</i>	9	5	25
	Emerald Dove	<i>Chalcophaps indica</i>	<i>Chalcophaps indica</i>	6	3	40
	Spotted Dove*	<i>Streptopelia chinensis</i>	<i>Spilopelia chinesis</i>	3	2	5
	Bar Shouldered Dove	<i>Geopelia humeralis</i>	<i>Geopelia humeralis</i>	1	1	15
Galliformes	Japanese Quail*	<i>Coturnix japonica</i>	<i>Coturnix japonica</i>	703	168	7
	King Quail	<i>Coturnix chinensis</i>	<i>Synoicus chinensis</i>	400	124	7
	Helmeted Guineafowl*	<i>Numida meleagris</i>	<i>Numida meleagris</i>	139	42	25
	Indian Peafowl*	<i>Pavo cristatus</i>	<i>Pavo cristatus</i>	120	47	100
	Domestic Turkey*	<i>Meleagris gallopavo</i>	<i>Meleagris gallopavo</i>	97	33	28
	Ring-Necked Pheasant*	<i>Phasianus colchicus</i>	<i>Phasianus colchicus</i>	41	12	25
	Golden Pheasant*	<i>Chrysolophus pictus</i>	<i>Chrysolophus pictus</i>	35	16	57

	Northern Bobwhite*	<i>Colinus virginianus</i>	<i>Colinus virginianus</i>	26	11	23
	California Quail*	<i>Callipepla californica</i>	<i>Callipepla californica</i>	25	14	43
	Lady Amherst's Pheasant*	<i>Chrysolophus amherstiae</i>	<i>Chrysolophus amherstiae</i>	22	12	80
	Common Quail*	<i>Coturnix coturnix</i>	<i>Coturnix coturnix</i>	19	3	14
	Chicken*	<i>Gallus gallus domesticus</i>	<i>Gallus gallus domesticus</i>	16	2	8
	Chukar*	<i>Alectoris chukar</i>	<i>Alectoris chukar</i>	13	4	27
	Silver Pheasant*	<i>Lophura nycthemera</i>	<i>Lophura nycthemera</i>	4	2	30
	Reeve's Pheasant*	<i>Syrmaticus reevesii</i>	<i>Syrmaticus reevesii</i>	3	1	50
	Brown Quail	<i>Coturnix ypsilophora</i>	<i>Synoicus ypsikophorus</i>	2	1	25
	Stubble Quail	<i>Coturnix pectoralis</i>	<i>Coturnix pectoralis</i>	2	1	
Passeriformes	Domestic Canary*	<i>Serinus canaria</i>	<i>Serinus canaria</i>	1667	465	25
	Zebra Finch	<i>Taeniopygia guttata</i>	<i>Taeniopygia guttata</i>	698	160	5
	Gouldian Finch	<i>Erythrura gouldiae</i>	<i>Erythrura gouldiae</i>	598	169	25
	Java Finch*	<i>Lonchura oryzivora</i>	<i>Lonchura oryzivora</i>	130	21	10
	Painted Finch	<i>Emblema pictum</i>	<i>Emblema pictum</i>	94	41	25
	European Goldfinch*	<i>Carduelis carduelis</i>	<i>Carduelis carduelis</i>	86	27	25
	Orange-Breasted Waxbill*	<i>Amandava subflava</i>	<i>Amandava subflava</i>	72	29	25
	Red-Cheeked Cordon-Bleu*	<i>Uraeginthus bengalus</i>	<i>Uraeginthus bengalus</i>	54	26	35
	African Firefinch*	<i>Lagonosticta rubricata</i>	<i>Lagonosticta rubricata</i>	51	20	20
	Double-Barred Finch	<i>Taeniopygia bichenovii</i>	<i>Taeniopygia bichenovii</i>	48	20	25
	Star Finch	<i>Neochmia ruficauda</i>	<i>Neochmia ruficauda</i>	48	20	30
	Blue-Faced Parrotfinch	<i>Erythrura trichroa</i>	<i>Erythrura trichroa</i>	45	18	30
	Red-Throated Parrotfinch*	<i>Erythrura psittacea</i>	<i>Erythrura psittacea</i>	44	21	50
	Yellow-Fronted Canary*	<i>Crithagra mozambica</i>	<i>Crithagra mozambica</i>	41	18	60
	Chestnut-Breasted Mannikin	<i>Lonchura castaneothorax</i>	<i>Lonchura castaneothorax</i>	31	14	30
	Long-Tailed Finch	<i>Poephila acuticauda</i>	<i>Poephila acuticauda</i>	31	13	34
	Cuban Finch*	<i>Tiaris canorus</i>	<i>Tiaris canorus</i>	26	13	30
	Tricolored Parrotfinch*	<i>Erythrura tricolor</i>	<i>Erythrura tricolor</i>	25	11	50
	Common Waxbill*	<i>Estrilda astrild</i>	<i>Estrilda astrild</i>	24	11	30
	Hooded Siskin*	<i>Spinus magellanicus</i>	<i>Spinus magellanicus</i>	24	11	75
	Red-Billed Firefinch*	<i>Lagonosticta senegala</i>	<i>Lagonosticta senegala</i>	23	10	28
	Black-Headed Munia*	<i>Lonchura malacca</i>	<i>Lonchura malacca</i>	20	10	35
Red-Whiskered Bulbul*	<i>Pycnonotus jocosus</i>	<i>Pycnonotus jocosus</i>	18	10	110	

	Society Finch*	<i>Lonchura striata</i>	<i>Lonchura striata</i>	17	6	9
	European Greenfinch*	<i>Chloris chloris</i>	<i>Chloris chloris</i>	15	7	20
	Plum-Headed Finch	<i>Neochmia modesta</i>	<i>Neochmia modesta</i>	15	7	30
	Diamond Firetail	<i>Stagonopleura guttata</i>	<i>Stagonopleura guttata</i>	14	5	75
	African Silverbill*	<i>Euodice cantans</i>	<i>Euodice cantans</i>	11	5	33
	Masked Finch	<i>Poephila personata</i>	<i>Poephila personata</i>	10	4	70
	Red-Browed Finch	<i>Neochmia temporalis</i>	<i>Neochmia temporalis</i>	10	5	20
	Cut-Throat Finch*	<i>Amadina fasciata</i>	<i>Amadina fasciata</i>	9	5	28
	Green-Winged Pytilia*	<i>Pytilia melba</i>	<i>Pytilia melba</i>	8	4	45
	Silvereye Finch	<i>Zosterops lateralis</i>	<i>Zosterops lateralis</i>	8	4	50
	Southern Red Bishop*	<i>Euplectes orix</i>	<i>Euplectes orix</i>	7	3	60
	Crimson Finch	<i>Neochmia phaeton</i>	<i>Neochmia phaeton</i>	7	4	50
	Pictorella Mannikin	<i>Heteromunia pectoralis</i>	<i>Heteromunia pectoralis</i>	7	3	50
	Yellow-Crowned Bishop*	<i>Euplectes afer</i>	<i>Euplectes afer</i>	6	3	263
	Red Siskin*	<i>Spinus cucullatus</i>	<i>Spinus cucullatus</i>	6	4	213
	Red-Winged Pytilia*	<i>Pytilia phoenicoptera</i>	<i>Pytilia phoenicoptera</i>	6	3	58
	Red Avadavat*	<i>Amandava amandava</i>	<i>Amandava amandava</i>	5	3	85
	Black-Throated Finch	<i>Poephila cincta</i>	<i>Poephila cincta</i>	5	3	50
	Red Fody Finch, Red Fody*	<i>Foudia madagascariensis</i>	<i>Foudia madagascariensis</i>	4	2	60
	Blue-Capped Cordon-Bleu*	<i>Uraeginthus cyanocephalus</i>	<i>Uraeginthus cyanocephalus</i>	4	2	198
	Yellow-Rumped Mannikin	<i>Lonchura flaviprymna</i>	<i>Lonchura flaviprymna</i>	4	2	80
	Pin-Tailed Whydah*	<i>Vidua macroura</i>	<i>Vidua macroura</i>	3	1	333
	Orange-Cheeked Waxbill*	<i>Estrilda melpoda</i>	<i>Estrilda melpoda</i>	2	1	
	Blue-Black Grassquit*	<i>Volatinia jacarina</i>	<i>Volatinia jacarina</i>	2	2	23
	Common Blackbird*	<i>Turdus merula</i>	<i>Turdus merula</i>	1	1	100
	Song Thrush*	<i>Turdus philomelos</i>	<i>Turdus philomelos</i>	1	1	600
	White-Headed Munia*	<i>Lonchura maja</i>	<i>Lonchura maja</i>	1	1	40
	Eastern Whipbird	<i>Psophodes olivaceus</i>	<i>Psophodes olivaceus</i>	1	1	
Psittaciformes	Budgerigar	<i>Melopsittacus undulatus</i>	<i>Melopsittacus undulatus</i>	10022	2718	20
	Cockatiel	<i>Nymphicus hollandicus</i>	<i>Nymphicus hollandicus</i>	2457	1020	55
	Rose-Ringed Parakeet*	<i>Psittacula krameri</i>	<i>Psittacula krameri</i>	1971	898	120
	Rainbow Lorikeet	<i>Trichoglossus haematodus</i>	<i>Trichoglossus haematodus</i>	927	520	150
	Green-Cheeked Parakeet*	<i>Pyrrhura molinae</i>	<i>Pyrrhura molinae</i>	820	356	125
	Rosy-Faced Lovebird*	<i>Agapornis roseicollis</i>	<i>Agapornis roseicollis</i>	805	330	40

Alexandrine Parakeet*	<i>Psittacula eupatria</i>	<i>Psittacula eupatria</i>	546	320	250
Eclectus Parrot	<i>Eclectus roratus</i>	<i>Eclectus roratus</i>	507	359	600
Yellow-Collared Lovebird*	<i>Agapornis personatus</i>	<i>Agapornis personatus</i>	302	99	35
Fischer's Lovebird*	<i>Agapornis fischeri</i>	<i>Agapornis fischeri</i>	275	117	45
Monk Parakeet*	<i>Myiopsitta monachus</i>	<i>Myiopsitta monachus</i>	244	131	200
Princess Parrot	<i>Polytelis alexandrae</i>	<i>Polytelis alexandrae</i>	218	102	100
Bourke's Parrot	<i>Neopsephotus bourkii</i>	<i>Neopsephotus bourkii</i>	204	78	40
Galah	<i>Cacatua roseicapilla</i>	<i>Eolophus roseicapilla</i>	185	120	123
Sun Conure*	<i>Aratinga solstitialis</i>	<i>Aratinga solstitialis</i>	181	116	323
Red-Rumped Parrot	<i>Psephotus haematonotus</i>	<i>Psephotus haematonotus</i>	166	72	40
Scaly-Breasted Lorikeet	<i>Trichoglossus chlorolepidotus</i>	<i>Trichoglossus chlorolepidotus</i>	160	90	125
Turquoise Parrot	<i>Neophema pulchella</i>	<i>Neophema pulchella</i>	120	40	50
Blue-And-Yellow Macaw*	<i>Ara ararauna</i>	<i>Ara ararauna</i>	116	87	3750
Turquoise-Fronted Amazon*	<i>Amazona aestiva</i>	<i>Amazona aestiva</i>	108	61	800
Pacific Parrotlet*	<i>Forpus coelestis</i>	<i>Forpus coelestis</i>	105	39	200
Eastern Rosella	<i>Platycercus eximius</i>	<i>Platycercus eximius</i>	96	51	90
Sulphur-Crested Cockatoo	<i>Cacatua galerita</i>	<i>Cacatua galerita</i>	85	76	400
Red-Crowned Parakeet	<i>Cyanoramphus novaezelandiae</i>	<i>Cyanoramphus novaezelandiae</i>	83	38	75
Crimson-Bellied Parakeet*	<i>Pyrrhura perlata</i>	<i>Pyrrhura perlata</i>	70	37	168
Scarlet-Chested Parrot	<i>Neophema splendida</i>	<i>Neophema splendida</i>	70	34	50
Crimson Rosella	<i>Platycercus elegans</i>	<i>Platycercus elegans</i>	63	30	90
Red-Tailed Black Cockatoo	<i>Calyptorhynchus banksii</i>	<i>Calyptorhynchus banksii</i>	54	40	800
Plum-Headed Parakeet*	<i>Psittacula cyanocephala</i>	<i>Psittacula cyanocephala</i>	52	31	130
Hooded Parrot	<i>Psephotus dissimilis</i>	<i>Psephotus dissimilis</i>	51	26	100
Pale-Headed Rosella	<i>Platycercus adscitus</i>	<i>Platycercus adscitus</i>	47	19	100
Australian Ringneck	<i>Barnardius zonarius</i>	<i>Barnardius zonarius</i>	44	20	100
Red-Breasted Parakeet*	<i>Psittacula alexandri</i>	<i>Psittacula alexandri</i>	43	26	150
Australian King Parrot	<i>Alisterus scapularis</i>	<i>Alisterus scapularis</i>	43	23	150
Long-Billed Corella	<i>Cacatua tenuirostris</i>	<i>Cacatua tenuirostris</i>	43	21	213
Yellow-Crowned Amazon*	<i>Amazona ochrocephala</i>	<i>Amazona ochrocephala</i>	41	25	900
African Grey Parrot*	<i>Psittacus erithacus</i>	<i>Psittacus erithacus</i>	38	24	4000
Lilian's Lovebird*	<i>Agapornis lilianae</i>	<i>Agapornis lilianae</i>	36	4	60
Yellow-Headed Amazon*	<i>Amazona oratrix</i>	<i>Amazona oratrix</i>	35	18	1875

Red-Collared Lorikeet	<i>Trichoglossus rubritorquis</i>	<i>Trichoglossus rubritorquis</i>	35	20	250
Black-Headed Parrot*	<i>Pionites melanocephalus</i>	<i>Pionites melanocephalus</i>	34	21	850
Red-Winged Parrot	<i>Aprosmictus erythropterus</i>	<i>Aprosmictus erythropterus</i>	34	14	150
Black-Capped Lory*	<i>Lorius lory</i>	<i>Lorius lory</i>	33	18	700
Musk Lorikeet	<i>Glossopsitta concinna</i>	<i>Glossopsitta concinna</i>	33	18	60
Jandaya Parakeet*	<i>Aratinga jandaya</i>	<i>Aratinga jandaya</i>	32	23	313
Superb Parrot	<i>Polytelis swainsonii</i>	<i>Polytelis swainsonii</i>	27	16	88
Senegal Parrot*	<i>Poicephalus senegalus</i>	<i>Poicephalus senegalus</i>	26	14	1125
Pink Cockatoo	<i>Lophochroa leadbeateri</i>	<i>Lophochroa leadbeateri</i>	25	15	450
Western Rosella	<i>Platycercus icterotis</i>	<i>Platycercus icterotis</i>	25	13	163
Rose-Crowned Parakeet*	<i>Pyrrhura rhodoccephala</i>	<i>Pyrrhura rhodoccephala</i>	23	15	200
Black-Capped Parakeet*	<i>Pyrrhura rupicola</i>	<i>Pyrrhura rupicola</i>	22	15	350
Little Corella	<i>Cacatua sanguinea</i>	<i>Cacatua sanguinea</i>	22	17	133
Dusky Lorikeet*	<i>Pseudeos fuscata</i>	<i>Pseudeos fuscata</i>	21	14	500
Elegant Parrot	<i>Neophema elegans</i>	<i>Neophema elegans</i>	21	16	55
Varied Lorikeet	<i>Psitteuteles versicolor</i>	<i>Psitteuteles versicolor</i>	19	5	220
Barred Parakeet*	<i>Bolborhynchus lineola</i>	<i>Bolborhynchus lineola</i>	18	12	500
White-Bellied Parrot*	<i>Pionites leucogaster</i>	<i>Pionites leucogaster</i>	18	10	2600
Regent Parrot	<i>Polytelis anthopeplus</i>	<i>Polytelis anthopeplus</i>	18	8	125
Red-Shouldered Macaw*	<i>Diopsittaca nobilis</i>	<i>Diopsittaca nobilis</i>	17	11	825
Red And Green Macaw*	<i>Ara chloropterus</i>	<i>Ara chloropterus</i>	16	12	8000
Nanday Parakeet*	<i>Nandayus nenday</i>	<i>Nandayus nenday</i>	16	12	200
Purple-Crowned Lorikeet	<i>Glossopsitta porphyrocephala</i>	<i>Glossopsitta porphyrocephala</i>	16	7	150
Golden-Shouldered Parrot	<i>Psephotus chrysopterygius</i>	<i>Psephotus chrysopterygius</i>	16	7	95
Bluebonnet	<i>Northiella haematogaster</i>	<i>Northiella haematogaster</i>	15	8	138
Maroon-Bellied Parakeet*	<i>Pyrrhura frontalis</i>	<i>Pyrrhura frontalis</i>	14	7	175
Red-Capped Parrot	<i>Purpureicephalus spurius</i>	<i>Purpureicephalus spurius</i>	13	7	200
Golden-Capped Parakeet*	<i>Aratinga auricapillus</i>	<i>Aratinga auricapillus</i>	12	8	950
Golden-Collared Macaw*	<i>Primolius auricollis</i>	<i>Primolius auricollis</i>	11	7	1750
Pearly Parakeet*	<i>Pyrrhura lepida</i>	<i>Pyrrhura lepida</i>	11	7	150
Red Lory*	<i>Eos bornea</i>	<i>Eos bornea</i>	11	8	1000
Northern Rosella	<i>Platycercus venustus</i>	<i>Platycercus venustus</i>	11	6	325
Mulga Parrot	<i>Psephotus varius</i>	<i>Psephotus varius</i>	10	5	65
Scarlet Macaw*	<i>Ara macao</i>	<i>Ara macao</i>	8	5	8000

Yellow-Naped Amazon*	<i>Amazona auropalliata</i>	<i>Amazona auropalliata</i>	7	4	
Red-Bellied Parrot*	<i>Poicephalus rufiventris</i>	<i>Poicephalus rufiventris</i>	7	5	800
Ornate Lorikeet*	<i>Trichoglossus ornatus</i>	<i>Trichoglossus ornatus</i>	6	3	
Yellow-Crowned Parakeet*	<i>Cyanoramphus auriceps</i>	<i>Cyanoramphus auriceps</i>	5	5	88
Meyer's Parrot*	<i>Poicephalus meyeri</i>	<i>Poicephalus meyeri</i>	5	4	
Golden Parakeet*	<i>Guaruba guarouba</i>	<i>Guaruba guarouba</i>	5	3	
Yellow-Bibbed Lory*	<i>Lorius chlorocercus</i>	<i>Lorius chlorocercus</i>	5	4	1350
Black Lory*	<i>Chalcopsitta atra</i>	<i>Chalcopsitta atra</i>	4	4	600
Blue Winged Parakeet*	<i>Psittacula columboides</i>	<i>Psittacula columboides</i>	4	3	125
Red-Lored Amazon*	<i>Amazona autumnalis</i>	<i>Amazona autumnalis</i>	4	2	
Green Rosella	<i>Platycercus caledonicus</i>	<i>Platycercus caledonicus</i>	4	2	200
White-Fronted Amazon*	<i>Amazona albifrons</i>	<i>Amazona albifrons</i>	3	2	800
Yellow-Tailed Black Cockatoo	<i>Calyptorhynchus funereus</i>	<i>Zanda funerea</i>	3	3	
Lord Derby's Parakeet*	<i>Psittacula derbiana</i>	<i>Psittacula derbiana</i>	2	1	400
Peach-Fronted Parakeet*	<i>Aratinga aurea</i>	<i>Eupsittula aurea</i>	2	1	
Fiery-Shouldered Conure*	<i>Pyrrhura egregia</i>	<i>Pyrrhura egregia</i>	2	1	500
Yellow-Streaked Lory*	<i>Chalcopsitta sintillata</i>	<i>Chalcopsitta scintillata</i>	2	1	
Chattering Lory*	<i>Lorius garrulus</i>	<i>Lorius garrulus</i>	2	2	625
Little Lorikeet	<i>Glossopsitta pusilla</i>	<i>Glossopsitta pusilla</i>	2	1	175
Rock Parrot	<i>Neophema petrophila</i>	<i>Neophema petrophila</i>	2	2	85
Vinaceous-Breasted Amazon*	<i>Amazona vinacea</i>	<i>Amazona vinacea</i>	1	1	
Double-Eyed Fig Parrot	<i>Cyclopsitta diophthalma</i>	<i>Cyclopsitta diophthalma</i>	1	1	

Supplementary Information 2-2

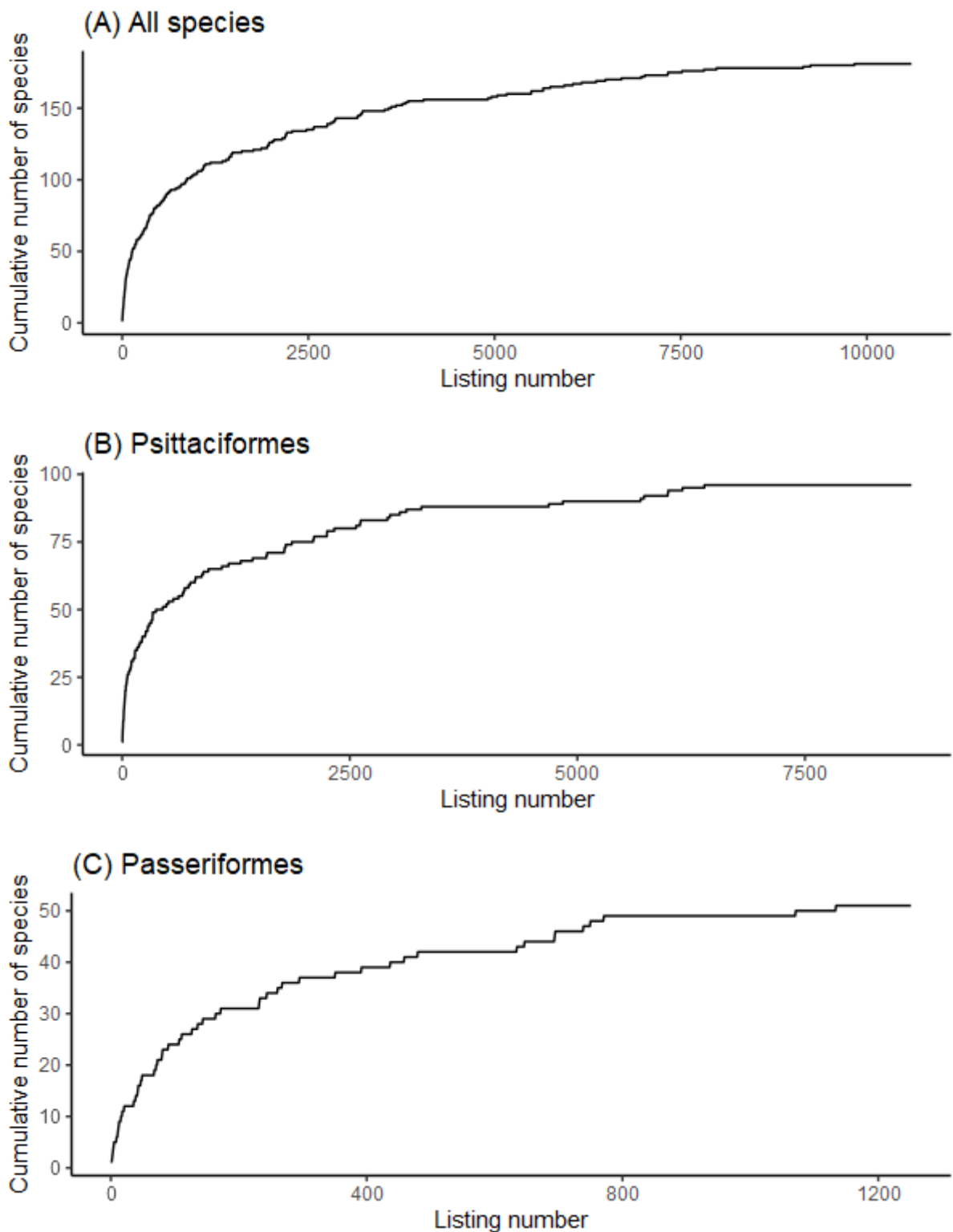


Figure S12-2.1: Species accumulation curves for (A) all online advertisements (listings); (B) subset for Psittaciformes; and (C) subset for Passeriformes. Both orders had different numbers of listings, hence the different axis scales. The listing number order the listings were manually cleaned.

Table SI2-2.1: Species which had less than two advertisements with the price advertised, where median price could not be calculated. These species were excluded from further analysis.

Order	Species	Common name	Listings	Abundance
Psittaciformes	<i>Amazona auropalliata</i>	Yellow-Naped Amazon	4	7
	<i>Amazona autumnalis</i>	Red-lored amazon	2	4
	<i>Amazona vinacea</i>	Vinaceous-breasted amazon	1	1
	<i>Aratinga aurea</i>	Peach-fronted parakeet	1	2
	<i>Calyptorhynchus funereus</i>	Yellow-tailed black cockatoo	3	3
	<i>Chalcopsitta sintillata</i>	Yellowish-streaked lory	1	2
	<i>Cyclopsitta diophthalma</i>	Double-eyed fig parrot	1	1
	<i>Guaruba guarouba</i>	Golden parakeet	3	5
	<i>Poicephalus meyeri</i>	Meyer's parrot	4	5
	<i>Trichoglossus ornatus</i>	Ornate lorikeet	3	6
Passeriformes	<i>Estrilda melpoda</i>	Orange-cheeked waxbill	1	2
	<i>Psophodes olivaceus</i>	Eastern whipbird	1	1

Supplementary Information 2-3

Table SI2-3.1: Species characteristics not used in analysis.

Characteristic	Source	Unit	Description	Prediction	Removal reason
Appearance & behaviour					
Maximum longevity	Myhrvold et al. (2015)	years	Oldest recorded age in captivity or in the wild.	Long-lived species may be sold less frequently, as they occupy aviaries for longer periods.	Missing for >10% of species
Trade & availability					
CITES	CITES Appendix listing	NL, III, II or I	Appendix listing, relates to the level of restrictions to online trade	May affect the availability of species in Australia. However, most species cannot be imported into Australia unless they are on the Live Import List, which prevents the trade of most CITES listed species.	Most species are under the same Appendix and lacks enough contrasts for the models. (Passerines: 1 in I, 2 in II, and 45 Not Listed. Parrots: 10 in I, 69 in II, and 4 Not Listed.)
IUCN	IUCN Red List rating	IUCN rating	International Union for Conservation of Nature extinction risk	More threatened species may be perceived as more “rare”, and more desirable.	Most species have the same rating. (Passerines: 2 were Endangered, 1 Near Threatened, and 45 Least Concern. Parrots: 7 Endangered, 5 Vulnerable, 10 Near Threatened, and 61 Least Concern.)
Wild-caught	Recorded in data cleaning	Presence	If advertisement listed if the bird was wild caught	There may be desirability for a wild-caught bird with wild genetics or viewed as “purer”.	Only two advertisements mentioned wild caught

Supplementary Information 2-4

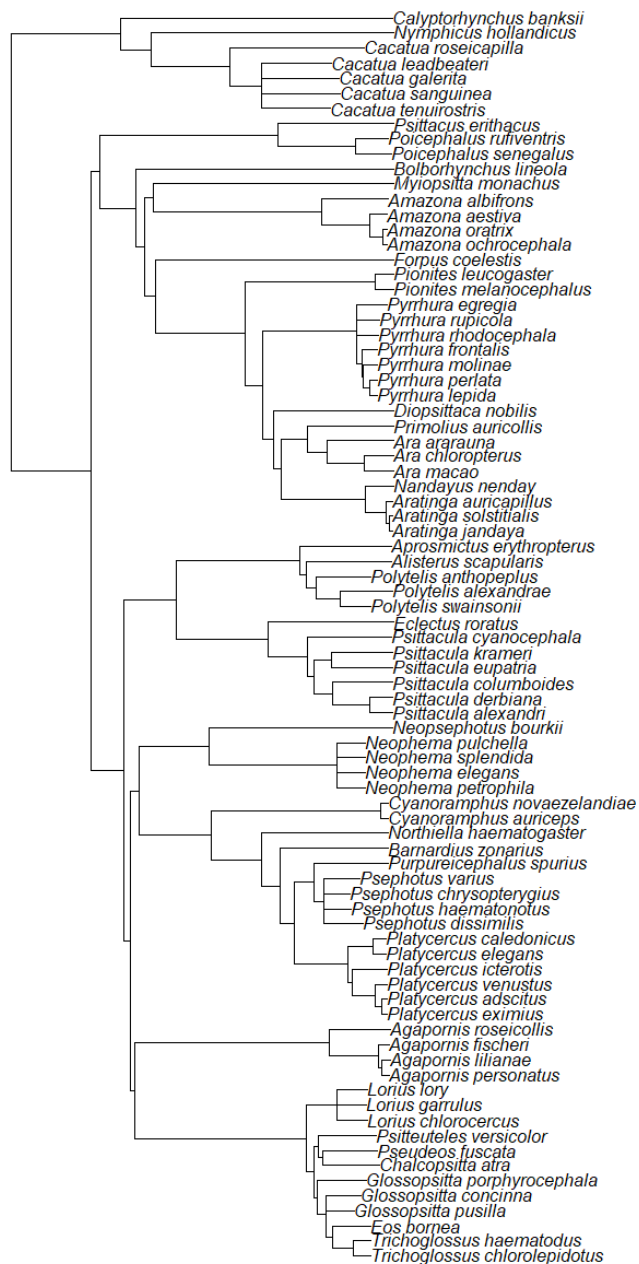


Figure SI2-4.1: phylogenetic consensus tree for parrots (Psittaciformes) in online trade, created using 1000 trees from BirdTree.org.

Table SI2-4.1: List of variables used in the candidate models for parrots

Model	Variable 1 Breeding & handling	Variable 2 Trade & availability	Variable 3 Appearance & behaviour
1	Body mass		
2	Level of care		
3	Mutations		
4	Hand-raised		
5	Annual fecundity		
6		Provenance	
7		Median price	
8		Range size	
9			Song complexity
10			Intelligence (EQ)
11			Plumage colour
12	Body mass	Provenance	
13	Level of care	Provenance	
14	Mutations	Provenance	
15	Hand-raised	Provenance	
16	Annual fecundity	Provenance	
17	Body mass	Median price	
18	Level of care	Median price	
19	Mutations	Median price	
20	Hand-raised	Median price	
21	Annual fecundity	Median price	
22	Body mass	Range size	
23	Level of care	Range size	
24	Mutations	Range size	
25	Hand-raised	Range size	
26	Annual fecundity	Range size	
27	Body mass		Song complexity
28	Level of care		Song complexity
29	Mutations		Song complexity
30	Hand-raised		Song complexity
31	Annual fecundity		Song complexity
32	Body mass		Intelligence (EQ)
33	Level of care		Intelligence (EQ)
34	Mutations		Intelligence (EQ)
35	Hand-raised		Intelligence (EQ)
36	Annual fecundity		Intelligence (EQ)
37	Body mass		Plumage colour
38	Level of care		Plumage colour
39	Mutations		Plumage colour
40	Hand-raised		Plumage colour
41	Annual fecundity		Plumage colour
42		Provenance	Song complexity
43		Median price	Song complexity
44		Range size	Song complexity
45		Provenance	Intelligence (EQ)

46		Median price	Intelligence (EQ)
47		Range size	Intelligence (EQ)
48		Provenance	Plumage colour
49		Median price	Plumage colour
50		Range size	Plumage colour
51	Body mass	Provenance	Song complexity
52	Level of care	Provenance	Song complexity
53	Mutations	Provenance	Song complexity
54	Hand-raised	Provenance	Song complexity
55	Annual fecundity	Provenance	Song complexity
56	Body mass	Median price	Song complexity
57	Level of care	Median price	Song complexity
58	Mutations	Median price	Song complexity
59	Hand-raised	Median price	Song complexity
60	Annual fecundity	Median price	Song complexity
61	Body mass	Range size	Song complexity
62	Level of care	Range size	Song complexity
63	Mutations	Range size	Song complexity
64	Hand-raised	Range size	Song complexity
65	Annual fecundity	Range size	Song complexity
66	Body mass	Provenance	Intelligence (EQ)
67	Level of care	Provenance	Intelligence (EQ)
68	Mutations	Provenance	Intelligence (EQ)
69	Hand-raised	Provenance	Intelligence (EQ)
70	Annual fecundity	Provenance	Intelligence (EQ)
71	Body mass	Median price	Intelligence (EQ)
72	Level of care	Median price	Intelligence (EQ)
73	Mutations	Median price	Intelligence (EQ)
74	Hand-raised	Median price	Intelligence (EQ)
75	Annual fecundity	Median price	Intelligence (EQ)
76	Body mass	Range size	Intelligence (EQ)
77	Level of care	Range size	Intelligence (EQ)
78	Mutations	Range size	Intelligence (EQ)
79	Hand-raised	Range size	Intelligence (EQ)
80	Annual fecundity	Range size	Intelligence (EQ)
81	Body mass	Provenance	Plumage colour
82	Level of care	Provenance	Plumage colour
83	Mutations	Provenance	Plumage colour
84	Hand-raised	Provenance	Plumage colour
85	Annual fecundity	Provenance	Plumage colour
86	Body mass	Median price	Plumage colour
87	Level of care	Median price	Plumage colour
88	Mutations	Median price	Plumage colour
89	Hand-raised	Median price	Plumage colour
90	Annual fecundity	Median price	Plumage colour
91	Body mass	Range size	Plumage colour
92	Level of care	Range size	Plumage colour
93	Mutations	Range size	Plumage colour
94	Hand-raised	Range size	Plumage colour
95	Annual fecundity	Range size	Plumage colour

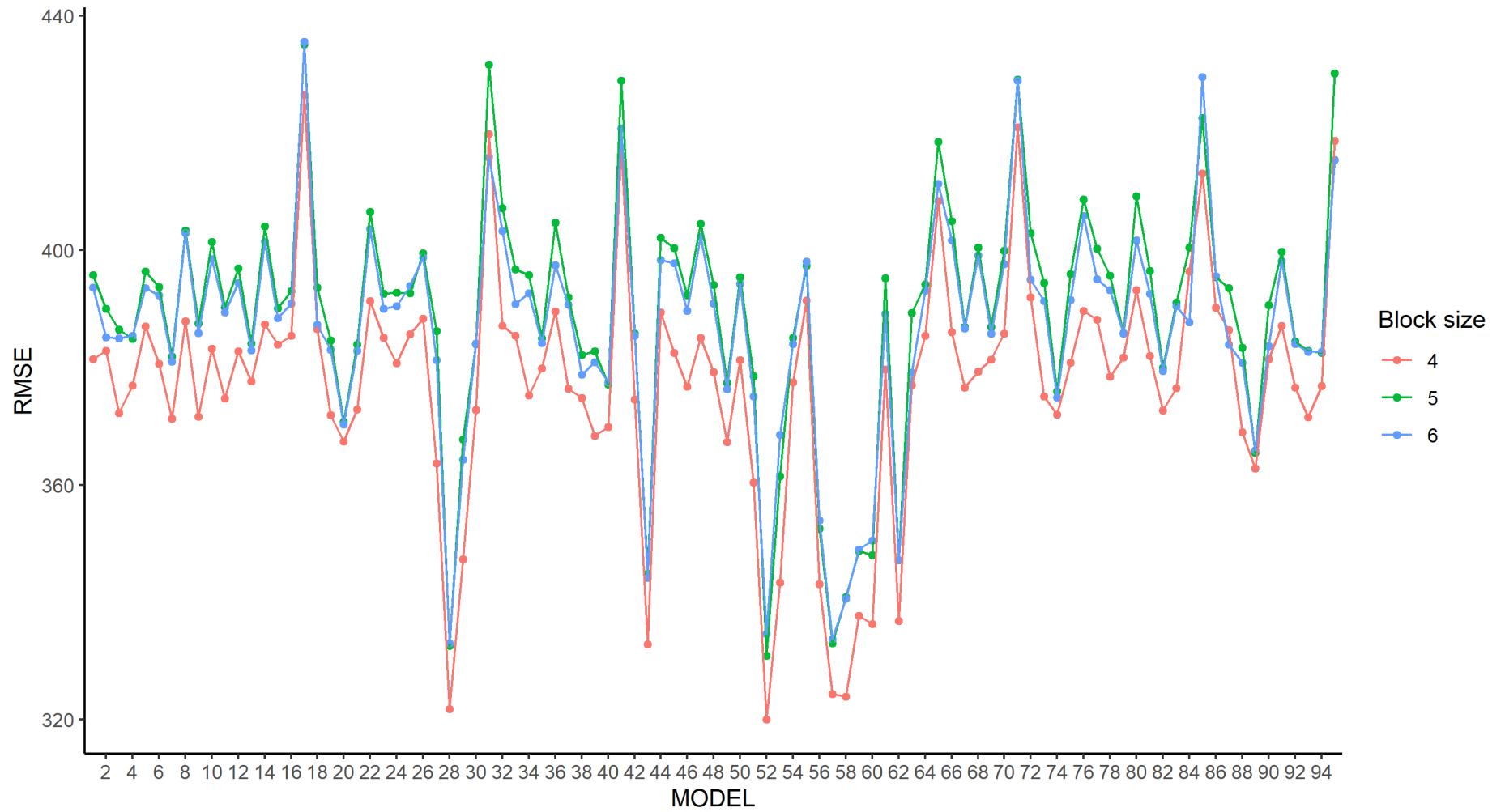


Figure SI2-4.2: Parrot model performance for three block sizes, ranked using root mean square error (RMSE) according to (Roberts et al. 2017). Initial block sizes were decided by visual inspection of the phylogeny (Figure SI2-4.1). Block size 4 was selected, as it consistently had the lowest RMSE for most models.

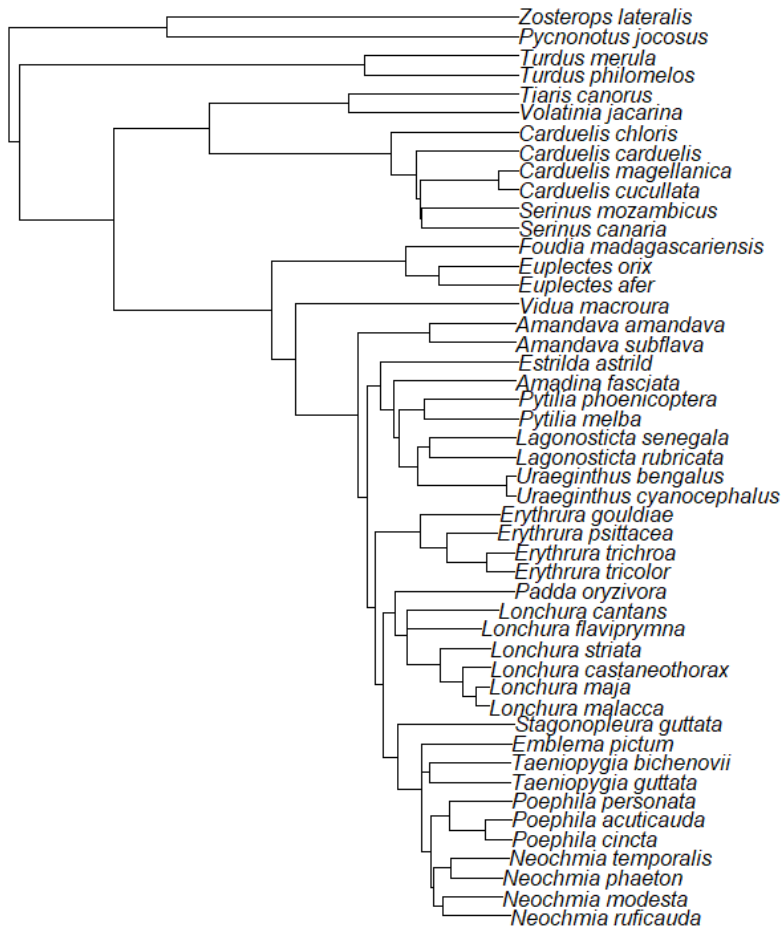


Figure SI2-4.3: phylogenetic consensus tree for passerines (Passeriformes) in online trade, created using 1000 trees from BirdTree.org.

Table SI2-4.2: List of variables used in the candidate models for passerines.

Model	Variable 1 Breeding & handling	Variable 2 Trade & availability	Variable 3 Appearance & behaviour
1	Body mass		
2	Level of care		
3	Mutations		
4	Annual fecundity		
5	Provenance		
6	Median price		
7	Range size		
8	Song complexity		
9	Intelligence (EQ)		
10	Plumage colour		
11	Body mass	Provenance	
12	Level of care	Provenance	
13	Mutations	Provenance	
14	Annual fecundity	Provenance	
15	Body mass	Median price	
16	Level of care	Median price	
17	Mutations	Median price	
18	Annual fecundity	Median price	
19	Body mass	Range size	
20	Level of care	Range size	
21	Mutations	Range size	
22	Annual fecundity	Range size	
23	Body mass		Song complexity
24	Level of care		Song complexity
25	Mutations		Song complexity
26	Annual fecundity		Song complexity
27	Body mass		Intelligence (EQ)
28	Level of care		Intelligence (EQ)
29	Mutations		Intelligence (EQ)
30	Annual fecundity		Intelligence (EQ)
31	Body mass		Plumage colour
32	Level of care		Plumage colour
33	Mutations		Plumage colour
34	Annual fecundity		Plumage colour
35		Provenance	Song complexity
36		Median price	Song complexity
37		Range size	Song complexity
38		Provenance	Intelligence (EQ)
39		Median price	Intelligence (EQ)
40		Range size	Intelligence (EQ)
41		Provenance	Plumage colour
42		Median price	Plumage colour
43		Range size	Plumage colour
44	Body mass	Provenance	Song complexity
45	Level of care	Provenance	Song complexity

46	Mutations	Provenance	Song complexity
47	Annual fecundity	Provenance	Song complexity
48	Body mass	Median price	Song complexity
49	Level of care	Median price	Song complexity
50	Mutations	Median price	Song complexity
51	Annual fecundity	Median price	Song complexity
52	Body mass	Range size	Song complexity
53	Level of care	Range size	Song complexity
54	Mutations	Range size	Song complexity
55	Annual fecundity	Range size	Song complexity
56	Body mass	Provenance	Intelligence (EQ)
57	Level of care	Provenance	Intelligence (EQ)
58	Mutations	Provenance	Intelligence (EQ)
59	Annual fecundity	Provenance	Intelligence (EQ)
60	Body mass	Median price	Intelligence (EQ)
61	Level of care	Median price	Intelligence (EQ)
62	Mutations	Median price	Intelligence (EQ)
63	Annual fecundity	Median price	Intelligence (EQ)
64	Body mass	Range size	Intelligence (EQ)
65	Level of care	Range size	Intelligence (EQ)
66	Mutations	Range size	Intelligence (EQ)
67	Annual fecundity	Range size	Intelligence (EQ)
68	Body mass	Provenance	Plumage colour
69	Level of care	Provenance	Plumage colour
70	Mutations	Provenance	Plumage colour
71	Annual fecundity	Provenance	Plumage colour
72	Body mass	Median price	Plumage colour
73	Level of care	Median price	Plumage colour
74	Mutations	Median price	Plumage colour
75	Annual fecundity	Median price	Plumage colour
76	Body mass	Range size	Plumage colour
77	Level of care	Range size	Plumage colour
78	Mutations	Range size	Plumage colour
79	Annual fecundity	Range size	Plumage colour

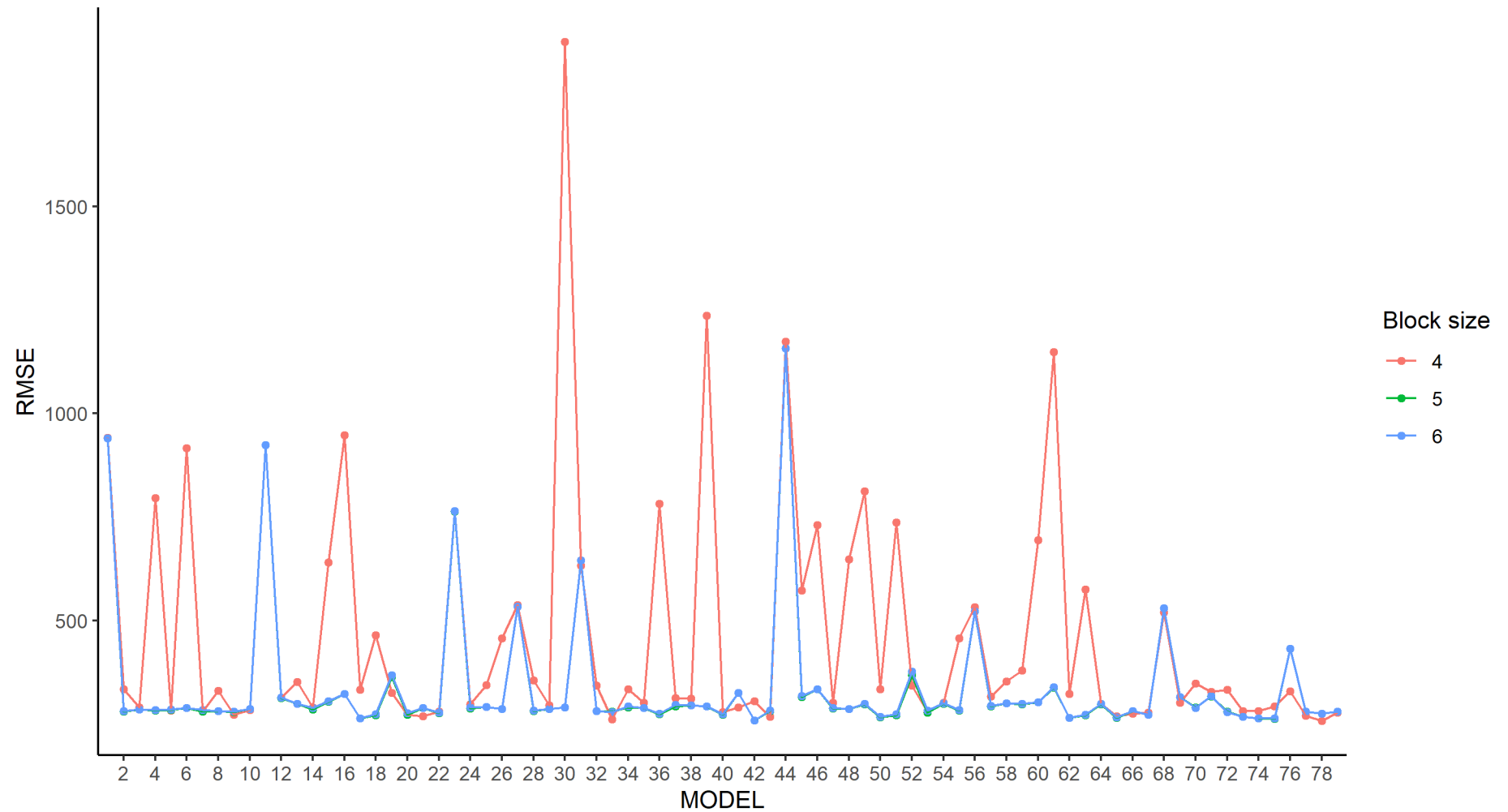


Figure SI2-4.4: Passerine model performance for three block sizes, ranked using root mean square error (RMSE) according to (Roberts et al. 2017). Initial block sizes were decided by visual inspection of the phylogeny (Figure SI2-4.1). Block sizes 5 and 6 had almost identical RMSE values, so the larger block size (5) was favoured.

Table SI2-4.3: Top performing models and model performance (root mean square error (RMSE) and mean absolute error (MAE)) for parrots selected by $\Delta\text{RMSE} < 10$, using cross-validation techniques with training data block size of 5. Variable 1 is a characteristic from the breeding & handling group, variable 2 from trade & availability, and variable 3 from appearance & behaviour. These models were refit with the full dataset to calculate R^2 .

Model				Model performance		
#	Variable 1	Variable 2	Variable 3	RMSE	MAE	R^2
52	Level of care	Provenance	Song complexity	320.0	134.7	0.64
28	Level of care		Song complexity	321.8	132.7	0.62
58	Mutations	Median price	Song complexity	323.9	136.6	0.66
57	Level of care	Median price	Song complexity	324.4	131.5	0.65

Table SI2-4.4: Top performing models and model performance (root mean square error (RMSE) and mean absolute error (MAE)) for passerines selected by $\Delta\text{RMSE} < 10$, using cross-validation techniques with training data block size of 5. Variable 1 is a characteristic from the breeding & handling group, variable 2 from trade & availability, and variable 3 from appearance & behaviour. These models were refit with the full dataset to calculate R^2 .

Model				Model performance		
#	Variable 1	Variable 2	Variable 3	RMSE	MAE	R^2
42		Median price	Plumage colour	258.6	92.3	0.73
75	Annual fecundity	Median price	Plumage colour	262.6	97.9	0.74
17	Mutations	Median price		263.4	111.3	0.73
74	Mutations	Median price	Plumage colour	263.7	103.2	0.73
65	Care level	Range size	EQ	265.1	101.7	0.60
62	Mutations	Median price	EQ	265.8	113.3	0.73
50	Mutations	Median price	Song complexity	266.4	109.9	0.73
73	Care level	Median price	Plumage colour	267.6	102.5	0.74

Table SI2-4.5: Model averaging results for species characteristics for parrots and passerines, using models in tables A4.3 and A4.4 and ranked by RMSE. Characteristics are ordered by their relative importance (RI).

Order	Grouping	Characteristic	RI	Est	CI min	CI max	SE	Adj SE	z	Pr(> z)
Parrots	Appearance & behaviour	Song complexity	1.000	1.968	1.398	2.537	0.286	0.291	6.766	0.000
	Breeding & handling	Level of care	0.914	-0.912	-1.229	-0.595	0.160	0.162	5.633	0.000
	Trade & availability	Provenance	0.602	0.482	-0.046	1.010	0.265	0.269	1.789	0.074
	Trade & availability	Median price	0.153	-1.292	-2.058	-0.526	0.386	0.391	3.305	0.001
	Breeding & handling	Mutations	0.086	0.963	0.288	1.638	0.339	0.344	2.797	0.005
Passerines	Trade & availability	Median price	0.956	-3.145	-4.461	-1.828	0.659	0.672	4.682	0.000
	Appearance & behaviour	Plumage colour	0.843	-0.047	-0.098	0.003	0.025	0.026	1.836	0.066
	Breeding & handling	Mutations	0.166	1.264	0.343	2.185	0.457	0.470	2.689	0.007
	Breeding & handling	Annual fecundity	0.093	-0.082	-0.199	0.035	0.058	0.060	1.376	0.169
	Appearance & behaviour	Intelligence (EQ)	0.080	-2.765	-8.007	2.476	2.634	2.674	1.034	0.301
	Breeding & handling	Level of care	0.051	-0.613	-1.727	0.500	0.564	0.568	1.080	0.280
	Trade & availability	Range size	0.044	-0.771	-1.179	-0.364	0.202	0.208	3.708	0.000
	Appearance & behaviour	Song complexity	0.014	0.159	-0.354	0.672	0.254	0.262	0.609	0.543

Where Est is the estimate, SE is standard error, adj SE is the adjusted standard error CI is 95% confidence interval, and RI is the sum of model weights for the models the variable is present (i.e. relative importance).

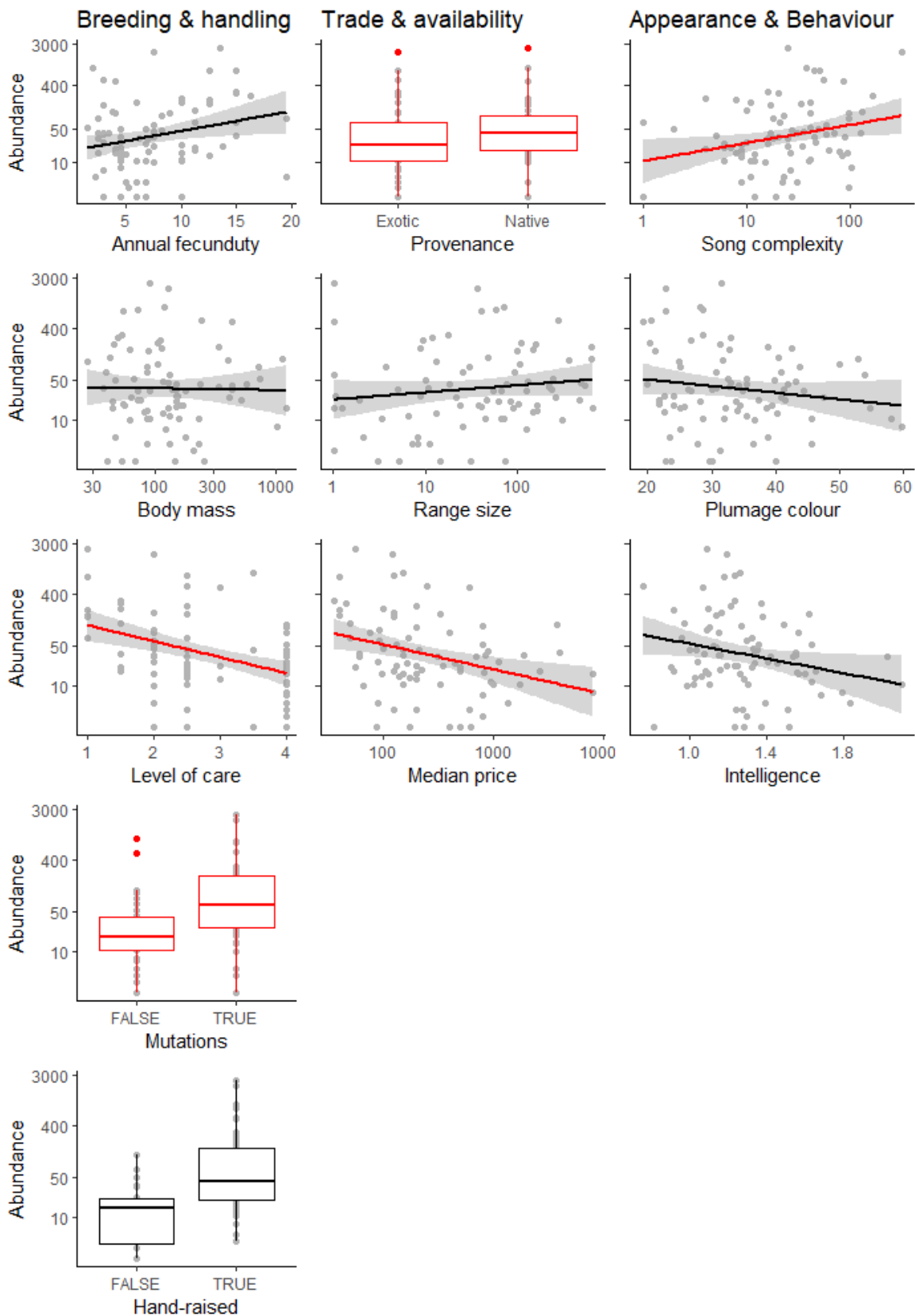


Figure SI2-4.5: Linear regression with 95% confidence intervals and boxplot prediction plots for relationships between parrot species characteristics and abundance. Characteristics which were identified to be strongly associated with species abundance by model selection are coloured red (Table SI2-4.5).

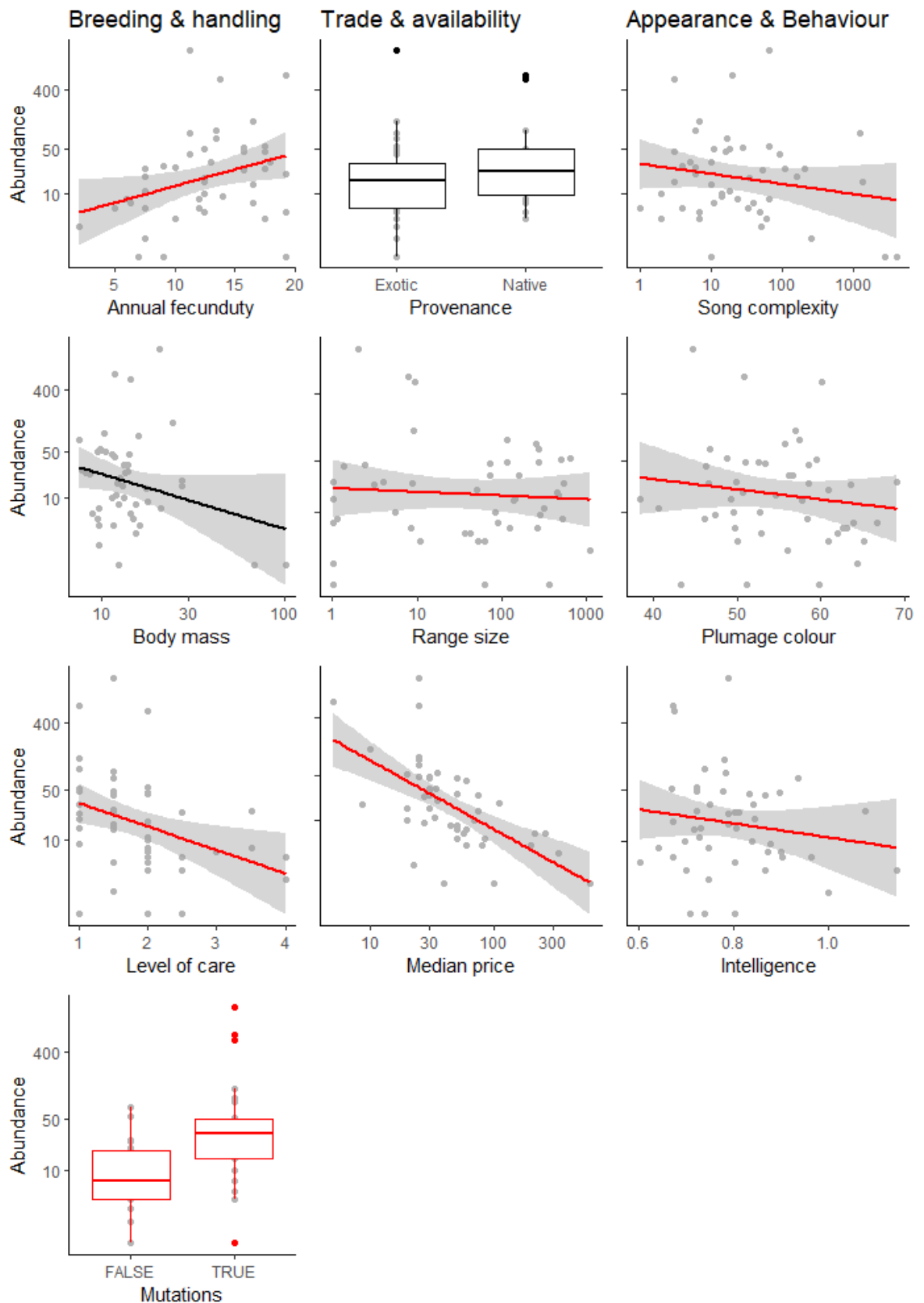


Figure SI2-4.6: Linear regression with 95% confidence intervals and boxplot prediction plots for passerine species characteristics. Characteristics which were identified to be strongly associated with species abundance by model selection are coloured red (Table SI2-4.5).

Supplementary Information 2-5

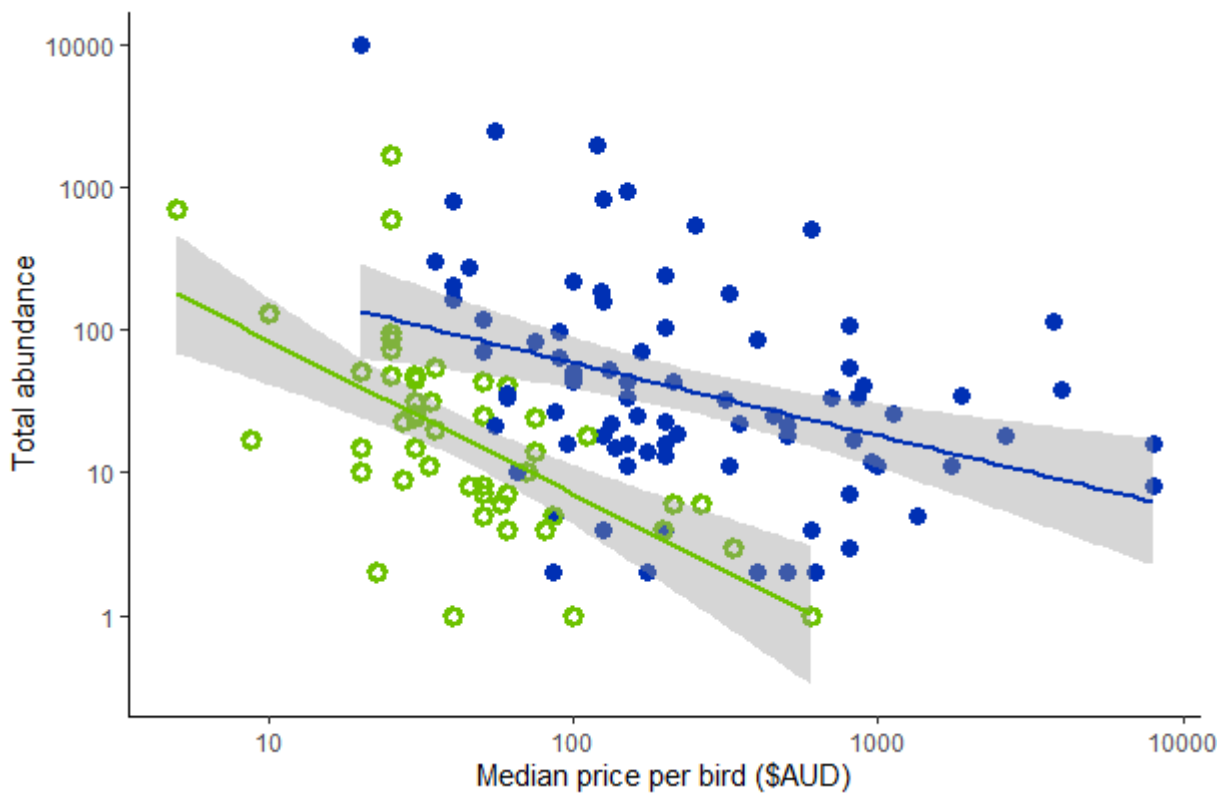


Figure SI2-5.1: Relationship between median price and number of individuals traded per species for Passeriformes (green; $R^2 = 0.364$, $F_{1,47} = 28.47$, $p < 0.001$) and Psittaciformes (blue; $R^2 = 0.14$, $F_{1,82} = 14.03$, $p < 0.001$).

Supplementary Information 3-1

Table SI3-1.1: Total number of individuals selected for analysis, collected through the Feather Forensics citizen science program. Some *Cacatua* individuals could not be identified to species, and are listed as *Cacatua spp.*

Genus	Species	Captive individuals	Wild individuals
<i>Eolophus</i>	<i>Eolophus roseicapilla</i>	17	55
<i>Cacatua</i>	<i>Cacatua galerita</i>	6	6
	<i>Cacatua sanguinea</i>	5	13
	<i>Cacatua tenuirostris</i>	2	1
	<i>Cacatua spp.</i>	0	14

Table SI1.2: Subset of individuals used to test within-individual variation, and the sample sizes of body (B), wing (W), and other (O) feathers analysed.

Genus	Species	ID	Origin	B	W	O
<i>Eolophus</i>	<i>Eolophus roseicapilla</i>	GC019	Captive	4	2	0
	<i>Eolophus roseicapilla</i>	GC020	Captive	3	2	0
	<i>Eolophus roseicapilla</i>	GC022	Captive	0	3	3
	<i>Eolophus roseicapilla</i>	GC023	Captive	3	3	3
	<i>Eolophus roseicapilla</i>	GC029	Captive	3	1	1
	<i>Eolophus roseicapilla</i>	GC031	Captive	3	1	3
	<i>Eolophus roseicapilla</i>	GW036	Wild	2	3	3
	<i>Eolophus roseicapilla</i>	GW037	Wild	3	3	3
	<i>Eolophus roseicapilla</i>	GW038	Wild	5	3	3
<i>Cacatua</i>	<i>Cacatua sanguinea</i>	DC004	Captive	3	0	3
	<i>Cacatua galerita</i>	SC056	Captive	3	3	1
	<i>Cacatua galerita</i>	SC057	Captive	3	3	4
	<i>Cacatua galerita</i>	SC059	Captive	3	4	1
	<i>Cacatua galerita</i>	SW062	Wild	3	3	0

Supplementary Information 3-2

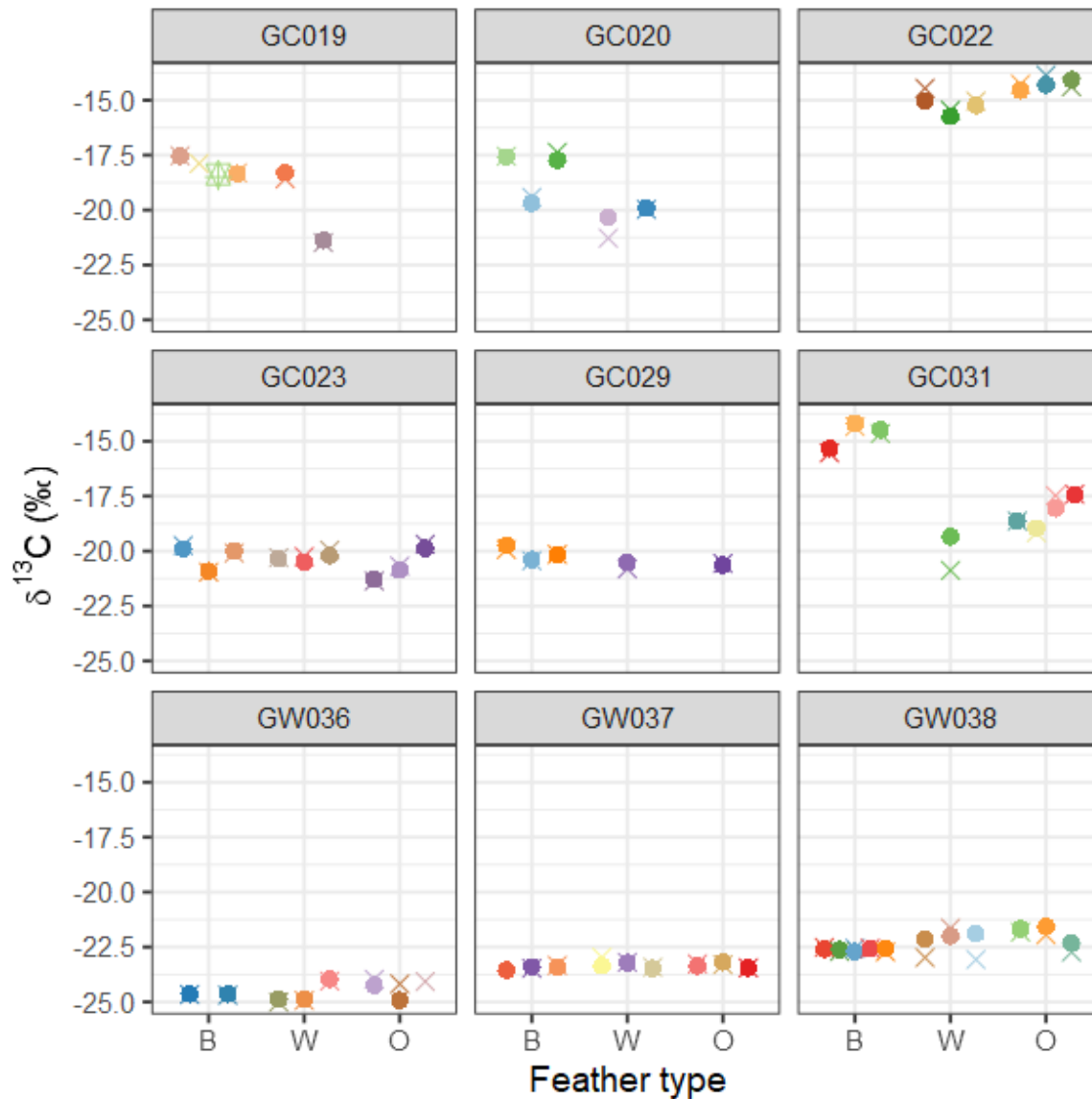


Figure SI3-2.1: $\delta^{13}\text{C}$ values from nine *Eolophus* individuals used in the pilot analysis to investigate within-individual values. From each bird, we measured $\delta^{13}\text{C}$ in three feather types: body (B), wing (W) and other (O), with replicates of each feather, represented by different colours. We measured two replicates per feather, shown with crosses and circles of matching colours.

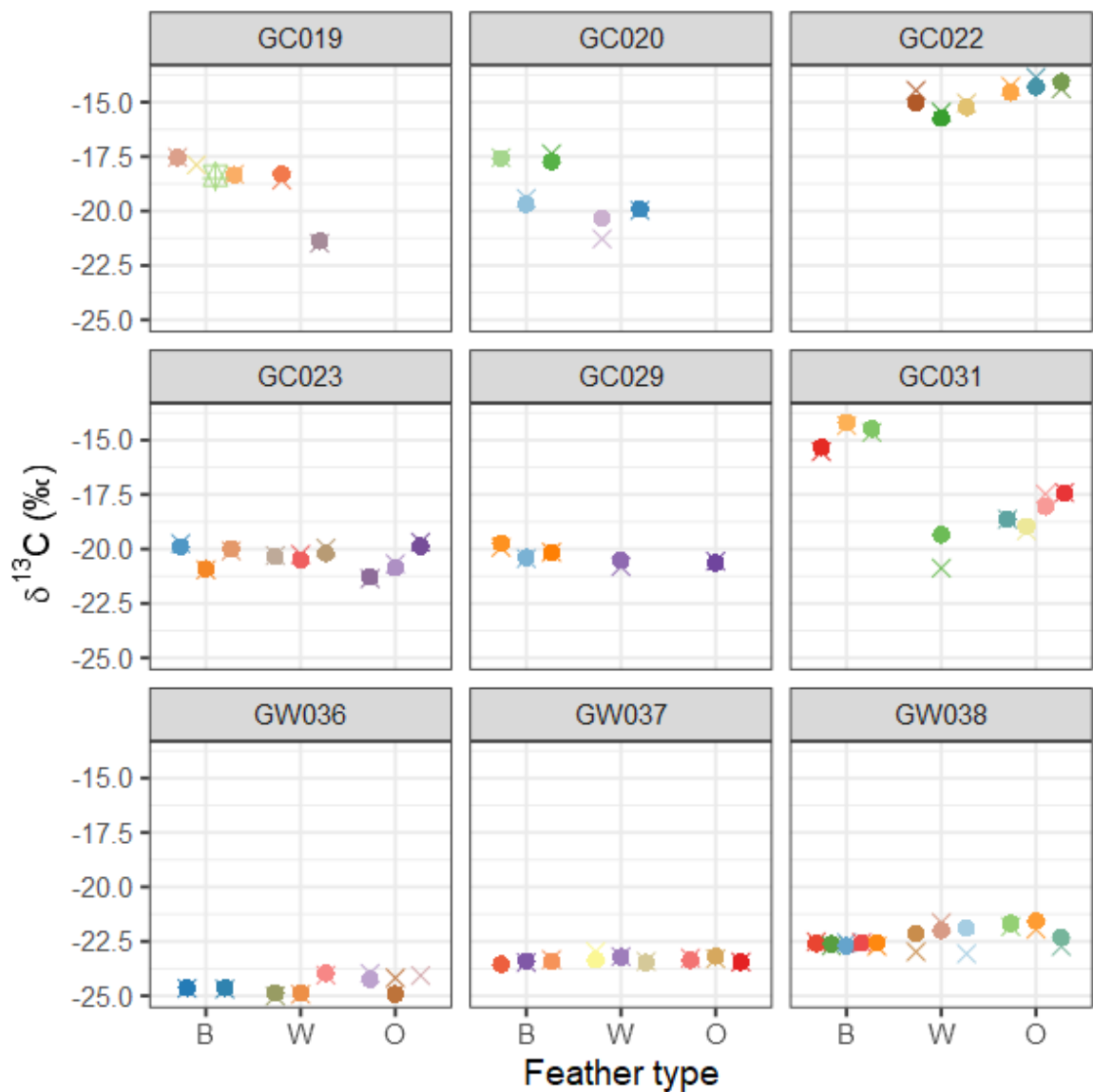


Figure SI3-2.2: $\delta^{15}\text{N}$ values from nine *Eolophus* individuals used in the pilot analysis to investigate within-individual values. From each bird, we measured $\delta^{13}\text{C}$ in three feather types: body (B), wing (W) and other (O), with replicates of each feather, represented by different colours. We measured two replicates per feather, shown with crosses and circles of matching colours.

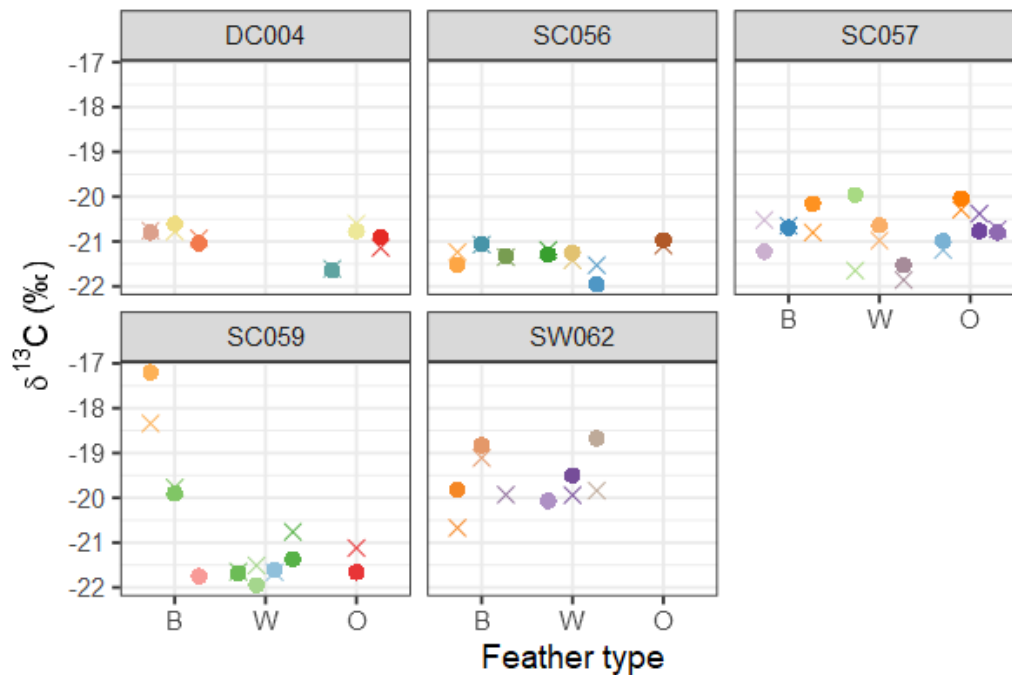


Figure SI3-2.3: $\delta^{13}\text{C}$ values from five *Cacatua* individuals used in the pilot analysis to investigate within-individual values. From each bird, we measured $\delta^{13}\text{C}$ in three feather types: body (B), wing (W) and other (O), with replicates of each feather, represented by different colours. We measured two replicates per feather, shown with crosses and circles of matching colours.

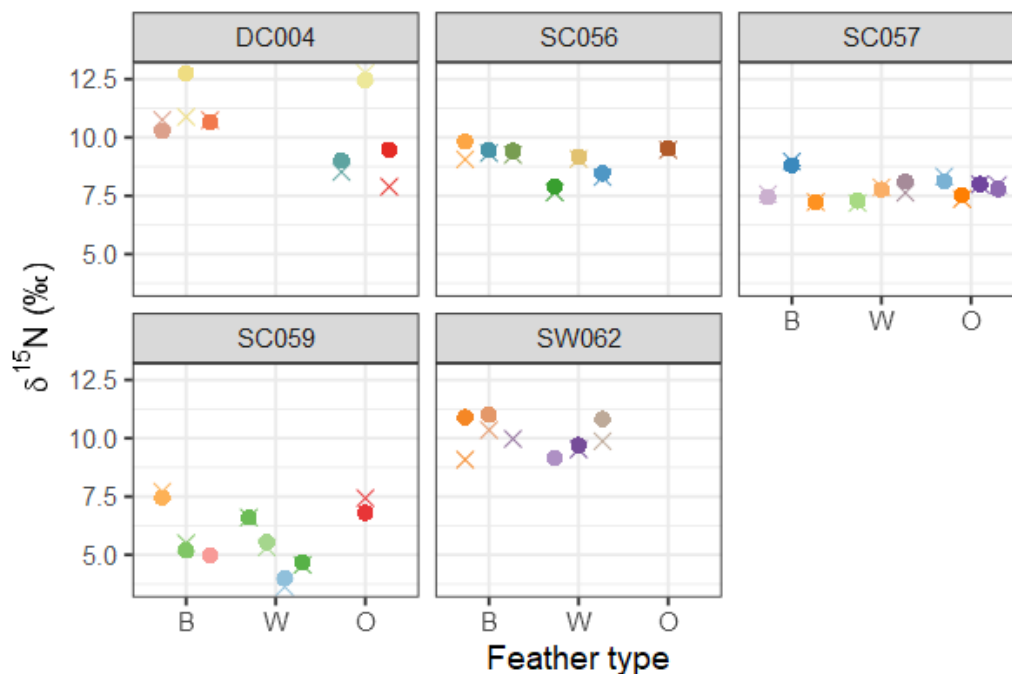


Figure SI3-2.3: $\delta^{15}\text{N}$ values from five *Cacatua* individuals used in the pilot analysis to investigate within-individual values. From each bird, we measured $\delta^{15}\text{N}$ in three feather types: body (B), wing (W) and other (O), with replicates of each feather, represented by different colours. We measured two replicates per feather, shown with crosses and circles of matching colours.

Supplementary Information 3-3

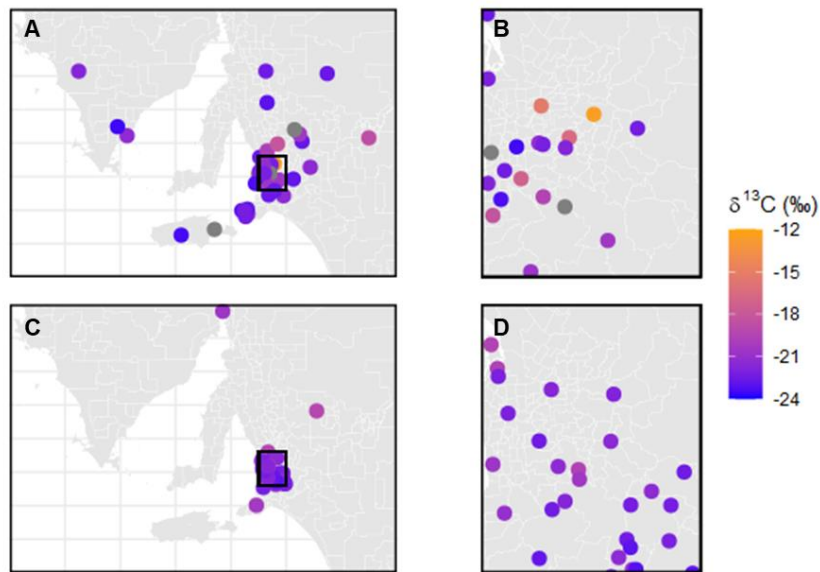


Figure SI3-3.1: $\delta^{13}\text{C}$ means for wild *Eolophus* (A & B) and *Cacatua* (C&D), mapped by the location the feather was found in South Australia (A & C), and in the City of Adelaide (B&D). As points are precise to postcode, individual points are plotted at the centroid of the postcode. We found evidence for spatial autocorrelation in *Eolophus* (Moran's $I = 0.3$, $p < 0.01$), but not for *Cacatua* ($I = 0.2$, $p = 0.06$).

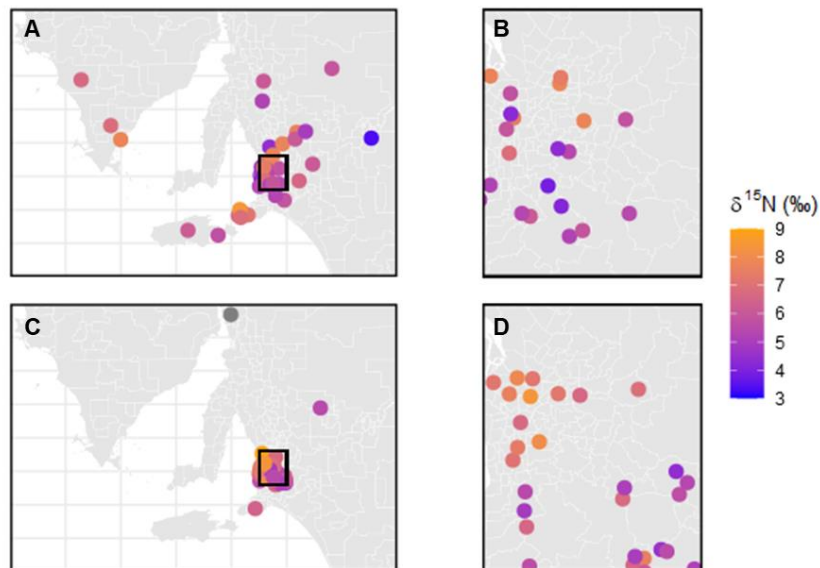


Figure SI3-3.2: $\delta^{15}\text{N}$ means for wild *Eolophus* (A & B) and *Cacatua* (C&D), mapped by the location the feather was found in South Australia (A & C), and in the City of Adelaide (B&D). As points are precise to postcode, individual points are plotted at the centroid of the postcode. We found evidence for spatial autocorrelation in *Cacatua* for $\delta^{15}\text{N}$ ($I = 0.3$, $p < 0.01$), but not *Eolophus* ($I < 0.01$, $p = 0.8$).

Supplementary Information 3-4

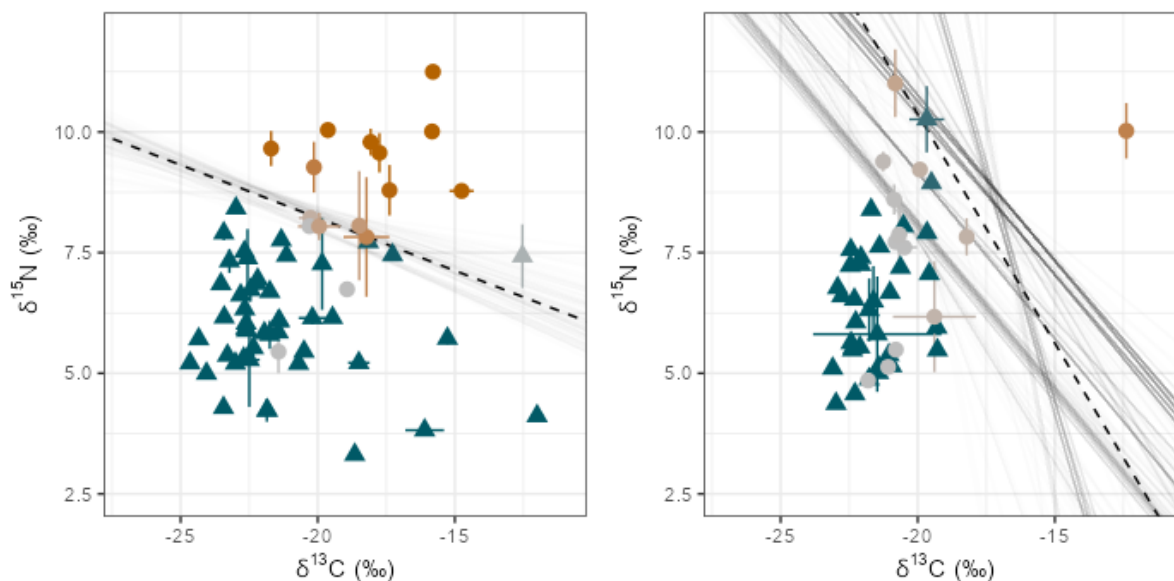


Figure SI3-4.1: Boundary lines for *Eolophus* (left) and *Cacatua* (right) from the SVM classification models, not correcting for small sample sizes (i.e., not using the Synthetic Minority Oversampling Technique). Individual means and 95% confidence intervals are coloured by their classification accuracy (light grey points = 100% incorrectly classified). The mean optimised boundary line (dashed) and all optimised boundary estimates were calculated over 1000 iterations.

Table SI3-4.1: Performance measures for linear SVM classification models, presented as means and standard deviations from over 1000 iterations. Metrics closer to 1 indicate greater model performance.

	Accuracy	Precision	Recall	F1
<i>Eolophus</i>	0.88 ± 0.02	0.73 ± 0.04	0.85 ± 0.04	0.78 ± 0.03
<i>Cacatua</i>	0.74 ± 0.03	0.53 ± 0.04	0.73 ± 0.05	0.61 ± 0.04

Supplementary information 4-1

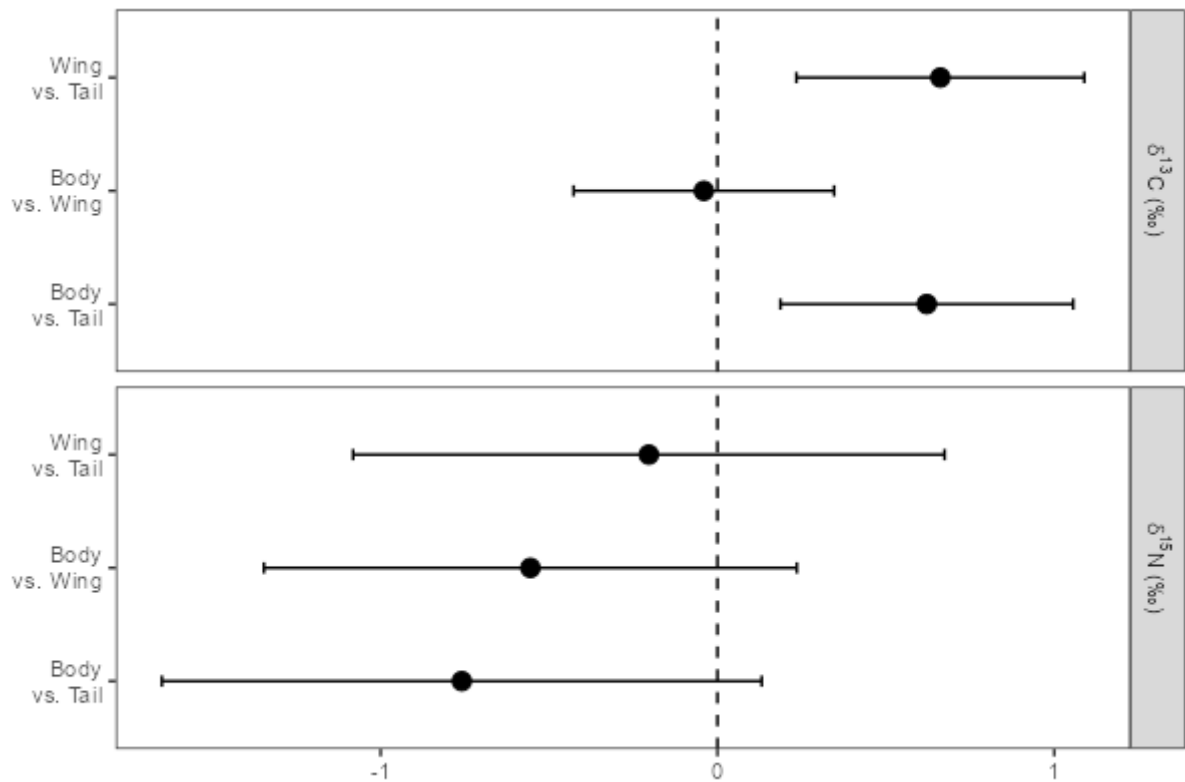


Figure SI4-1.1: Pairwise contrasts of feather types for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. Statistical support for differences in isotope concentration between the feather types are where the confidence interval for a comparison does not overlap with zero.

Supplementary information 4-2

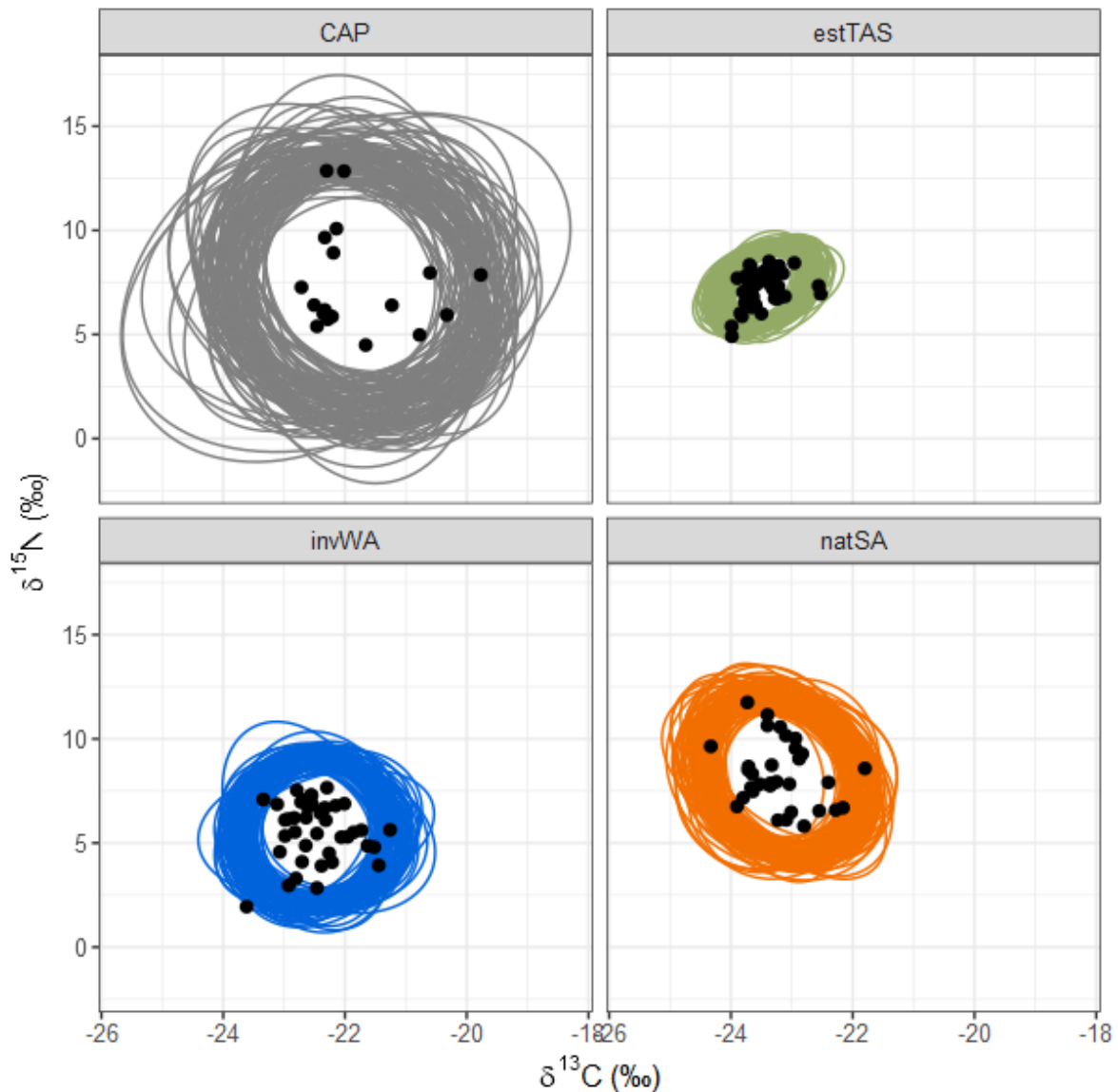


Figure SI4-2.1: Multivariate normal ellipses over 10,000 draws for the four populations: captive (CAP), the recently established Tasmanian population (estTAS), the invasive Western Australian population (invWA), and the native South Australian population (natSA). Ellipses were calculated using pooled individual means (black points).

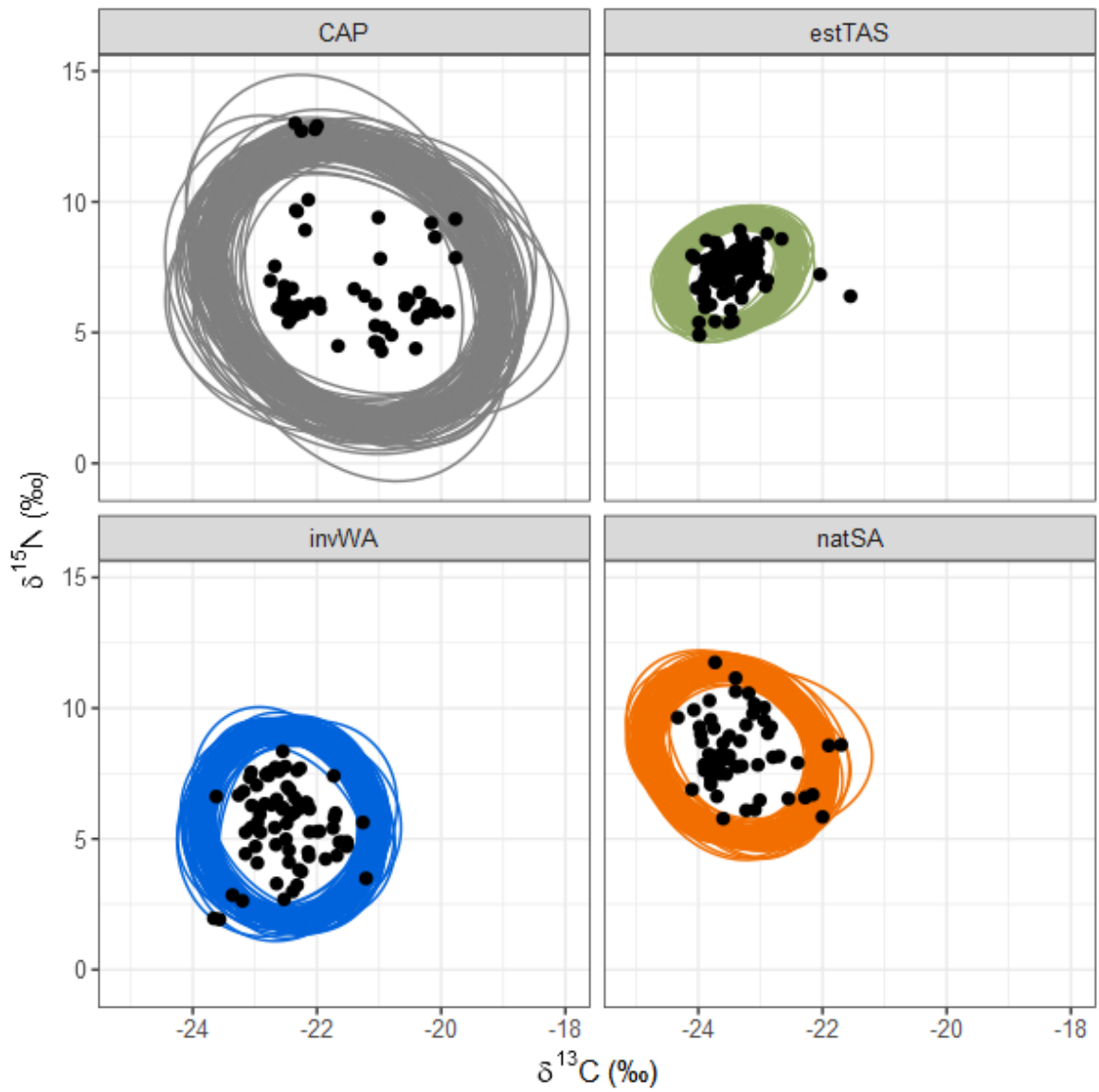


Figure SI4-2.2: Multivariate normal ellipses over 10,000 draws for the four populations: captive (CAP), the recently established Tasmanian population (estTAS), the invasive Western Australian population (invWA), and the native South Australian population (natSA). Ellipses were calculated using all, unpooled data (black points).

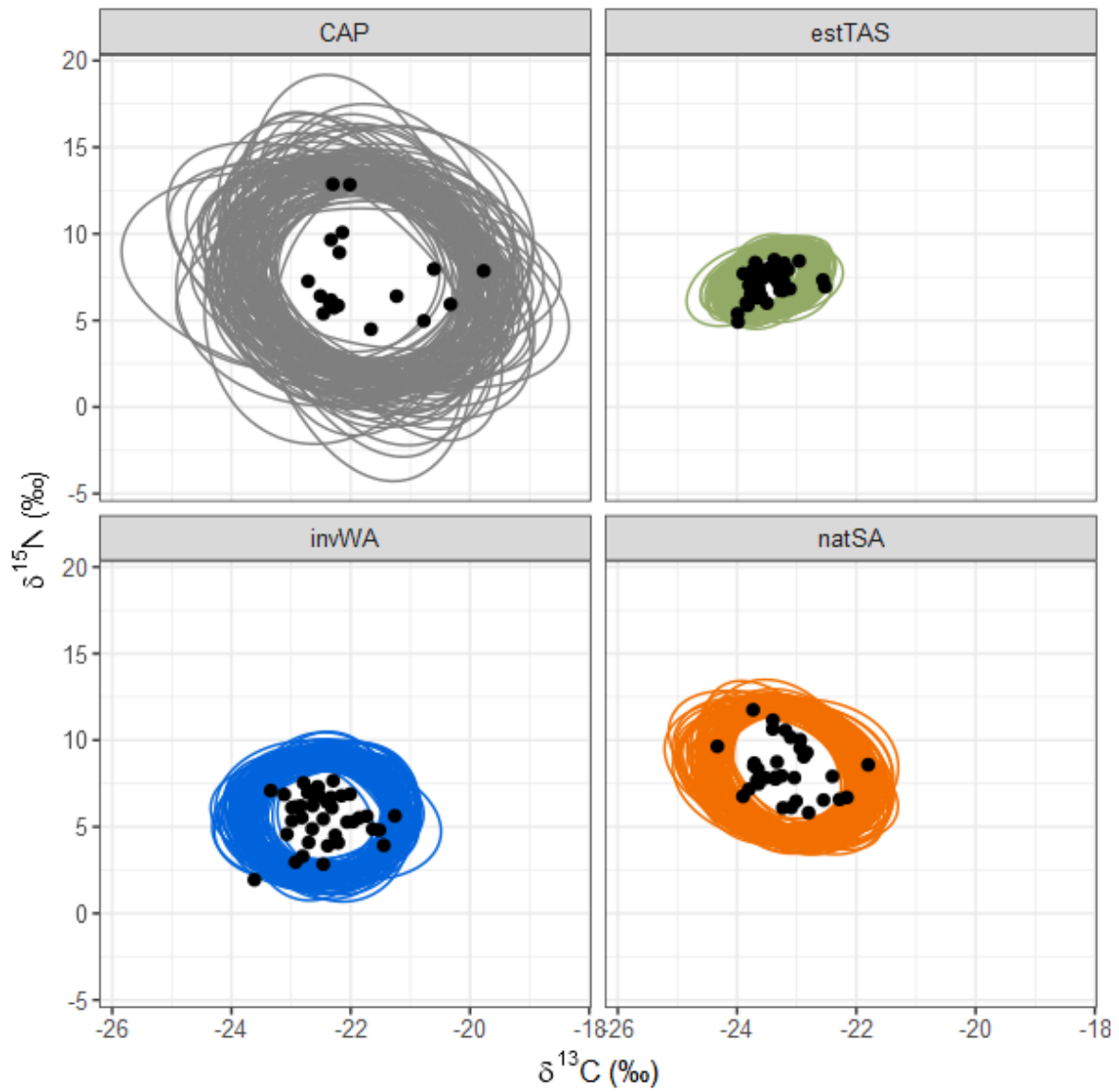


Figure SI4-2.3: Multivariate t ellipses over 10,000 draws for the four populations: captive (CAP), the recently established Tasmanian population (estTAS), the invasive Western Australian population (invWA), and the native South Australian population (natSA). Ellipses were calculated using pooled individual means (black points).

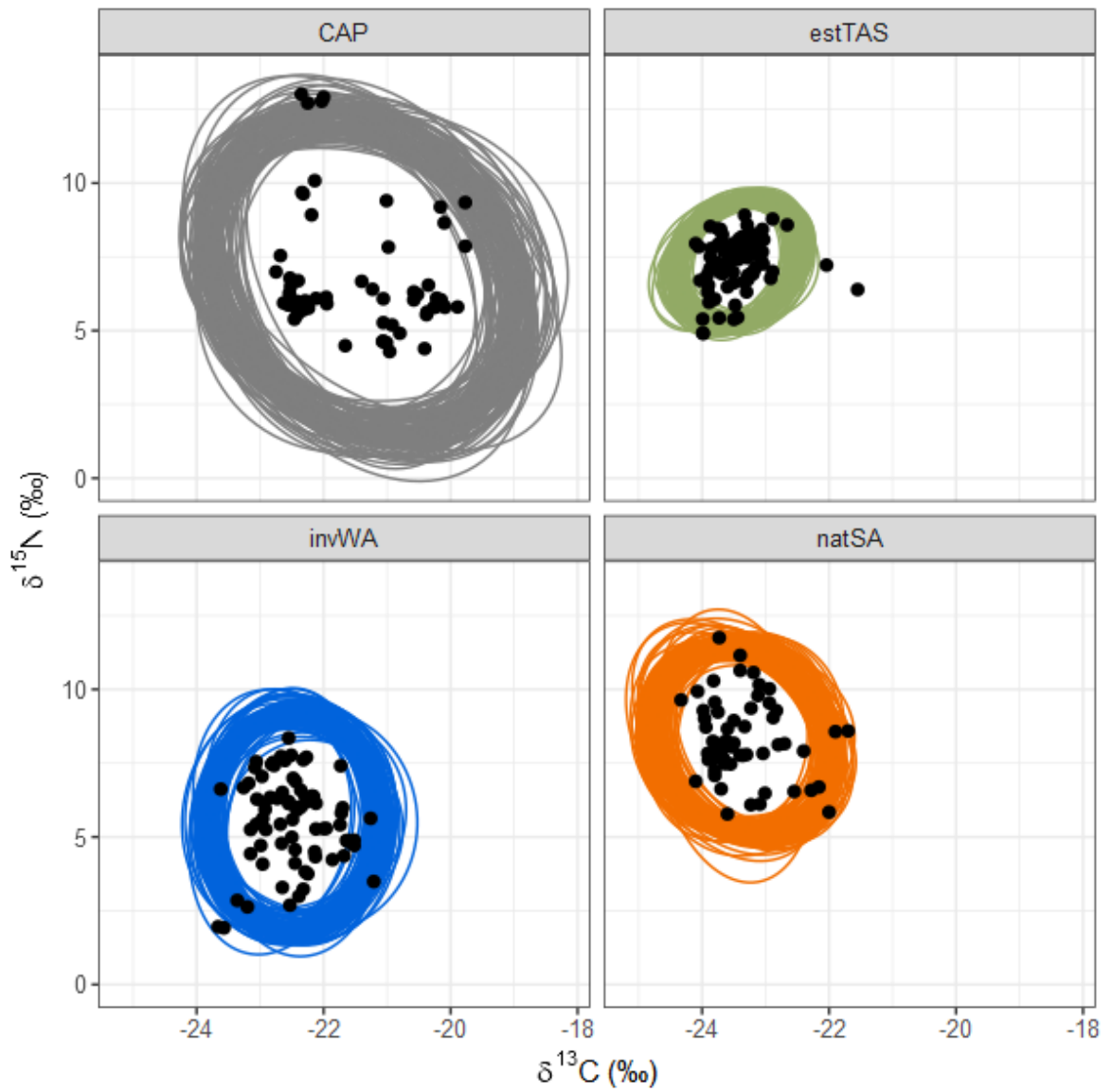


Figure SI4-2.4: Multivariate t ellipses over 10,000 draws for the four populations: captive (CAP), the recently established Tasmanian population (estTAS), the invasive Western Australian population (invWA), and the native South Australian population (natSA). Ellipses were calculated using all unpooled data (black points).

Supplementary Information 4-3

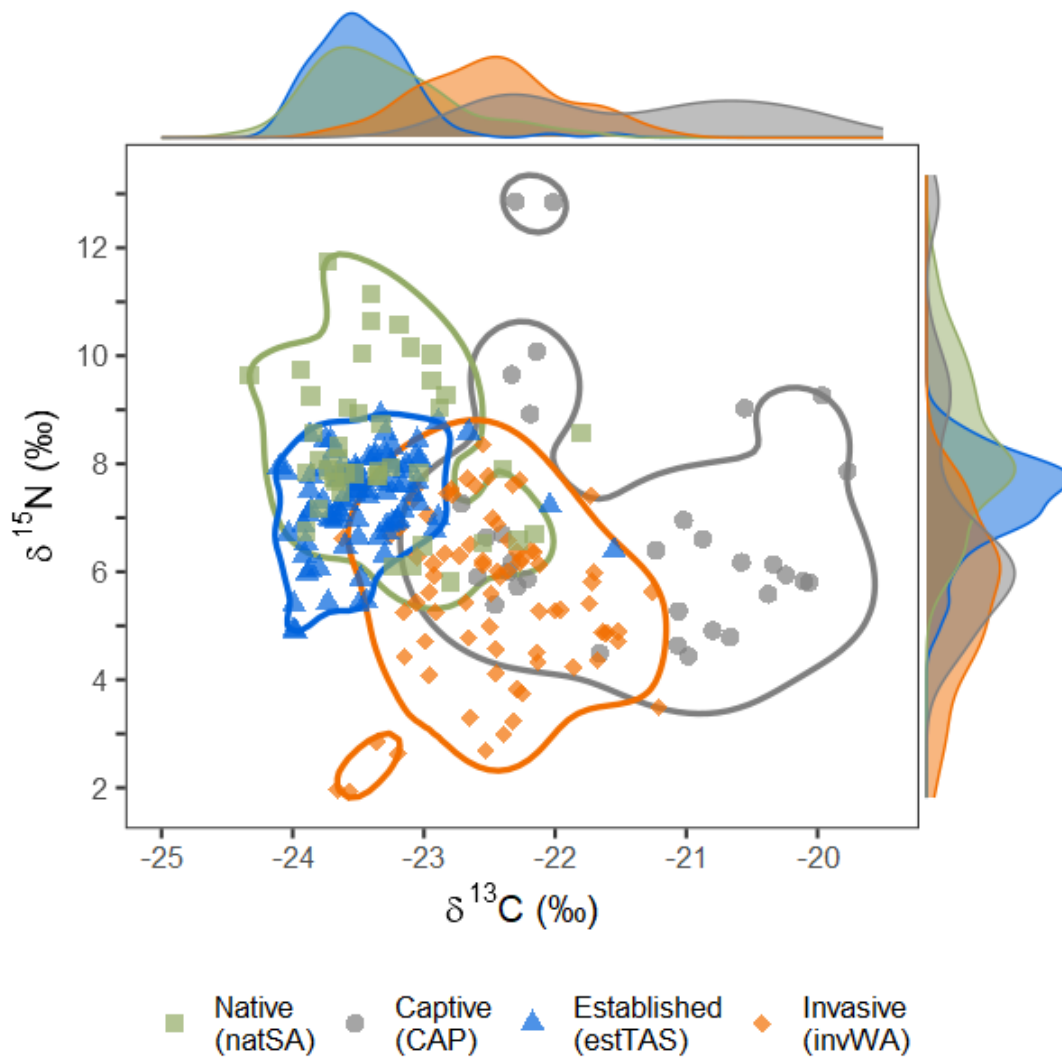


Figure SI4-3.1: Boundaries of the discriminant analysis to classify all individual feathers rather than averaging the isotope values among feathers within individual birds. Axes show density plots for each isotope.

Table SI4-3.1: Results of the discriminant analysis, using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ to classify individuals to their respective populations. Misclassified individuals are marked by an asterisk, and accuracy relates to the number of correctly classified individuals.

		Classification			
		CAP	natSA	estTAS	invWA
Population	CAP	38	0	0	19*
	natSA	0	27	26*	9*
	estTAS	0	6*	80	4*
	invWA	1*	0	6*	69

Supplementary Information 5-1

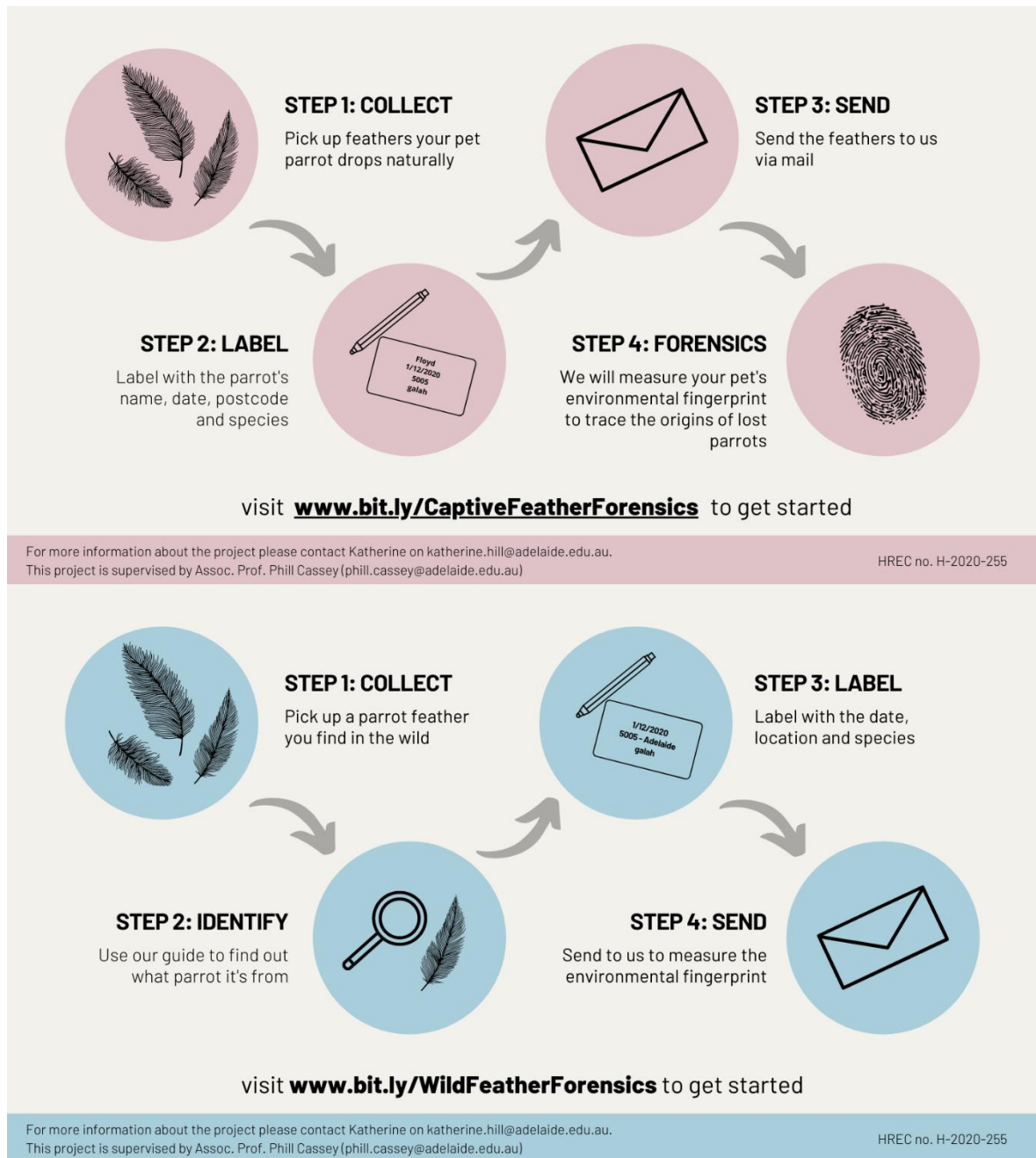


Figure SI5-1.1: Social media advertisements for the Feather Forensics citizen science project, with separate instructions for owners of captive birds (top), and members of the public (bottom).

Feather Forensics

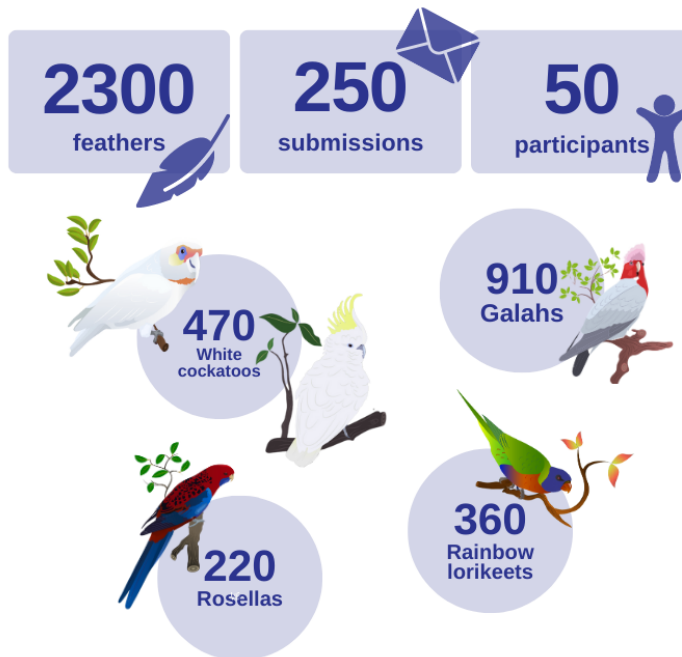
Summer 2020-21 update

Happy World Parrot Day!

Today also marks six months since we launched the Feather Forensics Project. In that time, you've helped us collect the feathers we need to create and test our forensic tool to trace the origins of lost Australian parrots.

We want to take this opportunity to say a huge thank you for your contributions to the project. We have now finished counting the submissions we received over the summer, and were overwhelmed by the number of submissions – well done to everyone for all of their hard work feather hunting!

Here's what we have so far:



But, the project doesn't end here. We are still accepting submissions, and the more feathers we receive, the more species we can add to this forensic tool!

You may have noticed that the number of feathers you find has reduced. This is because Australian parrots lose and grow new feathers over summer. However, if you or someone you know has a pet Australian parrot from the species listed above, please let them know about the project! We are still looking for feathers from captive birds.

Thank you to all that have participated so far. Your contributions are directly helping us to find ways to trace the origins of lost native Australian parrots.

We have a website!
If you would like to know more about the project, visit www.featherforensics.com

This research is supported by:



Figure SI5-1.2: Summary email provided to participants after six months of the project launch.

Full dataset of stable carbon and nitrogen isotopes of parrot feathers

The following data was collected for Chapters 3 and 4 of this thesis. Data includes deidentified metadata for feathers collected through the Feather Forensics citizen science program.

Data dictionary

FieldName	Description	Datatype
Sample	Unique identifier to sample	text
Species_group	Data subsets used in thesis	text
Species_name	Scientific species name	text
Provenance	Origin of feather; captive or wild, or for Lorikeets, population	text
ID	Unique identifier for each individual bird	text
Postcode	Postcode location of feather collection	integer
Date	Date of feather collection	Date
Feather_type	Feather type: wing (w), body (B), tail (T), crest (C), or other (O).	Text
Feather_replicate	Between-feather replicate for that feather_type	text
Replicate	Within-feather replicate for that feather_replicate	text
d13C	$\delta^{13}\text{C}$ measurement	numeric
d15N	$\delta^{15}\text{N}$ measurement	numeric
CN	C:N ratio	numeric

Sample	Species_group	Species_name	Provenance	ID	Postcode	Date	Feather_type	Feather_replicate	Replicate	d13C	d15N	CN
GC001BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC019	NA	1/10/2019	B	A	1	-17.53	9.11	2.68
GC001BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC019	NA	1/10/2019	B	A	2	-17.55	9.94	2.61
GC001BB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC019	NA	1/10/2019	B	B	1	-17.88	9.49	2.67
GCG11BC3	Galahs	<i>Eolophus roseicapilla</i>	captive	GC019	NA	19/09/2019	B	C	3	-18.50	9.83	2.90
GCG11BC4	Galahs	<i>Eolophus roseicapilla</i>	captive	GC019	NA	19/09/2019	B	C	4	-18.38	9.89	2.84
GCG11BD1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC019	NA	19/09/2019	B	D	1	-18.31	10.11	2.70
GCG11BD2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC019	NA	19/09/2019	B	D	2	-18.34	10.17	2.74
GCG11WA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC019	NA	19/09/2019	W	A	1	-21.48	9.25	2.80
GCG11WA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC019	NA	19/09/2019	W	A	2	-21.38	9.01	2.85
GC001WB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC019	NA	1/10/2019	W	B	1	-18.58	10.92	2.78
GC001WB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC019	NA	1/10/2019	W	B	2	-18.30	10.58	2.77
GCA15BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC020	5112	15/02/2022	B	A	1	-17.55	9.30	2.75
GCA15BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC020	5112	15/02/2022	B	A	2	-17.58	9.05	2.77
GCA15BB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC020	5112	15/02/2022	B	B	1	-19.42	5.77	2.82
GCA15BB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC020	5112	15/02/2022	B	B	2	-19.69	5.99	2.86
GCA15BC1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC020	5112	15/02/2022	B	C	1	-17.37	8.49	2.77
GCA15BC2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC020	5112	15/02/2022	B	C	2	-17.72	8.34	2.81
GCA15WA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC020	5112	15/02/2022	W	A	1	-21.28	6.37	2.89
GCA15WA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC020	5112	15/02/2022	W	A	2	-20.31	5.84	2.96
GCA15WB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC020	5112	15/02/2022	W	B	1	-19.97	7.15	2.86
GCA15WB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC020	5112	15/02/2022	W	B	2	-19.91	8.14	2.87
GCA16BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC021	5112	15/02/2022	B	A	1	-19.72	9.96	2.86
GCA16BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC021	5112	15/02/2022	B	A	2	-19.54	10.12	2.87
GCG13BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	B	A	1	-22.29	9.11	2.65
GCG13BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	B	A	2	-22.33	9.31	2.72
GCG13BA3	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	B	A	3	-20.20	7.83	2.64
GCG13BB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	B	B	1	-22.84	6.04	2.70
GCG13BB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	B	B	2	-22.83	5.85	2.70
GCG13BC1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	B	C	1	-22.41	5.54	2.68
GCG13BC2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	B	C	2	-22.44	5.71	2.70
GCG13OA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	O	A	1	-14.27	9.58	2.70
GCG13OA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	O	A	2	-14.55	9.38	2.70
GCG13OB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	O	B	1	-13.86	9.17	2.68
GCG13OB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	O	B	2	-14.30	8.76	2.72
GCG13OC1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	O	C	1	-14.39	8.98	2.68
GCG13OC2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	O	C	2	-14.07	8.88	2.69
GCG13WA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	W	A	1	-14.46	9.59	2.73
GCG13WA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	W	A	2	-15.05	9.53	2.73
GCG13WB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	W	B	1	-15.46	9.10	2.78
GCG13WB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	W	B	2	-15.73	8.95	2.74
GCG13WC1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	W	C	1	-15.04	7.98	2.71
GCG13WC2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC022	5022	NA	W	C	2	-15.24	8.34	2.68
GCU03BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	B	A	1	-19.75	8.31	2.64
GCU03BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	B	A	2	-19.89	8.19	2.68
GCU03BB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	B	B	1	-20.96	7.97	2.68
GCU03BB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	B	B	2	-20.91	8.22	2.73
GCU03BC1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	B	C	1	-20.09	8.13	2.69
GCU03BC2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	B	C	2	-20.00	8.50	2.70
GCU03OA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	O	A	1	-21.36	7.79	2.78
GCU03OA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	O	A	2	-21.28	8.32	2.75
GCU03OB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	O	B	1	-20.68	8.39	2.73
GCU03OB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	O	B	2	-20.87	8.33	2.68
GCU03OC1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	O	C	1	-19.69	8.22	2.66
GCU03OC2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	O	C	2	-19.87	8.39	2.66
GCU03WA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	W	A	1	-20.30	8.29	2.73
GCU03WA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	W	A	2	-20.35	8.49	2.71
GCU03WB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	W	B	1	-20.25	8.76	2.71

GCU03WB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	W	B	2	-20.49	8.49	2.75
GCU03WC1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	W	C	1	-19.96	8.22	2.70
GCU03WC2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC023	5064	11/02/2021	W	C	2	-20.20	8.59	2.80
GCG04BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC024	NA	3/04/2018	B	A	1	-21.40	5.67	2.68
GCG04BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC024	NA	3/04/2018	B	A	2	-21.46	5.22	2.66
GCC13BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC025	5067	1/07/2021	B	A	1	-20.30	8.05	2.75
GCG14BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC026	NA	NA	B	A	2	-15.83	10.01	2.69
GCG06BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC027	NA	2/03/2018	B	A	2	-18.93	6.74	2.67
GCG02BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC028	5038	1/03/2018	B	A	1	-17.50	9.27	2.73
GCG03BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC028	5038	14/03/2018	B	A	1	-17.50	9.23	2.73
GCG02BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC028	5038	1/03/2018	B	A	2	-17.13	8.24	2.63
GCG03BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC028	5038	14/03/2018	B	A	2	-17.40	8.43	2.68
GCC02BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC029	5232	1/12/2021	B	A	1	-19.93	9.79	2.80
GCC02BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC029	5232	1/12/2021	B	A	2	-19.74	9.69	2.81
GCC02BB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC029	5232	1/12/2021	B	B	1	-20.44	8.53	2.82
GCC02BB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC029	5232	1/12/2021	B	B	2	-20.39	8.33	2.83
GCC02BC1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC029	5232	1/12/2021	B	C	1	-20.15	9.61	2.83
GCC02BC2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC029	5232	1/12/2021	B	C	2	-20.18	9.67	2.83
GCC02OA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC029	5232	1/12/2021	O	A	1	-20.56	9.12	2.86
GCC02OA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC029	5232	1/12/2021	O	A	2	-20.63	8.88	2.85
GCC02WA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC029	5232	1/12/2021	W	A	1	-20.81	8.27	2.92
GCC02WA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC029	5232	1/12/2021	W	A	2	-20.52	9.26	2.89
GCG08BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC030	NA	1/03/2019	B	A	1	-17.80	9.78	2.68
GCG08BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC030	NA	1/03/2019	B	A	2	-17.70	9.36	2.61
GC005BD1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	5082	13/11/2019	B	D	1	-15.53	8.74	2.74
GC005BD2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	5082	13/11/2019	B	D	2	-15.33	8.59	2.73
GC005BE1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	5082	13/11/2019	B	E	1	-14.33	8.75	2.74
GC005BE2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	5082	13/11/2019	B	E	2	-14.19	8.77	2.71
GC005BF1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	5082	13/11/2019	B	F	1	-14.65	8.89	2.69
GC005BF2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	5082	13/11/2019	B	F	2	-14.48	8.93	2.78
GC004OA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	NA	14/10/2019	O	A	1	-18.63	6.96	2.74
GC004OA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	NA	14/10/2019	O	A	2	-18.63	6.90	2.69
GC004OB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	NA	14/10/2019	O	B	1	-19.16	6.71	2.72
GC005OB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	5082	13/11/2019	O	B	1	-17.48	8.25	2.81
GC004OB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	NA	14/10/2019	O	B	2	-18.96	6.91	2.75
GC005OB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	5082	13/11/2019	O	B	2	-18.06	7.92	2.80
GC005OC1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	5082	13/11/2019	O	C	1	-17.41	9.57	2.93
GC005OC2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	5082	13/11/2019	O	C	2	-17.43	9.23	2.84
GC005WA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	5082	13/11/2019	W	A	1	-20.88	6.36	2.83
GC005WA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC031	5082	13/11/2019	W	A	2	-19.35	7.10	2.98
GCG09BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC032	NA	1/03/2019	B	A	1	-18.40	8.64	2.67
GCG09BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC032	NA	1/03/2019	B	A	2	-18.57	7.48	2.68
GCC14BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC033	NA	1/01/2022	B	A	1	-15.80	11.25	2.72
GCA08BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC034	5114	15/02/2022	B	A	1	-20.59	7.86	2.77
GCA08BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC034	5114	15/02/2022	B	A	2	-20.66	7.59	2.74
GCA08BA4	Galahs	<i>Eolophus roseicapilla</i>	captive	GC034	5114	15/02/2022	B	A	4	-20.98	7.51	2.81
GCA08BA5	Galahs	<i>Eolophus roseicapilla</i>	captive	GC034	5114	15/02/2022	B	A	5	-21.11	7.56	2.81
GCA08BB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC034	5114	15/02/2022	B	B	1	-18.53	8.44	2.75
GCA08BB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC034	5114	15/02/2022	B	B	2	-18.60	8.49	2.80
GCA08BB4	Galahs	<i>Eolophus roseicapilla</i>	captive	GC034	5114	15/02/2022	B	B	4	-18.39	8.50	2.88
GCA08BB5	Galahs	<i>Eolophus roseicapilla</i>	captive	GC034	5114	15/02/2022	B	B	5	-18.53	8.72	2.84
GCA08BC1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC034	5114	15/02/2022	B	C	1	-21.17	7.79	2.82
GCA08BC2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC034	5114	15/02/2022	B	C	2	-20.90	7.97	2.84
GCG07BA1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC035	NA	2/03/2018	B	A	1	-21.70	9.98	2.71
GCG07BA2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC035	NA	2/03/2018	B	A	2	-21.61	9.22	2.70
GCG07BB1	Galahs	<i>Eolophus roseicapilla</i>	captive	GC035	NA	2/03/2018	B	B	1	-21.70	9.95	2.75
GCG07BB2	Galahs	<i>Eolophus roseicapilla</i>	captive	GC035	NA	2/03/2018	B	B	2	-21.79	9.48	2.73
GWN54BD1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	B	D	1	-24.66	5.21	2.68

GWN54BD2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	B	D	2	-24.64	5.11	2.70
GWN54BE1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	B	E	1	-24.69	5.21	2.77
GWN54BE2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	B	E	2	-24.64	5.31	2.75
GWN54TA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	T	A	1	-23.97	5.01	2.72
GWN54TA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	T	A	2	-24.24	5.15	2.73
GWN54TB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	T	B	1	-24.18	5.06	2.68
GWN54TB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	T	B	2	-24.92	5.26	2.75
GWN54TC1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	T	C	1	-24.07	4.86	2.75
GWN54TC2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	T	C	2	-24.12	5.28	3.44
GWN54WA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	W	A	1	-25.01	5.41	2.78
GWN54WA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	W	A	2	-24.87	5.35	2.70
GWN54WB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	W	B	1	-24.93	5.35	2.81
GWN54WB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	W	B	2	-24.87	5.29	2.80
GWN54WC1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	W	C	1	-24.05	5.09	2.71
GWN54WC2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW036	5047	29/01/2021	W	C	2	-23.97	4.98	2.70
GWF36BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	B	A	2	-23.55	4.41	3.01
GWF36BB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	B	B	1	-23.47	4.27	2.82
GWF36BB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	B	B	2	-23.40	4.36	2.83
GWF36BC1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	B	C	1	-23.34	4.34	2.76
GWF36BC2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	B	C	2	-23.42	4.05	2.82
GWF36OA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	O	A	1	-23.27	4.68	2.84
GWF36OA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	O	A	2	-23.36	4.43	2.82
GWF36OB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	O	B	1	-23.30	4.34	2.87
GWF36OB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	O	B	2	-23.19	4.85	2.79
GWF36OC1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	O	C	1	-23.45	4.64	2.78
GWF36OC2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	O	C	2	-23.45	4.67	2.80
GWF36WA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	W	A	1	-22.97	4.36	2.85
GWF36WA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	W	A	2	-23.35	4.53	2.85
GWF36WB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	W	B	1	-23.20	4.35	2.85
GWF36WB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	W	B	2	-23.22	4.66	2.80
GWF36WC1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	W	C	1	-23.42	4.80	2.92
GWF36WC2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW037	5118	2/10/2018	W	C	2	-23.47	4.70	2.88
GWN52BD1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	B	D	1	-22.52	6.07	2.70
GWN52BD2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	B	D	2	-22.60	6.13	2.76
GWN52BE1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	B	E	1	-22.70	6.06	2.81
GWN52BE2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	B	E	2	-22.61	6.14	2.75
GWN52BF1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	B	F	1	-22.56	6.19	2.67
GWN52BF2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	B	F	2	-22.70	5.99	2.68
GWN52BG1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	B	G	1	-22.56	5.98	2.80
GWN52BG2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	B	G	2	-22.58	5.88	2.76
GWN52BH1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	B	H	1	-22.72	5.81	2.67
GWN52BH2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	B	H	2	-22.57	6.08	2.67
GWN52TA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	T	A	1	-21.82	4.87	2.67
GWN52TA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	T	A	2	-21.68	5.00	2.66
GWN52TB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	T	B	1	-21.94	4.97	2.67
GWN52TB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	T	B	2	-21.56	4.95	2.74
GWN52TC1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	T	C	1	-22.73	5.65	2.79
GWN52TC2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	T	C	2	-22.32	5.21	2.70
GWN52WA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	W	A	1	-22.98	6.28	2.84
GWN52WA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	W	A	2	-22.14	5.32	2.76
GWN52WB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	W	B	1	-21.64	5.11	2.70
GWN52WB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	W	B	2	-22.00	5.39	2.75
GWN52WC1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	W	C	1	-23.07	6.15	2.73
GWN52WC2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW038	5454	21/08/2020	W	C	2	-21.89	5.28	2.73
GWC11BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW070	5132	18/02/2021	B	A	1	-12.50	7.76	2.76
GWC11BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW070	5132	18/02/2021	B	A	2	-12.57	7.09	2.73
GWC12BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW071	5107	18/02/2021	B	A	1	-22.60	7.69	2.70
GWC12BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW071	5107	18/02/2021	B	A	2	-22.52	7.08	2.66

GWC21BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW073	5076	21/02/2021	B	A	1	-22.30	5.77	2.68
GWC21BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW073	5076	21/02/2021	B	A	2	-22.69	4.78	2.68
GWC27BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW074	5333	17/05/2021	B	A	1	-18.70	3.34	2.66
GWC27BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW074	5333	17/05/2021	B	A	2	-18.60	3.29	2.65
GWC32BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW075	5042	6/05/2021	B	A	1	-18.30	5.22	2.66
GWC32BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW075	5042	6/05/2021	B	A	2	-18.70	5.22	2.65
GWC39BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW076	5118	9/04/2021	B	A	2	-19.78	6.78	2.68
GWC39BA3	Galahs	<i>Eolophus roseicapilla</i>	wild	GW076	5118	9/04/2021	B	A	3	-19.90	7.75	2.65
GWC40BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW077	2650	28/03/2022	B	A	1	-21.80	5.65	2.67
GWC40BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW077	2650	28/03/2022	B	A	2	-21.70	5.95	2.65
GWC47ABA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW078	5153	18/04/2022	B	A	2	-20.50	5.45	2.64
GWF01WA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW079	6443	30/11/2019	W	A	1	-23.39	7.12	2.85
GWF01WA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW079	6443	30/11/2019	W	A	2	-22.86	7.16	2.88
GWF01WB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW080	6443	30/11/2019	W	B	1	-23.13	8.24	2.85
GWF01WB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW080	6443	30/11/2019	W	B	2	-23.32	7.66	2.84
GWF01WC1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW081	6443	30/11/2019	W	C	1	-22.40	9.88	2.87
GWF01WC2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW081	6443	30/11/2019	W	C	2	-22.04	10.04	2.77
GWF01WD1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW082	6443	30/11/2019	W	D	1	-21.86	9.06	2.86
GWF01WD2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW082	6443	30/11/2019	W	D	2	-18.40	5.64	2.82
GWF07WA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW083	5006	20/01/2021	W	A	1	-21.60	6.31	2.84
GWF07WA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW083	5006	20/01/2021	W	A	2	-21.75	6.93	2.89
GWF11BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW084	5360	25/12/2020	B	A	1	-18.15	7.72	2.76
GWF34ABA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW085	5605	16/04/2021	B	A	1	-21.33	7.76	2.58
GWF34BBA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW086	5607	13/04/2021	B	A	1	-23.53	6.85	2.57
GWF34CBA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW087	5670	14/04/2021	B	A	1	-21.75	6.69	2.59
GWF44BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW088	5221	11/12/2021	B	A	1	-24.34	5.71	2.51
GWF46BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW089	5223	21/11/2021	B	A	1	-23.41	6.16	2.50
GWG04BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW090	5038	NA	B	A	1	-17.27	7.45	2.51
GWG05BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW091	5238	1/12/2019	B	A	2	-21.40	6.09	2.63
GWH02WA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW092	5052	27/10/2020	W	A	1	-21.93	7.09	2.87
GWH02WA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW092	5052	27/10/2020	W	A	2	-20.85	6.47	2.87
GWH19BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW093	5061	13/01/2020	B	A	1	-15.33	5.78	2.77
GWH19BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW093	5061	13/01/2020	B	A	2	-15.21	5.66	2.69
GWH20BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW094	5051	9/11/2019	B	A	1	-16.46	3.85	2.71
GWH20BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW094	5051	9/11/2019	B	A	2	-15.74	3.79	2.62
GWH20BB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW095	5051	9/11/2019	B	B	1	-11.88	4.12	2.69
GWH20BB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW095	5051	9/11/2019	B	B	2	-12.12	4.11	2.68
GWH30WA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW096	5052	4/12/2020	W	A	1	-18.89	5.26	2.92
GWH30WA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW096	5052	4/12/2020	W	A	2	-22.14	6.09	2.88
GWH35WA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW097	5052	15/11/2020	W	A	1	-22.15	6.17	2.96
GWH35WA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW097	5052	15/11/2020	W	A	2	-22.06	6.24	2.96
GWH36BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW098	5051	15/03/2021	B	A	1	-19.46	6.15	2.64
GWK16BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW099	5000	12/12/2019	B	A	1	-23.47	7.83	2.72
GWK16BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW099	5000	12/12/2019	B	A	2	-23.38	7.98	2.72
GWK18BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW100	5000	21/11/2019	B	A	1	-22.02	5.90	2.70
GWK18BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW100	5000	21/11/2019	B	A	2	-21.87	5.77	2.75
GWK18BB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW101	5000	21/11/2019	B	B	1	-22.38	5.41	2.71
GWK18BB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW101	5000	21/11/2019	B	B	2	-22.31	5.64	2.69
GWK22BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW102	5255	19/02/2020	B	A	1	-21.44	5.85	2.67
GWK23BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW103	5000	11/07/2020	B	A	1	-21.78	4.35	2.66
GWK23BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW103	5000	11/07/2020	B	A	2	-21.93	4.11	2.67
GWK23BB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW104	5000	11/07/2020	B	B	1	-21.84	4.26	2.69
GWK23BB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW104	5000	11/07/2020	B	B	2	-21.84	4.21	2.71
GWK25BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW105	5000	7/11/2019	B	A	1	-21.14	7.44	2.71
GWK37BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW106	5356	14/04/2021	B	A	1	-22.71	7.57	2.71
GWK37BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW106	5356	14/04/2021	B	A	2	-22.63	7.47	2.80
GWK37BB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW107	5356	14/04/2021	B	B	1	-20.45	6.08	2.78
GWK37BB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW107	5356	14/04/2021	B	B	2	-19.94	6.21	2.70

GWK37BC1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW108	5356	14/04/2021	B	C	1	-24.07	4.94	2.70
GWK37BC2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW108	5356	14/04/2021	B	C	2	-24.04	5.05	2.67
GWK46BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW109	5417	1/02/2021	B	A	1	-22.62	5.93	2.69
GWK49BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW110	5254	1/09/2021	B	A	1	-22.81	6.62	2.66
GWN24BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW111	5161	31/12/2020	B	A	1	-23.29	5.37	2.61
GWN30BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW112	5204	31/12/2020	B	A	1	-21.41	6.10	2.75
GWN30BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW112	5204	31/12/2020	B	A	2	-21.44	6.07	2.67
GWN30BB1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW113	5204	31/12/2020	B	B	1	-22.31	6.61	2.65
GWN30BB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW113	5204	31/12/2020	B	B	2	-22.59	6.85	2.68
GWN30BC1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW114	5204	31/12/2020	B	C	1	-23.17	7.20	2.70
GWN30BC2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW114	5204	31/12/2020	B	C	2	-23.27	7.45	2.68
GWN30BD1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW115	5204	31/12/2020	B	D	1	-22.99	8.46	2.74
GWN30BD2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW115	5204	31/12/2020	B	D	2	-22.97	8.38	2.67
GWN30BE1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW116	5204	31/12/2020	B	E	1	-22.27	6.86	2.66
GWN30BE2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW116	5204	31/12/2020	B	E	2	-22.20	6.86	2.67
GWN53BA1	Galahs	<i>Eolophus roseicapilla</i>	wild	GW117	5047	29/01/2021	B	A	1	-22.19	6.89	2.73
GWN53BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW117	5047	29/01/2021	B	A	2	-22.19	7.00	2.73
GWN74BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW118	5157	14/01/2022	B	A	2	-20.70	5.20	2.71
GWN76BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW119	5201	5/12/2021	B	A	2	-22.70	5.31	2.62
GWN76BB2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW120	5201	5/12/2021	B	B	2	-22.60	5.88	2.70
GWN78BA2	Galahs	<i>Eolophus roseicapilla</i>	wild	GW121	5453	2/04/2022	B	A	2	-23.00	5.20	2.61
GWC20CBA1	Galahs	NA	wild	GW072	NA	NA	B	A	1	-22.66	6.33	2.60
MWK46BA1	Lorikeets	<i>Glossopsitta concinna</i>	wild	MW151	5000	1/02/2021	B	A	1	-23.24	9.56	2.85
LCC06BA1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040A	5025	7/12/2021	B	A	1	-22.32	9.63	2.80
LCC06BA2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040A	5025	7/12/2021	B	A	2	-22.34	9.68	2.81
LCC06BB1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040B	5025	7/12/2021	B	B	1	-22.25	12.71	2.90
LCC06BB2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040B	5025	7/12/2021	B	B	2	-22.35	13.01	2.90
LCC06BC1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040C	5025	7/12/2021	B	C	1	-22.03	12.77	2.81
LCC06BC2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040C	5025	7/12/2021	B	C	2	-22.00	12.91	2.81
LCC06TA1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040D	5025	7/12/2021	T	A	1	-22.92	8.21	2.95
LCC06TA2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040D	5025	7/12/2021	T	A	2	-22.84	7.94	2.99
LCC06WA1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040E	5025	7/12/2021	W	A	1	-22.75	6.99	2.92
LCC06WA2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040E	5025	7/12/2021	W	A	2	-22.68	7.54	2.88
LCC06WB1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040F	5025	7/12/2021	W	B	1	-23.98	5.62	2.88
LCC06WB2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040F	5025	7/12/2021	W	B	2	-24.01	5.41	2.88
LCC06WC1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040G	5025	7/12/2021	W	C	1	-22.12	6.09	2.97
LCC06WC2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC040G	5025	7/12/2021	W	C	2	-22.54	6.26	2.93
LCS02BA1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC041	4151	1/02/2021	B	A	1	-20.16	9.19	2.76
LCS02BA2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC041	4151	1/02/2021	B	A	2	-19.77	9.34	2.68
LCS02TA1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC041	4151	1/02/2021	T	A	1	-19.30	7.08	2.98
LCS02TA2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC041	4151	1/02/2021	T	A	2	-20.96	10.14	2.91
LCS02TB1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC041	4151	1/02/2021	T	B	1	-21.43	8.76	2.96
LCS02TB2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC041	4151	1/02/2021	T	B	2	-21.29	8.65	2.89
LCS02WA1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC041	4151	1/02/2021	W	A	1	-20.10	8.65	2.66
LCS02WA2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC041	4151	1/02/2021	W	A	2	-21.01	9.40	2.75
LCS02WB1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC041	4151	1/02/2021	W	B	1	-21.40	6.67	2.79
LCS02WB2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC041	4151	1/02/2021	W	B	2	-20.35	6.54	2.74
LCS02WC1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC041	4151	1/02/2021	W	C	1	-20.98	7.83	2.70
LCS02WC2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC041	4151	1/02/2021	W	C	2	-21.06	6.08	2.80
LCA10TA1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC042	5112	15/02/2022	T	A	1	-22.25	6.43	2.96
LCA10TA2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC042	5112	15/02/2022	T	A	2	-22.55	6.20	2.91
LCA03BA1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC043	5095	15/02/2022	B	A	1	-22.63	5.94	2.82
LCA03BA2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC043	5095	15/02/2022	B	A	2	-22.56	5.87	2.83
LCA03BB1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC043	5095	15/02/2022	B	B	1	-22.53	6.78	2.90
LCA03BB2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC043	5095	15/02/2022	B	B	2	-22.52	6.50	2.88
LCA03BC1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC043	5095	15/02/2022	B	C	1	-22.40	6.69	2.86
LCA03BC2	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC043	5095	15/02/2022	B	C	2	-22.59	7.33	2.57
LCA04BA1	Lorikeets	<i>Trichoglossus moluccanus</i>	captive	LC044H	5095	15/02/2022	B	A	1	-21.95	5.91	2.79

LCA04BA2	Lorikeets	Trichoglossus moluccanus	captive	LC044H	5095	15/02/2022	B	A	2	-21.96	6.13	2.78
LCA04BA4	Lorikeets	Trichoglossus moluccanus	captive	LC044H	5095	15/02/2022	B	A	4	-22.42	5.53	2.85
LCA04BA5	Lorikeets	Trichoglossus moluccanus	captive	LC044H	5095	15/02/2022	B	A	5	-22.52	5.87	2.90
LCA04BB1	Lorikeets	Trichoglossus moluccanus	captive	LC044I	5095	15/02/2022	B	B	1	-22.33	5.69	2.91
LCA04BB2	Lorikeets	Trichoglossus moluccanus	captive	LC044I	5095	15/02/2022	B	B	2	-22.24	5.76	2.72
LCA04BC1	Lorikeets	Trichoglossus moluccanus	captive	LC044J	5095	15/02/2022	B	C	1	-22.42	5.99	2.87
LCA04BC2	Lorikeets	Trichoglossus moluccanus	captive	LC044J	5095	15/02/2022	B	C	2	-22.29	6.01	2.85
LCA06BA1	Lorikeets	Trichoglossus moluccanus	captive	LC045	5095	15/02/2022	B	A	1	-23.04	4.35	2.65
LCA06BB1	Lorikeets	Trichoglossus moluccanus	captive	LC045	5095	15/02/2022	B	B	1	-21.66	4.49	2.80
LCA17WA2	Lorikeets	Trichoglossus moluccanus	captive	LC046K	5223	20/05/2022	W	A	2	-21.23	6.40	2.72
LCA17WB2	Lorikeets	Trichoglossus moluccanus	captive	LC046L	5223	20/05/2022	W	B	2	-19.77	7.86	2.82
LCA17WC2	Lorikeets	Trichoglossus moluccanus	captive	LC046M	5223	20/05/2022	W	C	2	-22.19	8.92	2.74
LCA17WD2	Lorikeets	Trichoglossus moluccanus	captive	LC046N	5223	20/05/2022	W	D	2	-22.14	10.08	2.87
LCC12TA1	Lorikeets	Trichoglossus moluccanus	captive	LC047	4210	10/12/2021	T	A	1	-21.89	3.75	2.94
LCC12TA2	Lorikeets	Trichoglossus moluccanus	captive	LC047	4210	10/12/2021	T	A	2	-22.04	3.52	2.91
LCC12TB1	Lorikeets	Trichoglossus moluccanus	captive	LC047	4210	10/12/2021	T	B	1	-21.97	3.40	2.94
LCC12TB2	Lorikeets	Trichoglossus moluccanus	captive	LC047	4210	10/12/2021	T	B	2	-21.98	3.55	2.95
LCC12TC1	Lorikeets	Trichoglossus moluccanus	captive	LC047	4210	10/12/2021	T	C	1	-21.94	3.55	2.93
LCC12TC2	Lorikeets	Trichoglossus moluccanus	captive	LC047	4210	10/12/2021	T	C	2	-21.96	3.61	2.95
LCS03BA1	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	B	A	1	-20.96	4.29	2.73
LCS03BA2	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	B	A	2	-21.01	4.59	2.72
LCS03BB1	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	B	B	1	-20.80	4.91	2.69
LCS03BC1	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	B	C	1	-21.06	5.27	2.69
LCS03BD1	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	B	D	1	-21.07	4.63	2.74
LCS03BD2	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	B	D	2	-21.06	4.64	2.75
LCS03TA1	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	T	A	1	-22.44	7.45	2.89
LCS03TA2	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	T	A	2	-22.41	7.44	2.92
LCS03TB1	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	T	B	1	-21.39	5.33	2.94
LCS03TB2	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	T	B	2	-21.35	5.22	2.94
LCS03WA1	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	W	A	1	-20.92	5.19	2.90
LCS03WA2	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	W	A	2	-20.41	4.39	2.83
LCS03WB1	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	W	B	1	-20.24	5.80	2.66
LCS03WB2	Lorikeets	Trichoglossus moluccanus	captive	LC048	5042	17/12/2020	W	B	2	-19.89	5.80	2.72
LCC01BA1	Lorikeets	Trichoglossus moluccanus	captive	LC049	2307	10/12/2021	B	A	1	-22.46	5.39	2.65
LCC04BA1	Lorikeets	Trichoglossus moluccanus	captive	LC050	5039	7/12/2021	B	A	1	-20.58	6.04	2.78
LCC04BA2	Lorikeets	Trichoglossus moluccanus	captive	LC050	5039	7/12/2021	B	A	2	-20.58	6.31	2.79
LCC04BB1	Lorikeets	Trichoglossus moluccanus	captive	LC050	5039	7/12/2021	B	B	1	-20.37	5.63	2.82
LCC04BB2	Lorikeets	Trichoglossus moluccanus	captive	LC050	5039	7/12/2021	B	B	2	-20.38	5.54	2.91
LCC04BC1	Lorikeets	Trichoglossus moluccanus	captive	LC050	5039	7/12/2021	B	C	1	-20.15	6.04	2.80
LCC04BC2	Lorikeets	Trichoglossus moluccanus	captive	LC050	5039	7/12/2021	B	C	2	-20.52	6.23	2.93
LCC04WA1	Lorikeets	Trichoglossus moluccanus	captive	LC050	5039	7/12/2021	W	A	1	-20.26	5.79	2.90
LCC04WA2	Lorikeets	Trichoglossus moluccanus	captive	LC050	5039	7/12/2021	W	A	2	-20.22	6.10	2.85
LCC04WB1	Lorikeets	Trichoglossus moluccanus	captive	LC050	5039	7/12/2021	W	B	1	-20.12	5.86	2.89
LCC04WB2	Lorikeets	Trichoglossus moluccanus	captive	LC050	5039	7/12/2021	W	B	2	-20.09	5.79	2.87
WL101BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP216	NA	NA	B	A	1	-21.60	4.88	2.66
WL101BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP216	NA	NA	B	B	1	-22.12	6.14	2.63
WL102BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP217	NA	NA	B	A	1	-22.49	5.59	2.69
WL102BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP217	NA	NA	B	B	1	-23.18	6.82	2.64
WL103BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP218	NA	NA	B	A	1	-22.73	6.30	2.66
WL103BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP218	NA	NA	B	B	1	-22.55	6.13	2.71
WL104BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP219	NA	NA	B	A	1	-22.55	8.35	2.71
WL104BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP219	NA	NA	B	B	1	-22.55	6.20	2.67
WL105BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP220	NA	NA	B	A	1	-23.15	5.25	2.70
WL105BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP220	NA	NA	B	B	1	-22.14	4.50	2.74
WL106BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP221	NA	NA	B	A	1	-22.36	6.58	2.62
WL106BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP221	NA	NA	B	B	1	-23.08	7.35	2.64
WL107BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP222	NA	NA	B	B	1	-21.96	5.29	2.89
WL108BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP223	NA	NA	B	A	1	-23.20	2.63	2.83

WL108BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP223	NA	NA	B	B	1	-22.65	3.29	2.71
WL109BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP224	NA	NA	B	A	1	-22.26	6.24	2.61
WL109BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP224	NA	NA	B	B	1	-22.82	7.46	2.68
WL110BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP225	NA	NA	B	A	1	-21.74	5.41	2.70
WL110BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP225	NA	NA	B	B	1	-21.72	5.81	2.66
WL111BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP226	NA	NA	B	A	1	-21.26	4.85	3.69
WL111BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP226	NA	NA	B	B	1	-21.26	5.63	2.68
WL112BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP227	NA	NA	B	A	1	-22.96	4.08	2.64
WL112BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP227	NA	NA	B	B	1	-22.45	4.11	2.63
WL113BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP228	NA	NA	B	A	1	-23.36	2.85	2.66
WL113BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP228	NA	NA	B	B	1	-22.25	3.75	2.63
WL114BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP229	NA	NA	B	A	1	-23.57	1.92	2.70
WL114BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP229	NA	NA	B	B	1	-23.66	1.96	2.66
WL115BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP230	NA	NA	B	A	1	-22.61	7.59	2.56
WL115BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP230	NA	NA	B	B	1	-21.70	5.99	2.57
WL116BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP231	NA	NA	B	A	1	-22.48	6.99	2.60
WL116BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP231	NA	NA	B	B	1	-22.18	6.39	2.62
WL117BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP232	NA	NA	B	A	1	-22.12	5.27	2.59
WL117BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP232	NA	NA	B	B	1	-22.00	5.28	2.55
WL118BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP233	NA	NA	B	A	1	-22.16	6.37	2.59
WL118BB2	Lorikeets	Trichoglossus moluccanus	Perth	LP233	NA	NA	B	B	2	-22.65	6.51	2.63
WL201BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP234	NA	NA	B	A	1	-21.62	4.85	2.50
WL201BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP234	NA	NA	B	B	1	-21.64	4.88	2.55
WL202BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP235	NA	NA	B	A	1	-22.29	6.36	2.53
WL202BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP235	NA	NA	B	B	1	-21.73	7.41	2.57
WL203BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP236	NA	NA	B	A	1	-22.84	6.34	2.75
WL203BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP236	NA	NA	B	B	1	-22.51	7.77	2.73
WL204BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP237	NA	NA	B	A	1	-23.06	5.43	2.73
WL204BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP237	NA	NA	B	B	1	-22.91	5.25	2.73
WL205BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP238	NA	NA	B	A	1	-22.45	4.57	2.70
WL205BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP238	NA	NA	B	B	1	-22.32	3.23	2.73
WL206BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP239	NA	NA	B	A	1	-22.53	2.69	2.72
WL206BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP239	NA	NA	B	B	1	-22.39	2.99	2.74
WL207BAB1	Lorikeets	Trichoglossus moluccanus	Perth	LP240	NA	NA	A	B	1	-22.78	7.54	2.74
WL207BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP240	NA	NA	B	A	1	-22.79	7.53	2.76
WL208BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP241	NA	NA	B	A	1	-22.44	6.01	2.74
WL208BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP241	NA	NA	B	B	1	-22.78	7.42	2.82
WL209BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP242	NA	NA	B	A	1	-22.27	7.70	2.68
WL209BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP242	NA	NA	B	B	1	-22.32	7.61	2.67
WL210BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP243	NA	NA	B	A	1	-22.27	6.18	2.65
WL210BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP243	NA	NA	B	B	1	-22.36	6.01	2.68
WL211BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP244	NA	NA	B	A	1	-23.26	6.67	2.77
WL211BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP244	NA	NA	B	B	1	-22.97	7.05	2.79
WL212BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP245	NA	NA	B	A	1	-22.96	5.62	2.84
WL212BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP245	NA	NA	B	B	1	-22.68	5.43	2.73
WL213BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP246	NA	NA	B	A	1	-22.99	4.71	2.69
WL213BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP246	NA	NA	B	B	1	-23.15	4.43	2.74
WL214BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP247	NA	NA	B	B	1	-22.93	6.15	NA
WL215BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP248	NA	NA	B	A	1	-21.68	4.36	2.69
WL215BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP248	NA	NA	B	B	1	-21.21	3.49	2.66
WL216BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP249	NA	NA	B	A	1	-22.92	5.93	2.67
WL216BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP249	NA	NA	B	B	1	-23.05	6.28	2.65
WL217BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP250	NA	NA	B	A	1	-22.29	3.82	2.64
WL217BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP250	NA	NA	B	B	1	-22.13	4.33	2.64
WL218BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP251	NA	NA	B	A	1	-23.06	7.55	2.65
WL218BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP251	NA	NA	B	B	1	-23.62	6.62	2.71
WL219BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP252	NA	NA	B	A	1	-21.52	4.71	2.61
WL219BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP252	NA	NA	B	B	1	-21.52	4.89	2.60

WL220BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP253	NA	NA	B	A	1	-22.66	4.78	2.60
WL220BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP253	NA	NA	B	B	1	-21.86	4.23	2.60
WL221BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP254	NA	NA	B	A	1	-22.44	6.88	2.64
WL221BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP254	NA	NA	B	B	1	-22.67	7.73	2.64
WL222BA1	Lorikeets	Trichoglossus moluccanus	Perth	LP255	NA	NA	B	A	1	-22.42	5.91	2.70
WL222BB1	Lorikeets	Trichoglossus moluccanus	Perth	LP255	NA	NA	B	B	1	-22.50	4.99	2.74
TL101A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT169	NA	NA	B	A	1	-23.60	7.78	2.87
TL101B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT169	NA	NA	B	B	1	-23.64	7.73	2.98
TL102A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT170	NA	NA	B	A	1	-23.71	8.43	2.92
TL102B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT170	NA	NA	B	B	1	-23.68	8.25	2.94
TL103A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT171	NA	NA	B	A	1	-23.53	7.43	2.94
TL103B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT171	NA	NA	B	B	1	-23.28	7.62	2.91
TL104A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT172	NA	NA	B	A	1	-24.05	7.84	2.91
TL104B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT172	NA	NA	B	B	1	-23.29	8.58	2.92
TL105A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT173	NA	NA	B	A	1	-23.43	7.51	2.89
TL105B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT173	NA	NA	B	B	1	-23.25	8.04	2.92
TL106A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT174	NA	NA	B	A	1	-23.52	7.51	2.92
TL106B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT174	NA	NA	B	B	1	-23.57	7.80	2.94
TL107A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT175	NA	NA	B	A	1	-23.06	8.14	2.90
TL107B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT175	NA	NA	B	B	1	-23.60	6.48	2.89
TL108A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT176	NA	NA	B	A	1	-23.16	7.61	2.95
TL108B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT176	NA	NA	B	B	1	-23.75	8.45	2.90
TL109A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT177	NA	NA	B	A	1	-23.29	7.47	2.86
TL109B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT177	NA	NA	B	B	1	-23.22	7.99	3.08
TL110A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT178	NA	NA	B	A	1	-23.24	6.91	2.91
TL110B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT178	NA	NA	B	B	1	-24.03	6.70	2.97
TL111A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT179	NA	NA	B	A	1	-23.67	7.04	2.94
TL111B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT179	NA	NA	B	B	1	-23.87	6.02	2.92
TL112A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT180	NA	NA	B	A	1	-21.55	6.39	2.88
TL112B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT180	NA	NA	B	B	1	-23.50	7.49	2.92
TL113A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT181	NA	NA	B	A	1	-23.30	8.22	2.91
TL113B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT181	NA	NA	B	B	1	-23.24	7.97	2.93
TL114A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT182	NA	NA	B	A	1	-23.24	8.31	2.91
TL114B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT182	NA	NA	B	B	1	-23.58	7.28	2.93
TL115A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT183	NA	NA	B	A	1	-23.28	6.87	2.87
TL115B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT183	NA	NA	B	B	1	-23.21	7.59	2.92
TL116A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT184	NA	NA	B	A	1	-23.34	6.65	2.92
TL116B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT184	NA	NA	B	B	1	-22.89	7.00	2.92
TL117A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT185	NA	NA	B	A	1	-23.66	7.17	2.89
TL117B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT185	NA	NA	B	B	1	-23.62	7.32	2.88
TL118A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT186	NA	NA	B	A	1	-23.92	6.87	2.88
TL118B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT186	NA	NA	B	B	1	-23.87	8.53	2.89
TL119A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT187	NA	NA	B	A	1	-24.10	7.95	2.88
TL119B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT187	NA	NA	B	B	1	-22.66	8.58	2.85
TL120A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT188	NA	NA	B	A	1	-23.86	7.15	2.88
TL120B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT188	NA	NA	B	B	1	-23.44	5.45	2.92
TL121A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT189	NA	NA	B	A	1	-23.57	7.85	2.86
TL121B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT189	NA	NA	B	B	1	-23.04	7.26	2.82
TL122A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT190	NA	NA	B	A	1	-23.64	7.88	2.85
TL122B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT190	NA	NA	B	B	1	-23.86	7.78	2.84
TL123A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT191	NA	NA	B	A	1	-23.42	8.10	2.84
TL123B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT191	NA	NA	B	B	1	-23.33	8.91	2.83
TL124A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT192	NA	NA	B	A	1	-23.99	4.92	2.88
TL124B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT192	NA	NA	B	B	1	-23.98	4.90	2.86
TL201A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT193	NA	NA	B	A	1	-23.48	5.86	2.90
TL201B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT193	NA	NA	B	B	1	-23.71	6.96	2.87
TL202A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT194	NA	NA	B	A	1	-23.08	7.45	2.88
TL202B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT194	NA	NA	B	B	1	-22.04	7.22	2.85

TL203A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT195	NA	NA	B	A	1	-23.05	8.43	2.86
TL203B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT195	NA	NA	B	B	1	-23.37	8.18	2.89
TL204A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT196	NA	NA	B	A	1	-23.63	7.06	2.83
TL204B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT196	NA	NA	B	B	1	-23.52	7.77	2.86
TL205A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT197	NA	NA	B	A	1	-23.52	7.94	2.84
TL205B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT197	NA	NA	B	B	1	-23.66	7.70	2.87
TL206A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT198	NA	NA	B	A	1	-23.52	7.82	2.91
TL206B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT198	NA	NA	B	B	1	-22.92	6.77	2.84
TL207A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT199	NA	NA	B	A	1	-23.50	6.62	2.89
TL207B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT199	NA	NA	B	B	1	-23.50	5.38	2.88
TL208A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT200	NA	NA	B	A	1	-23.20	6.92	2.81
TL208B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT200	NA	NA	B	B	1	-23.35	7.70	2.93
TL209A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT201	NA	NA	B	A	1	-23.20	6.98	2.91
TL209B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT201	NA	NA	B	B	1	-23.43	7.41	2.94
TL210A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT202	NA	NA	B	A	1	-23.16	7.13	2.90
TL210B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT202	NA	NA	B	B	1	-23.30	6.31	2.88
TL211A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT203	NA	NA	B	A	1	-23.05	7.67	2.93
TL211B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT203	NA	NA	B	B	1	-23.51	7.62	2.93
TL212A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT204	NA	NA	B	A	1	-23.38	8.11	2.89
TL212B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT204	NA	NA	B	B	1	-23.87	7.50	2.85
TL213A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT205	NA	NA	B	A	1	-23.72	7.01	2.94
TL213B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT205	NA	NA	B	B	1	-23.88	7.06	2.96
TL214A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT206	NA	NA	B	A	1	-23.51	7.87	2.89
TL215B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT207	NA	NA	B	B	1	-23.99	5.39	2.88
TL216A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT208	NA	NA	B	A	1	-23.03	8.08	2.89
TL216B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT208	NA	NA	B	B	1	-22.89	8.78	2.87
TL217A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT209	NA	NA	B	A	1	-23.51	7.63	2.87
TL217B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT209	NA	NA	B	B	1	-23.77	7.31	2.93
TL218A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT210	NA	NA	B	A	1	-23.51	6.98	2.89
TL218B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT210	NA	NA	B	B	1	-23.90	6.54	2.91
TL219A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT211	NA	NA	B	A	1	-23.75	7.92	2.86
TL219B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT211	NA	NA	B	B	1	-23.67	6.93	2.91
TL220A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT212	NA	NA	B	A	1	-23.89	5.96	2.87
TL220B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT212	NA	NA	B	B	1	-23.80	6.07	2.90
TL221A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT213	NA	NA	B	A	1	-23.73	5.43	2.85
TL221B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT213	NA	NA	B	B	1	-23.91	6.31	2.90
TL222A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT214	NA	NA	B	A	1	-29.17	7.41	2.05
TL222B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT214	NA	NA	B	B	1	-23.28	6.73	2.92
TL223A1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT215	NA	NA	B	A	1	-23.13	7.98	2.90
TL223B1	Lorikeets	Trichoglossus moluccanus	Tasmania	LT215	NA	NA	B	B	1	-23.16	7.87	2.89
LWM09BA1	Lorikeets	Trichoglossus moluccanus	wild	LW051	NA	NA	B	A	1	-23.19	10.57	2.78
LWF35BA1	Lorikeets	Trichoglossus moluccanus	wild	LW052	5005	30/10/2020	B	A	1	-23.73	11.75	2.76
LWF37BA1	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	B	A	1	-23.62	8.26	2.80
LWF37BA2	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	B	A	2	-23.69	7.94	2.83
LWF37BB1	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	B	B	1	-23.67	7.61	2.77
LWF37BB2	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	B	B	2	-23.53	8.05	2.79
LWF37BC1	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	B	C	1	-23.72	7.92	2.87
LWF37BC2	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	B	C	2	-23.65	7.58	2.79
LWF37TA1	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	T	A	1	-24.98	8.23	3.61
LWF37TA2	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	T	A	2	-24.48	8.43	3.29
LWF37TB1	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	T	B	1	-23.98	8.06	2.79
LWF37TB2	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	T	B	2	-24.03	8.80	2.87
LWF37TC1	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	T	C	1	-24.25	8.32	3.11
LWF37TC2	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	T	C	2	-24.29	8.53	3.05
LWF37WA1	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	W	A	1	-23.72	8.15	2.74
LWF37WA2	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	W	A	2	-23.96	9.01	2.86
LWF37WB1	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	W	B	1	-23.80	9.56	2.91
LWF37WB2	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	W	B	2	-24.07	9.93	2.85

LWF37WC1	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	W	C	1	-23.23	9.36	2.71
LWF37WC2	Lorikeets	Trichoglossus moluccanus	wild	LW053	5051	23/09/2021	W	C	2	-23.94	8.72	2.89
LWF38BA1	Lorikeets	Trichoglossus moluccanus	wild	LW054	5005	13/10/2021	B	A	1	-23.67	7.66	2.62
LWF40BA1	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	B	A	1	-23.78	7.89	2.75
LWF40BA2	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	B	A	2	-23.83	8.24	2.72
LWF40BB1	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	B	B	1	-23.89	7.83	2.68
LWF40BB2	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	B	B	2	-23.91	7.83	2.74
LWF40BC1	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	B	C	1	-23.73	7.89	2.66
LWF40TA1	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	T	A	1	-24.62	7.97	3.18
LWF40TA2	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	T	A	2	-24.23	8.55	2.93
LWF40TB1	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	T	B	1	-25.62	9.98	4.14
LWF40TB2	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	T	B	2	-25.09	10.02	3.66
LWF40TC1	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	T	C	1	-24.39	9.25	3.44
LWF40TC2	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	T	C	2	-24.13	9.19	3.15
LWF40WA2	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	W	A	2	-23.50	8.94	2.77
LWF40WB1	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	W	B	1	-23.98	9.28	2.86
LWF40WB2	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	W	B	2	-23.75	9.23	2.71
LWF40WC1	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	W	C	1	-23.12	9.79	2.66
LWF40WC2	Lorikeets	Trichoglossus moluccanus	wild	LW055	5006	17/11/2021	W	C	2	-23.82	10.29	2.84
LWC17BA1	Lorikeets	Trichoglossus moluccanus	wild	LW122	5085	6/02/2021	B	A	1	-23.50	8.18	2.70
LWC17BA2	Lorikeets	Trichoglossus moluccanus	wild	LW122	5085	6/02/2021	B	A	2	-23.55	7.47	2.72
LWC22BA1	Lorikeets	Trichoglossus moluccanus	wild	LW123	5076	1/03/2021	B	A	1	-22.70	8.16	2.65
LWC22BA2	Lorikeets	Trichoglossus moluccanus	wild	LW123	5076	1/03/2021	B	A	2	-23.80	7.72	2.64
LWC22BB1	Lorikeets	Trichoglossus moluccanus	wild	LW124	5076	1/03/2021	B	B	1	-23.90	7.62	2.63
LWC22BB2	Lorikeets	Trichoglossus moluccanus	wild	LW124	5076	1/03/2021	B	B	2	-22.80	8.12	2.66
LWC24BA1	Lorikeets	Trichoglossus moluccanus	wild	LW125	5076	14/02/2021	B	A	1	-21.90	8.57	2.68
LWC24BA2	Lorikeets	Trichoglossus moluccanus	wild	LW125	5076	14/02/2021	B	A	2	-21.70	8.59	2.65
LWC24BB1	Lorikeets	Trichoglossus moluccanus	wild	LW126	5076	14/02/2021	B	B	1	-24.30	6.70	4.05
LWC24BB2	Lorikeets	Trichoglossus moluccanus	wild	LW126	5076	14/02/2021	B	B	2	-24.00	6.49	3.62
LWC32BA1	Lorikeets	Trichoglossus moluccanus	wild	LW127	5042	6/05/2021	B	A	1	-23.80	7.26	2.75
LWC32BA2	Lorikeets	Trichoglossus moluccanus	wild	LW127	5042	6/05/2021	B	A	2	-23.80	7.08	2.75
LWC32BB1	Lorikeets	Trichoglossus moluccanus	wild	LW128	5042	6/05/2021	B	B	1	-23.60	8.67	2.84
LWC32BB2	Lorikeets	Trichoglossus moluccanus	wild	LW128	5042	6/05/2021	B	B	2	-23.70	7.97	2.81
LWC33BA1	Lorikeets	Trichoglossus moluccanus	wild	LW129	5039	7/04/2021	B	A	1	-23.30	7.79	2.70
LWC33BA2	Lorikeets	Trichoglossus moluccanus	wild	LW129	5039	7/04/2021	B	A	2	-23.40	7.77	2.69
LWC33BB1	Lorikeets	Trichoglossus moluccanus	wild	LW130	5039	7/04/2021	B	B	1	-24.10	6.89	2.83
LWC33BB2	Lorikeets	Trichoglossus moluccanus	wild	LW130	5039	7/04/2021	B	B	2	-23.70	6.63	2.82
LWC47BBA1	Lorikeets	Trichoglossus moluccanus	wild	LW131	5153	15/04/2022	B	A	1	-22.00	5.84	2.75
LWC47BBA2	Lorikeets	Trichoglossus moluccanus	wild	LW131	5153	15/04/2022	B	A	2	-23.60	5.78	2.73
LWF12BA1	Lorikeets	Trichoglossus moluccanus	wild	LW132	5006	21/01/2021	B	A	1	-24.33	9.64	2.76
LWF16BA1	Lorikeets	Trichoglossus moluccanus	wild	LW133	5006	22/01/2021	B	A	1	-22.55	6.54	2.67
LWF33BA1	Lorikeets	Trichoglossus moluccanus	wild	LW134	5081	15/07/2018	B	A	1	-22.28	6.58	2.67
LWH12BA1	Lorikeets	Trichoglossus moluccanus	wild	LW135	5052	16/12/2019	B	A	1	-23.09	6.11	2.81
LWH18BA1	Lorikeets	Trichoglossus moluccanus	wild	LW136	5051	9/12/2019	B	A	1	-23.04	7.83	2.67
LWH36BA1	Lorikeets	Trichoglossus moluccanus	wild	LW137	5051	15/03/2021	B	A	1	-23.33	8.74	2.76
LWK02BA1	Lorikeets	Trichoglossus moluccanus	wild	LW138	5034	11/10/2020	B	A	1	-23.01	6.48	2.75
LWK32BA1	Lorikeets	Trichoglossus moluccanus	wild	LW139	5000	15/02/2021	B	A	1	-23.10	10.16	2.64
LWK38BA1	Lorikeets	Trichoglossus moluccanus	wild	LW140	5000	15/04/2021	B	A	1	-23.40	10.64	2.67
LWK39BA1	Lorikeets	Trichoglossus moluccanus	wild	LW141	5000	15/02/2021	B	A	1	-23.40	11.15	2.76
LWK50BA2	Lorikeets	Trichoglossus moluccanus	wild	LW142	5006	1/09/2021	B	A	2	-22.94	10.02	2.81
LWK50BB2	Lorikeets	Trichoglossus moluccanus	wild	LW143	5006	1/09/2021	B	B	2	-23.36	7.76	2.82
LWN01BA1	Lorikeets	Trichoglossus moluccanus	wild	LW144	5051	22/10/2020	B	A	1	-23.64	7.48	2.71
LWN06BA1	Lorikeets	Trichoglossus moluccanus	wild	LW145	5051	13/10/2020	B	A	1	-22.16	6.69	2.69
LWN08BA2	Lorikeets	Trichoglossus moluccanus	wild	LW146	5052	15/09/2020	B	A	2	-23.23	6.09	2.83
LWN11BA2	Lorikeets	Trichoglossus moluccanus	wild	LW147	5083	15/09/2020	B	A	2	-22.94	9.54	2.70
LWN11BB2	Lorikeets	Trichoglossus moluccanus	wild	LW148	5083	15/09/2020	B	B	2	-22.83	9.28	2.77
LWN48BA1	Lorikeets	Trichoglossus moluccanus	wild	LW149	5006	19/10/2020	B	A	1	-22.88	9.04	2.67
LWN78BA2	Lorikeets	Trichoglossus moluccanus	wild	LW150	5453	2/04/2022	B	A	2	-22.40	7.91	2.76

CCA05BA1	NA	<i>Eolophus roseicapilla x Cacatua sanguinea</i>	captive	GxDC039	5095	15/02/2022	B	A	1	-21.99	11.99	2.81
CCA05BA2	NA	<i>Eolophus roseicapilla x Cacatua sanguinea</i>	captive	GxDC039	5095	15/02/2022	B	A	2	-21.96	12.09	2.76
CCA05BB1	NA	<i>Eolophus roseicapilla x Cacatua sanguinea</i>	captive	GxDC039	5095	15/02/2022	B	B	1	-22.01	11.86	2.77
CCA05BB2	NA	<i>Eolophus roseicapilla x Cacatua sanguinea</i>	captive	GxDC039	5095	15/02/2022	B	B	2	-21.94	11.90	2.79
CCA05BC1	NA	<i>Eolophus roseicapilla x Cacatua sanguinea</i>	captive	GxDC039	5095	15/02/2022	B	C	1	-21.78	11.74	2.77
CCA05BC2	NA	<i>Eolophus roseicapilla x Cacatua sanguinea</i>	captive	GxDC039	5095	15/02/2022	B	C	2	-21.65	11.62	2.75
GCA05WA1	NA	<i>Eolophus roseicapilla x Cacatua sanguinea</i>	captive	GxDC039	5095	15/02/2022	W	A	1	-22.09	11.88	2.85
GCA05WA2	NA	<i>Eolophus roseicapilla x Cacatua sanguinea</i>	captive	GxDC039	5095	15/02/2022	W	A	2	-22.20	11.83	2.81
SCA16BA1	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	B	A	1	-21.24	9.06	2.84
SCA16BA2	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	B	A	2	-21.52	9.82	2.82
SCA16BB1	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	B	B	1	-21.07	9.33	2.83
SCA16BB2	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	B	B	2	-21.06	9.45	2.79
SCA16BC1	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	B	C	1	-21.35	9.25	2.89
SCA16BC2	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	B	C	2	-21.32	9.42	2.83
SCA16TA1	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	T	A	1	-21.09	9.47	2.84
SCA16TA2	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	T	A	2	-20.97	9.53	2.84
SCA16WA1	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	W	A	1	-21.19	7.64	2.80
SCA16WA2	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	W	A	2	-21.29	7.88	2.79
SCA16WB1	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	W	B	1	-21.42	9.08	2.81
SCA16WB2	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	W	B	2	-21.25	9.18	2.79
SCA16WC1	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	W	C	1	-21.53	8.30	2.85
SCA16WC2	White cockatoos	<i>Cacatua galerita</i>	captive	SC056	5112	15/02/2022	W	C	2	-21.96	8.46	2.83
SCA12BA1	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	B	A	1	-20.52	7.57	2.86
SCA12BA2	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	B	A	2	-21.23	7.45	2.77
SCA12BB1	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	B	B	1	-20.65	8.97	2.85
SCA12BB2	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	B	B	2	-20.69	8.81	2.82
SCA12BC1	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	B	C	1	-20.80	7.23	2.84
SCA12BC2	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	B	C	2	-20.16	7.23	2.83
SCA12CA1	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	C	A	1	-21.19	8.33	2.81
SCA12CA2	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	C	A	2	-20.99	8.13	2.79
SCA12TA1	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	T	A	1	-20.29	7.36	2.81
SCA12TA2	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	T	A	2	-20.04	7.52	2.79
SCA12TB1	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	T	B	1	-20.38	7.99	2.84
SCA12TB2	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	T	B	2	-20.77	8.00	2.80
SCA12TC1	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	T	C	1	-20.73	7.96	2.78
SCA12TC2	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	T	C	2	-20.80	7.79	2.82
SCA12WA1	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	W	A	1	-21.65	7.19	2.79
SCA12WA2	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	W	A	2	-19.96	7.28	2.84
SCA12WB1	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	W	B	1	-20.98	7.86	2.84
SCA12WB2	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	W	B	2	-20.64	7.77	2.79
SCA12WC1	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	W	C	1	-21.86	7.63	2.87
SCA12WC2	White cockatoos	<i>Cacatua galerita</i>	captive	SC057	5112	15/02/2022	W	C	2	-21.53	8.11	2.81
SCA01BC1	White cockatoos	<i>Cacatua galerita</i>	captive	SC058	5095	15/02/2022	B	C	1	-21.81	4.85	2.85
SCA02BA1	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	B	A	1	-18.34	7.71	2.86
SCA02BA2	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	B	A	2	-17.20	7.46	2.82
SCA02BB1	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	B	B	1	-19.77	5.50	2.88
SCA02BB2	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	B	B	2	-19.90	5.19	2.89
SCA02BC2	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	B	C	2	-21.75	4.99	2.81
SCA02CA1	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	C	A	1	-21.12	7.43	2.84
SCA02CA2	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	C	A	2	-21.66	6.81	2.80
SCA02WA1	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	W	A	1	-21.65	6.60	2.83
SCA02WA2	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	W	A	2	-21.68	6.60	2.84
SCA02WB1	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	W	B	1	-21.51	5.32	2.81
SCA02WB2	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	W	B	2	-21.95	5.54	2.97
SCA02WC1	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	W	C	1	-21.66	3.63	2.83
SCA02WC2	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	W	C	2	-21.60	3.99	2.80
SCA02WD1	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	W	D	1	-20.76	4.57	2.85
SCA02WD2	White cockatoos	<i>Cacatua galerita</i>	captive	SC059	5095	15/02/2022	W	D	2	-21.37	4.68	2.80

SCS04BA1	White cockatoos	<i>Cacatua galerita</i>	captive	SC060	5083	27/02/2021	B	A	1	-20.80	5.49	2.68
SC003BA1	White cockatoos	<i>Cacatua galerita</i>	captive	SC061	NA	1/12/2020	B	A	1	-20.90	8.76	2.72
SC003BA2	White cockatoos	<i>Cacatua galerita</i>	captive	SC061	NA	1/12/2020	B	A	2	-20.82	8.44	2.69
SWM17BA1	White cockatoos	<i>Cacatua galerita</i>	wild	SW062	5700	27/07/2008	B	A	1	-20.67	9.08	2.70
SWM17BA2	White cockatoos	<i>Cacatua galerita</i>	wild	SW062	5700	27/07/2008	B	A	2	-19.82	10.90	2.67
SWM17BB1	White cockatoos	<i>Cacatua galerita</i>	wild	SW062	5700	27/07/2008	B	B	1	-19.11	10.35	2.72
SWM17BB2	White cockatoos	<i>Cacatua galerita</i>	wild	SW062	5700	27/07/2008	B	B	2	-18.83	11.01	2.66
SWM17BC1	White cockatoos	<i>Cacatua galerita</i>	wild	SW062	5700	27/07/2008	B	C	1	-19.93	9.97	2.70
SWM17WA2	White cockatoos	<i>Cacatua galerita</i>	wild	SW062	5700	27/07/2008	W	A	2	-20.07	9.14	2.63
SWM17WB1	White cockatoos	<i>Cacatua galerita</i>	wild	SW062	5700	27/07/2008	W	B	1	-19.94	9.52	2.66
SWM17WB2	White cockatoos	<i>Cacatua galerita</i>	wild	SW062	5700	27/07/2008	W	B	2	-19.50	9.70	2.67
SWM17WC1	White cockatoos	<i>Cacatua galerita</i>	wild	SW062	5700	27/07/2008	W	C	1	-19.84	9.87	2.64
SWM17WC2	White cockatoos	<i>Cacatua galerita</i>	wild	SW062	5700	27/07/2008	W	C	2	-18.67	10.82	2.66
SWC04BA2	White cockatoos	<i>Cacatua galerita</i>	wild	SW152	3150	6/02/2021	B	A	2	-20.95	5.15	2.66
SWC12BA1	White cockatoos	<i>Cacatua galerita</i>	wild	SW153	5108	18/02/2021	B	A	1	-19.50	8.94	2.74
SWC22BA1	White cockatoos	<i>Cacatua galerita</i>	wild	SW154	5076	7/03/2021	B	A	1	-21.90	6.65	2.64
SWC22BA2	White cockatoos	<i>Cacatua galerita</i>	wild	SW154	5076	7/03/2021	B	A	2	-21.64	5.98	2.70
SWC22BB1	White cockatoos	<i>Cacatua galerita</i>	wild	SW155	5076	7/03/2021	B	B	1	-21.50	6.86	2.63
SWC22BB2	White cockatoos	<i>Cacatua galerita</i>	wild	SW155	5076	7/03/2021	B	B	2	-21.73	6.12	2.69
SWF28BA1	White cockatoos	<i>Cacatua galerita</i>	wild	SW156	5171	21/01/2021	B	A	1	-22.30	5.61	2.67
SWF28BA2	White cockatoos	<i>Cacatua galerita</i>	wild	SW156	5171	21/01/2021	B	A	2	-22.40	5.46	2.61
SWF30BA1	White cockatoos	<i>Cacatua galerita</i>	wild	SW157	5157	18/12/2020	B	A	1	-22.77	6.60	2.60
SWF32BA1	White cockatoos	<i>Cacatua galerita</i>	wild	SW158	5042	3/01/2021	B	A	1	-21.01	6.67	2.63
SWH17BA1	White cockatoos	<i>Cacatua galerita</i>	wild	SW159	5062	20/02/2020	B	A	1	-19.58	7.06	2.66
SWH54BA1	White cockatoos	<i>Cacatua galerita</i>	wild	SW160	5052	25/01/2022	B	A	1	-20.52	8.05	2.64
SWK10BA1	White cockatoos	<i>Cacatua galerita</i>	wild	SW161	5000	21/11/2020	B	A	1	-21.39	7.63	2.68
SWK10BB1	White cockatoos	<i>Cacatua galerita</i>	wild	SW162	5000	21/11/2020	B	B	1	-22.07	7.40	2.69
SWN27BA2	White cockatoos	<i>Cacatua galerita</i>	wild	SW163	5159	29/01/2021	B	A	2	-21.77	4.88	2.71
SWN32BA2	White cockatoos	<i>Cacatua galerita</i>	wild	SW164	5156	4/01/2021	B	A	2	-22.38	5.48	2.72
SWN49BA1	White cockatoos	<i>Cacatua galerita</i>	wild	SW165	5006	29/10/2020	B	A	1	-22.08	7.25	2.63
SWN49BB1	White cockatoos	<i>Cacatua galerita</i>	wild	SW166	5006	29/10/2020	B	B	1	-21.70	8.39	2.62
DCA13BA1	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC001	5112	15/02/2022	B	A	1	-20.48	7.47	2.82
DCA13BA2	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC001	5112	15/02/2022	B	A	2	-20.26	7.67	2.80
DCA13BB1	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC001	5112	15/02/2022	B	B	1	-19.92	7.50	2.80
DCA13BB2	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC001	5112	15/02/2022	B	B	2	-19.91	7.59	2.80
DCA13BC1	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC001	5112	15/02/2022	B	C	1	-21.26	7.81	2.80
DCA13BC2	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC001	5112	15/02/2022	B	C	2	-21.10	7.61	2.81
DCA15BA1	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC002	5112	15/02/2022	B	A	1	-20.81	7.72	2.63
DCC03BA1	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC003	5232	1/12/2021	B	A	1	-21.08	5.13	2.65
CCA07BA1	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC004	5114	15/02/2022	B	A	1	-20.76	10.75	2.79
CCA07BA2	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC004	5114	15/02/2022	B	A	2	-20.80	10.27	2.78
CCA07BB1	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC004	5114	15/02/2022	B	B	1	-20.78	10.88	2.78
CCA07BB2	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC004	5114	15/02/2022	B	B	2	-20.61	12.75	2.79
CCA07BC1	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC004	5114	15/02/2022	B	C	1	-20.93	10.74	2.81
CCA07BC2	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC004	5114	15/02/2022	B	C	2	-21.04	10.66	2.81
DCA07OA1	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC004	5114	15/02/2022	O	A	1	-21.61	8.52	2.78
DCA07OA2	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC004	5114	15/02/2022	O	A	2	-21.65	9.01	2.78
DCA07OB1	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC004	5114	15/02/2022	O	B	1	-20.60	12.76	2.76
DCA07OB2	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC004	5114	15/02/2022	O	B	2	-20.77	12.46	2.76
DCA07OC1	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC004	5114	15/02/2022	O	C	1	-21.14	7.89	2.79
DCA07OC2	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC004	5114	15/02/2022	O	C	2	-20.90	9.48	2.79
DCS10BA1	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC005	NA	21/01/2021	B	A	1	-18.20	8.02	2.70
DCS10BA2	White cockatoos	<i>Cacatua sanguinea</i>	captive	DC005	NA	21/01/2021	B	A	2	-18.23	7.63	2.65
DBB01BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW006	5251	25/03/2022	B	A	2	-22.43	5.63	2.74
DBB10BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW007	5251	25/03/2022	B	A	2	-22.29	4.57	2.73
DBB11BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW008	5251	25/03/2022	B	A	2	-22.44	7.56	2.69
DBB12BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW009	5251	25/03/2022	B	A	2	-22.92	6.77	2.71
DBB13BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW010	5251	25/03/2022	B	A	2	-22.98	4.37	2.69

DBB02BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW011	5251	25/03/2022	B	A	2	-22.31	6.53	2.71
DBB03BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW012	5251	25/03/2022	B	A	2	-22.11	5.54	2.68
DBB04BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW013	5251	25/03/2022	B	A	2	-21.43	5.13	2.70
DBB05BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW014	5251	25/03/2022	B	A	2	-21.43	5.01	2.65
DBB06BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW015	5251	25/03/2022	B	A	2	-21.05	5.38	2.66
DBB07BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW016	5251	25/03/2022	B	A	2	-22.26	6.06	2.66
DBB08BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW017	5251	25/03/2022	B	A	2	-23.10	5.10	2.69
DWK25BA1	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW065	5000	7/11/2019	B	A	1	-22.46	7.23	2.65
DWK50BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW066	5006	1/09/2021	B	A	2	-20.63	7.19	2.74
DWK50BB2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW067	5006	1/09/2021	B	B	2	-19.66	7.91	2.69
DWN20BA1	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW068	5203	30/12/2020	B	A	1	-20.28	6.42	2.72
DWN20BA2	White cockatoos	<i>Cacatua sanguinea</i>	wild	DW068	5203	30/12/2020	B	A	2	-22.67	5.20	2.69
TCA09BA1	White cockatoos	<i>Cacatua tenuirostris</i>	captive	TC063	5112	15/02/2022	B	A	1	-19.92	9.22	2.64
TCS05BA1	White cockatoos	<i>Cacatua tenuirostris</i>	captive	TC064	NA	1/01/2021	B	A	1	-12.40	10.32	2.68
TCS05BA2	White cockatoos	<i>Cacatua tenuirostris</i>	captive	TC064	NA	1/01/2021	B	A	2	-12.39	9.73	2.66
TWC09BA2	White cockatoos	<i>Cacatua tenuirostris</i>	wild	TW167	5320	20/03/2021	B	A	2	-19.28	5.48	2.68
WWC09BA1	White cockatoos	NA	wild	WW168	NA	NA	B	A	1	-19.30	5.95	2.69