# RISK

## ASSESSMENT FOR THE IMPORT AND KEEPING OF EXOTIC VERTEBRATES IN AUSTRALIA

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Department of Agriculture, Fisheries and Forestry



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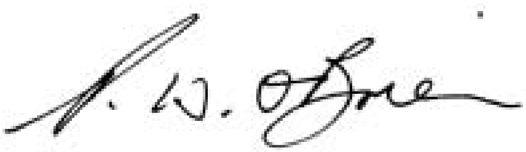
# Foreword

Exotic vertebrates (mammals, birds, reptiles and amphibians) introduced into Australia can establish wild pest populations that harm agriculture and forestry costing hundreds of millions of dollars annually. They can also cause untold harm to Australian native species and ecosystems. Exotic grazing and browsing species already present in Australia, such as rabbits and goats, compete with stock and native animals for food and water and cause severe land degradation through overgrazing and destruction of regenerating trees and shrubs. Exotic predators, such as cats and foxes, can kill, maim or harass native species or livestock. Exotic birds, such as starlings, compete for nest holes and food with native birds.

Unfortunately, there is a risk that new exotic species could establish as wild pests in Australia. These could be species that are already being kept in captivity, for example as companion animals or as display animals in zoos, or they could be animals that are imported into Australia in the future. If such animals escaped, or were illegally released, into a favourable environment, they could start to breed in the wild and spread to new locations. Once they are widespread, eradication becomes virtually impossible.

Not all exotic species pose the same level of threat for establishing a wild pest population. Is it possible to distinguish between species that pose a high risk and those that pose a lower risk? This report addresses this question and, based on a review of world scientific literature and an analysis of past exotic vertebrates to Australia, concludes that there is a suite of factors that separates high and low-risk species. This information is used to construct a scientifically based risk assessment model to evaluate the risk that an exotic species released into the wild will establish a wild population, and if it does, the risk that it will become a pest.

The Bureau of Rural Sciences produced this report for the Vertebrate Pests Committee as part of the National Feral Animal Control Program, a Natural Heritage Trust initiative. The report provides information and guidance that will assist the Commonwealth and State and Territory Governments assess and manage the risks posed by the import and keeping of exotic vertebrates. To encourage acceptance and use of the model as a basis for assessing the risk posed by the import and keeping of exotic vertebrates, comment has been sought from State, Territory and Commonwealth Government agencies throughout its development. The scientifically based model presented in this report will help government policy makers, quarantine officials and wildlife managers reduce the risk that new exotic species will establish and cause harm.



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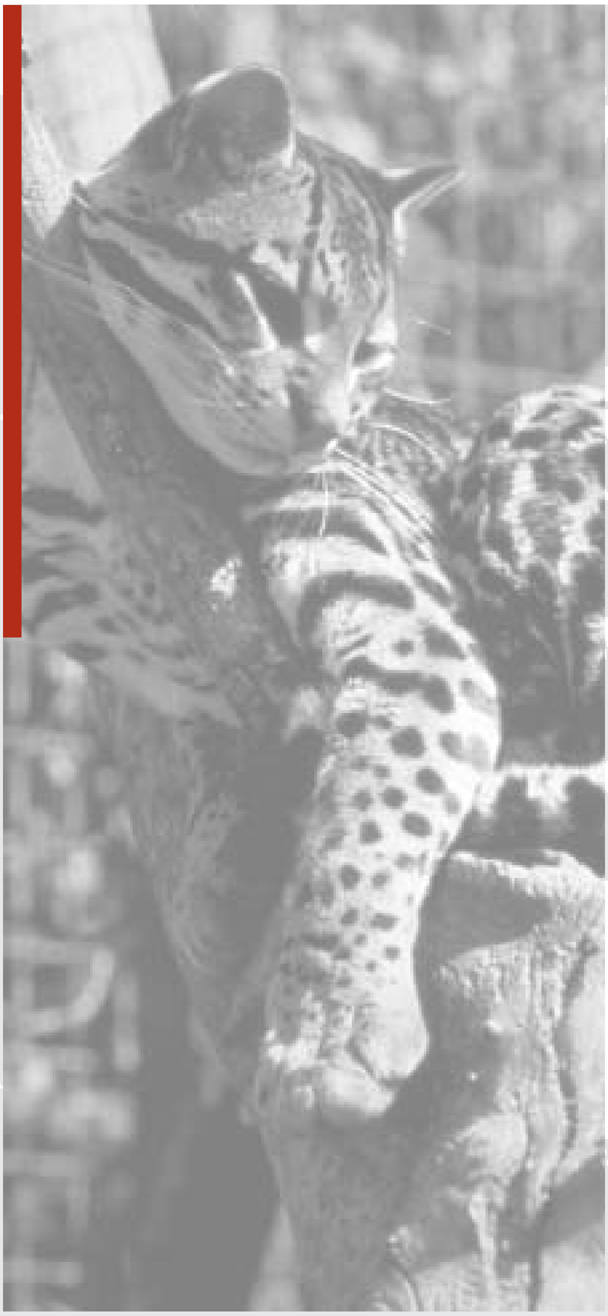


# Summary

## Key points

At least 25 exotic mammals, 20 birds, one amphibian and four reptiles have already established wild populations on mainland Australia and at least eight more exotic species have colonised offshore islands.

***New species may find their way into the wild, establish and become pests.***

Many of these introduced species are pests that have adverse impacts on agriculture and the environment. This is not just a legacy from the past. There is a risk that additional species now kept in captivity, or newly imported species, may find their way into the wild, establish and become pests.

Risk assessment processes for importing and keeping exotic animals now have an important role to play in reducing the likelihood of new species establishing and causing adverse impacts in Australia. Risk assessment involves identifying hazardous events, in this case the establishment of new exotic vertebrate pest species in Australia, and estimating the likelihood that such events will occur and the probable consequences if they do.

***Risk assessment processes have an important role to play in reducing the likelihood of new species establishing and causing harm***

This report evaluates literature reviews and research on past introductions of mammals and birds into Australia and overseas to determine which factors have the most significant influence on whether introduced species succeed or fail to establish exotic populations. In addition, the attributes of established species that become pests of

Source: Adelaide Zoological Gardens

primary production or the environment are compared with the attributes of non-pest species. The results of these analyses are used to develop a more quantitative model for risk assessment for use by government agencies and the Vertebrate Pests Committee. This exotic vertebrate risk assessment model has a sound scientific basis and a transparent decision mechanism.

***This exotic vertebrate risk assessment model has a sound scientific basis and a transparent decision mechanism.***

There are several layers of risk associated with the importing and keeping of exotic species. The likelihood of escape or wilful release depends on such elements as the security of premises, keeping restrictions, and keeper and community attitudes. Also, there is always the chance that individual animals that find their way to freedom may cause harm, for example, if they are powerful carnivores, destructive or poisonous. The major risk factors are the potential to establish in the wild, the potential failure to eradicate and the potential to become a pest.

# Factors influencing establishment in the wild

Worldwide about one-third of bird species and two-thirds of mammal species released into new environments establish exotic wild populations. On the Australian mainland, 42% of introduced exotic bird species and 69% of introduced exotic mammal species have established permanent wild populations.

***Worldwide about one–third of bird species and two–thirds of mammal species released into new environments establish exotic wild populations.***

Based on the success or failure of past introductions of exotic mammals and birds to Australia, a number of factors were identified that influence whether an exotic species released in Australia will establish in the wild. These factors need confirmation by rigorous scientific studies, all have exceptions, and chance events play a large part. Despite this uncertainty, together they can be used to predict the likelihood that a new species will establish:

- Introduction effort — the release of large numbers of animals at different times and places enhances the chance of successful establishment. For introductions of exotic birds and mammals to Australia, the number of individuals released, the number of introduction sites and the number of introduction events is correlated with introduction success. The threshold minimum population size for successful invasion is not known for most species. An approximate estimate is that if less than about 20 individuals are released, in many circumstances survival is unlikely. Small numbers of released animals are more susceptible to extinction from such factors as increased risk of predation, not finding a mate, or competition with native species. Chance events, such as random fluctuations in the proportions of males and females, accidents, fires and floods are also likely to drive small populations to extinction. Nevertheless, despite this general principle of small numbers of animals being less successful, there are many examples of less than ten individuals, and sometimes even single pairs, establishing exotic populations. Repeated releases over an extended period increase the chance of successful invasion simply because the release experiment is repeated many times, under different biotic and abiotic conditions, for example, in different climates and seasons and with variations in the fitness of released animals.

Source: Adelaide Zoological Gardens

- Climate match — For exotic birds and mammals introduced to Australia, the better the match between the climate in a species' overseas geographic range and Australian climates, the greater the risk of establishment.
- Extent of geographic range — The larger the overseas geographic range size the greater the risk of establishment success for exotic birds and mammals in Australia.
- History of invasiveness — A history of establishing exotic populations elsewhere in the world increases the risk of establishment for exotic birds and mammals introduced to Australia. However, when predicting a species' establishment potential, this criterion must be used with caution. Many species have not had the opportunity to demonstrate their invasive potential because they have not been released in new environments.
- Mammals vs birds — Exotic mammals have a higher establishment success rate than exotic birds both in Australia and overseas.

***The release of large numbers of animals at different times and places enhances the chance of successful establishment.***

- Taxonomic group — Exotic gamebirds (Order: Galliformes) have a lower establishment success rate than other bird taxa on the Australian mainland, but they have done well on offshore Australian islands and overseas. Otherwise, taxonomic grouping gives little indication of a species' likelihood of establishing. Often a species will be highly successful at establishing exotic populations whereas close relatives that are also introduced to the same environments repeatedly fail or do poorly.
- Body mass — There is a correlation between female body mass and establishment success for exotic birds introduced to Australia and New Zealand.
- Fecundity — Number of broods produced per season is correlated with establishment success for exotic birds introduced to Australia.
- Sedentary vs migratory — Non-migratory exotic birds introduced to New Zealand and non-migratory exotic mammals introduced to Australia are more successful at establishing exotic populations than migratory species.

- Generalist vs specialist diet — Nearly all established exotic birds and mammals in Australia and overseas have broad diets, suggesting that dietary generalists may be more successful invaders than dietary specialists with restricted diets. However, as few species with specialist diets have been introduced to Australia, this hypothesis is largely untested.
- Commensal with humans — All the exotic bird and mammal species that have successfully established in Australia are able to live in heavily human-disturbed habitats in their overseas geographic ranges, suggesting that species able to live commensally with humans may be successful invaders. However, as few species that are not human commensals have been introduced to Australia, this hypothesis is largely untested.

***There are many examples of less than ten individuals, and sometimes even single pairs, establishing exotic populations.***

- Wild vs captive — Wild-caught animals are more successful at establishing exotic populations than are captive-bred animals.
- Recent vs past — Historical timing of introductions is correlated with establishment success for exotic birds in Australia with more recent introductions being more successful.
- Location of introduction — Animals released in disturbed habitats may be more likely to establish than animals released in undisturbed habitats.

## Factors influencing feasibility of eradication

Eradication is the permanent removal of all wild living individuals of a species from a defined area. While there have been many eradications of introduced mammals from islands, no eradication campaign against any widely established exotic vertebrate species has ever been successful on any continent, despite numerous large-scale attempts and the huge potential benefits of success.

***No eradication campaign against any widely established exotic vertebrate species has ever been successful on any continent, despite numerous large-scale attempts.***

One of the factors influencing whether a species that establishes in the wild is a cause for concern is the ease with which it can be eradicated. Six criteria can be used to assess the feasibility of eradicating exotic species, although they do not enable a quantitative assessment of the probability that eradication can be achieved:

- Rate of removal exceeds rate of increase at all population densities
- Immigration is zero
- All animals are at risk
- Animals can be detected at low densities
- Discounted cost benefit analysis favours eradication over control
- Suitable socio-political environment.

If all six criteria cannot be met, an eradication attempt on a well-established mainland population is unlikely to be successful.

The timing of an eradication attempt in relation to establishment will also influence the probability of eradication being achieved. The sooner eradication is attempted after establishment, the higher the chance of success. Some eradication attempts have been successful on continents where the attempt was made on a newly established exotic species, when numbers were still low and the population was restricted to a small area. Even if eradication campaigns are implemented when animal numbers and the area infested are still small, there is no guarantee of success, and eradication attempts may not be worthwhile.

Eradication of newly established exotic vertebrates in Australia is only likely to be achievable if appropriate, adequately-resourced, contingency plans are in place to ensure that escapes are reported, newly established populations are detected and reported, and containment and control programs are mounted rapidly. To date, early eradication has been achieved for few exotic vertebrates in Australia.

***Eradication of newly established exotic vertebrates in Australia is only likely to be achievable if appropriate, adequately-resourced, contingency plans are in place.***

Because the numbers, distribution and location of escaped animals and any progeny have a major influence on whether or not eradication is achievable, and because these factors are virtually impossible to predict with any certainty, evaluating the feasibility of eradication for any given species is extremely difficult. Further, the social and political factors that affect the planning and implementation of an eradication campaign are even more uncertain. In Australia, few eradication campaigns have been conducted against newly established exotic vertebrates, and no attempts have been made to eradicate recently established populations of red-eared

*Source: Adelaide Zoological Gardens*

sliders (*Trachemys scripta elegans*). Given that assessing the probability of the success of an eradication attempt is so difficult and that eradication is rarely attempted, using the feasibility of eradication as a component of risk assessment seems inadvisable, and it is not included in the risk assessment model presented in this report.

## Factors influencing pest potential

A pest can be defined as an animal that has a detrimental effect on economic, social or conservation values or resources. Around 50% of exotic mammals and birds around the world are considered to be pests.

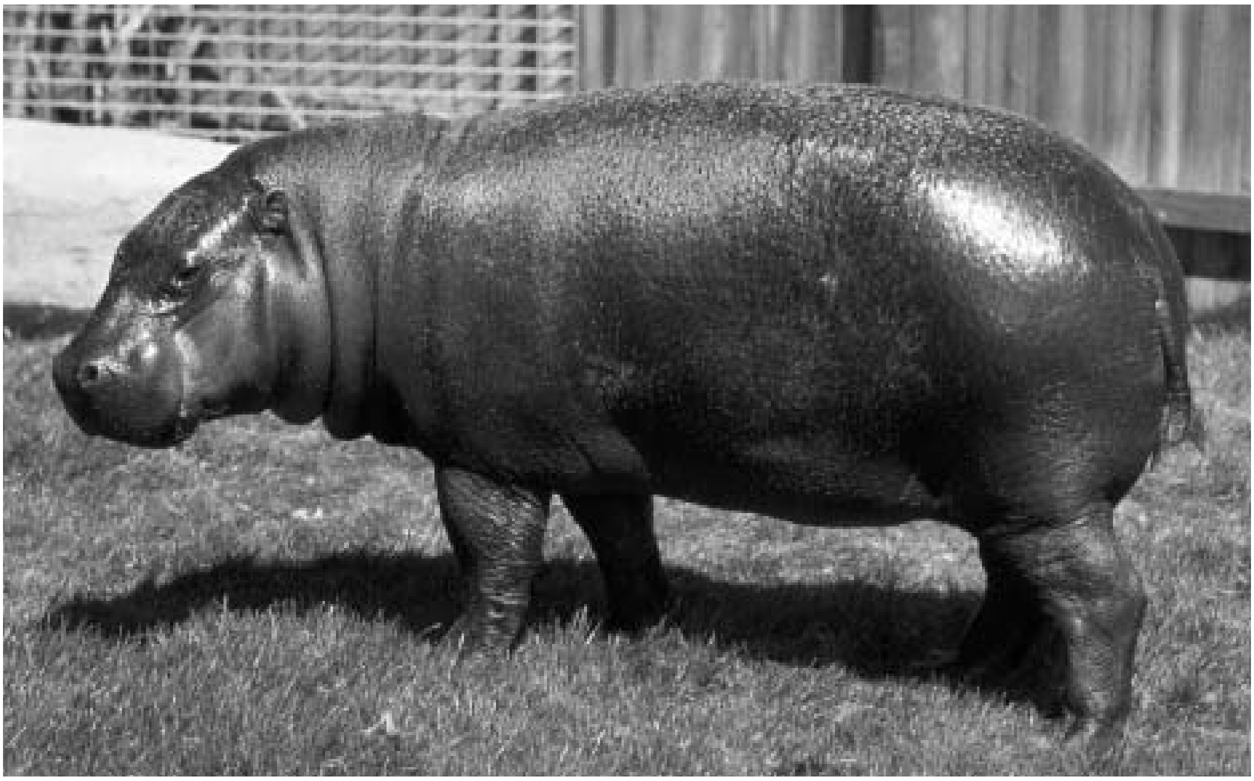
Of the 20 exotic bird species established on mainland Australia, nine are perceived to be moderate or serious pests and a further seven have potential to become pests if they increase in abundance, making a total of 80% of exotic bird species that are pests or potential pests. Of the 24 exotic mammal species established on mainland Australia, 14 are moderate or serious pests and a further four are minor pests, that is, a total of 75% of exotic mammal species are pests. The cane toad, the single exotic amphibian in Australia is a serious pest. The four exotic reptiles have so far established only localised populations and none are yet considered pests.

***Of the 24 exotic mammal species established on mainland Australia, 14 are moderate or serious pests***

Exotic vertebrates can reduce agricultural or forestry productivity by causing: losses to crops, livestock, poultry, forestry and stored produce; land degradation; structural damage to farm buildings, equipment, fences, roads, banks or drainage systems; and flow-on effects to other industries. Exotic vertebrates can cause environmental damage by predation and harassment of native fauna, competition with or disturbance of native fauna, grazing and browsing on native plants, harbouring or spreading diseases to native fauna and hybridising with native fauna. Secondary flow-on effects that may also detrimentally affect native plants and animals include disruption of community structure and food webs. Such flow-on effects are usually more difficult to predict than direct effects. When new species establish wild populations in a region, a roughly equivalent number of resident species usually become extinct. Islands are particularly prone to environmental damage and to species extinctions. Australian mammals, birds and reptiles are more severely affected by introduced species than the fauna of any other continent. Exotic vertebrates can also be agents in the spread of parasites or diseases affecting people, and can cause social problems through noise or pollution or damage to buildings, vehicles and aircraft. Finally, vertebrate pest control measures are costly and time-consuming, and can harm non-target species and the environment.

Several factors can be used to predict whether new exotic mammals and birds will become pests if they establish wild populations in Australia. These are:

- Pest status elsewhere — Nearly all exotic species that are considered to be pests in Australia are also considered to be pests in at least parts of their overseas range.
- Climate match — Climate matching between species' overseas distributions and Australian environments is significantly correlated with the geographic range of established species and most exotic species that are widespread in Australia are considered pests.
- Extent of geographical range — The geographic range size of exotic vertebrates in Australia is significantly correlated with their overseas geographic range size and most exotic species that are widespread in Australia are considered to be pests.
- Population density elsewhere — Most exotic mammals and birds that are considered to be serious pests in Australia are common or abundant in at least part of their overseas range.
- Mammal vs bird — Exotic mammals are more likely to have harmful economic effects on agriculture and forestry than exotic birds, and exotic mammals are also more likely to have serious ecological impacts on native species than are exotic birds, although it is possible ecological impacts have been underestimated for birds.
- Taxonomic group (mammals) — Mammal taxa particularly prone to cause damage to agriculture or forestry are Canidae (foxes and dogs), Mustelidae (stoats and ferrets), Cervidae (deer), Bovidae (cattle, sheep and goats), Leporidae (rabbits and hares), Equidae (horse family) and Muridae (rats and mice).



Source: Adelaide Zoological Gardens

- Taxonomic group (birds) — Bird taxa particularly prone to cause agricultural damage include Psittaciformes (parrots), Anatidae (ducks, geese and swans), Fringillidae (old-world finches), Passeridae (sparrows and weavers), Sturnidae (starlings and mynas), and Corvidae (crows).
- Predators — Species that kill, maim or harass domestic animals or wildlife overseas are likely to do so in Australia.
- Grazers and browsers — Species that are grazers or browsers are more likely to cause habitat changes than are other herbivores.
- Disease vectors — Species that harbour or transmit pathogens that affect domestic animals, wildlife or people overseas, may also act as reservoirs or vectors of diseases in Australia.
- Competitors — Species that can use resources on which Australian domestic animals or wildlife depend are potential competitors with these species.
- Commensal with humans — Species that can live in human-disturbed habitats overseas are more likely to establish in similar habitats in Australia and have a higher risk of causing agricultural damage, spreading diseases to domestic animals and people, and being a social nuisance.

So few exotic reptiles and amphibian species have established in Australia that it is not possible to make generalisations from past introductions about the attributes that might contribute to establishment success and potential pest status. Therefore, in the risk assessment model presented in this report, it is assumed that the same risk factors that apply to the establishment and pest potential of exotic mammals and birds also apply to exotic reptiles and amphibians.

Collectively, these factors can be used to predict the pest potential of exotic vertebrates introduced to Australia, but there will be always be a degree of doubt. The possible development of new, unpredictable behaviour patterns and of phenotypic or genotypic shifts, for example, bring a strong element of uncertainty to risk assessments. Not only is such assessment uncertain, but the consequences of a wrong decision are likely to be economically and environmentally expensive, so a precautionary approach is desirable.

***The possible development of new behaviour patterns or genotypic shifts, bring a strong element of uncertainty to risk assessments so a precautionary approach is desirable.***

Control of widespread pests is nearly always expensive. In Australia, vertebrate pest control has not reduced damage to acceptable levels for any of the major exotic pest species, and most control techniques are not fully target-specific and many are not humane. Because the use of control techniques is considered unlikely to prevent a species' pest potential being realised, the availability of control techniques is not included in the risk assessment model presented in this report.

## Using the risk assessment model to determine a species' VPC Threat Category

The risk assessment model is for use by the Vertebrate Pests Committee (VPC), to place exotic vertebrate species into Threat Categories which can be used as a basis for setting appropriate import and keeping restrictions for Australia (Vertebrate Pests Committee in press). To determine a species' VPC Threat Category, three risk scores are calculated:

1. Danger posed by individual animals — risk that escaped individual animals will harm people.
2. Establishment likelihood — risk that a species will establish a wild population in Australia.
3. Establishment consequence — risk that an established population of the species will cause harm (become a pest).

The scores are then used to determine the species' VPC Threat Category: either extreme, serious, moderate or low.

The model does not assess the risk that the import of exotic vertebrates will introduce disease agents into Australia. This risk is assessed under a separate process conducted by Biosecurity Australia in the Commonwealth Department of Agriculture, Fisheries and Forestry.

## Terminology

Because application of the following terms is non-uniform, their use in this report is defined below:

Native species: a species found within its native range (in Australia this means that it is indigenous to Australia).

Exotic species: a species which is introduced to outside its native range (in Australia this means that it is non-native to Australia).

Established species: a species with a free-living self-sustaining population outside its native range.

Invasive species: an exotic species that establishes a wild population and spreads beyond the place of introduction and becomes abundant (Richardson et al. 2000).

Niche: That aspect of the environment which especially fits the structural, functional, and behavioural characteristics (requirements) of a species (de Vos and Petrides 1967).

# Introduction

Australia is an isolated continent with valuable agricultural industries and a highly diverse native flora and fauna. A suite of introduced terrestrial vertebrate species has established wild populations on the mainland: at least 25 mammals, 20 birds, four reptiles and one amphibian (Appendix A). Additional species have established on Australia's offshore islands; among them another seven birds. Many of these introduced species are pests that have adverse impacts on agriculture and the environment. They cost Australia in excess of $420 million a year in lost agricultural production, control and research (Bomford and Hart 2002). Introduced herbivores contribute to land degradation by overgrazing and browsing, which lowers the future production capacity in many areas. Grazing, predation and competition by non-indigenous vertebrates are also major threats to many endangered native species and communities, although these significant costs have yet to be quantified. It is desirable to prevent additions to this expensive and damaging array of pests. On a global scale, non-indigenous species are now recognized as one of the leading threats to native biodiversity and ecosystem function as well as a leading cause of economic losses to agriculture (Kolar and Lodge 2001; Pimental 2002). As a signatory of the *Convention on Biodiversity, 1992*, Article 8(h), the Australian Government has an obligation to prevent the introduction of, to control or to eradicate exotic species which threaten ecosystems, habitats or species (Jenkins 1996; Sharp 1999).

Many exotic species are kept in captivity in Australia for their recreational, commercial and conservation benefits, and there are continual applications made to import and keep new species. Australian wildlife and quarantine authorities support a process of risk assessment and risk management to evaluate and manage any threats that imported exotic species could pose to agriculture and the environment.

*Source: Peter Bird, Animal and Plant Control Commission, South Australia*

Greater global travel and the lifting of trade restrictions have resulted in increased rates of exotic species introductions to many countries (American Ornithologists' Union Conservation Committee 1991; Lodge 1993b; Williamson 1996; Holmes 1998; Enserink 1999; McKinney and Lockwood 1999; Mack et al. 2000; Kolar and Lodge 2001). Recent developments to free world trade are likely to increase the numbers of exotic animals imported into and kept in Australia, and hence the risk of their establishing wild exotic populations here. World trade in exotic pets has increased greatly in recent decades and there are now numerous magazines dedicated to the subject of keeping these species. Much of the exotic pet trade is dominated by reptiles and birds, although the trade in mammals and amphibians is also significant. For example, the United Kingdom legally imports more than one million exotic live reptiles and amphibians annually, including iguanas, boas, pythons, chameleons and geckos. These species are frequently imported and traded privately and in pet shops. In 1996, the United Kingdom legally imported many exotic vertebrates regulated under the *Convention on International Trade in Endangered Species* (CITES), including 16 000 exotic birds, 25 000 exotic reptiles and amphibians and 2800 exotic mammals, plus a far greater number of non-CITES listed exotic vertebrates and an unknown number of illegally imported animals (TRAFFIC 1999). The USA imports more than 1.7 million exotic reptiles annually for the pet trade. In 1997, the USA exported 8.7 million farmed red-eared slider turtles (Franke and Telecky 2001), a species that has recently established wild populations in Australia.

***Introduced species cost Australia in excess of $420 million a year in lost agricultural production, control and research.***

Policy makers trying to restrict traffic in undesirable exotic species are hampered by inadequate knowledge about which species pose a risk. Yet governments have to make decisions on risks associated with exotic vertebrate imports and any scientific guidance will be helpful to them, even if predictions have a fairly high level of uncertainty. Preventing invasions of exotic animals is far less costly than post-establishment control (Mack et al. 2000). However, preventing the import of all exotic vertebrate species is neither feasible nor desirable. Restrictive policies can lead to smuggling, economic disadvantages and political pressures by interest groups (Mack et al. 2000). The import of exotic species into Australia is controlled by the Department of Agriculture, Fisheries and Forestry under the *Quarantine Act 1908* and by the Department of the Environment and Heritage under the *Environment Protection and Biodiversity Conservation Act 1999.* Once exotic animals are in Australia, State and Territory governments also have legislative control over their trade and keeping. The national Vertebrate Pests Committee provides advice to governments on the threats to agriculture and the environment posed by exotic vertebrates kept in Australia or proposed for import. The Committee follows the Office Internationale des Epizootics (OIE) International Animal Health Code of transparency, hazard identification, risk assessment, risk management and risk communication (Vertebrate Pests Committee in press).

Bomford (1991) published criteria for assessing the risks of importing exotic vertebrates into Australia. These criteria were developed on the premise that the import and keeping of exotic vertebrates should be subject to a risk assessment that uses all available scientific expertise and knowledge on the biology of the species being assessed. Bomford's (1991) criteria were designed to operate as a checklist and decision guide to ensure decision makers took account of all relevant information, and could not be used to create quantitative risk scores.

Source: Unknown

***Preventing the import of all exotic vertebrate species is neither feasible nor desirable.***

This report re-evaluates Bomford's (1991) criteria, supplemented with information from more recent literature reviews and analyses of past introductions of mammals and birds into Australia, to assess which factors have the most significant influence on whether introduced species succeed or fail to establish exotic populations. The attributes of established species that became pests of primary production or the environment are compared with the attributes of non-pest species. The results of these analyses are used to develop a more quantitative model for risk assessment, for use by government agencies and the Vertebrate Pests Committee. This exotic vertebrate risk assessment model has a sound scientific basis and the decision mechanism is transparent. Nonetheless, there are practical limitations to the degree to which scientific knowledge can be used to predict the potential of introduced species to establish wild pest populations. Hence this model cannot do more than provide indicative assessments of risk, rather than make definite predictions.

The risk assessment model does not assess the risk that the import of exotic vertebrates could lead to the introduction of disease agents into Australia. This risk is assessed under a separate process conducted by Biosecurity Australia in the Commonwealth Department of Agriculture, Fisheries and Forestry.

The process of invasion by exotic species has been divided into four separate transition phases: transportation, release, establishment and spread (Williamson 1996). Several factors determine the probability that an exotic species will complete each transition successfully (Kolar and Lodge 2001). Of these four transition phases, this report focuses primarily on predicting the probability of establishment.

***These analyses that are used to develop a more quantitative model for risk assessment have a sound scientific basis.***

When species establish exotic populations, some will remain relatively localised around the point of introduction (non-invasive species), whereas others will spread widely (invasive species) (Kolar and Lodge 2001). The distinction between non-invasive species and invasive species is arbitrary and partly a function of time since introduction. Following establishment, some species have a period (sometimes of several decades) of slow population growth and restricted range, followed by rapid population growth and range expansion (Elton 1958; Williamson 1989; Dean 2000). Such species are sometimes called 'sleeper species' (Section 1.4.2).

*Source: Department of Agriculture, Western Australia.*

# SECTION 1

## Review of factors affecting the potential of an exotic vertebrate to establish and become a pest

Risk assessment involves identifying hazardous events (in this case the establishment of new exotic vertebrate pest species in Australia) and estimating the likelihood that such events will occur and the probable consequences if they do (Beer and Ziolkowski 1995). Factors that will contribute to this risk are the probability that:

- an escape or release will occur (Section 1.1)
- escaped or released individuals will cause harm (Section 1.2)
- escaped or released individuals will establish a free living population (Section 1.3)
- a newly established population can be eradicated (Section 1.4)
- if eradication fails, the exotic species will become a pest, causing economic, social or environmental harm, and the degree and types of such harm (Bomford 1991; U.S. Congress Office of Technology Assessment 1993) (Section 1.5).

## 1.1 Probability an escape or release will occur

### 1.1.1 Factors affecting the probability of escape or wilful release

Factors that may affect the probability of escape or wilful release are listed in Box A. Security regulations and improved community awareness can reduce the risk of accidental escape or release under normal conditions, but in the long term there can be no absolute security for any species. Physical barriers cannot be completely proof against releases due to:

- natural disasters such as floods, cyclones, fires or earthquakes
- vandalism, terrorism, civil unrest or war
- wilful release.

There are numerous examples of exotic species being freed during natural disasters (Mack et al. 2000). Presnall (1958) reports the escape of coypus (*Myocastor coypus*) from fur farms during floods in New Mexico and Oregon and a hurricane in Louisiana. Exotic populations established from each of these escapes. Nilsson (1981) reports the release of a flock of yellow-crowned Amazon parrots (*Amazona ochrocephala*) by a Californian aviculturist when fire threatened his collection, and of red-whiskered bulbuls (*Pycnonotus jocosus*) in southeastern Florida when vandals smashed their enclosure. These releases all resulted in the establishment of exotic populations.

Wilful releases could also occur if, for example, hunting groups wished to establish exotic populations of a game species. Similarly, people can deliberately release exotic species that they like to see in their gardens and neighbourhood. The population of Indian mynas (*Acridotheres tristis*) in Canberra stemmed from such a wilful release (Gregory-Smith 1985) and the establishment of an exotic population of rose-ringed parakeets in Britain is also believed to have been deliberate (*Psittacula krameri*) (England 1974). There has been a trend in Europe and the USA for animal liberation groups to liberate animals bred for the fur trade (Baker 1986; http://www.furcommission.com). This activity could well lead to the establishment of species such as mink (*Mustela vison*).

According to Temple (1992), there are 75 species of free-living exotic birds in the United States, of which 38% are pet bird species that established following escapes from captivity. Most of these species were held legally prior to escape. Temple (1992) considers that such introductions inevitably accompany the trade and keeping of exotic birds and that the accidental escape of birds legally imported and kept as pets is now the major pathway for the establishment of new exotic species in the United States.

Many more exotic species with pest potential are kept in private collections in North America and much of Europe than in Australia (Nilsson 1981). This is due to the voluminous import trade in exotic species (Rand 1980; Roet et al. 1980; Nilsson 1981; Bruggers 1982, 1983; United States Congress Office of Technology Assessment 1993). In these countries, the incidence of exotic species establishing wild populations has been higher in recent decades than in Australia (Long 1981; Nilsson 1981; Lever 1985, 1987).

## Box A: FACTORS AFFECTING POSSIBLE ESCAPE OR RELEASE

**1. Security of premises**

Important factors are:

- cage or enclosure security relative to the abilities of a species to climb, jump, fly, swim, tunnel or break out
- keeper numbers, skills, experience and work-load
- frequency and thoroughness of cages or enclosures inspections
- frequency and thoroughness of inspections of animals
- reporting requirements
- financial viability of owners
- adequacy of escape contingency plans.

**2. Keeping restrictions**

Imposing restrictions on the keeping of animals can reduce risk of escape. For example, the potential for the escape of enough individuals to form a viable breeding group can be reduced or prevented by requiring:

- limits on the number of locations at which a species is kept
- limits on numbers of animals which are kept together
- single sex collections
- sterilisation
- pinioning or other techniques to restrict movement.

While these keeping requirements could substantially reduce the risk of the escape of a viable breeding group, they have major limitations. For example:

- Highly regulated keeping restrictions are expensive to inspect and enforce and, hence, are subject to breaches. They also elicit continual pressure from interest groups to reduce or remove them. This is particularly so for restrictions aimed at preventing breeding, because one of the major reasons that small private collectors keep exotic species is to breed them.
- Sterilisation can be difficult to guarantee. For example, permits were available to allow people to keep neutered male ferrets and other exotic wildlife species in California until it was found that few government inspectors could ascertain whether an animal had been neutered and biologists found that intact males were entering the State. These violations prompted a policy change by the Fish and Game Commission and from 1986 all permits to keep neutered males were denied (Moore and Whisson 1998).
- Assessment of a safe number or density of animals requires detailed ecological data, which entails expensive, long-term research, and would have only limited reliability for risk prediction purposes.
- The permanent marking of individual animals kept under permit, by such techniques as individual tattooing or implantation of electronic microchip transponders, may discourage illegal trade or breeding, but such a system would be difficult and expensive to enforce.

**3. Community and keeper attitudes**

Attitudes or perceptions that may increase the probability of illegal keeping, escape or wilful release include:

- value of a species as a specimen, pet or item for trade
- desire by hunters or others to establish a wild population
- low perceived risk of illegal removal or release of animals from approved premises being detected or prosecuted
- low penalties imposed for loss or release
- low awareness of a species' potential pest status.

While penalties such as cancellation of permits, closure of premises, fines, prison sentences and confiscations may deter illegal releases, systems to impose such penalties have limitations. For example:

- inspection and enforcement are expensive
- it is often difficult to identify and successfully prosecute offenders
- existence of harsh penalties for infringements may discourage cooperation between keepers and government authorities
- imposition of penalties will not stop: illegal trade, keeping and theft if profits are substantial; illegal animal releases by some individuals or interest groups such as animal liberation and animal rights; releases caused by natural disasters; accidental escapes.

### 1.1.2 Risk assessment significance of potential to escape from captivity

The probability of individuals being released or escaping is determined mainly by the conditions under which species are kept, natural disasters, and any economic or social benefit perceived to be attached to their release. Hence, this probability is primarily affected by risk management strategies and to a far lesser degree by a species' attributes. Therefore, an assessment of the risk of release or escape is not included in this risk assessment model, even though it is recognised that some species' attributes (such as a species' ability to climb, dig or break out of an enclosure or cage) will make them more likely to escape.

## 1.2 Probability escaped or released individuals will cause harm

If they are aggressive, large, or otherwise dangerous, for example, predatory or venomous, then escaped or released individual animals may be able to cause significant damage, or directly harm people, pets, livestock or native animals.

## 1.3 Probability escaped or released individuals will establish a free-living population

According to some ecologists, only about 10% of exotic introductions to the wild succeed in establishing (Williamson 1996, 1999; Williamson and Fitter 1996; Holmes 1998; Enserink 1999; Smith et al. 1999). Analyses of past introductions of exotic birds and mammals reveals that this generalisation is doubtful for vertebrates (Table 1). Perhaps a more reasonable generalisation would be that around one–third of exotic bird species and two-thirds of exotic mammal species establish wild populations when introduced into new environments. Nevertheless, the actual figure is variable and uncertain.

### 1.3.1 Predicting establishment success

Recognition of invasion risk relies on identification of factors that correlate with the probability of successful establishment and can be measured without the introduction actually occurring (Lockwood 1999). There is a considerable scientific literature on the ecological theory of species' invasions, proposing a suite of factors that may influence whether or not exotic mammals and birds establish in new environments. These factors are listed below, each with a brief summary of the theory and the evidence, followed by an assessment of their practical significance for assessing the risk of new species establishing in Australia.

**(i) Introduction effort — numbers of animals released and number of places and times at which releases occur**

The release of large numbers of animals at different times and places enhances the chance of successful establishment (de Vos et al. 1956; Bohl and Bump 1970; Richter-Dyn and Goel 1972; May 1973; Jarvis 1980; Diamond and Case 1986; Newsome and Noble 1986; O'Connor 1986; Roughgarden 1986; Williamson and Brown 1986; Griffith et al. 1989; Mooney and Drake 1989; Pimm 1989, 1991; Williamson 1989, 1996, 1999; Bomford 1991; Beck et al. 1994; Veltman et al. 1996; Duncan 1997; Green 1997; Duncan et al. 2001; Forsyth and Duncan 2001; Kolar and Lodge 2001; Sakai et al. 2001; Forsyth et al. in press).

**Table 1:** Establishment success rates for exotic mammal and bird species.

| Taxonomic group and location | Proportion of introduced species that successfully established | Source |
|---|---|---|
| Birds on mainland Australia | 20 of 48 (42%) | Long 1981 |
| Birds in Europe | 13 of 85 (15%) | Udvardy 1969; Jarvis 1980 |
| Birds in New Zealand before 1907 | 25 of 72 (35%) | Veltman et al. 1996 |
| Birds in Hawaii | 38 of 70 (54%) | Williamson and Fitter 1996 |
| Birds in the world | 170 of 486 (35%) | Long 1981; Lockwood 1999 |
| Mammals in Australia | 24 of 35 (69%) | Myers 1986 |
| Mammals in Europe | 32 of 47 (68%) | Udvardy 1969; Jarvis 1980 |
| Ungulates in New Zealand between 1851 and 1926 | 11 of 14 (79%) | Forsyth and Duncan 2001 |

***Theory:*** Small populations (or small propagules of released animals) are more susceptible than large populations to extinction from such factors as increased risk of predation, not finding a mate, reduced breeding success or poorer hunting success or increased inter-specific competition (Williamson 1989; Dennis 2002). Demographic stochasticity, such as random fluctuations in the proportions of males and females, will play a major role in determining the survival of small populations, particularly for short-lived or monogamous species (May 1991; Lande 1993; Legendre et al. 1999). Environmental stochasticity, including chance events such as accidents, fires and floods, are also likely to drive small populations to extinction (MacArthur and Wilson 1967; Simberloff 1989; Williamson 1989; Stacey and Taper 1992; Caughley 1994; Caughley and Sinclair 1994). For some social species, behavioural patterns necessary for survival need to be learnt in an appropriate setting, and this may not occur when numbers are low (May 1991). Small populations may also lose genetic variability which may reduce the probability of long-term survival (Soulé 1987; May 1991). Ehrlich (1989) suggests that the release of more individuals may increase success rates because larger invading groups will have a greater pool of genetic variability. This might reduce founder effects and enhance the chances of rapid adaptive radiation in the new environment (Section 1.3.1xiv).

The minimum viable population size for successful invasion is not known for most species, but below a threshold of about 20 individuals, in many circumstances, survival is unlikely. Above this critical threshold, events affecting individuals are unlikely to have major demographic consequences. Below this threshold the population may drift randomly up or down, depending on chance events (Browning 1977). Thus, a population may establish even if its initial size is below the threshold, should numbers happen to drift above the threshold after introduction. There are many examples of propagule sizes of less than 10 individuals establishing exotic populations, sometimes even a single pair. These include the Macaque monkey (*Macaca fascicularis*), reindeer (*Rangifer tarandus*), Himalayan thar (*Hemitragus jemlahicus*), Himalayan porcupine (*Hystrix brachyura)* and stoat (*Mustela erminea*) (Roots 1976; Lever 1985; Baker 1986; Ehrlich 1986; Pimm 1989).

Repeated releases over an extended period will increase the chance of successful invasion simply because the release 'experiment' is repeated many times, under different biotic and abiotic conditions, including different climates and seasons, condition of released animals and numbers of natural enemies present (Crawley 1986; Green 1997)(Sections 1.3.1x, xii, xiii, xvii).

***Evidence:*** Kolar and Lodge (2001) reviewed eight studies of exotic bird introductions in various locations around the world. They found that all eight studies showed a statistically significant relationship between the number of individuals released and establishment success and that five of the eight studies showed a statistically significant relationship between the number of release events and establishment success. Griffith et al. (1989) found that, for birds, the success of establishment dropped sharply when the release propagule size was less than 20 individuals. Above a release propagule size of 40, success rate was asymptotic, as predicted by MacArthur and Wilson (1967).

Newsome and Noble (1986) analysed Long's (1981) data on establishment success of exotic birds in Australia, supplemented with additional data, and found that the number of individual birds introduced (three propagule size classes: < 20; 20–100; ≥101) had a highly significant ($P \leq 0.001$) influence on whether exotic birds established wild populations in Australia. Duncan et al. (2001) also analysed Long's (1981) data on bird introductions to Australia, supplemented with additional data (Birds Australia, unpublished information, 2000*)*. They found that, in addition to the number of individuals released being significantly correlated with introduction success ($P \leq 0.05$), the number of introduction sites and the number of introduction events were also highly significantly correlated with introduction success ($P \leq 0.001$). Only five out of 33 (15%) bird species that were reported to have been released at only one or two sites on mainland Australia established wild populations, compared to 19 of 20 (95%) of bird species that were released at three or more sites. Similarly, for exotic mammals released in Australia, introduction effort (the number of times a species was released) is significantly ($P < 0.001$) correlated with establishment success (Forsyth et al. in press). For exotic deer introduced to Victoria, the number of individuals released is significantly ($P < 0.01$) correlated with establishment success (Forsyth et al. in press).

Veltman et al. (1996) found that the minimum number of birds released and the number of release events were highly significantly correlated with establishment success for birds in New Zealand, and this was supported by later analyses conducted by Duncan (1997) and Green (1997). Dawson (1984) found that, for introductions of exotic birds in New Zealand, the probability of establishment for a species was about 10% when fewer than 10 individuals were introduced, but this increased to near certainty when over 1000 individuals were introduced.

Griffith et al. (1989) and Beck et al. (1994) also found that the number of individuals released had a significant effect on establishment success for native birds and mammals translocated for conservation, although Wolf et al. (1996) found that this factor was only statistically significant for birds, not for mammals.

***Risk assessment significance:*** The total number of individuals released, the number of release events, and the number of sites at which releases occur can affect establishment success and should be considered as key factors when managing the risk of exotic species establishing in Australia. Introduction effort can be managed by restricting which species are kept in Australia, the number of collections holding the species, the number of individuals held in each collection, and the security conditions for keeping species to reduce the probability of escapes and releases occurring (Section 1.1). The number of animals that escape or are released is likely to increase if more species are kept, in higher numbers, and in more locations. Hence, any changes to policy or management for exotic species that allow more species to be imported, or reduce restrictions on where exotic species can be held or the numbers held, are likely to increase the risk that more exotic species will establish wild populations in Australia.

**(ii) Climate match**

Climate match is a measure of the similarity between the sites of origin and release based on rainfall and temperature data. Potential species' ranges are predicted using a 'climate envelope' approach, in which the current distribution of a species is mapped and its climatic attributes measured, and then extralimital locations with matching climate attributes are determined and mapped. The expectation is that a species is likely to be able to establish in locations with a climate closely matched to that in its current range (Davis et al. 1998). Climate matching can be used to generate maps of probability of successful establishment of a species from any part of the world to a nominated target region (Nix and Wapshere 1986; Pheloung 1996; Sutherst et al. 1998; Duncan et al. 2001; Kriticos and Randall 2001). The suitability of Australian environments for the establishment of a species can be quantified on a broad scale by measuring the climate match between Australia and the overseas geographic range of a species (Nix and Wapshere 1986; Bomford 1991; Lodge 1993a, b; Sutherst et al. 1998; Williamson 1999; Duncan et al. 2001).

***Theory:*** A frequently stated hypothesis in the biological invasion literature is that species should have a greater chance of establishment if they are introduced to an area with a climate that closely matches that in their original range (Brown 1989; di Castri 1991; Mack 1996; Williamson 1996; Duncan et al. 2001). Nix and Wapshere (1986) suggest that climate matching accounts for 80–90% of the variance in establishment success of introduced birds in Australia, based on data published by Long (1981). Brown (1989), however, cautions that many animals can tolerate a much wider range of physical conditions than that in their current range. He gives examples of brown rats (*Rattus norvegicus*), house mice (*Mus domesticus*) and donkeys (*Equus asinus*) from temperate regions, which have colonised tropical Australia, and conversely, examples of tropical rusa deer (*Cervus timorensis*) and hog deer (*Cervus porcinus*), which have colonised temperate Australia. Similarly, Ehrlich (1989) suggests Long's (1981) data on introduced birds show species from 'stressful environments', such as deserts, often successfully invade moist tropical habitats, whereas species indigenous to 'benign habitats' rarely invade 'stressful environments'.

***Evidence:*** Long and Mawson (1991) found that two-thirds of exotic bird species that established in Australian Mediterranean climates had a natural range totally or partly in a Mediterranean climate. Duncan et al. (2001) reported that climate matching between species' overseas distributions and Australian environments is highly correlated with establishment success for exotic birds in Australia ($P \leq 0.01$). Blackburn and Duncan (2001a) found that for global exotic bird introductions, introduction success was significantly greater both when the difference between a species' latitude of origin and its latitude of introduction was small ($P \leq 0.0001$), and when species were introduced to locations within their native biogeographical regions ($P \leq 0.0001$). Both these factors would probably indicate a close climate match between area of origin and place of introduction (Simberloff 1989).

For exotic mammals introduced to Australia (Myers 1986; Bentley 1998; Long 2003), climate matching between species' overseas distributions and Australian environments (Appendix B, Table B3) is significantly ($P \leq 0.001$) correlated with establishment success (Forsyth et al. in press).

***Risk assessment significance:*** The climate match between a species' overseas geographic range and mainland Australia can be determined using CLIMATE software (Pheloung 1996; Appendix C). This software is used by Biosecurity Australia (in the Commonwealth Department of Agriculture, Fisheries and Forestry) to assess climate matches for exotic plants proposed for introduction to Australia**.** Species with a high climate match to Australia are most likely to establish here, and the level of climate match should be considered as a key factor when assessing the risk that other exotic species could also establish.

### (iii) Overseas geographic range size

Species that are widespread and abundant in their original range, particularly over extensive continental regions, are more likely to establish exotic populations (Long 1981; Lever 1985, 1987; Moulton and Pimm 1986; Brown 1989; Ehrlich 1989; Long and Mawson 1991; Williamson 1996, 1999; Lockwood 1999; Sakai et al. 2001; Blackburn and Duncan 2001a).

***Theory:*** According to Brown (1989), successful invaders tend to be native to continents and to extensive non-isolated habitats within continents, but he cautions this may be at least in part due to island species having had far fewer opportunities for invasion than continental species. Williamson (1996) suggests a wide geographic range could indicate flexible or generalist species, or good dispersers, and hence species that are more likely to invade successfully. Animals that are able to function in a wide range of physical conditions should be more successful than those only able to function in a narrow range. Exotic species with an ability to tolerate wide habitat and climatic variability may be more successful at establishing (Swincer 1986; Ehrlich 1989). Duncan et al. (2001) and Forsyth et al. (in press) suggest that species with a wide geographic range are more likely to have good climate matches to other regions and that they also tend to be introduced at more sites and in greater numbers than species that are less widespread. These factors could account for the greater introduction success of species with a wide geographic range.

Williamson (1996) suggests that there may be a relationship between invasion success and the abundance of a species in its native range. Few quantitative data are available on species' abundance but there is a weak positive correlation between abundance and geographic range size in many taxa (Williamson 1996; Holt et al. 1997). Hence, geographic range size might be a suitable surrogate for abundance.

***Evidence:*** Long and Mawson (1991) found that of the 12 exotic bird species that have established in Australian Mediterranean climates and become widespread and common, 11 (91%) have very large native ranges. In contrast, few if any of the more restricted, less common introduced bird species have large native ranges. Duncan et al. (2001) found that overseas geographic range size is significantly ($P \leq 0.01$) correlated with establishment success for exotic birds in Australia. Geographic range size is also a significant ($P \leq 0.0001$) correlate of introduction success for global bird introductions (Blackburn and Duncan 2001a).

For exotic mammals introduced to Australia (Myers 1986; Bentley 1998; Long 2003), overseas geographic range size (Appendix A, Table A1) is significantly ($P \leq 0.01$) correlated with establishment success (Forsyth et al. in press).

***Risk assessment significance:*** Because having a widespread overseas geographic range is a significant predictor of establishment success for exotic birds and mammals introduced to Australia, this variable should be considered as a key factor when assessing the risk that other exotic species could establish here.

### (iv) History of establishing exotic populations elsewhere

A proven history of invasiveness may indicate that a species has attributes that increase the risk of it becoming a successful invader in other areas (Bomford 1991; Williamson 1996, 1999; Duncan et al. 2001; Kolar and Lodge 2002).

***Theory:*** Species with attributes that predispose them to be good invaders could be expected to have demonstrated their invasiveness if they have previously been successfully introduced to new environments.

***Evidence:*** Duncan et al. (2001) found that, for exotic birds introduced to Australia, a history of establishing exotic populations elsewhere in the world was significantly ($P \leq 0.01$) correlated with establishment success. Similarly, Brooke et al. (1995) found that for exotic passeriform birds introduced to the island of Saint Helena, a history of establishing exotic populations elsewhere in the world was significantly ($P \leq 0.01$) correlated with establishment success. Forsyth et al. (in press) found that, for exotic mammals introduced to Australia, a history of establishing exotic populations elsewhere in the world was significantly ($P \leq 0.001$) correlated with establishment success in Australia.

Of the 25 exotic mammal species successfully introduced to Australia, all except three species (feral camel (C*amelus dromedarius*), European red fox (*Vulpes vulpes*) and Indian palm squirrel (*Funambulus pennanti*)) have also been successfully introduced elsewhere in the world (Appendix A, Table A1). Of these three species, two have demonstrated establishment potential overseas — according to Lever (1985) the camel temporarily established a feral population in the USA in the 1800s, and the European red fox also probably established wild populations in the USA in areas not originally inhabited by the conspecific American red fox (*V. v. fulva*).

***Risk assessment significance:*** Because a history of establishing exotic populations elsewhere is a significant predictor of establishment success for exotic mammals and birds introduced to Australia, this variable should be considered as a key factor when assessing the risk that other exotic species could establish here. However, many species that are potential exotics have not been transported to and released in new environments, so they have not had the opportunity to demonstrate their establishment potential. Hence, caution should be applied when using a history of establishment elsewhere to predict a species' establishment potential in Australia.

### (v) Taxonomic group

Mammals may be more likely than birds to establish exotic populations (Fox and Adamson 1979; Jarvis 1980; Moulton and Pimm 1986; Griffith et al. 1989; Wolf et al. 1996) (Table 1). Gamebirds may be less likely to establish than other birds (Duncan et al. 2001) and passerine birds may be more likely to establish than non-passerines (Williamson 1996; Green 1997; Dean 2000). Otherwise, taxonomic grouping usually gives little indication of a species' likelihood of establishing (Simberloff 1991; Lockwood 1999). Often close relatives of a species that is highly successful at establishing exotic populations, repeatedly fail or do poorly when introduced to the same environments (Ehrlich 1986; Simberloff 1991; Dean 2000).

***Theory:*** Long and Mawson (1991) consider that, for exotic birds introduced to Australia, the more evolutionarily advanced species, as determined from DNA analysis, are more successful. They suggest evolutionary advanced taxa tend to inhabit more recent human-made habitats.

***Evidence:*** Data showing that mammals have higher success rates than birds for establishing exotic populations are presented in Table 1. Wolf et al. (1996) also found mammals were more likely to establish self-sustaining populations than birds when native species were translocated or reintroduced for conservation. There are insufficient data to generalise about amphibians and reptiles.

However, there are many examples of species that have established successfully when close relatives have failed (Simberloff 1991).

Currently, DNA analysis data for birds are inadequate to statistically test Long and Mawson's (1991) hypothesis regarding higher success rates in evolutionally advanced taxa.

Lockwood (1999) analysed Long's (1981) and Lever's (1987) data on bird introductions around the world and found that the following families were more likely to hold successfully established exotic species than others: Anatidae, Phasianidae, Passeridae, Psittacidae, Columbidae, Rheidae and Odontophoridae. However, Lockwood's analysis indicated that the reason for the higher success of species in these families was their higher introduction effort rather than any intrinsic attributes of the species in these families. Larger numbers of species in these families have been transported, kept and released by people (mainly for pets or game). Lockwood also found that the families that had many successful species also had many that failed, and there was no difference between families in the proportion of successfully established species.

Duncan et al. (2001) found that gamebirds (Order: Galliformes) introduced to Australia were significantly ($P < 0.01$) less successful at establishing than other bird taxa. Only one of 11 species of introduced gamebird, the Indian peafowl (*Pavo cristatus*), has established on mainland Australia and this species has only small localised populations.

Although passerines have been more successful as invaders than non-passerines in Hawaii (Williamson 1996), New Zealand (Green 1997) and mainland southern Africa (Dean 2000), this may be due to differences in introduction effort rather than any intrinsic superior ability of passerines to establish and spread.

***Risk assessment significance:*** Because mammals generally have nearly double the success rate of birds for establishing exotic populations (Table 1), a more conservative approach to the import and keeping of mammals may be desirable.

Although gamebirds (order Galliformes) have so far had a low success rate in establishing exotic populations on mainland Australia (Duncan et al. 2001) and in the USA (Ebenhard 1988), some species have done well on offshore Australian islands and elsewhere in the world (Long 1981). Thus, it would be unwise to assume that gamebirds are unlikely to establish on the mainland given sufficient introduction effort.

The success (or failure) of close relatives to establish exotic populations in Australia or elsewhere should not be used as a guide for assessing the risk that a species could establish exotic populations in Australia.

**(vi) Body mass**

Animals with higher body mass may be more successful at establishing exotic populations than lighter, related species (Ehrlich 1986, 1989; Sol and Lefebvre 2000; Kolar and Lodge 2001; Sakai et al. 2001).

***Theory:*** According to Ehrlich (1986, 1989), the ecological literature suggests vertebrates in which the invading species is larger than most relatives should be more successful than ones where the invader is smaller than most relatives. However, di Castri (1991) stated that body size is not generally considered to be a major factor contributing to successful vertebrate invasions.

***Evidence:*** Duncan et al. (2001) found that, when the data analysis controlled for phylogenetic relatedness among species, $\log_{10}$ female body mass was weakly though significantly ($P < 0.05$) correlated with introduction success for exotic birds in Australia. Veltman et al. (1996) found female body mass was significantly ($P < 0.05$) correlated with establishment success for exotic birds introduced to New Zealand, and this finding was supported by a later analysis conducted by Green (1997). However, Blackburn and Duncan (2001a) found body mass explained only a small and non-significant amount of the variation when they modelled factors influencing establishment success for global introductions of exotic birds.

Forsyth et al. (in press) found no correlation between body mass and establishment success for mammals introduced to Australia.

***Risk assessment significance:*** If two related bird species are introduced to Australia in similar circumstances, and the adult females of one species have a higher average body mass, then this species may have a slightly higher chance of establishing a wild population. However, given that body mass can only be used to compare related bird species, this variable probably has little to offer for assessing establishment risk for individual species.

**(vii) Rate of population increase and related variables**

Some ecologists consider that high fecundity (average number of females produced by females surviving to reproductive age) and associated attributes (early sexual maturity, large clutch/litter size, high breeding frequency, short gestation and opportunistic breeding) contributes to successful vertebrate invasions (Jarvis 1980; O'Connor 1986; Ebenhard 1988; Ehrlich 1989; Griffith et al. 1989; di Castri 1991; Lidicker 1991; Lodge 1993b; Williamson 1999; Dean 2000; Sol and Lefebvre 2000; Sakai et al. 2001).

***Theory:*** The intrinsic rate of increase (*r*) of a species might be expected to determine the speed with which a small founding population can rise above the critical threshold number of about 20 individuals needed for demographic viability (Griffith et al. 1989; Pimm 1989). According to Lodge (1993a), a frequently cited suggestion is that invaders have high *r,* but he suggests that *r* may not be an important determinant of invasion success. Williamson (1989) also discusses *r* and *K* selection, where *r* indicates selection for high rates of increase and *K* indicates selection for high survival rates when a population is near environmental carrying capacity, as defined by Macarthur (1962). Williamson (1989) says ecologists dispute whether *r* is an important arbiter of invasive ability. Some ecologists suggest vertebrates with short generation times should be more successful invaders than those with long generation times (Ehrlich 1989; Lockwood 1999). In contrast, Crawley (1986) suggests high adult longevity ensures that offspring are produced over a protracted period, thus enhancing the probability of establishment by increasing the chances that offspring will encounter suitable conditions for establishment.

***Evidence:*** Duncan et al. (2001) found the average number of broods produced per season was weakly though significantly ($P < 0.05$) correlated with establishment success for exotic birds introduced to Australia. On the other hand, average clutch size was not correlated with establishment success (Newsome and Noble 1986; Duncan et al. 2001). Veltman et al. (1996) found neither the average number of broods produced per season nor the average clutch size were significant predictors of establishment success for exotic birds introduced to New Zealand. Forsyth et al. (in press) found that neither number of offspring produced per year, weaning age nor life span was correlated with establishment success for exotic mammals introduced to Australia. Wolf et al. (1996) found species' reproductive potential (number of offspring and first age of reproduction) was not significantly correlated with establishment success for native birds and mammals translocated for conservation. Green (1997) reported that clutch size was significantly negatively correlated with introduction success of exotic birds in New Zealand. Blackburn and Duncan (2001a) found generation time and population growth rate explained only a small and non-significant amount of the variation when they modelled factors influencing establishment success for global introductions of exotic birds.

No other factors relating to fertility or breeding success were found to be significantly correlated with establishment success in Australia or overseas for mammals or birds.

***Risk assessment significance:*** Because the number of broods produced per season is correlated with establishment success for exotic birds introduced to Australia, this variable could be considered as a possible contributory factor when assessing the risk that other exotic bird species might establish.

### (viii) Migratory behaviour

Non-migratory birds and mammals may be more successful at establishing exotic populations than migratory ones (Jarvis 1980; Rand 1980; O'Connor 1986; Veltman et al. 1996; Lockwood 1999; Sol and Lefebvre 2000; Kolar and Lodge 2001; Cassey 2002).

***Theory:*** Migratory species might be less likely to establish because their 'pre-programmed' movements might lead them away from potential mates and into unfavourable habitats (Veltman et al. 1996; Forsyth et al. in press). However there may be a distinction between species that are obligatory migrants, which probably do not establish easily, and species that are facultative migrants, which are probably not disadvantaged.

***Evidence:*** Veltman et al. (1996) found that, for exotic birds introduced in New Zealand, those that were migratory in their endemic range were significantly less likely to establish than those that were non-migratory ($P < 0.05$). Cassey (2002) found for exotic birds introduced around the world, those that were migratory in their endemic range were significantly less likely to establish than those that were non-migratory ($P < 0.05$). Rand (1980) noted that none of the 24 species of exotic birds established in Florida, USA, is migratory. Few migratory bird species have been successful invaders in Britain (O'Connor 1986). In contrast, Duncan et al. (2001) found that migratory birds were equally well represented in both successful and unsuccessful exotic bird introductions to the Australian mainland. Migratory behaviour is significantly negatively correlated ($P < 0.05$) with establishment success of exotic mammals introduced to Australia (Forsyth et al. in press).

***Risk assessment significance:*** Because non-migratory behaviour is a significant predictor of establishment success for exotic birds introduced to New Zealand and for exotic mammals introduced to Australia, this variable should be considered as a possible contributory factor when assessing the risk that other exotic species could establish.

### (ix) Diet

Animals with a broad diet (dietary generalists) may be more successful at establishing exotic populations than those with a restricted diet (dietary specialists) (Mayr 1965a; de Vos and Petrides 1967; Ricklefs 1973; Roots 1976; Jarman and Johnson 1977; Rand 1980; Lever 1985; Ehrlich 1986, 1989; Fox and Fox 1986; Holdgate 1986; Myers 1986; Ebenhard 1988; Simberloff 1989; Long and Mawson 1991; Redhead et al. 1991; Wolf et al. 1996; Lockwood 1999; Dean 2000; Sakai et al. 2001). An ability to incorporate new foods into the diet, or to develop new techniques to obtain food, may contribute to establishment success (Simmonds and Greathead 1977; Jarvis 1979, 1980; Ebenhard 1988).

***Theory:*** Many ecologists consider that omnivory contributes to many successful vertebrate invasions (di Castri 1991). Lidicker (1991) notes the most successful and widespread introduced mammals in California are omnivores and Mayr (1965b) suggests that parrots often succeed as invaders overseas in part because they have unspecialised diets.

Myers (1986) and Redhead et al. (1991) state that few ecologically specialised mammal invaders have succeeded in Australia, while many have failed. Myers (1986) suggests that ferrets, mongooses and squirrels failed to establish in Australia following their introduction because they are dietary specialists: ferrets because there are no alternative prey when nestling rabbits (*Oryctolagus cuniculus*) are unavailable; and Indian palm squirrels and eastern grey squirrels (*Sciurus carolinensis*) because both are food specialists whose requirements for nuts are not met by eucalypts.

Crawley (1986) suggests herbivores are more likely to establish than carnivores or detritivores because levels of competition in resident species are lower among herbivores.

***Evidence:*** Newsome and Noble (1986) classified exotic bird species introduced to Australia into broad diet categories and found that diet was not significantly correlated with introduction success. Duncan et al. (2001) categorised diets for exotic bird and mammal species introduced to mainland Australia (as herbivore, omnivore or carnivore) and found that diet was significantly though weakly correlated with establishment success ($P < 0.01$), with herbivores being less likely to establish than omnivores or carnivores. Veltman et al. (1996) also looked at these three categories for exotic birds introduced to New Zealand and found diet was not significantly correlated with establishment success. However, given that nearly all bird and mammal species introduced to Australia and New Zealand have generalist diets, the above analyses had little power to discriminate on the basis of diet and so their results do not mean that diet is not important for establishment success.

Veltman et al. (1996) found that the number of months in a year that birds included insects in their diet was significantly positively correlated with establishment success for exotic birds in New Zealand ($P < 0.05$).

Forsyth et al. (in press) found that diet (scored as herbivorous or other) was not significantly correlated with establishment success for exotic mammals introduced to Australia.

Griffith et al. (1989) analysed data on a large number of mammal and bird translocations around the world and found that herbivores had a higher establishment success rate (77%) than either omnivores (38%) or carnivores (48%). Wolf et al. (1996) updated and re-analysed Griffith et al.'s (1989) data and found that an omnivorous diet (as opposed to a carnivorous or herbivorous diet) was positively associated with successful establishment of self-sustaining populations for bird and mammal introductions.

***Risk assessment significance:*** Because many ecologists consider having a generalist diet increases the probability of establishment success, and because nearly all exotic vertebrates established in Australia do have generalist diets, this variable should be considered as a possible contributory factor when assessing the risk that new exotic species could establish here.

**(x) Ability to live in human-disturbed habitats**

Many ecologists consider that an ability to live in human-modified or other disturbed habitats, particularly agricultural or urban/suburban areas, is a major factor contributing to establishment success (Mayr 1965a; Wodzicki 1965; Roots 1976; Fox and Adamson 1979; Frith 1979; Jarvis 1979; Ehrlich 1986 and 1989; Myers 1986; Newsome and Noble 1986; Orians 1986; Ebenhard 1988; Brown 1989; Bomford 1991; di Castri 1991; Lidicker 1991; Ricciardi and Rasmussen 1998; Lockwood 1999; McKinney and Lockwood 1999; Dalmazzone 2000; Dean 2000; Mack et al. 2000; Sol 2000; Sakai et al. 2001).

***Theory:*** Exotic species which are pre-adapted to the types of habitat, food, shelter, predators or diseases present in Australia may be more successful at establishing (Roots 1976; Simmonds and Greathead 1977; Jarvis 1979, 1980; Ehrlich 1986, 1989; Redhead et al. 1991). For example, human-disturbed areas where exotic weeds are present may favour establishment of the exotic animals that eat them. However, Brown (1989) and Ricciardi and Rasmussen (1998) caution that the success of human commensal species as invaders may be due in part to opportunity, as these species are assisted to spread, both accidentally and purposefully. Many successful invaders use dispersal mechanisms that involve human activities. Hence, human commensals may have greater opportunity for establishing rather than having an intrinsic ability to be better at establishing.

The success of human commensals may also be partly due to many exotic animals coming from, and taking up residence in, human-modified habitats, where the types of food and shelter they are adapted to are present, so there is little need for their ecological niche to change for successful establishment. Long and Mawson (1991) suggest that introduced European plants have provided a food source and hence contributed to the success of exotic bird species that established in Australian

Mediterranean climates. Similarly, the introduction of cattle (*Bos* spp) enabled the cattle egret (*Ardeola ibis*) to establish in Australia.

New, unoccupied niches may be created in disturbed habitats. For example, few of Australia's native birds eat exotic weed seeds. When the European goldfinch (*Carduelis carduelis*) and European greenfinch (*C. chloris*) were introduced, they were able to use this food source, encountering little competition from native species (Frith 1979; Long and Mawson 1991).

Activities associated with agriculture may protect newly introduced small populations from environmental hazards, such as drought, flooding, parasites, predators and competitors, and hence allow them to grow to a size where they are not threatened with extinction by chance environmental events (Mack et al. 2000; Section 1.3.1xii).

Disturbed habitats often are able to support a high level of species diversity because environmental variation prevents any one species from dominating other species (Connell 1978). According to Redhead et al. (1991), human-modified habitats in Australia are the most invaded by introduced mammals. Lidicker (1991) says the most successful and widespread introduced mammals in California have also often benefited from suburban and agricultural developments, but he gives examples of exceptions to this generalisation, including the red fox, muskrat (*Ondatra zimbethicus*) and several ungulates.

***Evidence:*** The majority of bird (92%) and mammal species (94%) introduced to Australia are able to live in human-disturbed habitats in their native geographic range (Long 1981; Lever 1985). Newsome and Noble (1986) concluded from their analysis of Long's (1981) data on exotic bird introductions that 'the chief factor contributing to success for exotic introductions was being a human commensal'. In contrast, Duncan et al. (2001) found the ability to live commensally with humans was not significantly correlated with establishment success for exotic birds introduced to Australia. However, because nearly all the bird species that have been introduced to Australia (both successfully and unsuccessfully) have been human commensals, Duncan et al.'s analysis had little power to detect any effect due to this factor. Dean (2000) found all the exotic birds in mainland southern Africa are human commensals, and none have invaded undisturbed natural habitats.

***Risk assessment significance:*** Because many ecologists consider an ability to live in disturbed habitats increases the probability of establishment, and because most successfully established exotic vertebrates are human commensals, this variable should be considered as a possible contributory factor when assessing the risk that new exotic species could establish here.

### (xi) Source of animals

Wild caught animals are more successful at establishing exotic populations than captive-reared animals (Griffith et al. 1989; Wiley et al. 1992; Snyder et al. 1994; Wolf et al. 1996).

***Theory:*** Wild caught animals may have better skills in avoiding predators and seeking out mates, food and other resources needed for survival and breeding. Culturally determined repertoires of behaviour may be lost in captive-reared animals, which may significantly reduce their viability when released (May 1991).

***Evidence:*** Griffith et al. (1989) assessed the factors affecting the success rate of release programs to re-establish or augment small populations of rare and endangered species in the wild. They found that wild caught mammals and birds taken from high-density, expanding populations are more successful at establishing wild populations than captive-reared animals. Snyder et al. (1994) found releases of wild caught thick-billed parrots (*Rhynchopsitta pachyrhyncha*) in Arizona were more successful than releases of captive reared birds. Wolf et al. (1996) found wild caught mammals and birds were weakly correlated with successful establishment compared to captive-reared animals when species were reintroduced for conservation, but most animals in their samples were wild caught so their analyses lacked statistical power.

Little information is available on the individual histories of the founding animals for Australia's exotic bird and mammal populations, although some captive bred birds have established wild populations in Australia, probably including the ostrich (*Struthio camelus*), red jungle fowl (*Gallus gallus*), California quail (*Callipepla californicus*), peafowl, rock dove (*Columba livia*), spotted turtle-dove (*Streptopelia chinensis*), red-whiskered bulbul and the nutmeg mannikin (*Lonchura punctulata*) (Long 1981). For example, after storms released spotted turtle-doves from Adelaide zoo aviaries in 1931, they spread 200 kilometres from Clare to Victor Harbour within 20 years (Fraser 2001). Long's (in press) data for mammal introductions also indicates that many of the exotic mammal populations in Australia were founded by captive-reared animals, including the Indian palm squirrel, horse (*Equus caballus*), donkey, goat (*Capra hircus)*, feral camel, cat (*Felis catus*), dog (*Canis lupus familiaris*) and pig (*Sus scrofa*).

***Risk assessment significance:*** Because it is probable that wild caught individuals are more successful at establishing wild populations than their captive bred counterparts, to reduce the risk of escapes or releases occurring it may be desirable to restrict the import and keeping of wild caught exotic animals, and if necessary, to place stringent security restrictions on their keeping (Section 1.1).

**(xii) Suitable site — resources and enemies**

The availability of habitat near the release site that meets a species' physiological and ecological needs is important for establishment. Both habitat disturbance and an absence or low occurrence of natural enemies such as predators, parasites, diseases or competitors are often suggested to favour establishment (Crawley 1986; Goodman 1987a, b; Ehrlich 1989; Griffith et al. 1989; Case and Bolger 1991; May 1991; Lodge 1993b; Moulton 1993; Brooke et al. 1995; Williamson 1996, 1999; Duncan 1997; Enserink 1999; Sakai et al. 2001).

***Theory:*** The availability of refuges near the release site where animals can obtain food, water, shelter and protection from natural enemies is important for survival and reproduction (Crawley 1986; Goodman 1987a, b)(Section 1.3.1x).

Redhead et al. (1991) suggest that the inadequacy of Australian vegetation as browse is a contributing factor in the failure of many exotic mammal herbivores released in Australia, including 16 deer or deer-like animals. Similarly, di Castri (1991) noted that squirrels may not have succeeded in Australia because eucalyptus trees provide unsuitable food. Adverse habitat probably contributed to the failure of chaffinches and bullfinches to establish in Australia after they were introduced (Long and Mawson 1991).

Predators, parasites, diseases and competitors may reduce the chance of a species establishing, and their absence may increase it (Browning 1977; Crawley 1986; Myers 1986; Case 1991; Case and Bolger 1991; Brooke et al. 1995). The importance of competition and disease as a cause of failure may often be underestimated because these factors are difficult to measure and so their effects are rarely assessed (Crawley 1986; Lodge 1993b). Habitats where there are no resident species which have an ecological strategy similar to the introduced exotic species may be more likely to be invaded because the new species can fill a 'vacant niche' without competition from species with similar ecological strategies (de Vos et al. 1956; de Vos and Petrides 1967; Lever 1977; Browning 1977; Frith 1979; Jarvis 1979, 1980; Ayal and Safriel 1983; Walker and Valentine 1984; Baker 1986; Moulton and Pimm 1986; Williamson and Brown 1986; Brown 1989; Griffith et al. 1989; Williamson

1996; Duncan 1997). Conversely, habitats where similar resident species are present may have a 'biotic resistance' to being invaded. Brown (1989) suggests that introduced mammals in Australia, including carnivores, lagomorphs and ungulates, have been able to invade undisturbed habitats because native mammals do not fill these niches. Conversely, he proposes that, because the Australian native bird fauna is more diverse, Australian native birds have been more resistant to invasion by introduced exotic birds.

Islands usually have relatively fewer species than continents and hence may have more vacant niches (Elton 1958; MacArthur and Wilson 1967; Orians 1986), which may account for the suggested higher success rate of introduced species on islands compared to continents (Presnall 1958; Mayr 1965a; Wilson 1965; Simmonds and Greathead 1977; Jarvis 1979; Moulton and Pimm 1986; Ebenhard 1988). For example, rabbits have established on several islands off the North American coast but, despite thousands of escapes, not on the mainland (Presnall 1958).

***Evidence:*** The role of natural enemies in establishment success is difficult to measure and limited quantitative evidence could be found to support this theory. Case and Bolger (1991) and Case (1996) examined introduction success rates for exotic reptiles (primarily lizards) on Pacific islands and found communities with a rich reptile fauna were more resistant to invasion by exotic reptiles than communities with fewer reptile species. Duncan (1997) examined introduction success rates for exotic birds in four districts in New Zealand and Brooke et al. (1995) examined introduction success rates of passeriform birds introduced to the island of Saint Helena. Both studies found establishment success rates were higher where fewer bird species were already present. However, these relationships were not necessarily causal and Duncan (1997) suggested introduction effort could equally well have accounted for the variable levels of introduction success he observed. Case (1996) found that the richness of the native avifauna had no influence on establishment success when he examined data sets on exotic bird introductions to Australia, continental USA and various islands of the world. Blackburn and Duncan (2001a) also found that the species richness of receptor habitats had no influence on establishment success. They found that two of the most species-rich regions of the world, the Afrotropics and Central/South America were ranked among the easiest regions for birds to invade. Hence their model did not support a role for biotic resistance in introduction success.

When Sol (2000) and Blackburn and Duncan (2001a) modelled factors affecting establishment success of introduced birds around the world, they found that there was no correlation between introduction success and whether the introduction was to a mainland or island location, when varying introduction effort and non-random selection of species was accounted for. By far the majority of global bird introductions have been to islands (953 events) compared to mainland locations (425 events) (Long 1981; Blackburn and Duncan (2001b).

***Risk assessment significance:*** The potential relationships between an organism and possible parasites, predators, diseases and competitors are usually impossible to predict, except in a generalised, qualitative sense. These factors are difficult or expensive to measure quantitatively, so there is little evidence to support or reject their role in establishment success. Hence, these factors are unlikely to be of value for risk assessment and management. It would also be extremely difficult to rank habitat suitability objectively, so it is probably not possible to use this factor for quantitative risk assessment except for separating disturbed habitat from undisturbed habitat (Section 1.3.1x) and for climate matching (Section 1.3.1ii) The significance of the availability of suitable microhabitats and microclimates for vertebrates is largely unknown. Hence, it is difficult to quantify microclimate variables in a way that would be useful for managing the risk of species establishment. It is possibly easier for exotic species to establish on islands rather than on mainland sites, but the evidence is equivocal.

**(xiii) Timing of release**

The probability of establishment may be enhanced if a release event occurs when environmental conditions are well suited to survival and breeding. More recent introductions may also be more successful.

***Theory:*** Season, weather, the availability of food, water and shelter, and the abundance of predators, parasites, diseases and competitors (Sections 1.3.1x, xii) are all factors which may vary over time and affect establishment chances (Crawley 1987).

Many invasive species may have a higher chance of establishing in disturbed habitats (Section 1.3.1x). So, as human populations grow and more land is disturbed for agriculture and other human activities, the chances of released animals finding habitat suitable for establishment will increase.

***Evidence:*** Newsome and Noble (1986) found that the historical timing of introductions significantly affected invasion success for exotic birds in Australia, with more recent introductions being more often successful ($P < 0.001$). These authors found that less than 50% of exotic bird introductions to Australia were successful before 1900, compared to a 72% success rate between 1900 and 1949 and an 89% success rate since 1949.

***Risk assessment significance:*** Because establishment success is higher for more recent introductions to Australia, analyses based on historical records of introduction success, that is, most of the evidence presented in this report, are likely to underestimate the probability that future releases of exotic vertebrates will result in the establishment of wild populations. Because timing of release is important, species that are released on more occasions are likely to have a higher establishment success than species released less often (Section 1.3.1i).

**(xiv) Genotypic and phenotypic variability and behavioural flexibility**

Animals with high genotypic and phenotypic variability may be more successful at establishing (Jarvis 1980; Barrett and Richardson 1986; Ehrlich 1986; Fox and Fox 1986; Ehrlich 1989; Lockwood 1999). Behavioural flexibility may also be an advantage (Sol and Lefebvre 2000).

***Theory:*** High genotypic and phenotypic variability in diet, behaviour and nesting habits in different environments may increase establishment success because high variability increases the potential for rapid adaptive radiation. Sol and Lefebvre (2000) suggest behavioural flexibility enhanced the establishment success of exotic birds introduced to New Zealand.

***Evidence:*** Sol and Lefebvre (2000) found that for pairwise comparisons of closely related exotic birds introduced to New Zealand, relative brain size was a significant predictor of establishment success, after statistically accounting for the effect of introduction effort. They suggest behavioural flexibility is linked to relative brain size and allows animals to respond more rapidly to environmental change which is an advantage when invading novel habitats. No other quantitative evidence could be found to support this theory.

***Risk assessment significance:*** Williamson (1996) suggests that genetics currently have little to offer for the prediction of likelihood of establishment.

**(xv) Flocking or herding**

Some ecologists suggest that gregarious animals may be more successful than solitary ones at establishing exotic populations (Mayr 1965b; Jarvis 1980; Rand 1980; Ehrlich 1989; Dean 2000).

***Theory:*** Provided they are released in a group, animals which form flocks, herds or breeding colonies may be more successful invaders because this behaviour facilitates breeding when numbers are low. Grouping may also provide protection from predators and make foraging more efficient.

***Evidence:*** Newsome and Noble's (1986) analysis of Long's (1981) data on introduced birds in Australia found neither flocking behaviour nor flock size was significant in determining establishment success in Australia. Similarly, no correlation between flocking and establishment success of exotic birds was found either for Australia (Duncan et al. 2001) or New Zealand (Veltman et al. 1996). No evidence could be found to support a correlation between herding or grouping behaviour and establishment success for exotic mammal introductions.

***Risk assessment significance:*** Based on current evidence, flocking or herding behaviour probably has little value for predicting establishment success.

### (xvi) Dispersal ability

Animals with good dispersal abilities may be better invaders (Mayr 1965b; Sakai et al. 2001).

***Theory:*** Animals with good dispersal abilities might be better able to seek out habitats suitable for survival and reproduction (Mayr 1965b). Mayr (1965b) suggests that the parrot group succeeds as invaders overseas in part because they range widely in search of food resources and nesting holes.

***Evidence:*** No quantitative evidence could be found to support this theory.

***Risk assessment significance:*** Based on current evidence, dispersal behaviour probably has little value for predicting establishment success, and it would be difficult to quantify.

### (xvii) Individuals' age and health

A breeding group of fit, healthy young animals would have a better chance than one of less healthy or older animals approaching the end of their reproductive lifespan (Crawley 1986, 1989; Ehrlich 1989).

***Theory:*** The health (including disease status, parasite loading and any stress or debility associated with being kept in captivity) and age (including reproductive lifestage and sufficient lifespan to outlive unfavourable conditions) of the individual animals released may affect establishment chances (Crawley 1986, 1989; Ehrlich 1989).

***Evidence:*** No quantitative evidence could be found to support this theory.

***Risk assessment significance:*** Given future releases of exotic species are likely to be unintentional or illegal, managers are likely to have little opportunity to affect the age or health of released animals, so these variables are unlikely to be of use for managing the risk of new species establishing.

### (xviii) Fertilised female able to colonise alone

Some ecologists suggest that vertebrates in which the fertilised female is able to colonise alone should be more successful than those in which the female alone is unable to colonise (Ehrlich 1989).

***Theory:*** If a solitary pregnant female can found a population, this may increase the number of opportunities for establishment that occur compared to species that require a larger founding group.

***Evidence:*** No quantitative evidence could be found to support this theory.

***Risk assessment significance:*** Given the lack of evidence to support this theory and lack of ecological knowledge about which species would meet this criterion, this factor is unlikely to be of use for managing the risk of new species establishing.

### (ixx) Public and government attitudes and actions

Attempts to feed or shelter released animals might increase the chances of establishment. Conversely, attempts to recapture or destroy released animals may reduce the chances of establishment (Bomford 1991).

***Theory:*** Attempts to feed or shelter released animals may be more likely to occur for attractive or appealing animals and this might assist establishment by providing favourable 'microhabitats'. For example, when native birds are released or translocated for conservation purposes, assistance in the form of provision of nest boxes and food or protection from predators, may help populations establish (Butler and Merton 1992; Wiley et al. 1992; BirdLife International 2000; Cade 2000).

Attempts to recapture or destroy released animals may help prevent establishment (Section 1.4) and are probably more likely to occur if government policies and practices support them.

***Evidence:*** There appears to be no robust evidence that care following release, such as providing food, shelter or nest sites, increases establishment success for birds despite the great efforts that have sometimes been devoted to promote establishment success for species such as gamebirds. Lockwood (1999) suggested that if extra effort devoted to the establishment of species conferred a higher success rate, then families that hold more game and pet bird species would have a higher success rate than other families, because considerable effort is often made to establish such species. But she found no difference between families in the proportion of successfully established species.

Government actions to eradicate newly established populations of exotic birds have sometimes been successful. For example, colonies of Eurasian collared-dove and silver pheasant (*Lophura nycthemera*) which established in Western Australia were intentionally destroyed. Such attempts may also fail. For example, an attempt to eradicate the monk parakeet (*Myiopsitta monachus*) in the USA, undertaken when numbers were still relatively low, failed (Neidermeyer and Hickey 1977; Pruett-Jones and Tarvin 1998).

***Risk assessment significance****:* It is uncertain if dedicated assistance can help to establish populations. Attempts to capture or destroy released animals or their progeny can help to reduce the chances of establishment (Section 1.4).

### 1.3.2 Uncertainty in predicting establishment success

Scientific theory and knowledge is still far from the stage where it is possible to make certain predictions about the invasive capability of individual species. This uncertainty has led many experts to question whether it is even feasible to try to reliably predict whether exotic animals could establish in a new country (Ehrlich 1989; Williamson 1989; di Castri 1991; Lidicker 1991; Norton et al. 1996; Enserink 1999). For example, some experts believe that current ecological theory on animal invasions is inadequate to make quantitative scientific predictions (Crawley 1986; Brown 1989; Simberloff 1989). Ehrlich (1989) states that 'One certainty is that population biologists are still a long way from any comprehensive quantitative theory of what determines the potential for becoming a successful invader'. He suggests that such a theory may not be possible because demographic and environmental stochasticity plays such a large part in any individual introduction that it is not possible to generate mathematical probability distributions of likely success. Nevertheless, he points out that, despite these high levels of uncertainty, what we do know is far from trivial, and ecological knowledge can contribute to assessing the probability of invasion success.

The 19 ecological and release-related attributes of successful invaders listed in Section 1.3.1 need further confirmation by rigorous scientific studies. All have exceptions and at best they can be used to give probabilistic estimates of whether an exotic species released in Australia is likely to establish an exotic population (Lodge 1993b). The power of the statistical tests has been relatively low because sample sizes are small for most studies of vertebrate introductions. Hence, a significant effect would have been detected only for factors that had a fairly major and consistent influence on establishment success, such as climate match and introduction effort. Where no significant effect has been found for a factor, such as for diet and human commensalism, this does not mean that it does not influence establishment success. Expert opinion, published in the scientific literature, suggests that all these factors are potentially important and, thus, they should be considered in risk assessments.

The modelling conducted by Duncan et al. (2001), which accounts for 100% of the variance in the success rates for establishment of exotic birds in Australia, is encouraging in that it clearly demonstrates which factors are important predictors of past establishment success. Similar factors also appear to influence establishment success of exotic mammals (Forsyth et al. in press). It is reasonable to assume that these same factors are likely to be important in determining which new exotic bird and mammal species pose a high risk for establishing in Australia in the future.

## 1.4 Probability of eradication

'Eradication' is defined here as the complete and permanent removal of all wild populations from Australia by a time-limited campaign. 'Time-limited' is important in this definition — eradication needs to be achieved by a fixed date. Without a specified end point an eradication campaign is *de facto* sustained control.

The only eradication successes on mainlands, for plants, insects or vertebrates, have been when the invader is detected soon after its introduction and is restricted to a small area of infestation (Long 1981; Dahlsten 1986). While there have been many eradications of introduced vertebrates from islands, no campaign against any widely established exotic vertebrate species has ever been successful on any continent, despite numerous large-scale attempts and the huge potential benefits of success (Dahlsten 1986; Macdonald et al. 1989; Usher 1989; Bomford and O'Brien 1995). Indeed, Dahlsten (1986) questions whether eradication of well-established pest species should even be attempted.

### 1.4.1 Criteria for determining feasibility of eradication

The following six criteria, developed by Bomford and O'Brien (1995), can be used to assess the feasibility of eradicating exotic species, although they do not enable a quantitative assessment of the probability that eradication can be achieved. Criteria 1–3 are essential for achieving eradication. Criteria 4–6 determine whether eradication is economically and socially desirable, and a preferable management option to sustained management of the pest species:

**Criterion 1: Rate of removal exceeds rate of increase at all population densities**

This is the primary criterion for eradication. If the removal rate does not exceed the rate of replacement at all population densities, eradication will not be achieved.

This may seem simple and obvious, but, in practice, it is an extremely stringent requirement for pest populations for three main reasons:

1. Many invasive species have high intrinsic rates of increase (Section 1.3.1vii).
2. The costs of finding and removing vertebrate pests often increase exponentially as density declines (Parkes 1993a; Maas 1997; Pople et al. 1998; Choquenot et al. 1999). Behavioural changes may make it more difficult to locate and kill animals, for example, they may become trap shy (Cowan 1992), or become nocturnal or more prone to hiding when hunted (Douglas 1971). The most difficult part of an eradication campaign is just before eradication is achieved. For example, it took 1000 hunter days to find and kill the last five feral goats from the 2943 ha Raoul Island in New Zealand, and the cost of removing the last five goats was over $30 000 each in current Australian dollars (Parkes 1990).
3. Populations subjected to control usually show compensatory population responses. When killing or

harvesting reduces populations, the fortunes of the remaining animals may be enhanced. Reduced competition for resources can lead to compensatory increases in breeding and survival (Caughley 1977, 1985; Caughley and Krebs 1983). These compensatory changes hasten the rate of recovery of a population. There is little information on the extent to which compensation occurs for most pest species, but annual rates of increase in culled populations have been estimated at 20 per cent for feral horses and 23 per cent for feral donkeys (Eberhardt et al. 1982; Choquenot 1990).

To determine whether this criterion can be met, both natural rates of increase and achievable rates of removal must be known or estimated for all population densities. If the removal rate declines to less than the rate of increase at low population densities, the population does not decline further. It is possible that, at very low population densities, the natural rate of increase may fall below zero due, for example, to difficulties in finding mates and demographic factors (Caughley and Sinclair 1994). If this occurs the population will decline to extinction without the need for further human intervention. Unfortunately, we do not know the population densities at which this may occur for any pest vertebrates. In addition, extinction risks due to demographic factors in small populations are stochastic effects, with unknown probabilities of population recovery or demise to extinction.

The area over which eradication is attempted will significantly affect the ability to meet this criterion (Parkes 1993b; Van Vuren 1992). In smaller areas, it is possible to concentrate effort, which makes eradication more efficient and easier to achieve (Parkes 1990).

**Criterion 2: Immigration is zero**

If animals can immigrate into the eradication area, or be released or escape from captive populations, then the system is unstable, and eradication will be unachievable or transient.

Release of the pest species back into the eradication area may be a problem. For example, recreational hunters are believed to have released goats as quarry, which compromised feral goat control operations in Australia (Henzell 1992).

**Criterion 3: All individuals must be at risk**

It is not necessary that the removal technique takes all animals at any one attempt, but all reproductive and potentially reproductive members of the population must be susceptible to removal for eradication to be feasible. If, for example, trap-shyness is inherited, or if animals develop neophobia or genetic resistance to poison baits, a subset of the population is not at risk and will not be eradicated. With many pest control techniques, some animals will not be susceptible.

Use of a combination of techniques may enable this criterion to be met. For example, eradication of brush-tailed possums (*Trichosurus vulpecula*) from Kapiti Island in New Zealand was achieved by a combination of trapping, poisoning and hunting with specially trained dogs, which ensured that all possums were at risk (Cowan 1992).

**Criterion 4: Pest can be monitored at low densities**

It can be extremely difficult to be absolutely certain that eradication has been achieved (Usher 1989), hence, this criterion is hard to meet for many species. If animals cannot be detected at low densities, there is no performance indicator to measure whether control efforts are still causing the population to decline, and no way of determining if eradication has been achieved. Nevertheless, the population measure does not have to be an absolute measure. An index of numbers is sufficient as long as it is sensitive to change close to zero, and intercepts the origin when plotted against true density.

**Criterion 5: Discounted cost–benefit analysis favours eradication over control**

Pest damage–density relationships will often influence whether eradication is economically desirable. In some instances, even low pest densities can cause significant damage. However, there are few reliable, quantitative measurements for agricultural or environmental damage inflicted by vertebrate pests. Most information on damage is qualitative, correlative or anecdotal. Thus, the data needed for accurate cost-benefit analyses are rarely available.

The eradication of pests is often considered cost-effective on islands that are the last refuge of a range of endangered species (Coblentz 1990; Cowan 1992; Van Vuren 1992). It may be impossible to save such species from extinction unless exotic mammalian herbivores and predators are first eradicated (Vitousek 1988).

Accurate prediction of the costs and duration of eradication is problematic, making it difficult to allocate funds in advance. Nevertheless, a commitment to fully fund an eradication campaign to its planned completion must be made up front, or it is likely that any attempt will fail.

Where there is a risk of recolonisation, the high cost of attempted eradication is unlikely to be justified. In California, there have been 27 'successful' eradication programs against insect species, but this includes one species (oriental fruit fly *Bactrocera dorsalis*) being eradicated 15 times (Dahlsten 1986)! As an alternative to eradication, sustained management of a new pest may be both environmentally and economically less costly.

Thus, the benefits of eradication must also be weighed against those for alternative strategies. Sustained or tactical control may be a more cost-effective approach for meeting the objective of damage control. In addition, the benefits of retaining the species need to be considered, as well as potential animal welfare concerns about the selected control techniques, and potential damage to resources and non-target species that may be inflicted by the eradication program. The muskrat eradication campaign in Britain killed many non-target animals, including otters (*Lutra lutra*), thousands of water voles (*Arvicola terrestris*) and native birds (Usher 1986). The ratio of muskrats to non-target species trapped was 1:7 (Usher 1989). Such high kill rates of non-target species would now be regarded as unacceptable (Gosling et al. 1988).

Discount rates have a greater impact on the current value of eradication than they do on sustained control. Eradication requires a large initial outlay but, if successful, benefits accumulate indefinitely and there are no further costs. Thus, high market discount rates generally make eradication less economically attractive than control. However, there is considerable debate about the selection of appropriate discount rates, particularly when non-market values, such as conservation and animal welfare, are considered.

When deciding whether to opt for eradication or control as a management option, the chance of failure of an eradication attempt should be considered. Eradication is a risky business, and a failed attempt will waste a lot of money because pest populations can recover rapidly from low numbers.

**Criterion 6: Suitable socio-political environment**

Even when technical and economic criteria can be met, social and political factors may play an overriding role in determining the prospects for successful eradication. The benefits of eradication as an alternative to sustained management must be convincing, mainly because of the high cost of most eradication attempts and because community attitudes may not favour the destruction of large numbers of wild animals. For moral, emotional or cultural reasons, many people oppose the killing of animals and may lobby against eradication attempts (Mack et al. 2000). Community resistance to eradication is also likely if the techniques used affect non-target species. Eradication attempts will almost certainly have negative impacts on non-target species and increasingly vocal and well educated groups protesting against these non-target impacts are capable of de-railing eradication programs (Myers et al. 2000).

To create the political will necessary to achieve eradication, reliable information on the impacts of target species on production or environmental resources is usually needed (Van Vuren 1992). According to Temple (1990), however, no matter how well justified by conservationists, programs aimed at reducing populations of exotic birds in the United States are almost invariably unpopular and controversial, and few wildlife agencies are willing to risk the 'bad press' that inevitably accompanies control efforts. Van Vuren (1992) provides a cautionary example in his account of an attempt by the United States Navy to eradicate feral goats from San Clemente Island off California using helicopter shooting. The Navy was sued by Give Our Animals Time (GOAT) and directed to restrict its activities to non-lethal control techniques, which proved ineffective. Similarly, proposals to control mute swans (*Cygnus olor*) and monk parakeets have been so contentious that they have been abandoned. Indeed, there are now laws specifically protecting wild populations of popular exotic species such as ring-necked pheasants (*Phasianus colchicus*), rock doves, mute swans and feral horses in the United States (Temple 1992), and exotic deer species in Victoria (J. Burley pers. comm., Department of Natural Resources and Environment, Victoria, 2001).

Conflicting community or administrative goals or legal barriers can also frustrate eradication attempts. Strong support from the wider community is needed before eradication should be attempted. The availability of humane and target-specific control techniques may determine whether this criterion can be met.

### 1.4.2 Practical considerations for meeting eradication criteria for exotic species

The timing of an eradication attempt in relation to establishment will influence the probability of eradication being achieved. The sooner eradication is attempted after establishment, the higher the chance of success (Usher 1989). Early detection, capture and eradication, would be greatly assisted by vigilance and reporting by the public. Animals that are large and conspicuous may be more readily reported than more cryptic species.

Once a species is well established and widespread it may be more difficult to meet the criteria for eradication:

- *Criterion 1* because
  - it is more difficult to concentrate effort over large areas; and
  - animals living wild from birth may be better able to survive and less amenable to capture or control than escapees from captivity or animals transferred from a different environment (Griffith et al. 1989; Williams and Moore 1989), so the chances of eradication may be correspondingly higher for the first arrivals compared to their offspring;
- *Criteria 3 and 4* because when more animals are present in more diverse habitats, the probability that some will be difficult to target for removal and monitoring is likely to increase;
- *Criterion 5* because cost will increase as the number of individuals and area to be covered increases; and
- *Criterion 6* because some members of the community may value having the species living wild or oppose the killing of wild animals.

There are many examples of newly established exotic species living in small numbers inconspicuously for decades and then suddenly undergoing rapid population growth when conditions become favourable (Elton 1958; Williamson 1989, 1996; Enserink 1999; Dean 2000; Mack et al. 2000). During the lag phase when a newly established exotic population remains small and localised, natural selection may occur to adapt the species to the new environment, although this theory is unproven (Crooks and Soule 1996; Mack et al. 2000). Species undergoing such a lag phase prior to a period of rapid population increase and spread are sometimes called 'sleeper species' (Low 1999). For example, the ring-necked pheasant failed to establish securely in California for 70 years and it was not until rice farming expanded that the population exploded (Frith 1979). In Australia, carp were present in relatively low numbers in many waterways for decades. Then, in the early 1960s, a new strain of carp (*Cyprinus carpio*), the Boolara strain, escaped and suddenly the carp population increased and spread rapidly through the Murray-Darling Basin (Koehn et al. 2000).

A wild population of ferrets (*Mustela putorius furo*) is currently in the early stage of establishment in Tasmania and thousands of ferrets have been released or escaped in Australia. There is a good match between the climate of the places where wild ferrets occur overseas and that of southern Australia (Forsyth et al. in press). It is possible that a run of favourable seasons and good food supply, or the release of new strains of ferrets that are closer to the wild polecat end of the genetic spectrum rather than the domesticated strains that are currently most common in Australia, could lead to a sudden rapid expansion of the wild ferret population.

Even if eradication campaigns are implemented when animal numbers and the area infested are still small, there is no guarantee of success, and eradication attempts may not be worthwhile. For example, a major campaign to eradicate the monk parakeet in the USA, attempted when numbers were still relatively low, was unsuccessful (Neidermeyer and Hickey 1977). It is probable that failure to prevent further releases of this species from captivity, together with the species' high dispersal powers contributed to the failure. With reference to recently introduced invading insects, Dahlsten (1986) considers 'eradication projects are generally biologically and ecologically unsound in addition to being costly and possibly uneconomic in the long run'.

Usher (1989) suggests that dispersal powers and the feasibility of isolating the species within the eradication area are the most significant factors affecting success of eradication attempts. Usher (1986) compared successful eradication campaigns conducted against muskrats and coypus to the unsuccessful campaign against mink in Britain. He argues that the successful eradications were related to low dispersal rates rather than low rates of increase. Both muskrats and coypus have high natural rates of increase and low dispersal rates (Gosling and Baker 1989, 1991). In contrast, mink have much lower rates of increase but much higher dispersal rates (Chanin 1981). Usher (1989) further suggests that the high dispersal distances of rabbits and feral pigs in Australia would be a barrier to eradication. Similarly, he believes that the high mobility of birds is the reason why there are few examples of their successful control, let alone eradication.

### 1.4.3 Risk assessment significance of probability of eradication

Eradication of newly established exotic vertebrates in Australia is only likely to be achievable if appropriate contingency plans are in place and adequately resourced to ensure that escapes are reported, newly established populations are detected and reported, and containment and control programs are mounted rapidly. To date, early eradication has been achieved for few exotic vertebrates in Australia.

Evaluating the feasibility of eradication measures, and the costs and benefits relative to the potential economic, environmental or social harm, at various points along the establishment process, is in theory, a desirable part of risk assessment. In the vast majority of cases, the costs of eradication will increase (usually steeply) as a population becomes established and more widespread and abundant. Similarly, the relative benefits of an eradication attempt decline the later eradication is attempted, because the probability of failure increases steeply. However, it will rarely be feasible to make any reliable estimates of the potential costs and benefits of eradication prior to a species establishing.

Because the numbers, distribution and location of escaped animals and any progeny will have a major influence on whether or not eradication will be achievable, and because these factors are virtually impossible to predict with any certainty, evaluating the feasibility of eradication for any given species is extremely difficult. Further, the social and political factors that would affect the planning and implementation of an eradication campaign are even more uncertain. In Australia, few eradication campaigns have been conducted against newly established exotic vertebrates, and no attempts have been made to eradicate recently established populations of exotic red-eared sliders. Given that eradication is rarely attempted, and assessing the probability of success is so difficult, including an assessment of the feasibility of eradication as a component of risk assessment seems inadvisable. It is more practicable and appropriate to consider eradication as a risk management issue.

## 1.5 Probability exotic species will become a pest

Is it possible to predict which exotic vertebrates would become pests if they established wild populations in Australia? In this context, a pest is defined as an animal that has, or has the potential to have, a detrimental effect on economic, social or conservation values or resources.

### 1.5.1 Types of damage caused by exotic pests

**(i) Reduce agricultural or forestry productivity**

Introduced mammals and birds cause economic losses of billions of dollars annually to agriculture and forestry around the world (Lever 1985, 1987; Pimental et al. 2000). In Australia, introduced vertebrates cost at least $420 million annually to agriculture (Bomford and Hart 2002). The main types of damage may be categorised as follows:

***Crop losses:*** Many exotic species eat or damage grain crops from sowing through to harvest. For example, many exotic rodents and birds are granivorous and cause major damage to cereal crops in the field (Murton and Wright 1968; Fleming et al. 1990; Bomford 1992; Caughley et al. 1998; Olsen 1998, 2000; Pimental et al. 2000). Many exotic birds also damage fruit crops, from flower bud stage through to harvest (Murton and Wright 1968; Wright et al. 1980; Long 1981; Fleming et al. 1990; Bomford 1992). Exotic mammals and birds also often damage other horticultural crops, including nuts, flowers and vegetables. Grazing, browsing and omnivorous species all pose risks.

***Stored produce losses:*** Exotic species, particularly rodents and some commensal birds, cause major damage to stored grain and animal feed (Smith 1992; Caughley et al. 1998; Pimental et al. 2000)

***Forestry losses:*** Grazing and browsing species often damage or kill seedlings, which can cause economic damage to both native and plantation forests. Some exotic mammals kill mature trees by ring-barking (Ebenhard 1988). Some exotic mammals and birds strip foliage and buds off mature trees.

***Competition with livestock for pasture, browse and water:*** Grazing and browsing may deplete food supply for stock and so lower productivity. In arid areas competition for scarce water supplies may occur. For example, direct competition for pasture, browse and water, especially by grazing and browsing mammals such as rabbits and feral goats, is a major cause of reduced stock production (Jackson 1988; Wilson et al. 1992; Dobbie et al. 1993; Williams et al. 1995; Choquenot et al. 1996; Parkes et al. 1996; Pimental et al. 2000). Meat and wool are the main industries threatened in Australia.

***Losses to intensive livestock and poultry facilities:*** In intensive livestock and poultry rearing facilities, exotic rodents, birds and other vertebrates can consume and contaminate food and water supplies, spread diseases and injure animals by biting (Weber 1979; Buckle and Smith 1994; Caughley et al. 1998; Pimental et al. 2000). For example, an introduced reptile in Guam, the brown tree snake (*Boiga irregularis*), takes and eats chickens, eggs and caged birds (Pimental et al. 2000).

***Predation and harassment of stock:*** Predatory and omnivorous mammals, such as feral dogs and foxes, can cause major agricultural losses (Saunders et al. 1995; Choquenot et al. 1996; Pimental et al. 2000; Fleming et al. 2001).

***Land degradation:*** Overgrazing of pasture and browse may lead to reduced vegetation cover and unfavourable changes in plant community structure, often resulting in the replacement of perennials by annuals and the spread of pasture species that are less palatable or less nutritious for stock (Williams et al. 1995; Parkes et al. 1996). Loss of trees and shrubs can also reduce shelter for stock. Trampling, soil compaction, trailing and soil rooting are other forms of land degradation often caused by exotic mammals (Dobbie et al. 1993; Choquenot et al. 1996). These changes can all reduce livestock productivity. Meat and wool are the main industries threatened in Australia.

Some species can assist in the spread of agricultural weeds; for example, the common myna spreads seeds of the harmful weed *Lantana camara* (Pimental et al. 2000).

***Flow-on effects to other industries:*** In addition to direct damage to agricultural products, there are multiplier effects on damage costs due to flow-on to associated industries. For example, the greatest losses to grapes in Australia are probably due to introduced starlings (*Sturnus vulgaris*). Australian grape growers are paid almost $1 billion annually for their grapes and any loss or damage to fruit due to starlings will directly reduce this figure. The annual wholesale value of sales by wine makers is around $1.7 billion, the retail value of domestic wine sales over $3 billion and the export value around $1.5 billion (R. Sinclair, Animal and Plant Control Commission, South Australia, pers. comm. 2001). Grape losses due to starlings affect productivity and profitability all along this production chain.

### (ii) Environmental damage

The World Conservation Union strongly discourages introductions of exotic species because of the damage they cause to natural ecosystems (International Union for the Conservation of Nature 1987). Islands are particularly prone to environmental damage and to native species extinctions (Moulton and Pimm 1986; Ebenhard 1988; Coblentz 1990; Simberloff 1995). Ebenhard (1988) describes the environmental damage inflicted on a global scale by 330 species of introduced birds and mammals. Macdonald et al. (1989) present data on endangered species worldwide whose populations are threatened by the impact of introduced species. These authors found that native Australian mammals, birds and reptiles are more severely affected by introduced species than the fauna of any other continent, and that Australian mammals are particularly vulnerable.

Elton (1958) described the risk of global homogenisation of species and the consequent loss of biological diversity. History shows that when new species establish wild populations in a region, a roughly equivalent number of resident species usually become extinct. Analyses of exotic bird introductions around the world conducted by Lockwood et al. (1999) indicate that established exotic species usually come from a small group of families whose species are already well represented around the world. In contrast, the resident species they replace are usually from less common families and are often endemic.

Vitousek et al. (1997) demonstrate that the numbers of mammal species present on each continent is tightly correlated with total land area. An extrapolation of their regression line indicates that if all the earth's continents were combined into a single landmass, the number of mammal species in the world could be expected to be half the current number. Vitousek et al. (1997) conclude that, if increased global trade breaks down the barriers to the movements of animals and plants between continents, allowing the world's continents to operate more like a single land mass, a large numbers of species extinctions can be expected across all taxa. An additional number of species are likely to suffer contractions in distributional range and declines in abundance (Vitousek et al. 1997). The net result of these trends is a global loss of biodiversity. Vitousek et al. (1997) consider that exotic species are reducing biogeographic species diversity to an extent that can be considered equivalent to climate change as a component of global change.

Under the *Convention on Biodiversity 1992*, invasive species are considered to be one of the main causes of species extinctions world wide (Glowka et al. 1994; Perrings et al. 2002). The Nature Conservancy in North America found that exotic species posed a threat to 49% of the 6500 species threatened with extinction (Holmes 1998). Only habitat alteration (affecting 85% of species) was a more significant threatening process. In Australia, grazing by rabbits, feral herbivores and livestock and predation by cats and foxes are perceived as major threatening processes for rare and endangered native mammals (Kennedy 1992) and birds (Garnett 1992); and grazing by exotic animals is a major threat to many endangered native plants (Leigh and Briggs 1992). Other impacts of introduced pests on native populations have rarely been studied and are open to debate.

Environmental damage caused by exotic species may be categorised as follows:

***Predation and harassment of native fauna:*** Exotic animals kill, maim or harass native fauna (Jones and Coman 1981; Hornsby 1982; Tisdell 1982; Thompson 1983; King 1984; Triggs et al. 1984; Lever 1985; Savidge 1987; Ebenhard 1988; Saunders et al. 1995; Choquenot et al. 1996; Olsen 1998; Pimental et al. 2000). However, because a predator includes a particular species in its diet, it does not necessarily follow that it has an ecological impact (Ebenhard 1988). Only if the predator causes sustained declines in abundance, or range contractions, is there an ecological effect on prey species.

Exotic species are strongly implicated in some extinctions and many declines in abundance (Jackson 1977; Lever 1977, 1985; Werner 1977; Simberloff 1981; Moors 1983; Baker 1986; Diamond and Case 1986; Ebenhard 1988; Atkinson 1989; Dickman 1996; Kinnear et al. 2002). Introduced predators are thought to have contributed to the extinction of 12 of Australia's 25 extinct bird taxa, affecting more species than any other threatening process (Garnett and Crowley 2000). In addition, predation by exotic carnivores is thought to be affecting 95 (36%) of Australia's 261 threatened bird taxa (Garnett and Crowley 2000). Ebenhard (1988) found that of 49 introduced predatory mammal species worldwide, 20 are reported in the scientific literature as having caused one or more indigenous populations to decline in abundance or become extinct, and eight bird species have had similar effects. He found that mammalian arboreal predators more often cause declines in prey populations than ground-living predators, and mammals that are strict predators have more effect on prey populations than do omnivorous predators.

***Competition with or disturbance of native fauna:*** Exotic species compete with native species for resources such as space, food, water, shelter and nest sites (de Vos and Petrides 1967; Rolls 1969; Roots 1976; Dawson and Ellis 1979; Frith 1979; Jarvis 1980; Temple 1981; Aslin 1983; Baker 1986; Ebenhard 1988; Atkinson 1989; Williams et al. 1995; Parkes et al. 1996; Olsen 1998, 2000; Garnett and Crowley 2000; Clarke et al. 2001). Much of the evidence for competition is circumstantial (Ebenhard 1988). Exotic species may interact with native species directly or indirectly through disturbance or competition for resources. For example, in Australia, feral goats compete with endangered brush-tailed (*Petrogale penicillata*) and yellow-footed (*P. xanthopus*) rock wallabies for shelter, food and water (Dawson and Ellis 1979; Parkes et al. 1996). Introduced competitors are thought to have contributed to the extinction of two of Australia's 25 extinct bird taxa (Garnett and Crowley 2000). In addition, competition by feral herbivores is thought to be affecting 49 (19%) of Australia's 261 threatened bird taxa (Garnett and Crowley 2000). Almost all parrots are hole nesters, which often leads to competition with native hole nesters (Ebenhard 1988). For example, in Mauritius the introduced rose-ringed parakeet excludes the endangered Mauritius parakeet (*Psittacula echo*) from nest holes (Jones 1980). In Australia, introduced starlings depose many native tree hole nesters (Garnett and Crowley 2000).

Long and Mawson (1991) suggest the nutmeg mannikin could displace some native finch species because the mannikin has wider breeding and feeding niches, although it is unclear whether this has occurred. Arthington (1991), Herbold and Moyle (1986) and Moyle et al. (1986) argue that introduced species do not fill 'vacant niches' as Simberloff (1981) concluded from his review of species introductions. Rather, they fit into the new environment by further compressing the 'realised niche' of one or more of the species already present, often to the point where the environment can no longer support the indigenous species (Moyle et al. 1986). In disturbed environments especially, introduced species may have a competitive advantage over native species.

***Grazing and browsing on native plants:*** Grazing and browsing on native plants may lead to declines in their abundance and range size or cause species extinctions (Ebenhard 1988; Atkinson 1989). In heavily grazed or browsed habitats, annual plants may replace perennials (Williams et al. 1995; Parkes et al. 1996). Exotic mammals mostly damage forests by preventing tree regeneration, although mature trees can also be killed by ring-barking (Ebenhard 1988). Even where trees are not killed, severe damage may be inflicted. For example, in the USA the introduced monk parakeet (*Myopsitta monachus*) can completely strip buds, flowers and fruits from the top one metre of elm and willow trees (Shields et al. 1974). Aquatic plant communities can also be damaged, for example, introduced mute swans in the USA alter the abundance of water plants (Cobb and Harlin 1980).

***Secondary flow-on effects in ecological communities:*** In addition to the direct effects of exotic species on native species — by predation, herbivory, competition or by vectoring diseases — there are also likely to be secondary flow-on effects to changes in community structure and food webs, which may detrimentally affect native plants and animals (Simberloff 1981; Ebenhard 1988; Atkinson 1989; Parker et al. 1999). Such changes are even more difficult to predict than direct effects

(Simberloff 1991). Predators and grazing–browsing species are the two groups that are likely to have the most significant community effects.

Introduced species may strip pasture or kill shrubs and trees, inducing soil erosion and other forms of land degradation (Lange and Graham 1983; Baker 1986; Cooke 1987; Ramakrishnan and Vitousek 1989; Williams et al. 1995; Parkes et al. 1996). Trampling and trailing may also cause erosion and stifle regeneration (Ebenhard 1988). Introduced species may also disturb areas of land by burrowing or damage the banks of waterways (Baker 1986; Gosling et al. 1988). In addition to harm caused in the area where erosion occurs, offsite effects may include lower water quality downstream in catchments and increased flooding and siltation, which can have harmful effects especially for aquatic species.

Exotic species may act as prey for predators and so support increased population densities of these predators. This in turn may have detrimental effects on the alternative prey species used by these predators; for example, in Australia, rabbits support populations of feral cats and foxes. When rabbit populations decline due to drought or disease, these predators can exert heavy predation pressure on native prey species (Newsome et al. 1997).

***Hybridising with native species and other genetic effects:*** Exotic species may hybridise with native species, corrupting their gene pool (de Vos and Petrides 1967; Baker 1986; Ratcliffe 1987; Ebenhard 1988; Atkinson 1989; Sakai et al. 2001). Even a few escapees can be sufficient to spread new, detrimental genes through native populations (Ebenhard 1988). Waterfowl are particularly susceptible to this problem (Weller 1969; Frith 1979; Lever 1987), especially when related species are held together in captivity, as their hybrids are often fertile (Ebenhard 1988). For example, feral mallards (*Anas platyrhynchos*) readily hybridise with the native Australian Pacific black duck (*A. superciliosa*) (Long 1981) and are a serious threat to several species of endangered *Anas* worldwide (BirdLife International 2000).

Exotic species may also have indirect genetic effects by altering patterns of natural selection or gene flow in native species in communities where they are introduced (Parker et al. 1999). However, there are few proven examples.

**(iii) Potential as agents in the spread of parasites or diseases**

Exotic wild animals could play a role in the spread and establishment of many exotic diseases in Australia, including rabies, foot-and-mouth disease, rinderpest and classical swine fever (Ebenhard 1988; Garner and O'Brien 1988; Wilson and O'Brien 1989; Gratz 1994; Ausvetplan Wild Animal Management Writing Group 2000). Exotic animals can also assist the spread of endemic diseases. For example, feral cattle and feral buffalo (*Bubalus bubalis*) assisted in the spread of brucellosis and tuberculosis in northern Australia (Wilson and O'Brien 1989) and the rock dove assists in the spread of many human and livestock diseases including ornithosis, histoplasmosis and encephalitis (Weber 1979).

Domestic stock, native species and people could be exposed to risks from transmissible endemic diseases or parasites present in exotic wild animal populations (Roots 1976; Fox and Adamson 1979; Weber 1979; Lever 1985; Ebenhard 1988; Atkinson 1989; Gratz 1994).

The effects of exotic diseases or parasites on native species are not well known (Ebenhard 1988). The extinction of several native Hawaiian bird species has been attributed to diseases brought in by exotic birds (Moulton and Pimm 1986), although the introduction of mosquitoes (*Culex spp*), which are disease vectors, may have been more significant (Ebenhard 1988).

#### (iv) Social nuisance and injury risks to people

Animals that are aggressive or poisonous can harm people (Section 1.2). Venomous snakes and aggressive large mammals that bite or charge are probably the highest risk categories, although smaller biting animals such as rodents and ferrets can also pose a risk, particularly to unattended babies and incapacitated people (Hitchcock 1994; Lund 1994.)

Some animals are a social nuisance and reduce amenity value, particularly around dwellings, offices and recreational areas. Faecal pollution, for example, that caused by rock doves, is often unsightly and may damage buildings (Weber 1979; Pimental et al. 2000). Some animals are unacceptably noisy, particularly around roost and nest sites. Others have nuisance or repulsive aspects, for example, cane toads (*Bufo marinus*).

#### (v) Structural damage

Exotic species can damage buildings, equipment, fences, roads, banks or drainage systems by polluting, burrowing, chewing or breaking (Wilson et al. 1992; Buckle and Smith 1994). Rodents can cause fires and telecommunications failures by gnawing electrical wires (Buckle and Smith 1994; Caughley et al. 1998). The introduced brown tree snake in Guam causes power-outages conservatively estimated to cost US$1 million per year (Fritts et al. 1987; Pimental et al. 2000). Monk parakeets in the USA build nests on electrical utilities causing damage and power outages (Avery et al. 2002).

#### (vi) Damage and costs of pest control measures

Attempts to control or eradicate introduced pests can have undesirable effects on non-target species populations. For example, eradication of coypus in Britain caused disturbance to native species such as the bittern (*Botaurus stellaris*) and otter (Usher 1986). The eradication program against muskrats in Britain employed gin (leg-hold) traps and took a large toll of non-target species, including over 6500 other mammals and birds in Scotland alone (Usher 1986, 1989; Gosling et al. 1988; Section 1.4.1). Control measures can also lead to contamination of the environment with pesticide residues (Gosling et al. 1988).

### 1.5.2 Predicting pest status

According to some ecologists, only about 10% of exotic species become widespread pests following their establishment (Williamson and Brown 1986; Williamson 1996, 1999; Williamson and Fitter 1996; Enserink 1999; Smith et al. 1999). However, a review of the pest status of exotic birds and mammals in Australia and elsewhere suggests that this generalisation is doubtful for vertebrates (Table 2). Perhaps a more realistic figure for exotic mammals and birds is that around 50% become pests, although the figure may be lower in relation to ecological impacts of exotic birds on populations of native plants and animals.

Assessing potential pest status is an exercise that is likely to have relatively high uncertainty and high consequences for a wrong decision. An analysis of factors associated with exotic pest species indicates that the following factors, which can be measured prior to the establishment of exotic species in the wild, could be used to help predict potential pest status:

**Table 2:** Proportion of exotic mammals and birds that are pests.

| Taxa and location | Proportion of introduced species that are pests | Source |
|---|---|---|
| Exotic mammals in Australia | 15/25 (60%) of species are moderate or serious pests of agriculture and/or the environment and a further four species are minor pests (total of 75% of species are pests) | Wilson et al. (1992); Clarke et al. (2001) |
| Exotic birds on mainland Australia | 9/20 (45%) of species are moderate or serious pests. A further seven species have potential to become pests if they become more abundant (total of 80% of species are pests or potential pests) | Long (1981) |
| Exotic mammals in California | 11/18 (61%) of species are pests, 28% are serious pests | Smallwood and Salmon (1992) |
| Exotic birds in California | ≥5/20 (25%) of species are pests, 15% are serious pests | Smallwood and Salmon (1992) |
| Exotic birds in the United States | 54/97 (56%) of species are pests | Pimental et al. (2000); Temple (1992) |
| Exotic mammals established around the world | 50/67 (75%) of species damage agriculture or forestry | Lever (1985) |
| Exotic mammals established around the world | At least 40% (of 788 successful introductions of 118 species) are linked to ecological impacts on populations of native plants or animals | Ebenhard (1988) |
| Exotic birds established around the world | 52/133 (39%) of species are reported to damage agricultural crops | Lever (1987) |
| Exotic birds established around the world | 5% (of 771 successful introductions of 212 species) are linked to ecological impacts on populations of native plants or animals* | Ebenhard (1988) |

*Although Ebenhard (1988) found literature records linking only 5% of exotic bird introductions to ecological impacts on populations of native plants or animals, he considered this was likely to be a considerable underestimate. He suggested that the main effects of introduced birds are as competitors with native species and as vectors or reservoirs of disease, both of which are hard to demonstrate, poorly documented and rarely reported, so total damage levels caused by introduced birds are likely to be much higher than reported levels.

**(i) Pest status overseas**

***Theory:*** If a species is a pest in other countries, then the attributes that cause it to be a pest there (Section 1.5.1) might also operate in Australia.

***Evidence:*** The pest status of the 20 exotic birds, 24 exotic mammals, four reptiles and the single amphibian established on mainland Australia can be ranked according to the harm they cause to industry, the environment and society (Fleming et al. 1990; Wilson et al. 1992; Olsen 2000; Clarke et al. 2001). If these exotic species are ranked into broad pest categories as: (1) not a pest or only a minor pest; (2) moderate pest; or (3) serious pest (Appendix A), then it is possible to look at species attributes that are correlated with these pest status categories.

All the species that are considered moderate or serious pests in Australia are also considered to be significant pests somewhere in their overseas range (Appendix A). The only exception to this generalisation is the feral camel which does not occur in the wild overseas.

***Risk assessment significance:*** If it is assumed that this correlation between overseas pest status and Australian pest status will hold true for future introductions of exotic vertebrates to Australia, then an assessment of a species' overseas pest status will provide a guide to its pest potential in Australia.

**(ii) Climate match**

***Theory:*** The level of climate match between exotic birds' and mammals' overseas geographic ranges and Australia is strongly correlated with their geographic range sizes in Australia. In other words, species with a good climate match to Australia tend to become widespread here, that is, they have a high probability of becoming invasive following their establishment (Duncan et al. 2001; Forsyth et al. in press). Most of the exotic species that are widespread in Australia are considered pests, so climate match is likely to be correlated with pest status.

***Evidence:*** There is a correlation between mammal and bird species' pest status in Australia and the degree of climate match between their overseas range and Australia. All of the seven exotic mammals that are considered to be serious pests in Australia (rabbit, feral goat, feral pig, fox, feral dog, feral cat and house mouse; Appendix A) have extreme or very high climate matches between their overseas geographic ranges and Australia and the difference between the climate match indices (Appendix B, Table B2) of these seven serious pests and the 18 exotic mammals that are lesser pests (Appendix A, Table A1) is statistically significant ($P < 0.01$). For exotic mammals established in Australia, having a high climate match between Australia and their overseas range is significantly ($P < 0.001$) correlated with their Australian geographic range (Forsyth et al. in press). For exotic birds established in Australia, six of the nine species (67%) that are considered moderate or serious pests have an extremely high climate match to Australia, whereas only two of the 11 (18%) bird species that are not considered pests have an extreme climate match (Appendices A and B). The difference between the climate match indices (Appendix B, Table B2) of the nine bird species that are moderate or serious pests and the 11 species that are minor or non-pests (Appendix A, Table A1) is significant ($P < 0.05$). For exotic birds, a good climate match between their overseas geographic range and Australia is also significantly ($P < 0.01$) correlated with their current Australian geographic range (Duncan et al. 2001).

***Risk assessment significance:*** If the correlation between climate match and pest status holds true for future introductions of exotic mammals and birds to Australia, then an assessment of the climate match between their overseas range and Australia may help predict their potential pest status here. When there is a high climate match to areas in Australia where threatened or potentially vulnerable ecological communities or species occur, or where potentially vulnerable agricultural industries are located, this should indicate a higher level of risk.

**(iii) Overseas geographic range size**

***Theory:*** Species that have wide geographic ranges overseas may be more likely to become serious pests in Australia. Geographic range size is also correlated with abundance for many taxa including mammals and birds (Blackburn et al. 1997; Holt et al. 1997) and with traits associated with higher rates of population growth (Forsyth et al. in press).

***Evidence:*** The average overseas geographic range size of the nine exotic bird species that are considered to be moderate or serious pests in Australia (Appendix A, Table A1) is significantly ($P < 0.05$) greater than that of the eleven exotic birds considered to be minor pests or not pests. The average overseas geographic range size of the 15 exotic mammal species that are moderate or serious pests in Australia is also greater than that of the ten exotic mammals that are minor or non-pests (Appendix A, Table A1).

***Risk assessment significance:*** A more cautious approach to the import and keeping of species that are widespread overseas may be desirable.

**(iv) Abundance in overseas range**

***Theory*:** Most mammals and birds that are considered to be serious pests occur at high densities (Ebenhard 1988; Wilson et al. 1992). Grazing and browsing species that can reach high densities have the potential to contribute to land degradation.

***Evidence*:** All the mammals species that are serious pests in Australia are abundant here, as are the two serious bird pests. These species all reach high densities in their overseas ranges.

***Risk assessment significance*:** The occurrence of a species at high densities in any part of its overseas geographic range could be considered as a risk factor for its potential pest status in Australia, but obtaining data on overseas abundance is difficult and usually only subjective estimates are available. However, Freeland (1989, 1990) reports that some exotic animal populations in Australia have reached densities up to 45 times those recorded in their native habitats, so a low overseas density will not necessarily indicate that a species would not become a pest were it to establish in Australia.

**(v) Taxonomic group**

***Theory:*** Some taxonomic groups may have attributes that make them more likely to become pests than others.

***Evidence:*** Of the 24 exotic mammal species established in Australia, seven (29%) are considered to be serious pests (Wilson et al. 1992; Appendix A). On the other hand, of the 20 exotic bird species established on mainland Australia, only two (10%) are considered to be serious pests, although a further 14 birds are considered to be minor or moderate pests or potential pests (Long 1981; Fleming et al. 1990; Olsen 2000; Appendix A). Similarly, overseas studies also indicate that there are more records of exotic mammals than of exotic birds having harmful effects on agriculture, forestry and native species (Table 2; Ebenhard 1988; Atkinson 1989).

Of the exotic mammal species reviewed by Lever (1985), families particularly prone to cause damage to agriculture or forestry are: Canidae (foxes and dogs), Mustelidae (stoats and ferrets), Cervidae (deer), Bovidae (cattle, sheep and goats), Leporidae (rabbits and hares), Equidae (horse family) and Muridae (rats and mice). Of the exotic bird species reviewed by Long (1981) and Lever (1987), taxa particularly prone to cause agricultural damage include Psittaciformes (parrots), Fringillidae (old-world finches), Ploceidae (sparrows and weavers), Sturnidae (starlings and mynas), Anatidae (ducks, geese and swans) and Corvidae (crows). Many of the bird and mammal species that Lever (1985) did not report as inflicting damage were only present in small numbers.

Ebenhard (1988) found that the Orders of predatory mammals that have the most impact on prey population abundance when they establish exotic populations are, in descending order: Carnivora, Artiodactyla and Rodentia. He found the Orders of exotic mammals that have the worst effect on habitat when they establish exotic populations are, in descending order: Marsupialia, Artiodactyla, Lagomorpha, Perissodactyla and Rodentia. By contrast, he found that fewer than 1% of introduced birds have been demonstrated to cause habitat changes and there are only a few reports of predatory introduced birds affecting prey populations.

Birds in the Families Anatidae (waterfowl) and Phasianidae (pheasants, francolins, partridges and quail) are more likely to form hybrids with closely related species than are other bird groups, and most hybrids are fertile (Ebenhard 1988).

***Risk assessment significance:*** Higher proportions of exotic mammals than of birds are considered to be serious economic pests. A far higher proportion of mammals than of birds has been demonstrated to have serious ecological impacts, particularly on islands, although it is possible such impacts have been underestimated for birds. Hence, it may be desirable to take a more cautious approach to the import and keeping of exotic mammals compared to birds.

Particular caution may be advisable for the import and keeping of:

- mammals in the Orders that have been demonstrated to have detrimental effects on prey abundance and/or habitat degradation, that is, Carnivora, Artiodactyla, Rodentia, Lagomorpha, Perissodactyla, Rodentia and Marsupialia
- mammals in the Families that are particularly prone to cause agricultural damage, that is, Canidae, Mustelidae, Cervidae and Leporidae
- birds in the families that are particularly prone to cause agricultural damage, that is, Psittaciformes, Fringillidae, Ploceidae, Sturnidae, Anatidae and Corvidae
- birds in the Families that are likely to hybridise with native species, that is, Anatidae and Phasianidae, where they have close relatives among Australian native birds.

There is insufficient information on introductions and impacts of exotic reptiles and amphibians to make generalisations about taxonomic factors.

**(vi) Predators**

***Theory:*** Species that kill, maim or harass domestic animals or wildlife could become pests in Australia.

***Evidence:*** Ebenhard (1988) found that of 425 introduction events of exotic predatory mammals around the world, 32% have been linked to declines in the abundance of prey species. He found that strict predators (which are found in the orders Carnivora and Insectivora) are significantly ($P < 0.001$) more likely to affect prey abundance than omnivorous predators (such as the feral pig and rats). Among the strict predators, he found that arboreal mammals (such as the cat) are significantly ($P < 0.001$) more likely to affect prey abundance than ground dwelling species (such as the mongoose), although this difference did not apply to omnivorous predators. Prey species on islands are particularly vulnerable to introduced predators.

Ebenhard found that of 771 introduction events of 221 exotic bird species (of all diet groups) only 11 introduction events (1.4%) were reported to have impacts on prey populations.

Although there have been few studies on the effects of insectivorous exotic species on prey populations, Ebenhard (1988) considered that insectivorous birds and small mammals must undoubtedly affect prey populations of insects, gastropods, spiders and others.

***Risk assessment significance:*** A cautious approach to the import and keeping of predatory mammals, particularly strict predators that are arboreal, is desirable. Because their impacts are little studied, a cautious approach may also be desirable for insectivorous small mammals and birds.

**(vii) Grazers and browsers**

***Theory:*** Species that are grazers or browsers are more likely to cause habitat changes than are other herbivores.

***Evidence:*** Ebenhard (1988) found that, for introductions of exotic herbivores around the world, there were significantly ($P < 0.001$) more records of habitat changes caused by grazers or browsers than by other herbivores. (See also Section 1.5.1)

***Risk assessment significance:*** A more cautious approach to the import and keeping of grazing and browsing species may be desirable.

**(viii) Ecological niche**

***Theory:*** If a species uses or could potentially use resources that Australian domestic animals or wildlife also use, then there is the potential for competition. Any introduced species will fill a new, but not vacant, niche. This is because the animal creates its niche when it establishes and uses resources previously used by other species, even if these species are only detritivores (Simberloff 1981, 1991; Herbold and Moyle 1986). Just because there is not a species present at a particular trophic level in a community does not mean that introducing one will do no harm — one problem with invading species is that they often create an ecological role for themselves that did not exist before in the invaded ecosystem. An example is the devastating roles of cats, rats and pigs on ground nesting birds on islands with no native land-based mammalian predators. When introduced to a new environment, a species may also behave differently than it does in its native range (Smallwood and Salmon 1992).

Two types of competition may occur (Pianka 1978). Different species may use common resources that are in short supply (exploitation competition), or different species seeking a common and abundant resource may harm each other in the process, for example, by aggressive behaviour (interference competition). Introduced starlings can exclude native parrots from nest holes in trees (Olsen 2000), an example of interference competition. When pasture biomass is low, introduced rabbits eat pasture which would otherwise be eaten by sheep (Choquenot 1992), an example of exploitation competition. Interference and exploitation competition may cause the less competitive species to become less abundant or to shift its food or habitat. If the competition is severe and sustained it may lead to competitive exclusion, that is extinction of the less competitive species in the area of range overlap (Ebenhard 1988).

***Evidence:*** Competition is difficult to measure and even more difficult to predict. Therefore, the importance of competition may be underestimated because its effects are rarely assessed (Crawley 1986; Ebenhard 1988; Lodge 1993b). However, there have been many clear demonstrations of: the role of exotic herbivores as competitors for pasture with livestock and native species (Williams et al. 1995; Parkes et al. 1996); the role of both exotic birds and mammals as competitors for space, for example, breeding territories (Ebenhard 1988); and the role of exotic hole-nesting birds as competitors with native bird species for nest sites (Ebenhard 1988; Olsen 2000).

***Risk assessment significance:*** A more cautious approach to the import and keeping of species that could use resources, such as food, nest sites or space, that are limiting for livestock or wildlife in Australia may be desirable. The concept of a vacant niche is not useful for making predictions as to whether an introduced species will have an ecological impact.

**(ix) Ability to assist in the spread of disease**

***Theory:*** When exotic animals arrive in a country they may bring disease and parasitic organisms with them that can then spread to native species and domestic animals (Ebenhard 1988). Even when they do not bring diseases and parasites with them, by acting as reservoirs or vectors, exotic wild animals can still assist in the spread of both exotic and endemic diseases or parasites that affect domestic animals, wildlife or people.

***Evidence:*** There are many cases of exotic diseases, which affect wildlife, domestic animals or people, being transported to countries in infected animals. For example, transport of domestic stock has spread rinderpest and foot-and-mouth disease around the world (Ebenhard 1988). There are also many examples of exotic species acting as reservoirs or vectors for diseases. For instance, introduced brush-tailed possums are a reservoir for bovine tuberculosis in New Zealand (Coleman et al. 1999). Feral pigs have the potential to play a role in the spread of foot-and-mouth disease should this disease ever establish in Australia (Choquenot et al. 1996). Introduced starlings, sparrows and feral pigeons carry many diseases and parasites that pose significant health risks to people and poultry and possibly native bird species (Weber 1979; Ebenhard 1988). There appears to be little exchange of ectoparasites between introduced and native species, perhaps due to an advanced host specialisation (Ebenhard 1988).

***Risk assessment significance:*** The ability of animals to be infected by significant diseases and parasites is often known or can be established by testing (although testing is expensive). The ecology of a species in its native range, and climate matching, could be used to determine how significant the risk was that a wild population would assist in the spread of unwanted diseases. It is desirable to take a more cautious approach to the import and keeping of species which pose a high threat of spreading serious exotic or endemic diseases to people, wildlife or domestic animals.

**(x) Ability to live in human-disturbed habitats**

***Theory:*** Species which can live in human-disturbed habitats may establish more widespread populations and present a higher risk of causing agricultural damage, spreading diseases to domestic animals and people, and being a social nuisance. However, such species might be less likely to invade undisturbed habitats and, hence, less likely to have significant ecological effects on native species (Ebenhard 1988).

***Evidence:*** Virtually all the exotic birds, mammals, reptiles and amphibians that have established exotic populations in Australia are able to live commensally with people in disturbed habitats. This generalisation also applies to most exotic species established elsewhere in the world. Therefore, the question of whether exotic species without this ability could become significant pests remains largely untested.

***Risk assessment significance:*** It is possible that species that are unable to live commensally with people in disturbed habitats may pose less risk of becoming pests should they establish exotic populations in Australia, but this theory is yet to be tested.

**(xi) Availability and cost of effective control techniques**

***Theory:*** The effectiveness, cost, humaneness and target specificity of control techniques differ between species.

***Evidence:*** The cost of controlling established exotic pests is high in Australia (Bomford and Hart 2002). For some species, such as feral cats, there are no techniques available to reduce populations to the levels considered necessary to protect prey populations over large areas. While poisons are effective for controlling many species, their delivery can be expensive, they are often not target specific, and their use can raise animal welfare concerns (Olsen 1998).

***Risk assessment significance:*** The availability of suitable techniques to control exotic species could be considered in a pest risk assessment. To be effective, control techniques need to be able to reduce pest populations to densities where the level of damage they cause is considered acceptable. Control must also be humane, target specific, and not too expensive to deliver in the habitats and bioclimatic regions where a species is likely to establish. However, control of widespread pests is nearly always extremely expensive and, in Australia, control activities have not reduced damage to acceptable levels for any of the major exotic pest species (Bomford and Hart 2002). Also, most currently used control techniques are neither fully target specific nor humane. Therefore, the availability of control techniques is not considered relevant in assessing the risks of an exotic species becoming a pest, although a more cautious approach to the import and keeping of species for which control techniques are not available may be desirable.

### 1.5.3 Factors contributing to uncertainty in assessing pest potential

The outcome of any species' introduction is hard to predict, as it depends on a multitude of factors (Laycock 1966; Simberloff 1981; Roughgarden 1986; Crawley 1987; Ebenhard 1988). For a species that does establish, many factors also contribute to the uncertainty of making reliable predictions about its pest potential. Thus, assessment of potential pest status is likely to have uncertain accuracy and there are high consequences for a wrong decision.

The following factors contribute to the uncertainty in predicting pest potential:

(i) The possible development of new, unpredictable behaviour patterns, and of phenotypic or genotypic shifts, brings a strong element of uncertainty to risk assessments (de Vos et al. 1956; Laycock 1966; de Vos and Petrides 1967; Petrides 1968; Simmonds and Greathead 1977; Baker and Moeed 1979; Jarvis 1980; Ralph 1984; Lever 1985, 1987; Ehrlich 1986, Mooney et al. 1986; Ebenhard 1988; Smallwood and Salmon 1992; Sakai et al. 2001). For example, when myna, bulbul (*Pycnonotus cafer* and *P. jocosus*), white-eye (*Zosterops japonicus*), sparrow (*Passer domesticus*), finch (*Cardinalis cardinalis*, *Lonchura punctulata,* and *Padda oryzivora*) and house finch (*Carpodacus mexicanus*) were introduced to Hawaii they adopted opportunistic nectivory as a new feeding technique (Ralph 1984). This adaptation would not have been foreseen, as none of these species are traditional nectar feeders.

When different types of resources are available in the new environment, new behaviour patterns may arise. In addition, a species' fundamental niche may be broader than its realised niche in its natural environment, where competition or predation from other species prevents it using some resources (de Vos et al. 1956). When released from these restraints, the species may considerably expand its niche. In such cases, species that are not pests in their natural range may become so in the new environment (Fox 1984). One such example is the eastern grey squirrel (*Sciurus carolinensis*), which is not a pest in its native environment, but causes major economic damage to trees and gardens in Britain and South Africa, where it was introduced (de Vos and Petrides 1967; Roots 1976; Lever 1977, 1985). Another example is the racoon-dog (*Nyctereutes procyonoides*) in the Caucasus, which reportedly changed its diet from the fish and crabs it eats in its native Japan, to birds, hares and poultry (de Vos and Petrides 1967).

(ii) Estimates of the potential extent and cost of damage that could be inflicted by a new exotic species require predictions of a species' potential population size in Australia. Although accurate population density forecasting is not currently feasible, it is possibly wise to assume that introduced species could reach densities at least equivalent to those in their source habitats, and possibly considerably higher if they are released from the restraints imposed in their natural habitat by competitors, parasites, diseases, predators, and by food species with co-evolved defence mechanisms (Freeland 1989, 1990). Although climatic matching can give some indication of an exotic species' potential distribution in Australia, realised distributions will be affected by presence of enemies (competitors, predators, diseases and parasites) and supplies of essential resources such as food, water and shelter, which in turn will often be affected by past and current landuse.

(iii) It is difficult to put an economic value on environmental impacts, especially on the conservation of rare species and on aesthetic values (Kahneman and Knetsch 1992; Pearce 1993; Pearce and Moran 1994; Bingham et al. 1995; Smith 1997; Sagoff 1998). Therefore, even if the extent of harm that introduced species could inflict on the Australia native species and natural ecosystems could be predicted accurately, assessment of the cost of this harm would be an extremely difficult task. However, this difficulty in placing a monetary value on declines in existence value of native species and natural ecosystems associated with invasive species should not deter policy makers from recognizing the importance of these impacts (Lovett 2000).

(iv) Species in some orders have been introduced more often than those in others. For example, in introductions around the world, carnivores (Carnivora) and even-toed ungulates (Artiodactyla) are over-represented, and rodents (Rodentia) and bats (Chiroptera) are under-represented, as compared to the representation of these species in the total world mammal fauna (Ebenhard 1988). In the birds, waterfowl (Anseriformes), gallinaceous birds (Galliformes), pigeons (Columbiformes) and parrots (Psittaciformes) are over-represented in introductions, and daytime birds of prey (Falconiformes), waders and gulls (Charadriiformes), kingfishers and bee-eaters (Coraciiformes) and pelagic birds (Sphenisciformes, Pelicaniformes and Procellariformes) are under-represented or absent (Ebenhard 1988). Hence, studies of the effects of past introductions may give a biased picture of what may happen if a species mix from different orders is introduced. Reptiles and amphibians have had such small numbers of successful introductions that, based on past introductions, it is not possible to draw any reliable generalisations about the attributes that might contribute to their pest status.

(v) Although flocking behaviour in birds is sometimes thought to be associated with crop damage and social nuisance behaviour, nearly all the exotic birds successfully introduced to Australia form flocks or roost communally, so it is not possible to compare the pest status of flocking and non-flocking exotic Australian birds. For exotic mammals in Australia, pests are evenly distributed between herding and non-herding species.

(vi) Smith et al. (1999) found that some risk assessment systems generate a high number of false positives — i.e. they identify species as likely to establish and become pests when this is not true. This bias occurs when only a small proportion of the species that are introduced actually establish and/or when only a small proportion of those species that do establish become pests. Given that for vertebrates roughly 50% of introduced species successfully establish (Table 1), and of species that do establish roughly 50% become pests (Table 2), this bias towards false positives will not occur. Smith et al. (1999) also found that pest risk assessment systems are not worthwhile if the relative losses that would occur if correct predictions are ignored (i.e. pest animals are let in) are small compared to the losses that would occur if animals that may be useful are excluded. Damage to biodiversity, the environment and agricultural production caused by exotic vertebrates already in Australia indicate that losses are often extremely high (Olsen 2000; Clarke et al. 2001, Bomford and Hart 2002). In contrast, unless introduced vertebrates will become important livestock species or be kept widely as pets, the benefits of importing them are relatively small and accrue only to a few people. Therefore the arguments presented by Smith et al. (1999) for ignoring the predictions of some risk assessment systems are not applicable to risk assessment systems for introductions of exotic vertebrates to Australia.

# SECTION 2

# The risk assessment procedure to determine VPC Threat Categories for exotic vertebrates

## 2.1 Information requirements for species risk assessments

The information listed in this Section is necessary for completion of the Risk Assessment Model in Section 2.2. The complete information set, together with full source references, is part of the report requirements for a risk assessment to determine a species' VPC Threat Category.

Author(s) and date(s) for sources of all listed information should be given with the information, e.g. Smith (1968), and full references should be listed at the end of the information set:

- For published information sources, give author, date, title of book or paper, the name of the journal or publisher, and page numbers.
- For unpublished information sources, give name of contact, date, organisation or affiliation, address, and the type of communication (e.g. letter, report, thesis) and its title, as appropriate.
- If information is unavailable for any questions, this should be clearly stated.

**1. Species to be categorised**

1.1 Common name

1.2 Scientific name

1.3 Scientific family

1.4 Present VPC Threat Category (if categorised)

1.5 Brief description of animal's appearance

**2. Ability to harm people**

2.1 Is the animal ever aggressive?

If 'yes', will the species:

- attack if defending young?
- attack if cornered or handled?
- make unprovoked attacks?

2.2 Are there any records of the species injuring people?

If 'yes', have injuries been:

- minor (no medical treatment required)
- significant (medical treatment required), or
- fatal

If significant or fatal injuries have been recorded, give details of circumstances and frequency.

2.3 What is the body weight range of adults?

2.4 Does the animal have organs capable of inflicting harm?

- sharp teeth
- claws
- spines
- sharp bill
- horns, antlers or tusks
- toxin-delivering organs.

2.5 If the species can release toxins that could harm people, is an antivenin available, and where?

2.6 Could irresponsible use of products taken from captive individuals of the species (such as toxins) pose a public safety risk (excluding the safety of anyone entering the animals' cage/enclosure or otherwise coming within contact range of the captive animal)?

If 'yes', give details of circumstances and frequency of any known occurrences.

**3. World distribution**

3.1 Provide a map of the current world geographic range of the species, separately marking native and exotic ranges. If the species is known to have had a wider range at any time over the past 500 years, include previous range on map (separately marked from current range).

3.2 List the countries where the species occurs naturally (native range) and also separately list any countries where the species has been successfully introduced and now occurs in the wild.

**4. Migratory behaviour**

4.1 Is the species a regular migrant in any part of its native range?

**5. Diet group**

5.1 Is the species a:

- strict carnivore (eats animal matter only)
- strict herbivore (eats plant matter only), or
- omnivore (eats a mixture of plant and animal matter).

5.2 If the species is a either a strict herbivore or a strict carnivore, does it have a:

- broad, generalised diet, or
- narrow, specialised diet.

**6. Habitat**

6.1 Can the species live in human-modified habitats (such as plantation forests, gardens, orchards, vineyards, crops, cities or towns, suburbs, buildings, improved pastures, dams, dams, channels or drains)?

**7. Pest status overseas**

7.1 Is the species considered a pest or has it ever been recorded causing damage to agriculture, livestock, poultry or forestry, or to native plants or animals or their habitats or otherwise disturbing natural communities?

If 'yes', describe types, levels and locations of harm.

7.2 Is the species a social nuisance or danger because of any of the following behaviours:

- forming large noisy colonies or flocks
- polluting equipment, buildings, parks or other public facilities with urine, droppings or nesting material
- invading buildings
- posing a risk to aircraft when present in flightways or at airports
- other (specify).

**8. Land degradation and damage to plants, crops and pasture from grazing and/or browsing**

8.1 Could the species reduce the ground vegetation cover to an extent where it could cause or increase soil erosion?

8.2 Has the species ever inflicted damage to trees, shrubs or their seedlings that has caused tree death or affected their value as timber?

8.3 Could the species inhibit tree seedling regeneration in forests and woodland?

8.4 Could a wild population of the species eat or damage any of the types of commodities listed in Table 3? Include damage caused by pollution with faeces or urine, or nesting activities. List susceptible commodoties in Table 3.

8.5 Could the species spread weeds?

If 'yes', specify types and methods of dispersal.

**Table 3 :** Commodities that could be damaged by a wild population of an exotic species.

| **Commodity** | **Potential for damage** | | | **Specify crop types if applicable** |
|---|---|---|---|---|
| | **None** | **Possible** | **Likely** | |
| Cereal grain in field | | | | |
| Oilseeds or coarse grains in field | | | | |
| Grain legumes | | | | |
| Sugarcane | | | | |
| Cotton | | | | |
| Stored grain or seeds | | | | |
| Stored animal feed | | | | |
| Fodder crops | | | | |
| Timber forests or plantation trees/seedlings | | | | |
| Nursery or garden plants | | | | |
| Stone fruits | | | | |
| Tropical fruits | | | | |
| Pome fruits (apples, pears etc) | | | | |
| Citrus fruits | | | | |
| Grapes | | | | |
| Other fruit (specify) | | | | |
| Nuts (specify) | | | | |
| Flowers or buds | | | | |
| Root vegetables | | | | |
| Leaf vegetables | | | | |
| Other (specify) | | | | |

**9. Harm to animals**

9.1 Does the species attack or prey on domestic or commercial animals?

If 'yes', what animals are targeted:

- cattle
- sheep or lambs
- pigs
- goats
- fish and other aquaculture/mariculture species (specify species)
- poultry (specify species)
- other livestock (specify species)
- companion pet animals (specify species)
- honey bees.

9.2 Does the species attack or prey on wildlife?

If 'yes', what animals are targeted:

- waders or waterfowl
- other birds (specify)
- mammals < 1 kg
- mammals 1–5 kg
- mammals > 5 kg
- reptiles (specify)
- amphibians (specify)
- vertebrate eggs (specify)
- fish (specify)
- aquatic invertebrates (specify)
- insects or other land invertebrates (specify).

9.3 If a mammal, can the species climb trees?

**10. Diseases and parasites**

10.1 Is the species susceptible to, or could it transmit, any diseases or parasites that can harm people?

If 'yes', specify all disease and parasite organisms and methods of transmission.

**11. Competition for resources**

11.1 Could wild populations of the species use any resources that might cause it to compete with livestock?

If 'yes', what types of resources could be used:

- pasture crops
- pasture grasses
- pasture herbs
- pasture browse
- water
- space
- rest or shelter sites
- other (specify).

If 'yes', what livestock species could be affected?

- sheep
- cattle
- goats
- other (specify).

11.2 Could wild populations of the species use the same resources as native Australian species?

If 'yes' or 'unknown', what types of resources could be used and which types of Australian native species could be affected:

- food (specify)
- water
- space
- rest or shelter sites (specify)
- nest sites
- other (specify).

11.3 What nest sites can the species use:

- tree hollow
- burrow
- cave
- building
- cliff face
- dam, lake, pond
- marsh, swamp, reed-bed
- particular ground surface (specify)
- particular vegetation type (specify)
- other (specify).

**12. Damage to wetlands and rivers**

12.1 Does the species nest, shelter or feed in or around any of the following habitats?
- marshes or swamps
- estuaries
- lakes, ponds or dams
- rivers, channels or streams
- banks of water bodies
- coastal beaches or sand dunes.

12.2 Does the species construct burrows or dig near or around waterways?

12.3 Does the species eat or disturb wetland vegetation?

12.4 Could the species cause pollution of water bodies?

**13. Damage to buildings, structures or equipment**

13.1 Could the species deface or physically damage buildings?
If 'yes', specify any damage it could cause.

13.2 Could the species damage fences?

13.3 Could the species damage equipment?
If 'yes', specify types of equipment and damage.

**14. Hybridisation**

14.1 Could the species hybridise with any Australian native species?
If 'yes', specify which Australian species could be at risk.

**Consultant's details**

Consultant's name:

Business address and contact details:

Signature:

Date:

**Source references in full:**

## 2.2 Introduction to the risk assessment model

The following model is a quantitative approach to risk assessment, based on comparisons of species that have established exotic populations with those that have failed, and associated scientific evidence presented in Section 1. In using this model, decision makers will need to be aware that the influence of chance, as well as the large number of variables that affect whether an exotic species can establish in a new environment, will lead to an unavoidable degree of uncertainty. Both environmental stochasticity and demographic stochasticity are difficult to model (Simberloff 1989). Although some attributes are often associated with species that establish exotic populations, there is no one combination of attributes that characterises such a species. Some successful invaders are relative specialists with few of the characteristics of 'ideal' invaders (Newsome and Noble 1986), yet other species with characteristics of 'good invaders' frequently fail to establish following their introduction (Ehrlich 1989). This makes it difficult to develop a general model that describes the attributes of a successful invader (Enserink 1999). Decision-makers need to be aware that values produced by quantitative or semi-quantitative models, such as the one published in this report, give only indicative probabilistic estimates. Such probabilistic estimates are the best that can be achieved with current levels of scientific knowledge about exotic vertebrate invasions (Lodge 1993b).

This model is designed to assess the establishment risk for species on mainland Australia. The probability that exotic species could establish on Tasmania, or other offshore islands, may be higher than the probability of establishment on the mainland, provided that the island has suitable climate for the species, although this has been questioned for birds (Sections 1.3.1xii, 2.5). Exotic species introduced to islands are much more likely to put native species at risk of extinction through competition, predations and/or habitat destruction, than exotic species introduced to the mainland (Sections 1.5.1ii, 1.5.2v,vi,vii). For this reason, there may be justification in applying tighter risk management restrictions for the introduction and keeping of exotic species on islands.

The model requires judgements to be made about the relative importance of resources that could be potentially damaged. Such decisions will greatly affect the model outputs (risk scores). For example, a rating system for potential exotic bird and mammal pests developed by Smallwood and Salmon (1992) gives a maximum potential agricultural damage score for a species of 52 points, but the maximum score for natural resource damage (including potential harm to endangered species, other wildlife and wildlife habitat, soil erosion and water degradation) is only 4 points and the maximum score for disease or aggressiveness to people or livestock and social nuisance value is also only 4 points. Therefore, in Smallwood and Salmon's (1992) model, potential agricultural damage was considered to account for 87% of all potential harm caused by an exotic species and, if a species was likely to pose a major threat to native species, but not threaten agricultural production, it would be given a low potential damage score.

Given that exotic vertebrates are known to cause high levels of harm to native species and natural communities in Australia and overseas, including many species extinctions (Section 1.5.1, Ebenhard 1988; Pimental et al. 2000), and that Australia ratified the International Convention on Biological Diversity in 1993, giving such a low weighting to potential natural resource damage would be inappropriate for an Australian model. Exotic mammals can spread many diseases and aggressive species can injure people. For example, 4.7 million people are bitten by feral and pet dogs annually in the USA, of which 800 000 require medical treatment and many are small children (Pimental et al. 2000). Hence, giving a low weighting to human health risks posed by exotic vertebrates is also considered to be inappropriate for an Australian model.

## 2.3 Risk assessment

Calculate the score for each of the following factors in the risk assessment model and enter it into Table 5.

**Stage A: Risks posed by captive or released individuals**

**A1. Risk to people from individual escapees**

Assess the risk that individuals of the species could harm people. (NB, this question only relates to aggressive behaviour shown by escaped or released individual animals. Question C11 relates to risk of harm from aggressive behaviour if the species establishes a wild population).

Aggressive behaviour, size, plus the possession of organs capable of inflicting harm, such as sharp teeth, claws, spines, a sharp bill, or toxin-delivering apparatus may enable individual animals to harm people. Any known history of the species attacking, injuring or killing people should also be taken into account. Assume the individual is not protecting nest or young. Choose one:

- Animal that sometimes attacks when unprovoked and is capable of causing serious injury (requiring hospitalisation) or fatality = **2**
- Animal that can make unprovoked attacks causing moderate injury (requiring medical attention) or severe discomfort but is highly unlikely (few if any records) to cause serious injury (requiring hospitalisation) if unprovoked OR animal that is unlikely to make an unprovoked attack but which can cause serious injury (requiring hospitalisation) or fatality if cornered or handled = **1**
- All other animals posing a lower risk of harm to people (ie animals that will not make unprovoked attacks causing injury requiring medical attention, and which, even if cornered or handled, are unlikely to cause injury requiring hospitalisation) = **0**.

*Risk to people from released individuals score* **A1 = 0–2.**

**A2. Risk to public safety from individual captive animals**

Assess the risk that irresponsible use of products obtained from captive individuals of the species (such as toxins) pose a public safety risk (excluding the safety of anyone entering the animals' cage/enclosure or otherwise coming within reach of the captive animals)

- Nil or low risk (highly unlikely or not possible) = **0**
- Moderate risk (few records and consequences unlikely to be fatal) = **1**
- High risk (feasible and consequences could be fatal) = **2**.

*Risk to public safety from products obtained from captive individuals score* **A2 = 0–2**.

**Stage B: Probability escaped or released individuals will establish a free-living population (see Section 1.3)**

**B1. Degree of climate match between species overseas range and Australia (see Appendix C for methology)**

Assess the climate match between the species' overseas geographic range (current and in the last millennium) and Australia using the CLIMATE software package (Pheloung 1996). If the overseas range of a species is largely unknown, use as the input range data the entire area of all continents where the species is known to occur, only excluding regions if they are known to have unsuitable climates or if surveys have shown the species to be absent.

Use the output data on numbers of climate matched grid squares in Australia to calculate a climate match score as follows:

Calculate the Climate Match Index: CMI = 60(number of 10% grid squares) + 6(number of 20% grid squares) + (number of 30% grid squares) + (number of 40% grid squares) + (number of 50% grid squares).

Convert CMI to a climate match (B1) score:

B1= **1** (very low) CMI <150

B1= **2** (low) CMI = 150–799

B1= **3** (moderate) CMI = 800–1999

B1= **4** (high) CMI = 2000–2599

B1= **5** (very high) CMI = 2600–4499

B1= **6** (extreme) CMI ≥ 4500 or overseas range unknown and climate match to Australia unknown.

*Climate match score* **B1 = 1–6**.

**B2. Exotic population established overseas**

- No exotic population ever established= **0**
- Exotic populations only established on small islands less than 50 000 square kilometres (Tasmania is 67 800 square kilometres) = **2**
- Exotic population established on an island larger than 50 000 square kilometres or anywhere on a continent = **4**.

*Exotic elsewhere score* **B2 = 0–4**.

**B3. Taxonomic class**

- Bird = **0**
- Mammal, reptile or amphibian = **1**.

*Taxonomic Class score* **B3 = 0–1**.

**B4. Non-migratory behaviour**

- Migratory in its native range = **0**
- Non-migratory in its native range or unknown = **1**.

*Non-migratory behaviour score* **B4 = 0–1**.

**B5. Diet**

- Specialist with a restricted range of foods = **0**
- Generalist with a broad diet of many food types or diet unknown = **1**.

*Diet score* **B5 = (0–1)**.

**B6. Lives in disturbed habitat**

- Only lives in undisturbed (natural) habitats = **0**
- Can live in human-disturbed habitats (including grazing and agricultural lands, forests that are intensively managed or planted for timber harvesting and/or urban–suburban environments) or habitat use unknown = **1**.

*Disturbed habitat score* **B6 = 0–1**.

**Stage C: Probability an exotic species would become a pest (see Section 1.5)**

**C1. Taxonomic group**

- Mammal in one of the orders that have been demonstrated to have detrimental effects on prey abundance and/or habitat degradation (Carnivora, Artiodactyla, Rodentia, Lagomorpha, Perissodactyla, Rodentia and Marsupialia) = **2**

AND/OR (Score 4 if affirmative for both these points)

Mammal in one of the families that are particularly prone to cause agricultural damage (Canidae, Mustelidae, Cervidae, Leporidae, Muridae, Bovidae) = **2**

- Bird in one of the families that are particularly prone to cause agricultural damage (Psittaciformes, Fringillidae, Ploceidae, Sturnidae, Anatidae and Corvidae) = **2**
- Bird in one of the families likely to hybridise with native species, Anatidae and Phasianidae, if there are relatives in the same genus among Australian native birds = **1**
- Other group = **0**.

*Taxonomic group score* **C1 = 0–4**.

**C2. Overseas range size (including current and past 300 years, natural and introduced range)**

- Overseas geographic range less than 10 million square kilometres = **0**
- Overseas geographic range 10–30 million square kilometres = **1**
- Overseas geographic range greater than 30 million square kilometres = **2**
- Overseas geographic range unknown = **2**.

*Overseas range score* **C2 = 0–2**.

**C3. Diet and feeding**

- Mammal that is a strict carnivore (eats only animal matter) and arboreal (climbs trees) = **3**
- Mammal that is a strict carnivore but not arboreal = **2**
- Mammal that is a non-strict carnivore (mixed animal–plant matter in diet) = **1**
- Mammal that is primarily a grazer or browser = **3**
- Other herbivorous mammal or not a mammal = **0**
- Unknown diet = **3**.

*Diet score* **C3 = 0–3**.

**C4. Competition with native fauna for tree hollows**

- Can nest or shelter in tree hollows = **2**
- Does not use tree hollows = **0**
- Unknown = **2**.

*Competition for nest hollows score* **C4 = 0–2**.

**C5. Overseas environmental pest status**

Has the species been assessed sufficiently to determine if it causes declines in abundance of any native species of plant or animal or causes degradation to any natural communities in any country or region of the world?

- The species is not an environmental pest in any country or region = **0**
- Minor environmental pest in any country or region = **1**
- Moderate environmental pest in any country or region = **2**
- Major environmental pest in any country or region = **3**
- Unassessed overseas environmental pest status = **3**.

*Overseas environmental pest status score* **C5 = 0–3**.

**C6. Climate match to areas with susceptible native species or communities**

Identify any native Australian animal or plant species or communities that could be threatened by the species if it were to establish a wild population here. (For example, if the species being assessed has a score of 1 or more for C3, C4 or C5 above, or for bullets 1 and 4 in C1 above, or if it could compete with, or prey or graze on native species). Compare the geographic distribution of these susceptible plants, animals or communities with the climate match output map of Australia for the species generated by the CLIMATE software package (Pheloung 1996; See Stage B1 above).

- The species has no grid squares within a 50% climate match that overlap the distribution of any susceptible native species or communities = **0**
- The species has no grid squares within a 30% climate match that overlap the distribution of any susceptible native species or communities, and 1–50 grid squares within a 50% climate match that overlap the distribution of any susceptible native species or communities = **1**
- The species has zero 10% climate match grid squares, and 1–9 grid squares within a 30% climate match, that overlap the distribution of any susceptible native species or communities = **2**
- The species has 1–9 10% climate match grid squares, and/or 10–29 grid squares within a 30% climate match, that overlap the distribution of any susceptible native species or communities = **3**
- The species has 10–20 10% climate match grid squares, and/or 30–100 grid squares within a 30% climate match, that overlap the distribution of any susceptible native species or communities = **4**
- The species has more than 20 10% climate match (closest match) grid squares, and/or more than 100 grid squares within a 30% climate match, that overlap the distribution of any susceptible native species or communities OR overseas range unknown and climate match to Australia unknown = **5**.

*Climate match to susceptible native species score* **C6 = 0–5**.

List susceptible Australian native species or natural communities that could be threatened.

**C7. Overseas primary production pest status**

Has the species been assessed sufficietly to determine if it damages crops or other primary production in any country or region of the world?

- The species does not damage crops or other primary production in any country or region = **0**
- Minor pest of primary production in any country or region = **1**
- Moderate pest of primary production in any country or region = **2**
- Major pest of primary production in any country or region = **3**
- Unassessed overseas primary production pest status = **3**.

*Overseas primary production pest status score* **C7 = 0–3**.

**C8. Climate match to susceptible primary production**

Assess Potential Commodity Impact Scores for each primary production commodity listed in Table 4, based on species' attributes (diet, behaviour, ecology) and pest status worldwide as:

- Nil (species does not have attributes to make it capable of damaging this commodity) = **0**
- Low (species has attributes making it capable of damaging this commodity and has had the opportunity but no reports or other evidence that it has ever caused any damage in any country or region) = **1**
- Moderate–serious (reports of damage exist but damage levels have never been high in any country or region and no major control programs against the species have ever been conducted OR the species has attributes making it capable of damaging this commodity but has not had the opportunity) = **2**
- Extreme (damage occurs at high levels to this or similar commodities and/or major control programs have been conducted against the species in any country or region and the listed commodity would be vulnerable to the type of harm this species can cause) = **3**.

Enter these Potential Commodity Impact Scores in Table 4, Column 3.

Calculate the Climate Match to Commodity Score (CMCS) for the species in Australia.

Australian Bureau of Statistics (ABS) data for commodity production figures by Statistical Local Area should assist with these assessments — examples are presented in Appendix D but these will need to be updated as more recent ABS data becomes available.

- None of the commodity is produced in areas where the species has a climate match within 70% = **0**
- Less than 10% of the commodity is produced in areas where the species has a climate match within 70% = **1**
- Less than 10% of the commodity is produced in areas where the species has a climate match within 50% = **2**
- Less than 50% of the commodity is produced in areas where the species has a climate match within 50% AND less than 10% of the commodity is produced in areas where the species has a climate match within 20% = **3**
- Less than 50% of the commodity is produced in areas where the species has a climate match within 50% BUT more than 10% of the commodity is produced in areas where the species has a climate match within 20% = **4**

OR

More than 50% of the commodity is produced in areas where the species has a climate match within 50% BUT less than 20% of the commodity is produced in areas where the species has a climate match within 20% = **4**

- More than 20% of the commodity is produced in areas where the species has a climate match within 20% OR overseas range unknown and climate match to Australia unknown = **5**.

Enter these Climate Match to Commodity Scores in Table 4, Column 4.

Calculate the Potential Commodity Damage Scores (CDS) by multiplying the Commodity Value Indices (CVI) in Table 4, Column 2 with the Potential Commodity Impact Scores (PCIS) in Column 3 and the Climate Match to Commodity Scores (CMCS) in Column 4, and enter the CDS for each commodity in Column 5. Sum the CDSs in Column 5 to get a TCDS for the species, then convert it to a C8 score using the conversion factors given below Table 4.

The Commodity Value Index (CVI in Table 4, Column 2) is an index of the value of the annual production value of a commodity. Adjustments to the CVI for a commodity will be required when potential damage by the species is restricted to a particular component of the commodity being assessed. For example, some exotic species may contaminate and consume food at feedlots, and hence cause potential harm to feedlot production of livestock, but not to livestock in the paddock. In such cases, the CVI should be adjusted down in proportion to the value of the susceptible component of the commodity.

**Table 4:** Calculating Total Commodity Damage Score. The Commodity Value Index scores in this table are derived from Australian Bureau of Statistics 1999–2000 data and will need to be updated if these values change significantly.

| **Column 1** | **Column 2** | **Column 3** | **Column 4** | **Column 5** |
|---|---|---|---|---|
| **Industry** | **Commodity Value Index** | **Potential Commodity Impact Score (0–3)** | **Climate Match to Commodity Score (0–5)** | **Commodity Damage Score (columns 2 x 3 x 4)** |
| Sheep (includes wool and sheep meat) | 10 | | | |
| Cattle (includes dairy and beef) | 10 | | | |
| Timber (includes native and plantation forests) | 10 | | | |
| Cereal grain (includes wheat, barley sorghum etc) | 10 | | | |
| Pigs | 2 | | | |
| Poultry and eggs | 2 | | | |
| Aquaculture(includes coastal mariculture) | 2 | | | |
| Cotton | 2 | | | |
| Oilseeds (includes canola, sunflower etc) | 2 | | | |
| Grain legumes (includes soybeans) | 2 | | | |
| Sugarcane | 2 | | | |
| Grapes | 2 | | | |
| Other fruit | 2 | | | |
| Vegetables | 2 | | | |
| Nuts | 1 | | | |
| Other livestock (includes goats, deer, camels, rabbits) | 1 | | | |
| Honey and beeswax | 1 | | | |
| Other horticulture (includes flowers etc) | 1 | | | |
| **Total Commodity Damage Score (TCDS)** | — | — | — | |

Convert Total Commodity Damage Score to Susceptible Primary Production score.

TCDS = 0 : C8 = **0**
TCDS = 1–19 : C8 = **1**
TCDS = 20–49 : C8 = **2**
TCDS = 50–99 : C8 = **3**
TCDS = 100–149 : C8 = **4**
TCDS ≥ 150 : C8 = **5**

*Susceptible Primary Production score* **C8 = 0–5**.

### C9. Spread disease

Assess the risk that the species could play a role in the spread of disease or parasites to other animals. This question only relates to the risk of the species assisting in the spread of diseases or parasites already present in Australia. The risk that individual animals of the species could carry exotic diseases or parasites in with them when they are imported into Australia is subject to a separate import risk analysis conducted by Biosecurity Australia.

- All birds and mammals (likely or unknown effect on native species and on livestock and other domestic animals) = **2**
- All amphibians and reptiles (likely or unknown effect on native species, generally unlikely to affect livestock and other domestic animals) = **1**.

*Disease spread score* **C9 = 1–2**.

### C10. Harm to property

Assess the risk that the species could inflict damage on buildings, vehicles, fences, roads or equipment by chewing or burrowing or polluting with droppings or nesting material. Estimate the total annual dollar value of such damage if the exotic species established throughout the area for which it has a climate match of 50% or higher, based on the climate match output map of Australia for the species generated by the CLIMATE software package (Pheloung 1996; See Stage B1 above).

Convert the property damage risk total annual dollar value to a property damage risk score:

| | | |
|---|---|---|
| $0 | : | C10 = **0** |
| $1–$10 million | : | C10 = **1** |
| $11–$50 million | : | C10 = **2** |
| more than $50 million | : | C10 = **3**. |

*Property damage score* **C10 = 0–3**.

### C11. Harm to people

Assess the risk that, if a wild population established, the species could cause harm to or annoy people. Aggressive behaviour, plus the possession of organs capable of inflicting harm, such as sharp teeth, tusks, claws, spines, a sharp bill, horns, antlers or toxin-delivering organs may enable animals to harm people. Any known history of the species attacking, injuring or killing people should also be taken into account. (see Stage A, Score A1). Take into account aggressive behaviour that may occur when the species is protecting nest or young. Some species are a social nuisance, especially those that live in close association with people, for example species that invade buildings, or those with communal roosts that can cause unacceptable noise. Also consider the risk that the species could become a reservoir or vector for parasites or diseases that affect people.

Based on the above assessment, score the risk of harm to people if the species established as follows:

- nil risk = **0**
- very low risk = **1**
- injuries, harm or annoyance likely to be minor and few people exposed: low risk = **2**
- injuries or harm moderate but unlikely to be fatal and few people at risk OR annoyance moderate or severe but few people exposed OR injuries, harm or annoyance minor but many people at risk: moderate risk = **3**
- injuries or harm severe or fatal but few people at risk: serious risk = **4**
- injuries or harm moderate, severe or fatal and many people at risk: extreme risk = **5**.

*Harm to people score* **C11 = 0–5**.

## 2.4 Decision process

**Table 5:** Score sheet for risk assessment model.

| Factor | | Score |
|---|---|---|
| A1. | Risk to people from individual escapees (0–2) | |
| A2. | Risk to public safety from individual captive animals (0–2) | |
| **Stage A. Risk to public safety from captive or released individuals: A = A1 + A2 (0–4)** | | |
| B1. | Degree of climate match between species overseas range and Australia (1–6) | |
| B2. | Exotic population established overseas (0–4) | |
| B3. | Taxonomic Class (0–1) | |
| B4. | Non-migratory behaviour (0–1) | |
| B5. | Diet (0–1) | |
| B6. | Lives in disturbed habitat (0–1) | |
| **B. Establishment risk score: B = B1 + B2 + B3 + B4 + B5 + B6 (1–14)** | | |
| C1. | Taxonomic group (0–4) | |
| C2. | Overseas range size (0–2) | |
| C3. | Diet and feeding (0–3) | |
| C4. | Competition with native fauna for tree hollows (0–2) | |
| C5. | Overseas environmental pest status (0–3) | |
| C6. | Climate match to areas with susceptible native species or communities (0–5) | |
| C7. | Overseas primary production pest status (0–3) | |
| C8. | Climate match to susceptible primary production (0–5) | |
| C9. | Spread disease (1–2) | |
| C10. | Harm to property (0–3) | |
| C11. | Harm to people (0–5) | |
| **C. Pest risk score for birds, mammals, reptiles and amphibians:<br>C = C1 + C2 + C3 + C4 + C5 + C6 + C7 + C8 + C9 + C10 + C11 (1–37)** | | |

To assign the species to a VPC Threat category, use the scores from Table 5 as the basis for the following decision process.

**Risk to public safety posed by captive or released individuals (A)**

A = 0 not dangerous

A = 1 moderately dangerous

A ≥ 2 highly dangerous

**Risk of establishing a wild population (B)**

For birds and mammals:

B < 7 low establishment risk

B = 7–8 moderate establishment risk

B = 9–10 high establishment risk

B > 10 extreme establishment risk

For reptiles and amphibians far less information is available to determine thresholds scores at which establishment is probable so, as a precautionary approach, thresholds for establishment risk threat categories are set lower than for birds and mammals.

For reptiles and amphibians:

| | |
|---|---|
| B < 3 | low establishment risk |
| B = 3–4 | moderate establishment risk |
| B = 5–6 | high establishment risk |
| B > 6 | extreme establishment risk |

**Risk of becoming a pest following establishment (C)**

| | |
|---|---|
| C < 9 | low pest risk |
| C = 9–14 | moderate pest risk |
| C = 15–19 | high pest risk |
| C > 19 | extreme pest risk |

**VPC Threat Category**

A species' VPC Threat Category is determined from the various combinations of its three risk scores (Table 6).

**Table 6:** VPC Threat Categories, based on: risk posed by captive or released individuals (A); establishment risk (B); and pest risk (C).

| Establishment risk[1] (B) | Pest risk[1] (C) | Risk posed by captive or released individuals (A) | VPC Threat Category |
|---|---|---|---|
| Extreme | Extreme | Highly Dangerous, Moderately Dangerous or Not Dangerous | Extreme |
| Extreme | High | Highly Dangerous, Moderately Dangerous or Not Dangerous | Extreme |
| Extreme | Moderate | Highly Dangerous, Moderately Dangerous or Not Dangerous | Extreme |
| Extreme | Low | Highly Dangerous, Moderately Dangerous or Not Dangerous | Extreme |
| High | Extreme | Highly Dangerous, Moderately Dangerous or Not Dangerous | Extreme |
| High | High | Highly Dangerous, Moderately Dangerous or Not Dangerous | Extreme |
| High | Moderate | Highly Dangerous, Moderately Dangerous or Not Dangerous | Serious |
| High | Low | Highly Dangerous, Moderately Dangerous or Not Dangerous | Serious |
| Moderate | Extreme | Highly Dangerous, Moderately Dangerous or Not Dangerous | Extreme |
| Moderate | High | Highly Dangerous, Moderately Dangerous or Not Dangerous | Serious |
| Moderate | Moderate | Highly Dangerous | Serious |
| Moderate | Moderate | Moderately Dangerous or Not Dangerous | Moderate |
| Moderate | Low | Highly Dangerous | Serious |
| Moderate | Low | Moderately Dangerous or Not Dangerous | Moderate |
| Low | Extreme | Highly Dangerous, Moderately Dangerous or Not Dangerous | Serious |
| Low | High | Highly Dangerous, Moderately Dangerous or Not Dangerous | Serious |
| Low | Moderate | Highly Dangerous | Serious |
| Low | Moderate | Moderately Dangerous or Not Dangerous | Moderate |
| Low | Low | Highly Dangerous | Serious |
| Low | Low | Moderately Dangerous | Moderate |
| Low | Low | Not Dangerous | Low |

[1]'Establishment Risk' is referred to as the 'Establishment Likelihood' and 'Pest Risk' is referred to as the 'Establishment Consequences' by the Vertebrate Pests Committee (in press).

## 2.5 Limitations of the risk assessment model for assessing VPC Threat Categories

There are several sources of uncertainty in the data and scientific knowledge used to develop this model, which are outlined in this section. These factors should be taken account of when VPC Threat Categories are used to manage the risk posed by the import and keeping of exotic vertebrates.

### Reptiles and amphibians

The risk assessment model in this report is based on scientific knowledge about invasive mammals and birds. There is no equivalent body of published knowledge about exotic reptiles and amphibians for either Australia or overseas countries. There are few records of introduction of these taxa to Australia, although one species for which good information exists, the cane toad, is considered a serious environmental pest. In this risk assessment model, an assumption is made that the factors that influence establishment success and pest potential for birds and mammals will also apply to reptiles and amphibians. However, as a precautionary approach, threshold scores for establishment risk threat categories for reptiles and amphibians are set lower than those for birds and mammals.

### Species on offshore islands and marine species

The CLIMATE matching software used in the risk assessment model does not compute the climate match to all offshore islands, so VPC threat categories calculated by this model for exotic species may not be appropriate for offshore islands. Some scientists consider that exotic species are more likely to establish on islands than on continents, although recent analyses of global bird introductions suggest this perception may be due to the higher rate of species introductions to islands compared to continents (Section 1.3.1xii). Exotic species are more likely to become pests if they do establish on islands (Long 1981; Lever 1985; Ebenhard 1988; Simberloff 1995; Section 1.5.2v, vi, viii). Similarly, CLIMATE does not compute the climate match for marine habitats, which would make it difficult to assess the suitability of Australian marine environments for marine species proposed for import and keeping. Further, no records were found of any exotic marine species being released in Australia, so the validity of the model for assessing establishment likelihood and pest potential is unknown. Therefore, it is strongly recommended that governments take precautionary approaches to the introduction of marine species and to the keeping of exotic vertebrate species on islands, particularly on any islands where there are vulnerable native species or communities. Prey species on islands are particularly vulnerable to introduced predators (Ebenhard 1988).

### Introduction effort

One of the factors most strongly influencing establishment success is introduction effort: the number sites where a species is introduced, the number of times introductions occur and the number of individuals released (Section 1.3.1i). Introduction effort is not included as a risk factor in assessing establishment risk in the model. This is because the introduction effort is determined by the management of a species, which is addressed by risk management (Vertebrate Pests Committee in press). However, given it is likely that the number of releases will be strongly influenced by the numbers of individuals that are kept, where they are kept, and the keeping conditions, it is highly desirable that species with a Serious VPC threat category are kept in limited numbers and in highly secure premises to reduce their establishment risk, and that species with an Extreme VPC threat category are not kept in Australia at all.

## Limitations to using climate matching for predicting potential Australian range

A species' actual overseas geographic range size may be smaller than its potential range. This is because the actual range may be restricted by competition, predation, the presence of diseases or parasites, or by inadequate supplies of suitable foods, shelter or nest sites (Section 1.5.3), or by habitat destruction due to human activities. Such factors may prevent a species living in otherwise climatically suitable habitats. Geographic barriers may also limit the range of some species. Hence a species may be capable of living under a wider climatic range than its current range indicates. In such cases, a species' climate match to Australia, based on its current overseas range, may well underestimate the potential range of suitable climates in Australia. Conversely, while climate matching may show that certain areas in Australia are climatically suitable for an exotic species to establish, the presence of potential competitors, predators, diseases or parasites, or inadequate supplies of suitable foods, shelter or nest sites, or habitat destruction due to human activities in Australia, may actually make some areas unsuitable. Hence, climate matching alone may not provide a fully accurate picture of the potential range of an exotic species.

## Stochastic factors and incomplete information

Chance events have a major influence on whether a given release event will lead to an exotic species establishing and becoming a pest (Sections 1.3.1i, 1.3.2 and 1.5.3). Also, scientific knowledge and theory in this field is far from complete. Therefore, any risk assessment techniques, including this risk assessment model, can only give fairly general estimates of the risks posed by a particular species. Hence, the import and keeping of all species should be managed with caution, because there can be no certainty that a species' introduction will not have unexpected consequences.

## Model not tested on an independent data set

This risk assessment model was largely developed on the basis of analyses of data on past successful and unsuccessful introduction of mammals and birds to Australia. The scores (Section 2.3) and cut-off thresholds (Section 2.4) attributed to each of the factors used to assess risk of establishment (Section 2.3 Stage B) and risk of becoming a pest (Section 2.3 Stage C) were selected and adjusted to give the highest predictive accuracy for the exotic mammals and birds that have already been introduced into Australia. However, past exotic species introductions are not a random sub-set of the world's vertebrate fauna, but tend to over-represent certain groups, such as species that are readily available because they are abundant and/or have a wide geographic range, species that are desirable for food, sport hunting or aesthetic appearance and species that come from temperate continents (Long 1981; Blackburn and Duncan 2001b; Long 2003). This bias may influence introduction outcomes. If future introductions do not have this same bias, the introductions' outcomes may differ, which will reduce the model's predictive ability. Hence it would be desirable to test the model on an independent data set. Because no such independent data set exists, the model's ability to accurately predict the results of species introductions can only be tested by its performance in correctly predicting the outcomes of future introductions.

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*Source: Adelaide Zoological Gardens*

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*Source: G. Chapman, CSIRO*

# Appendix A:

## Introductions of exotic vertebrates to Australia

**Table A1:** Exotic vertebrate introductions to Australia: overseas range sizes, overseas introductions, Australian introductions and overseas and Australian pest status. (Species list sources: Long 1981, 2003; Myers 1986; Cogger et al. 1993; Cogger 1994; Lever 1985; Bentley 1998; Birds Australia pers. comm., unpublished).

| Species | Overseas range size (million $km^2$) | Exotic population overseas | Migratory | Minimum number of individuals introduced[4] | Minimum number of introduction sites[4] | Minimum number of introduction events[4] | Overseas pest status | Australian pest status[5] |
|---|---|---|---|---|---|---|---|---|
| **Successful birds on mainland** | | | | | | | | |
| Ostrich *Struthio camelus* | 8 | Yes | No | 18 | 4 | 5 | 1 | 1 |
| Peafowl *Pavo cristatus* | 4 | Yes | No | 33 | 10 | 9 | 1 | 1 |
| Mute swan *Cygnus olor* | 11 | Yes | No | 12 | 5 | 5 | 2 | 1 |
| Mallard *Anas platyrhynchos* | 95 | Yes | Yes | 86 | 4 | 3 | 2 | 2 |
| Cattle egret *Ardeola ibis* | 54 | Yes | Yes | 18 | 1 | 1 | 1 | 1 |
| Rock dove *Columba livia* | 80 | Yes | No | 4 | many | many | 3 | 2 |
| Spotted turtle-dove *Streptopelia chinensis* | 11 | Yes | No | 57 | 10 | 7 | 2 | 2 |
| Laughing turtle-dove *S. senegalensis* | 44 | No | No | 4 | 3 | 3 | 3 | 2 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Eurasian collared-dove *S. decaocto* | 23 | Yes | No | 5 | 3 | 3 | 1 | 1 |
| Skylark *Alauda arvensis* | 57 | Yes | Yes | 526 | 13 | 8 | 2 | 1 |
| House sparrow *Passer domesticus* | 110 | Yes | No | 414 | 10 | 22 | 3 | 2 |
| Tree sparrow *P. montanus* | 70 | Yes | No | 68 | 4 | 3 | 3 | 1 |
| Nutmeg mannikin *Lonchura punctulata* | 9 | Yes | No | 8 | 4 | 4 | 2 | 1 |
| Greenfinch *Carduelis chloris* | 21 | Yes | Yes | 133 | 7 | 4 | 2 | 1 |
| European goldfinch *C. carduelis* | 33 | Yes | Yes | 223 | 5 | 4 | 1 | 2 |
| Red-whiskered bulbul *Pycnonotus jocosus* | 6 | Yes | No | 8 | 3 | 3 | 2 | 1 |
| Blackbird *Turdus merula* | 31 | Yes | Yes | 102 | 8 | 4 | 2 | 2 |
| Song thrush *T. philomelos* | 31 | Yes | Yes | 129 | 8 | 5 | 3 | 1 |
| European starling *Sturnus vulgaris* | 58 | Yes | Yes | 292 | 9 | 4 | 3 | 3 |
| Indian myna *Acridotheres tristis* | 11 | Yes | No | 277 | 11 | 9 | 2 | 3 |
| **Successful birds on offshore islands only** | | | | | | | | |
| Wild turkey *Meleagris gallopavo* | 8 | Yes | No | n/a | n/a | n/a | d/u | n/a |
| Helmeted guinea fowl *Numida meleagris* | 20 | Yes | No | n/a | n/a | n/a | d/u | n/a |
| Red jungle fowl *Gallus gallus* | 6 | Yes | No | n/a | n/a | n/a | d/u | n/a |
| California quail *Callipepla californicus* | 3 | Yes | No | n/a | n/a | n/a | d/u | n/a |
| Ring-necked pheasant *Phasianus colchicus* | 34 | Yes | No | n/a | n/a | n/a | d/u | n/a |
| Common redpoll *Carduelis flammea* | 75 | Yes | Yes | n/a | n/a | n/a | d/u | n/a |
| Java sparrow *Padda oryzivora* | 1 | Yes | No | n/a | n/a | n/a | 3 | n/a |
| **Birds established on mainland but later extinct** | | | | | | | | |
| Silver pheasant *Lophura nycthemera*[1] | 2 | Yes | No | 2 | 1 | 1 | d/u | n/a |
| Red bishop *Euplectes orix* | 13 | Yes | No | 4 | 2 | 2 | d/u | n/a |
| White-winged widow bird *E. albonotatus* | 6 | No | No | 2 | 1 | 1 | d/u | n/a |
| Black-headed mannikin *Lonchura malacca* | 7 | Yes | No | 2 | 1 | 1 | d/u | n/a |
| Red-vented bulbul *Pycnonotus cafer* | 6 | Yes | No | 4 | 2 | 2 | d/u | n/a |

| **Unsuccessful birds on mainland** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Helmeted guinea fowl *Numida meleagris*[2] | 20 | Yes | No | 170 | 3 | 6 | d/u | n/a |
| Red jungle fowl *Gallus gallus*[2] | 6 | Yes | No | 4 | 2 | 2 | d/u | n/a |
| California quail *Callipepla californicus*[2] | 3 | Yes | No | 267 | 6 | 5 | d/u | n/a |
| Ring-necked pheasant *Phasianus colchicus*[2] | 34 | Yes | No | 750 | 7 | 12 | d/u | n/a |
| Chukar partridge *Alectoris chukar* | 23 | Yes | No | 48 | 5 | 2 | d/u | n/a |
| Red-legged partridge *A. rufa* | 1 | Yes | No | 9 | 1 | 1 | d/u | n/a |
| Barbary partridge *A. barbara* | 3 | Yes | No | 2 | 1 | 1 | d/u | n/a |
| European (grey) partridge *Perdix perdix* | 32 | Yes | No | 4 | 2 | 2 | d/u | n/a |
| Himalayan monal *Lophophorus impejanus* | 1 | No | No | 2 | 1 | 1 | d/u | n/a |
| Crested fireback pheasant *Lophura ignita* | 1 | No | No | 2 | 1 | 1 | d/u | n/a |
| Common sandgrouse *Pterocles exustus* | 15 | No | No | 2 | 1 | 1 | d/u | n/a |
| Spur-winged goose *Plectropterus gambensis* | 16 | No | No | 4 | 2 | 2 | d/u | n/a |
| Canada goose *Branta canadensis* | 38 | Yes | Yes | 4 | 2 | 1 | d/u | n/a |
| Mandarin duck *Aix galericulata* | 3 | Yes | Yes | 2 | 1 | 1 | d/u | n/a |
| Eurasian turtle-dove *Streptopelia turtur* | 34 | No | No | 8 | 1 | 1 | d/u | n/a |
| Namaqua dove *Oena capensis* | 20 | No | No | 2 | 1 | 1 | d/u | n/a |
| Peach-faced lovebird *Agapornis roseicollis* | 2 | No | No | 3 | 2 | 1 | d/u | n/a |
| European robin *Erithacus rubecula* | 25 | No | Yes | 47 | 3 | 1 | d/u | n/a |
| Nightingale *Luscinia megarhynchos* | 16 | No | Yes | 4 | 1 | 1 | d/u | n/a |
| Java sparrow *Padda oryzivora* | 1 | Yes | No | 255 | 2 | 2 | d/u | n/a |
| Chaffinch *Fringilla coelebs* | 27 | Yes | Yes | 498 | 4 | 2 | d/u | n/a |
| Bramble finch *F. montifringilla* | 31 | No | Yes | 78 | 1 | 1 | d/u | n/a |
| Canary *Serinus canarius* | <0.1 | Yes | No | 20 | 2 | 2 | d/u | n/a |
| Siskin *Carduelis spinus* | 22 | No | Yes | 80 | 3 | 1 | d/u | n/a |
| Linnet *Acanthis cannabina* | 25 | No | Yes | 32 | 4 | 4 | d/u | n/a |
| Bullfinch *Pyrrhula pyrrhula* | 41 | No | No | 14 | 1 | 1 | d/u | n/a |
| Yellowhammer *Emberiza citrinella* | 47 | Yes | Yes | 34 | 3 | 3 | d/u | n/a |
| Ortolan bunting *E. hortulana* | 30 | No | Yes | 16 | 1 | 1 | d/u | n/a |
| House crow *Corvus splendens* | *5* | Yes | No | *53* | 4 | 2 | d/u | n/a |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Unsuccessful birds on offshore islands** | | | | | | | | |
| Egyptian Goose *Alopochen aegyptiacus* | 23 | Yes | No | n/a | n/a | n/a | d/u | n/a |
| **Successful mammals on mainland** | | | | | | | | |
| European rabbit *Oryctolagus cuniculus* | 8 | Yes | No | 26 | | ≥5 | 3 | 3 |
| European brown hare *Lepus capensis* | 7 | Yes | No | 8 | | ≥5 | 2 | 1 |
| Feral horse *Equus caballus* | 9 | Yes | No | many | | ≥5 | 2 | 2 |
| Feral donkey *E. asinus* | 8 | Yes | No | 2 | | ≥5 | 2 | 2 |
| Feral buffalo *Bubalus bubalis* | 4 | Yes | No | 27 | | ≤4 | 2 | 2 |
| Feral goat *Capra hircus* | 10 | Yes | No | many | | ≥5 | 3 | 3 |
| Fallow deer *Dama dama* | 11 | Yes | Yes | 49 | | ≥5 | 1 | 1 |
| Sambar deer *Cervus unicolor* | 5 | Yes | No | 18 | | ≥5 | 3 | 2 |
| Red deer *C. elaphus* | 36 | Yes | Yes | 37 | | ≥5 | 3 | 1 |
| Hog deer *C. porcinus* | 3 | Yes | No | 38 | | ≥5 | 1 | 1 |
| Chital deer *C. axis* | 2 | Yes | No | 22 | | ≥5 | 1 | 1 |
| Rusa deer *C. timorensis* | 1 | Yes | d/u | 14 | | ≥5 | 2 | 1 |
| Feral camel *Camelus dromedarius* | 3 | No | No | 2 | | ≥5 | 1 | 2 |
| Feral pig *Sus scrofa* | 76 | Yes | No | many | | ≥5 | 3 | 3 |
| European red fox *Vulpes vulpes* | 175 | No | No | 14 | | ≤4 | 3 | 3 |
| Dingo/feral dog *Canis lupus familiaris* | 197 | Yes | No | many | | ≥5 | 3 | 3 |
| Feral cat *Felis catus* | 15 | Yes | No | many | | ≥5 | 3 | 3 |
| Feral cattle *Bos taurus* | 2 | Yes | No | many | | ≥5 | 2 | 2 |
| Banteng *B. javanicus* | 1 | Yes | No | 2 | | ≤4 | 1 | 1 |
| Feral sheep *Ovis aries* | 6 | Yes | No | many | | ≥5 | 2 | 1 |
| House mouse *Mus domesticus* | 162 | Yes | No | many | | ≥5 | 3 | 3 |
| Black rat *Rattus rattus* | 58 | Yes | No | many | | ≥5 | 3 | 2 |
| Asian house rat *R. tanezumi* | 12 | Yes | No | 2 | | d/u | 3 | 2 |
| Brown rat *R. norvegicus* | 100 | Yes | No | many | | ≥5 | 3 | 1 |
| Indian palm squirrel *Funambulus pennanti* | 2 | No | No | 4 | | ≤4 | 1 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Mammals established on mainland but later extinct** | | | | | | | | |
| Indian black buck *Antilope cervicapra* | 1 | Yes | No | 8 | d/u | ≤4 | d/u | n/a |
| Eastern grey squirrel *Sciurus carolinensis* | 6 | Yes | No | 4 | d/u | ≤4 | d/u | n/a |
| **Unsuccessful mammals on mainland** | | | | | | | | |
| Ferret/polecat *Mustela putorius furo* | 15 | Yes | No | many | d/u | ≥5 | d/u | n/a |
| Indian grey mongoose *Herpestes javanicus* | 6 | Yes | Yes | 4 | d/u | ≤4 | d/u | n/a |
| Burchell's zebra *Equus burchelli* | 6 | Yes | Yes | 2? | d/u | ≤4 | d/u | n/a |
| Barasingha *Cervus duvauceli* | <1 | No | Yes | 4 | d/u | ≤4 | d/u | n/a |
| Japanese sika *C. nippon* | 6 | Yes | Yes | 2 | d/u | ≤4 | d/u | n/a |
| Eland *Tragelaphus oryx* | 5 | No | Yes | 2 | d/u | d/u | d/u | n/a |
| **Unconfirmed unsuccessful mammals on mainland**[3] | | | | | | | | |
| Lama/alpaca *Lama guanaco* | 1 | No | No | d/u | d/u | d/u | d/u | n/a |
| Vicuña *Vicugna vicugna* | <1 | No | No | d/u | d/u | d/u | d/u | n/a |
| Indian spotted mouse deer *Tragulus meminna* | <1 | No | No | d/u | d/u | d/u | d/u | n/a |
| Musk deer *Moschus moschiferus* | 22 | No | No | d/u | d/u | d/u | d/u | n/a |
| Chinese water deer *Hydropotes inermis* | 1 | Yes | No | d/u | d/u | d/u | d/u | n/a |
| Philippine sambar *Cervus marianus* | <1 | No | Yes? | d/u | d/u | d/u | d/u | n/a |
| African buffalo *Syncernus kaffir* | 8 | No | d/u | d/u | d/u | d/u | d/u | n/a |
| Roe deer *Capreolus capreolus* | 48 | No | No | d/u | d/u | d/u | d/u | n/a |
| Golden jackal *Canis aureus* | 20 | No | No | 10–20? | d/u | ≥5? | d/u | n/a |
| Moose *Alces alces* | 69 | Yes | Yes | d/u | d/u | d/u | d/u | n/a |
| **Successful mammals on offshore islands only** | | | | | | | | |
| Pacific rat *Rattus exulans* | 4 | Yes | No | n/a | n/a | n/a | d/u | n/a |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Successful amphibians on mainland** | | | | | | | | |
| Cane toad *Bufo marinus* | 10 | Yes | No | many | many | many | 3 | 3 |
| **Successful reptiles on mainland** | | | | | | | | |
| Asian house gecko *Hemidactylus frenatus* | d/u | Yes | d/u | d/u | d/u | d/u | 1 | 1 |
| Mourning gecko *Lepidodactylus lugubris* | d/u | d/u | d/u | d/u | d/u | d/u | 1 | 1 |
| Red-eared slider *Trachemys scripta elegans* | d/u | Yes | d/u | d/u | d/u | d/u | 1 | 1 |
| Flowerpot snake *Ramphotyphlops braminus* | d/u | d/u | d/u | d/u | d/u | d/u | 1 | 1 |
| **Successful reptiles on offshore islands only** | | | | | | | | |
| Wolf snake *Lycodon capucinus* | d/u | d/u | d/u | n/a | n/a | n/a | d/u | n/a |
| Grass-skink *Lygosoma bowringii* | d/u | d/u | d/u | n/a | n/a | n/a | d/u | n/a |

*n/a: not applicable*
*d/u: data unavailable or not evaluated*

1 The silver pheasant (*Lophura nycthemera)* colonies which established in the Porongorup ranges of Western Australia were intentionally destroyed (Long and Mawson 1991).

2 Failed to establish on mainland when introduced, but successfully established on offshore island.

3 Myers (1986) and/or Bentley (1998) listed these mammal species as being released on mainland Australia and having later 'died out', but their release could not be verified by additional supporting evidence. The numbers of individuals released and number of release events and places were probably low for all these species, except for golden jackals that were reported being released in Victoria as a substitute for foxes for sports hunting (Fitzpatrick 1878). It is probable that the released jackals were hunted down and killed soon after their release.

4 These data are the minimum number of introductions to the mainland and exclude introductions to Tasmania and other offshore islands. Number of introduction events for mammals is restricted to two categories due to limited data: ≤4 or ≥5 (Forsyth et al. in press).

5 Australian pest status: 1 = not a pest or minor pest; 2 = moderate pest; 3 = serious pest. These assessments based on Fleming et al. (1990), Wilson et al. (1992), Olsen (2000), Clark et al. (2001) and Bomford and Hart (2002).

Mean overseas range size of birds that are that are minor pests or not pests = 26.7 million square kilometres (n = 11). Mean overseas range size of birds that are that are moderate or serious pests = 52.6 million square kilometres (n = 9). One tailed student's t-test on $\log_{10}$ transformed data (to harmonize variances) shows overseas range size is statistically significantly correlated with pest status for exotic birds ($P$ = 0.034).

Mean overseas range size of mammals that are minor pests or not pests = 16.9 million square kilometres (n = 10). Mean overseas range size of mammals that are moderate or serious pests = 49.6 million square kilometres (n = 15). One tailed student's t-test on $\log_{10}$ transformed data (to harmonize variances) shows overseas range size is statistically significantly correlated with pest status for exotic mammals ($P$ = 0.039).

One tailed student's t-test on square root transformed data (to harmonize variances) shows climate match indices (Appendix B, Table B2) for mammal species that are serious pests in Australia (n = 7) are significantly ($P$ = 0.008) higher than climate match indices for mammal species that are lesser pests or not pests (n = 18).

One tailed student's t-test on square root transformed data (to harmonize variances) shows climate match indices (Appendix B, Table B2) for bird species that are moderate or serious pests in Australia (n = 9) are significantly ($P$ = 0.046) higher than climate match indices for bird species that are lesser pests or not pests (n = 11).

# Appendix B:

## Climate match data for mammals and birds introduced to mainland Australia

Climate matches are presented (Tables B1–B4) for species introduced to the Australian mainland. The CLIMATE software (Appendix C) does not calculate climate matches for offshore islands, except for Tasmania and a few other big islands.

**Table B1:** Climate matches[1] for mammals successfully introduced to mainland Australia. Species are listed in order of descending climate match.

| **Species** | **Climate match class (number of grid cells)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **10%** | **20%** | **30%** | **40%** | **50%** | **Climate Match Index[6]** | **Climate Match Score[6]** |
| Dingo/feral dog *Canis lupus*[2] | 41 | 1173 | 1234 | 201 | 2 | 19635 | 6 |
| House mouse *Mus domesticus* | 125 | 1048 | 1377 | 244 | 2 | 15411 | 6 |
| Brown rat *Rattus norvegicus* | 123 | 880 | 1328 | 451 | 14 | 14453 | 6 |
| Black rat *Rattus rattus*[3] | 105 | 937 | 1362 | 372 | 19 | 13675 | 6 |
| European brown hare *Lepus capensis* | 97 | 737 | 1106 | 825 | 30 | 12203 | 6 |
| Feral pig *Sus scrofa* | 83 | 630 | 1235 | 805 | 41 | 10841 | 6 |
| Feral cat *Felis catus*[4] | 41 | 319 | 758 | 629 | 638 | 6399 | 6 |
| European red fox *Vulpes vulpes* | 24 | 306 | 772 | 1137 | 536 | 5721 | 6 |
| Feral goat *Capra hircus* | 11 | 110 | 661 | 1352 | 586 | 3919 | 5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Chital deer *Cervus axis* | 5 | 165 | 912 | 869 | 665 | 3736 | 5 |
| Feral donkey *Equus asinus* | 0 | 133 | 861 | 864 | 686 | 3209 | 5 |
| Sambar deer *Cervus unicolor* | 10 | 141 | 505 | 528 | 439 | 2918 | 5 |
| Red deer *Cervus elaphus*[5] | 17 | 136 | 280 | 342 | 363 | 2821 | 5 |
| European rabbit *Oryctolagus cuniculus* | 20 | 136 | 238 | 211 | 165 | 2630 | 5 |
| Feral cattle *Bos taurus* | 7 | 47 | 244 | 708 | 699 | 2353 | 4 |
| Feral buffalo *Bubalus bubalis* | 5 | 121 | 464 | 481 | 377 | 2348 | 4 |
| Hog deer *Cervus porcinus* | 4 | 103 | 315 | 395 | 599 | 2167 | 4 |
| Fallow deer *Dama dama* | 10 | 138 | 299 | 165 | 163 | 2055 | 4 |
| Feral horse *Equus caballus* | 3 | 25 | 195 | 687 | 829 | 2041 | 4 |
| Banteng *Bos javanicus* | 3 | 86 | 317 | 396 | 610 | 2019 | 4 |
| Indian palm squirrel *Funambulus pennanti* | 0 | 0 | 6 | 401 | 659 | 1066 | 3 |
| Feral sheep *Ovis aries* | 0 | 43 | 193 | 268 | 158 | 877 | 3 |
| Feral camel *Camelus dromedarius* | 0 | 2 | 40 | 260 | 552 | 864 | 3 |
| Rusa deer *Cervus timorensis* | 5 | 35 | 55 | 80 | 133 | 778 | 2 |

[1] Climate matches are based on overseas distribution maps taken from: Long (1981) for birds; Lever (1985) for mammals; Parker (1990) for mammals; and Lund (1994) for rodents.

[2] The original world distribution of the wolf (*Canis lupus*) from Parker (1990) was taken as the input data for feral dog (*C. l. familiaris*) because taxonomic divisions of *C. l. familiaris* and *C. lupus* are unresolved (Fleming et al. 2001) and because no published reliable distribution maps of feral domestic dogs could be found. This probably underestimates the actual overseas range and hence climate match of dogs.

[3] Includes Asian black rat (*R. tanezumi*). C. S. Watts (in Strahan 1995: 60) states that 'it is almost certain there are two species of black rat in Australia… *Rattus rattus* and the Asian black rat (*R. tanezumi*)…', but no records confirming the introduction of the latter species could be found.

[4] Input data for world distribution of feral cats was based on a literature search conducted by David Forsyth (Department of Natural Resources and Environment, Victoria, pers. comm., 2001). This probably underestimates the actual overseas range and hence climate match of cats.

[5] Includes wapiti *C. e. canadensis.*

[6] Climate Match Index (CMI) and Climate Match Score (CMS) are calculated from the formula presented in Question B1 in the Risk Assessment Model (Section 2.3). Climate matches may be invalid for offshore islands, so data for species only introduced to offshore islands are not included in this table.

**Table B2:** Climate matches for mammals unsuccessfully introduced to mainland Australia. Species are listed in order of descending climate match.

| Species | Climate match class (number of grid cells) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10% | 20% | 30% | 40% | 50% | Climate Match Index[3] | Climate Match Score[3] |
| African buffalo *Syncernus kaffir*[1] | 28 | 218 | 429 | 695 | 716 | 4828 | 6 |
| Golden jackal *Canis aureus*[1] | 13 | 205 | 769 | 857 | 622 | 4298 | 5 |
| Burchell's zebra *Equus burchelli* | 17 | 145 | 441 | 838 | 767 | 3936 | 5 |
| Eland *Tragelaphus oryx* | 15 | 205 | 339 | 581 | 481 | 3531 | 5 |
| Indian black buck *Antilope cervicapra* | 3 | 128 | 836 | 857 | 481 | 3122 | 5 |
| Eastern grey squirrel *Sciurus carolinensis* | 25 | 120 | 238 | 185 | 199 | 2842 | 5 |
| Ferret–polecat *Mustela putorius*[2] | 20 | 144 | 233 | 205 | 126 | 2628 | 5 |
| Indian grey mongoose *Herpestes javanicus* | 5 | 110 | 320 | 600 | 551 | 2431 | 4 |
| Lama/alpaca *Lama guanicoe*[1] | 14 | 37 | 89 | 492 | 660 | 2303 | 4 |
| Roe deer *Capreolus capreolus*[1] | 10 | 165 | 287 | 181 | 242 | 2300 | 4 |
| Indian spotted mouse deer *Tragulus meminna*[1] | 0 | 24 | 432 | 488 | 422 | 1486 | 3 |
| Japanese sika *C. nippon* | 0 | 7 | 42 | 157 | 441 | 682 | 2 |
| Barasingha *Cervus duvauceli* | 0 | 2 | 26 | 103 | 229 | 370 | 2 |
| Musk deer *Moschus moschiferus*[1] | 0 | 0 | 0 | 58 | 207 | 265 | 2 |
| Philippine sambar *C. marianus*[1] | 1 | 5 | 13 | 24 | 55 | 182 | 2 |
| Chinese water deer *Hydropotes inervuis*[1] | 0 | 0 | 1 | 23 | 143 | 167 | 2 |
| Vicuna *Vicuna vicugna*[1] | 0 | 0 | 15 | 44 | 55 | 114 | 1 |
| Moose *Alces alces*[1] | 0 | 0 | 3 | 12 | 66 | 81 | 1 |

[1] Ten mammal species were reported by Myers (1986) as being released on mainland Australia and having subsequently died out, but their release could not be verified from other sources.

[2] Climate match for the ferret–polecat was calculated from the overseas geographic range of *Mustela putorias*, not from the much more restricted range of the ferret (*Mustela putorius furo*).

[3] Climate Match Index (CMI) and Climate Match Score (CMS) are calculated from the formula presented in Question B1 in the Risk Assessment Model (Section 2.3).

Table B3: Climate matches for birds successfully introduced to mainland Australia. Species are listed in order of descending climate match.

| Species | Climate match class (number of grid cells) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10% | 20% | 30% | 40% | 50% | Climate Match Index[1] | Climate Match Score[1] |
| House sparrow *Passer domesticus* | 155 | 1019 | 1242 | 363 | 17 | 17036 | 6 |
| Cattle egret *Ardeola ibis* | 130 | 1040 | 1322 | 265 | 32 | 15659 | 6 |
| Laughing turtle-dove *S. senegalensis* | 82 | 852 | 1259 | 553 | 39 | 11883 | 6 |
| Rock dove *Columba livia* | 82 | 846 | 1548 | 305 | 14 | 11863 | 6 |
| European starling *Sturnus vulgaris* | 65 | 552 | 1380 | 634 | 121 | 9347 | 6 |
| Ostrich *Struthio camelus* | 14 | 422 | 940 | 646 | 437 | 5395 | 6 |
| Blackbird *Turdus merula* | 28 | 218 | 523 | 876 | 715 | 5102 | 6 |
| Tree sparrow *P. montanus* | 21 | 279 | 573 | 628 | 757 | 4892 | 6 |
| Mallard *Anas platyrhynchos* | 25 | 179 | 386 | 794 | 785 | 4539 | 6 |
| European goldfinch *C. carduelis* | 27 | 191 | 276 | 382 | 936 | 4360 | 5 |
| Eurasian collared-dove *S. decaocto* | 9 | 280 | 756 | 805 | 548 | 4329 | 5 |
| Greenfinch *Carduelis chloris* | 27 | 185 | 279 | 176 | 287 | 3472 | 5 |
| Skylark *Alauda arvensis* | 25 | 159 | 280 | 204 | 318 | 3256 | 5 |
| Indian myna *Acridotheres tristis* | 9 | 156 | 516 | 626 | 620 | 3238 | 5 |
| Spotted turtle-dove *Streptopelia chinensis* | 7 | 149 | 471 | 597 | 696 | 3078 | 5 |
| Nutmeg mannikin *Lonchura punctulata* | 8 | 148 | 475 | 528 | 425 | 2796 | 5 |
| Red-whiskered bulbul *Pycnonotus jocosus* | 5 | 124 | 435 | 526 | 713 | 2718 | 5 |
| Peafowl *Pavo cristatus* | 3 | 58 | 507 | 551 | 407 | 1993 | 3 |
| Song thrush *T. philomelos* | 8 | 93 | 200 | 237 | 200 | 1675 | 3 |
| Mute swan *Cygnus olor* | 0 | 26 | 138 | 236 | 228 | 758 | 2 |

[1] Climate Match Index (CMI) and Climate Match Score (CMS) are calculated from the formula presented in Question B1 in the Risk Assessment Model (Section 2.3).

**Table B4:** Climate matches for birds unsuccessfully introduced to mainland Australia. Species are listed in order of descending climate match.

| **Species** | **Climate match class (number of grid cells)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **10%** | **20%** | **30%** | **40%** | **50%** | **Climate Match Index[2]** | **Climate Match Score[2]** |
| Namaqua dove *Oena capensis* | 81 | 659 | 1074 | 796 | 157 | 10841 | 6 |
| Red bishop *Euplectes orix*[1] | 67 | 626 | 1068 | 846 | 159 | 9849 | 6 |
| Spur-winged goose *Plectropterus gambensis* | 66 | 636 | 1081 | 786 | 196 | 9839 | 6 |
| Helmeted guinea fowl *Numida meleagris* | 53 | 426 | 742 | 818 | 625 | 7921 | 6 |
| Nightingale *Luscinia megarhynchos* | 23 | 910 | 283 | 175 | 294 | 7592 | 6 |
| White-winged widow bird *E. albonotatus*[1] | 33 | 246 | 536 | 892 | 746 | 5630 | 6 |
| Ring-necked pheasant *Phasianus colchicus* | 9 | 226 | 1019 | 897 | 559 | 4371 | 5 |
| Eurasian turtle-dove *Streptopelia turtur* | 23 | 185 | 285 | 325 | 1182 | 4282 | 5 |
| Peach-faced lovebird *Agapornis roseicollis* | 8 | 225 | 419 | 445 | 722 | 3416 | 5 |
| Linnet *Acanthis cannabina* | 23 | 183 | 279 | 179 | 285 | 3221 | 5 |
| Chaffinch *Fringilla coelebs* | 23 | 181 | 282 | 179 | 276 | 3203 | 5 |
| Common sandgrouse *Pterocles exustus* | 1 | 145 | 542 | 941 | 680 | 3093 | 5 |
| Red jungle fowl *Gallus gallus* | 8 | 133 | 314 | 428 | 853 | 2873 | 5 |
| Chukar partridge *Alectoris chukar* | 4 | 122 | 379 | 485 | 846 | 2682 | 5 |
| Black-headed mannikin *Lonchura malacca*[1] | 7 | 144 | 448 | 480 | 411 | 2623 | 5 |
| House crow *Corvus splendens* | 5 | 120 | 472 | 547 | 383 | 2422 | 4 |
| European robin *Erithacus rubecula* | 15 | 160 | 276 | 155 | 129 | 2420 | 4 |
| California quail *Callipepla californicus* | 5 | 20 | 137 | 712 | 1061 | 2330 | 4 |
| Yellowhammer *Emberiza citrinella* | 15 | 115 | 179 | 139 | 242 | 2150 | 4 |
| Ortolan bunting *E. hortulana* | 5 | 152 | 295 | 162 | 163 | 1832 | 3 |
| Red-vented bulbul *Pycnonotus cafer*[1] | 1 | 70 | 478 | 500 | 348 | 1806 | 3 |
| Barbary partridge *A. barbara* | 12 | 66 | 108 | 200 | 296 | 1720 | 3 |
| European (grey) partridge *Perdix perdix* | 5 | 199 | 265 | 180 | 140 | 1599 | 3 |
| Red-legged partridge *A. rufa* | 6 | 99 | 253 | 221 | 159 | 1587 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bullfinch *Pyrrhula pyrrhula* | 6 | 72 | 203 | 224 | 148 | 1367 | 3 |
| Silver pheasant *Lophura nycthemera*[1] | 1 | 26 | 128 | 232 | 287 | 863 | 3 |
| Siskin *Carduelis spinus* | 0 | 15 | 130 | 303 | 158 | 681 | 2 |
| Himalayan monal *Lophophorus impejanus* | 0 | 2 | 35 | 139 | 426 | 612 | 2 |
| Java sparrow *Padda oryzivora* | 0 | 14 | 55 | 132 | 155 | 426 | 2 |
| Canada goose *Branta canadensis* | 1 | 11 | 28 | 44 | 150 | 348 | 2 |
| Canary *Serinus canarius* | 0 | 0 | 2 | 57 | 276 | 335 | 2 |
| Mandarin duck *Aix galericulata* | 0 | 2 | 5 | 31 | 143 | 192 | 2 |
| Crested fireback pheasant *Lophura ignita* | 0 | 0 | 0 | 1 | 39 | 40 | 1 |
| Bramble finch *F. montifringilla* | 0 | 0 | 0 | 0 | 11 | 11 | 1 |

[1] Birds established on mainland but later extinct.

[2] Climate Match Index (CMI) and Climate Match Score (CMS) are calculated from the formula presented in Question B1 in the Risk Assessment Model (Section 2.3)

# Appendix C:

## CLIMATE matching model

The CLIMATE software (Pheloung 1996) contains data for 16 climate variables (Table C1) for approximately 8000 meteorological stations outside Australia. The geographical range (current and in the last millennium, excluding Australia) of an introduced species is plotted on a world map and the climate data from the meteorological stations that fall within the boundaries of that range are used as input data for that species.

Using a spatial resolution of 0.5 degrees (latitude x longitude), Australia is divided into 2795 grid points. The 16 climate variables are generated for each grid point based on long term data from meteorological stations in Australia (Nix 1986). For each of 16 climate variables at each of the input meteorological stations, the difference between the value for each input meteorological station and the value at each Australian grid point is divided by the global standard deviation for the variable to generate a standard score. A Euclidian distance is computed as the square root of the sum of the squares of the standard scores for each of the 16 climate variables, divided by 16. The resultant value is then compared to a normal distribution of reference scores that partition the normal distribution into percentage categories based on the area under the normal distribution curve. Scores within 10% of the mean score are those with the closest possible climate match, and scores of 80% or higher, which fall in the tails of the normal distribution, have the lowest climate match. CLIMATE repeats this matching process for all input meteorological stations. The closest matching score is then selected for each Australian grid square because, if a species occurs at an overseas location that closely matches the climate at a given Australian location, whether it also occurs at less well-matched overseas locations is irrelevant. Hence, a close climate match is identified for an Australian grid square if at least one of the overseas locations where the species occurs closely matches that grid square. For each species, the number of Australian grid squares allocated to each climate matching class is a measure of Australia's land area in that climate matching class.

**Table C1:** The 16 climate parameters (temperature and rainfall) used to estimate the extent of climatically matched habitat in the CLIMATE program (Pheloung 1996). Estimates of these parameters are derived from long term averages of monthly minimum and maximum temperatures and rainfall for each of the approximately 8000 meteorological stations in the CLIMATE database.

| Temperature parameters (°C) | Rainfall parameters (mm) |
|---|---|
| Mean annual | Mean annual |
| Minimum of coolest month | Mean of wettest month |
| Maximum of warmest month | Mean of driest month |
| Average range | Mean monthly CV |
| Mean of coolest quarter | Mean of coolest quarter |
| Mean of warmest quarter | Mean of warmest quarter |
| Mean of wettest quarter | Mean of wettest quarter |
| Mean of driest quarter | Mean of warmest quarter |

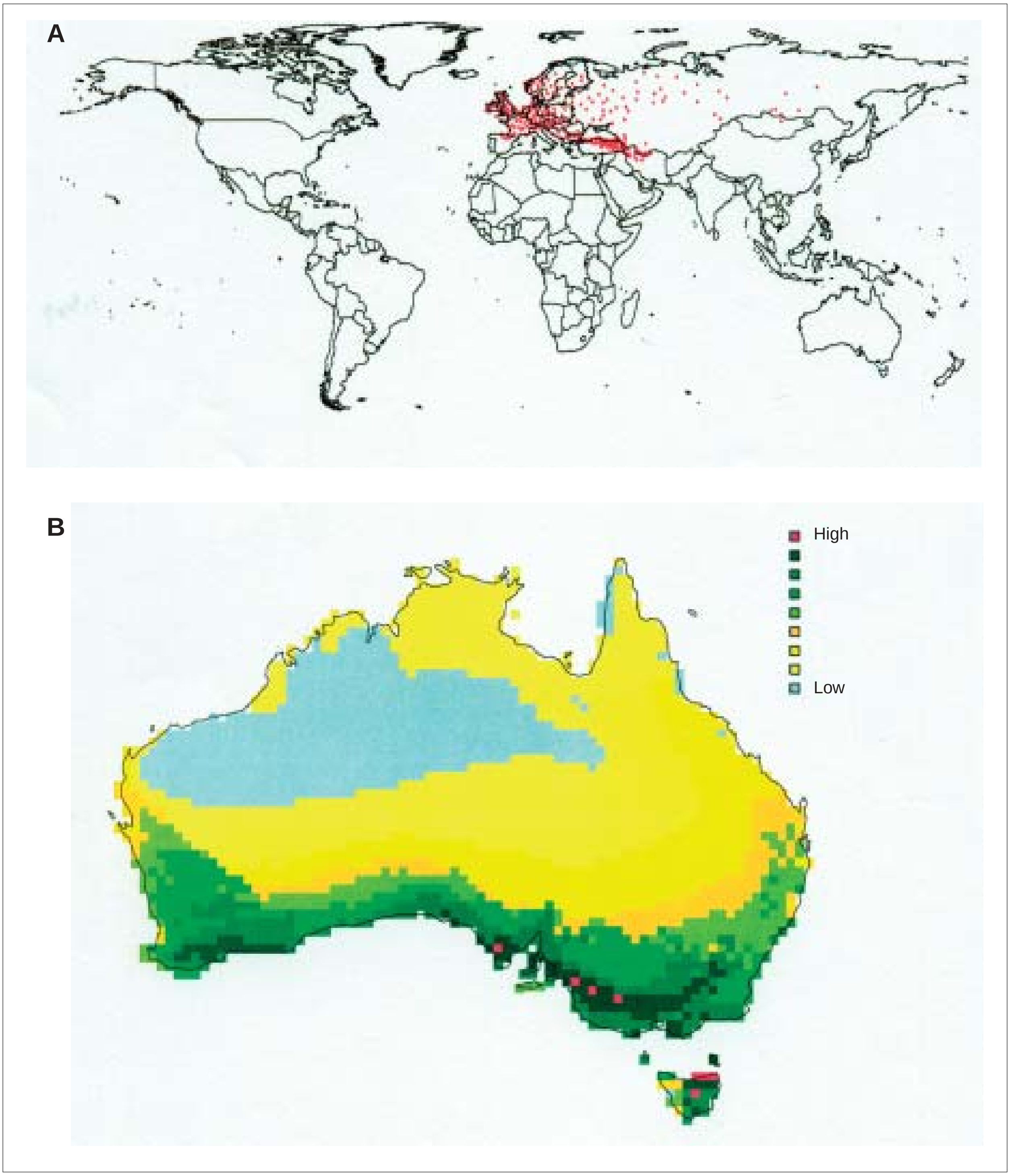



**Figure C1:** Input CLIMATE data for the song thrush. Each red point indicates a meteorological station within the song thrush's overseas range. (B) Output CLIMATE match map for the song thrush. The eight red grid squares indicate the highest level of climate match and the 599 light blue grid square indicate the lowest level of climate match.

The output from CLIMATE is a map of Australia showing the level of climate match in each 0.5 degree grid square and a written summary of the number of grid squares in each climate match category from 10% (highest match) to 90% (lowest match) (Appendix B).

CLIMATE was selected for use in the risk assessment model, in preference to alternatives such as CLIMEX or BIOCLIM (Kriticos and Randall 2001), because CLIMATE matches have been proven to be correlated with establishment success of birds and mammals introduced to Australia (Duncan et al. 2002; Forsyth et al. in press). CLIMATE is also simple to use and fully quantitative. Although CLIMEX (Sutherst et al. 1998) allows the user to include information about a species' adaptations to climate stressors, these data are not available for most species and therefore subjective judgements are often required. Sensitivity tests using CLIMEX, indicate that varying data input on a species' adaptations to climate stressors can give widely differing outputs in relation to areas of suitable Australian climate, and hence to any interpretation of the likelihood of a species being able to establish in Australia. Without expensive research it could be difficult to make any reliable scientific judgements selecting between the different possible CLIMEX outputs.

# Appendix D:

**Major agricultural commodities that could be damaged by exotic animals.**

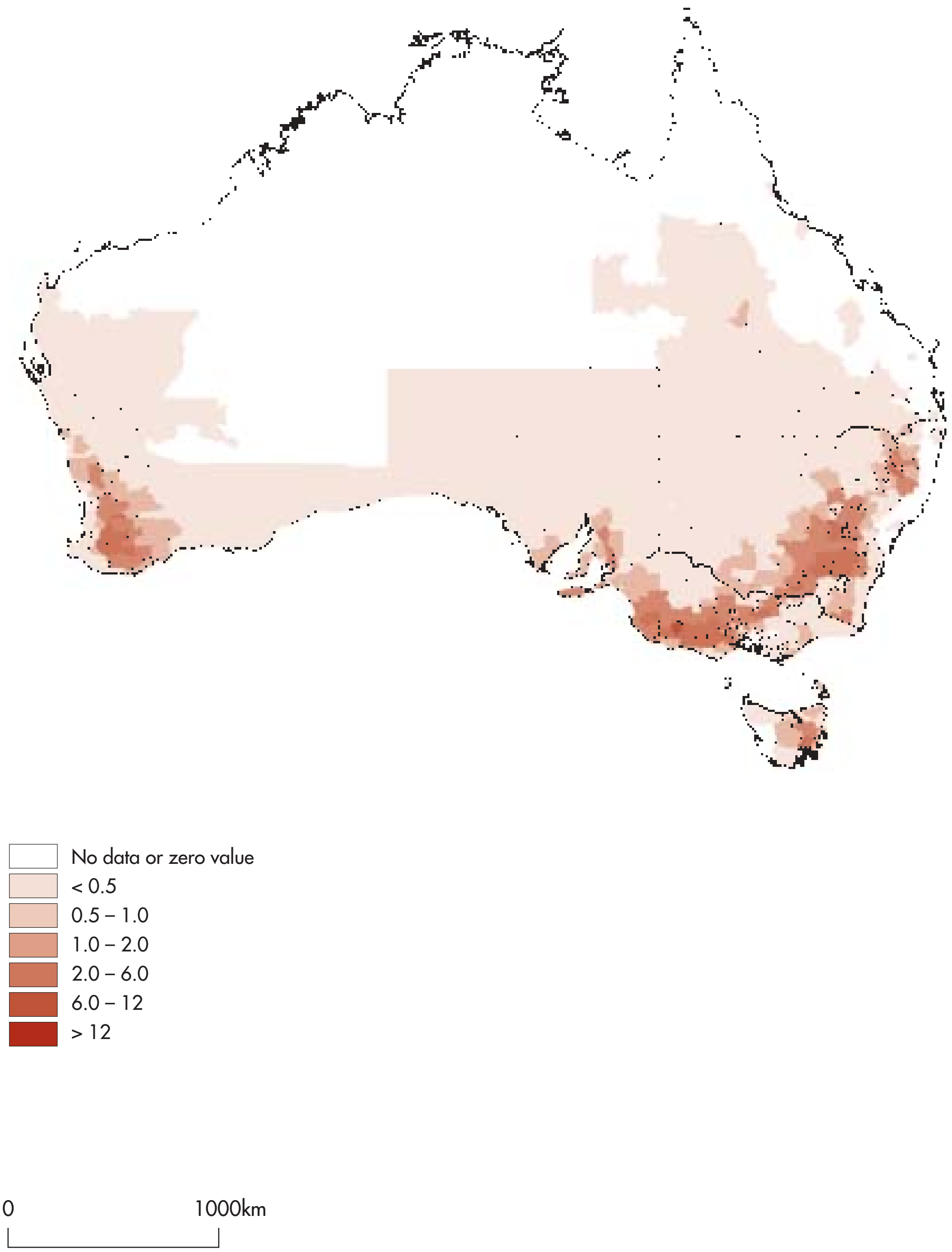
These maps show the intensity or value of major agricultural industries that could be harmed if new animal species established exotic populations in Australia. The data are classified into density or value of an industry averaged across statistical local areas, based on data from the 2001 agricultural census conducted by the Australian Bureau of Statistics (ABS).

These maps will need to be replaced with updated versions when new ABS statistics become available. New industries, or industries which have substantially increased in value since these maps were produced, may also need to be assessed.

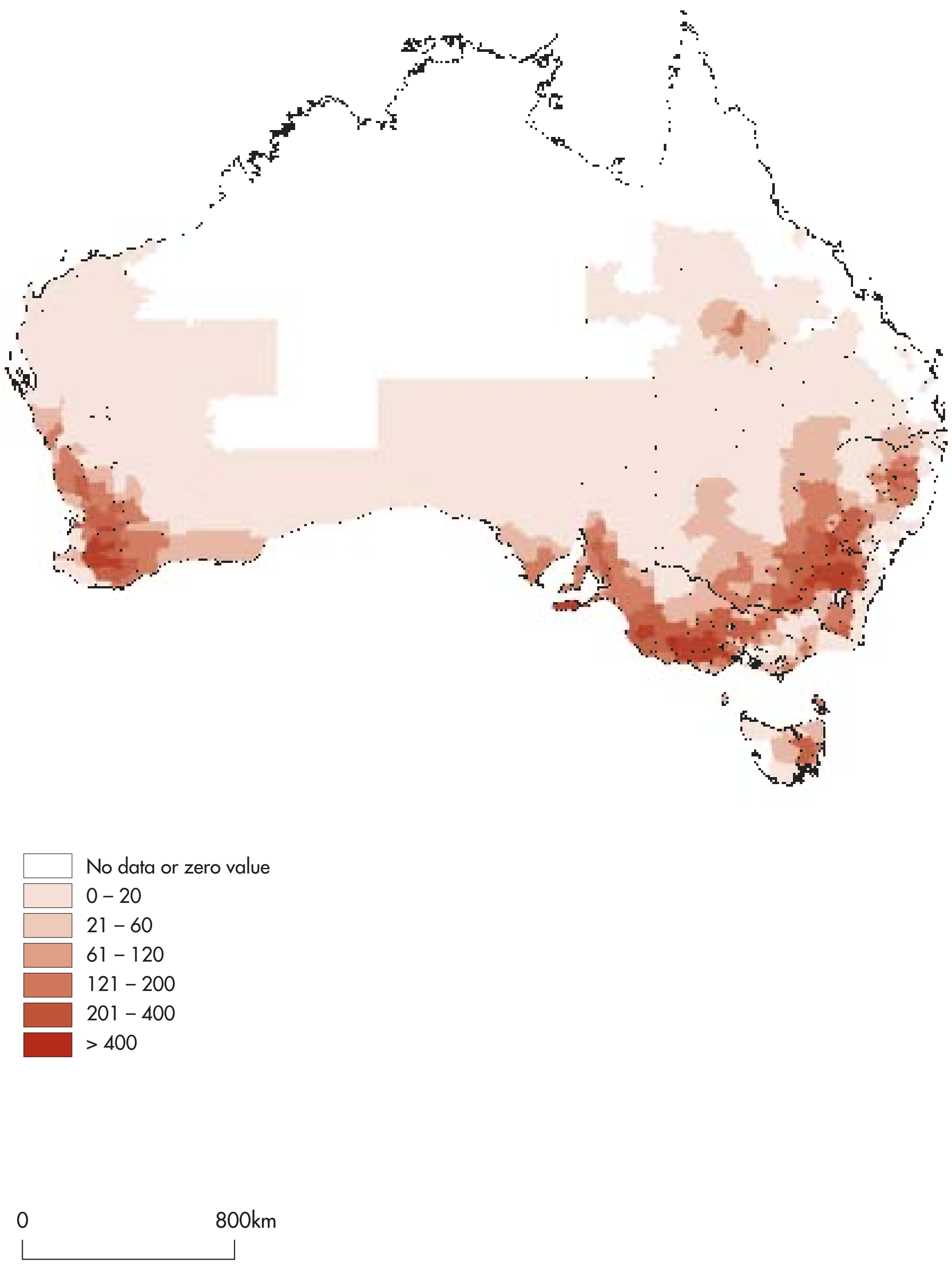
When considered together with the Australian climate match maps for an exotic species (Appendix C), these industry maps provide an indication of which industries fall within the species' potential geographic range in Australia (Section 2.2.C8). If there is a potential match, and the species is considered capable of causing harm to an industry, then the species will need to be given a Climate Match to Commodity Score for that industry (Section 2.2.C8; Table 4). Even in areas where an industry is not classified as intensive, its value across a wide geographic area may be high. For example, most cattle occur in southeast Australia, with low densities across northern Australia, but there is a valuable beef cattle industry in northern Australia based on low-density cattle grazing on rangeland pastures.

**Figure D1:** Major agricultural commodities in Australia
*(Data source: Australian Bureau of Statistics 2001)*

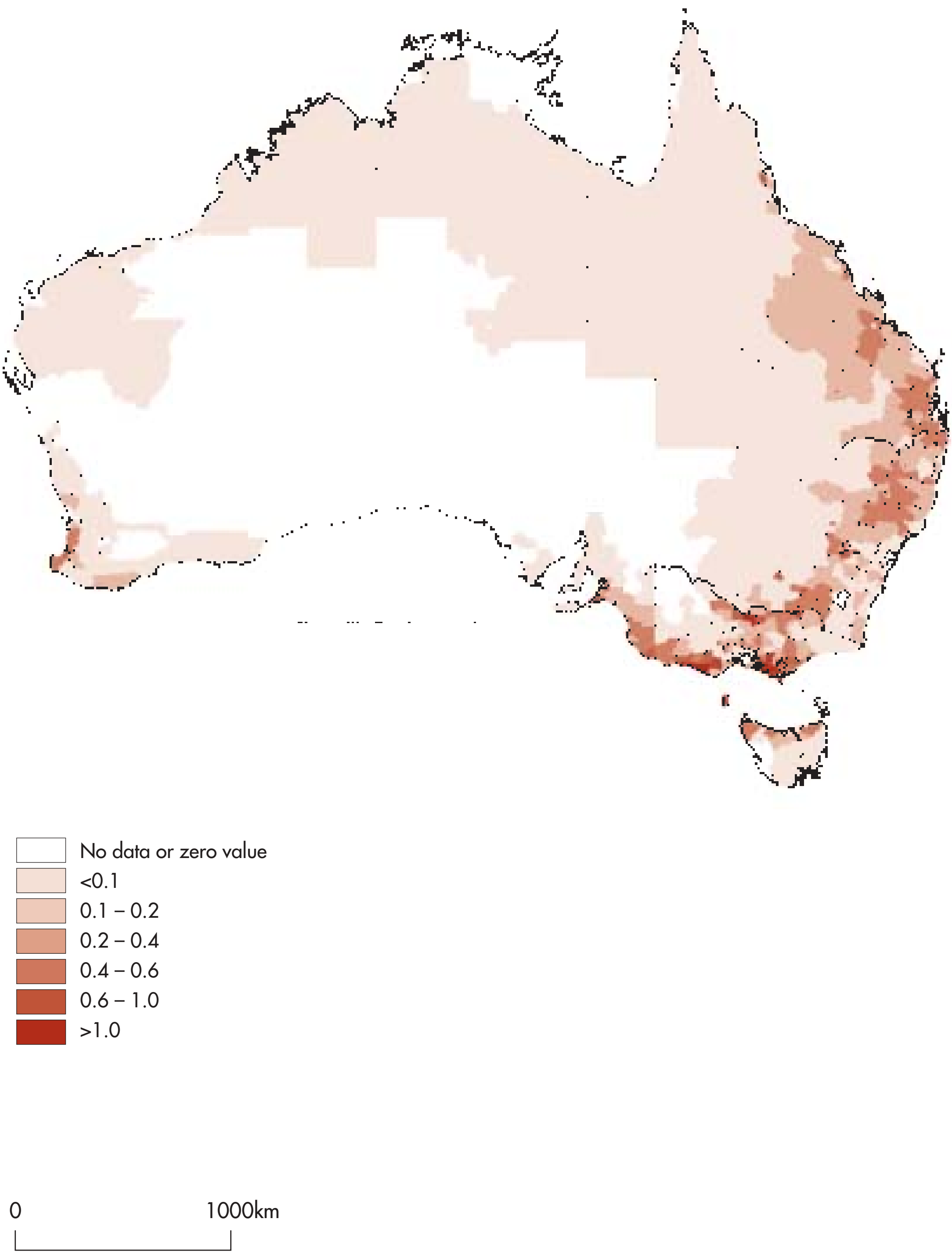
# Sheep and lambs (number/hectare)



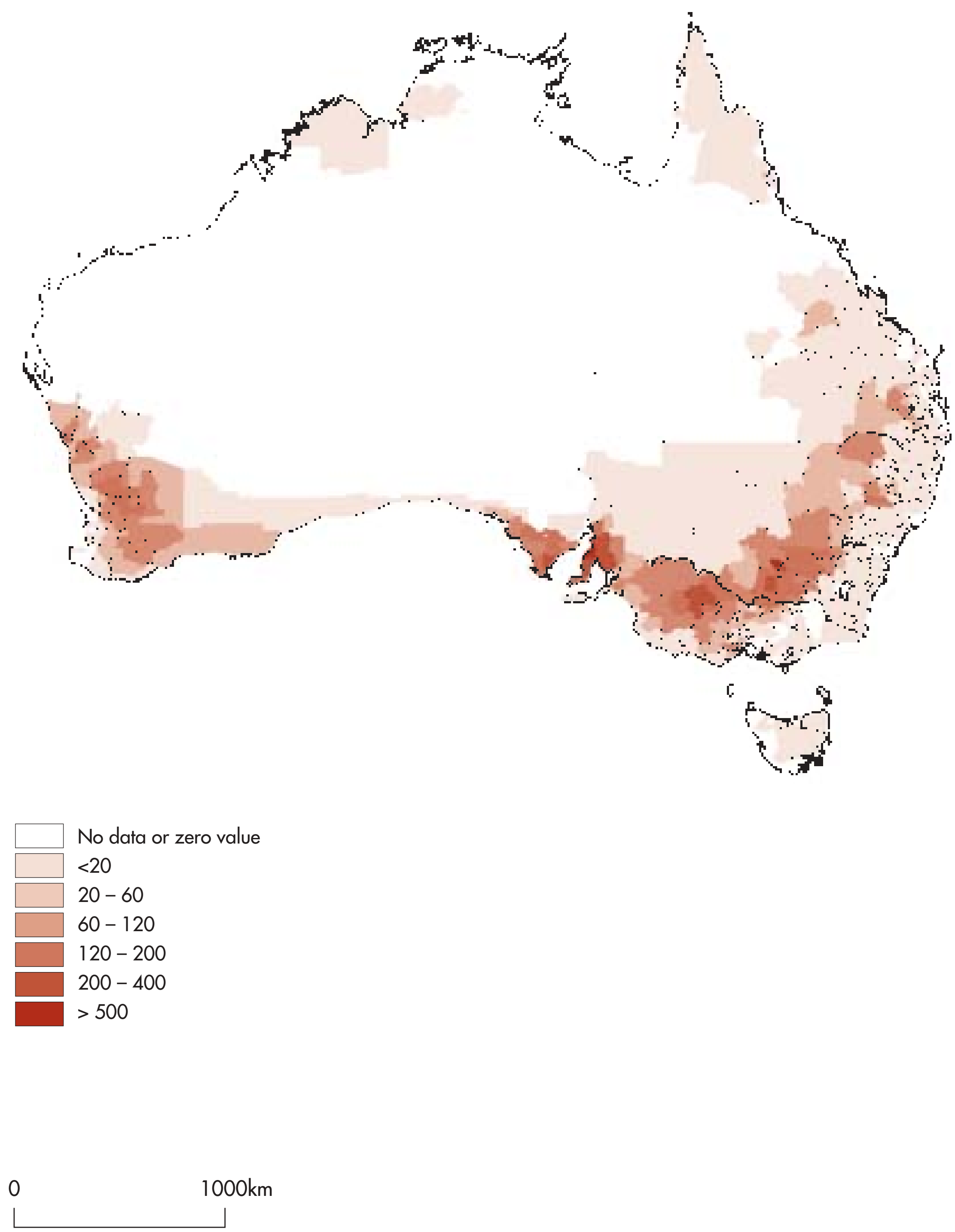
# Wool produced (kilograms/hectare)



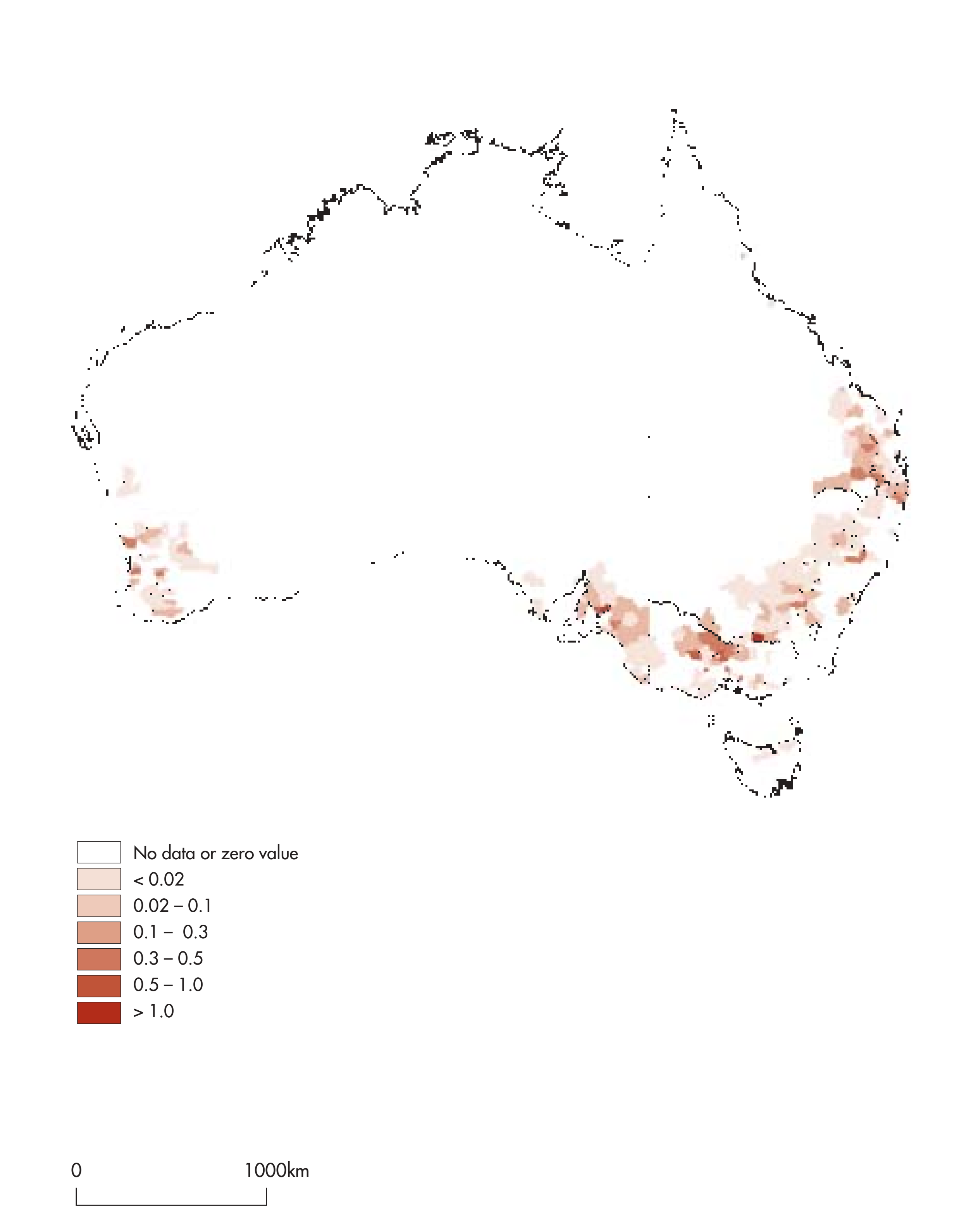
# Cattle and calves (number/hectare)



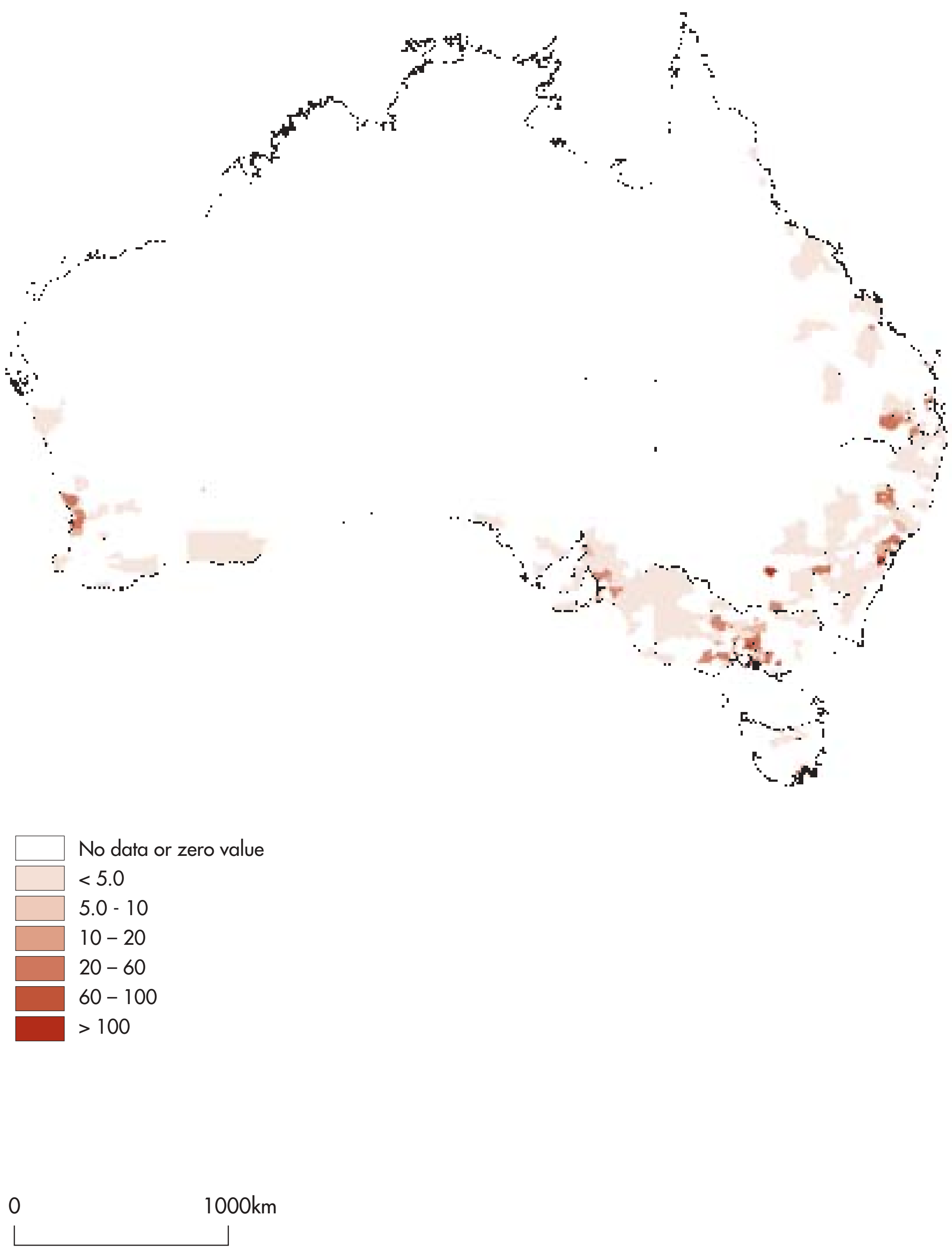
# Cereals for grain ($value/hectare)



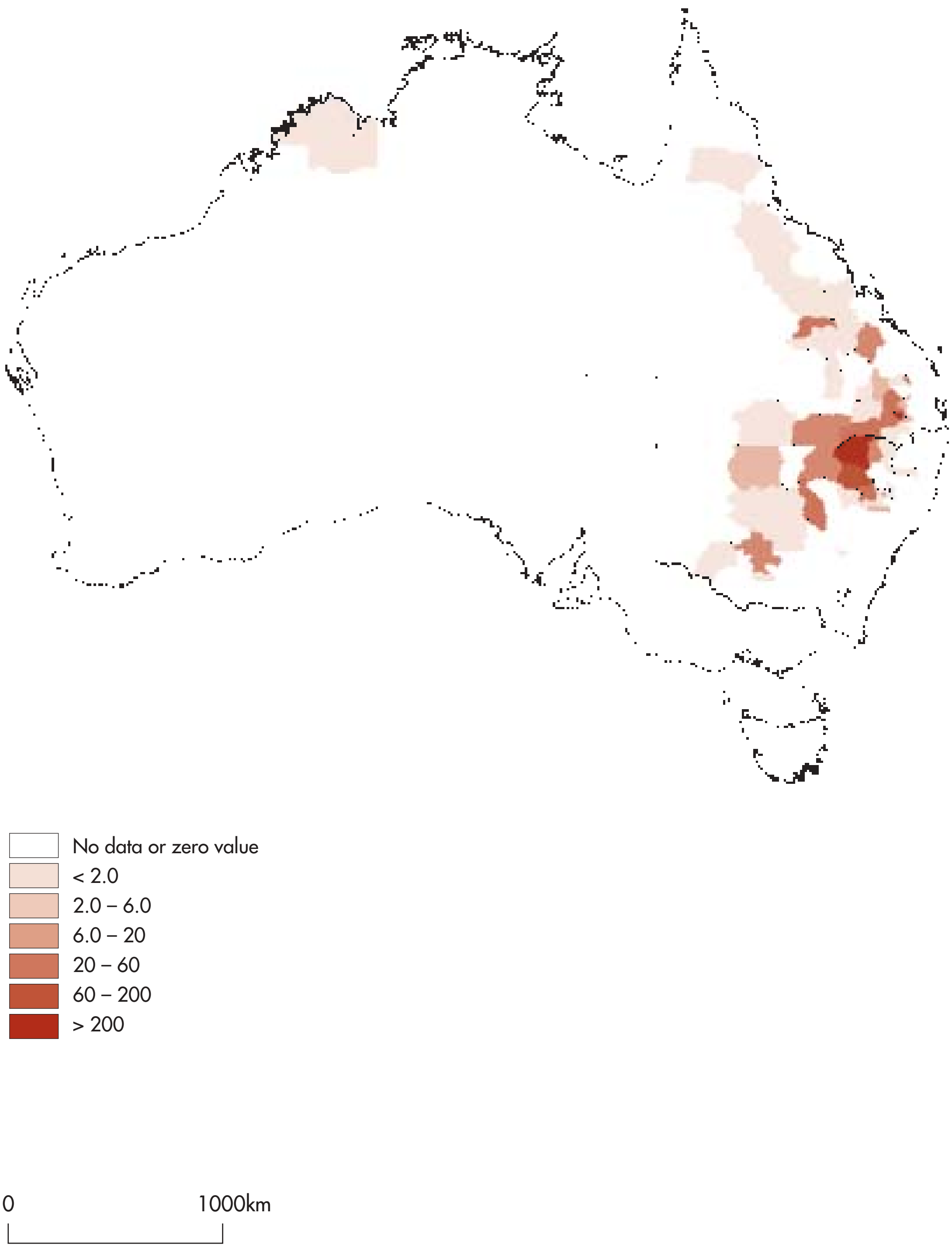
## Pigs (number/hectare)



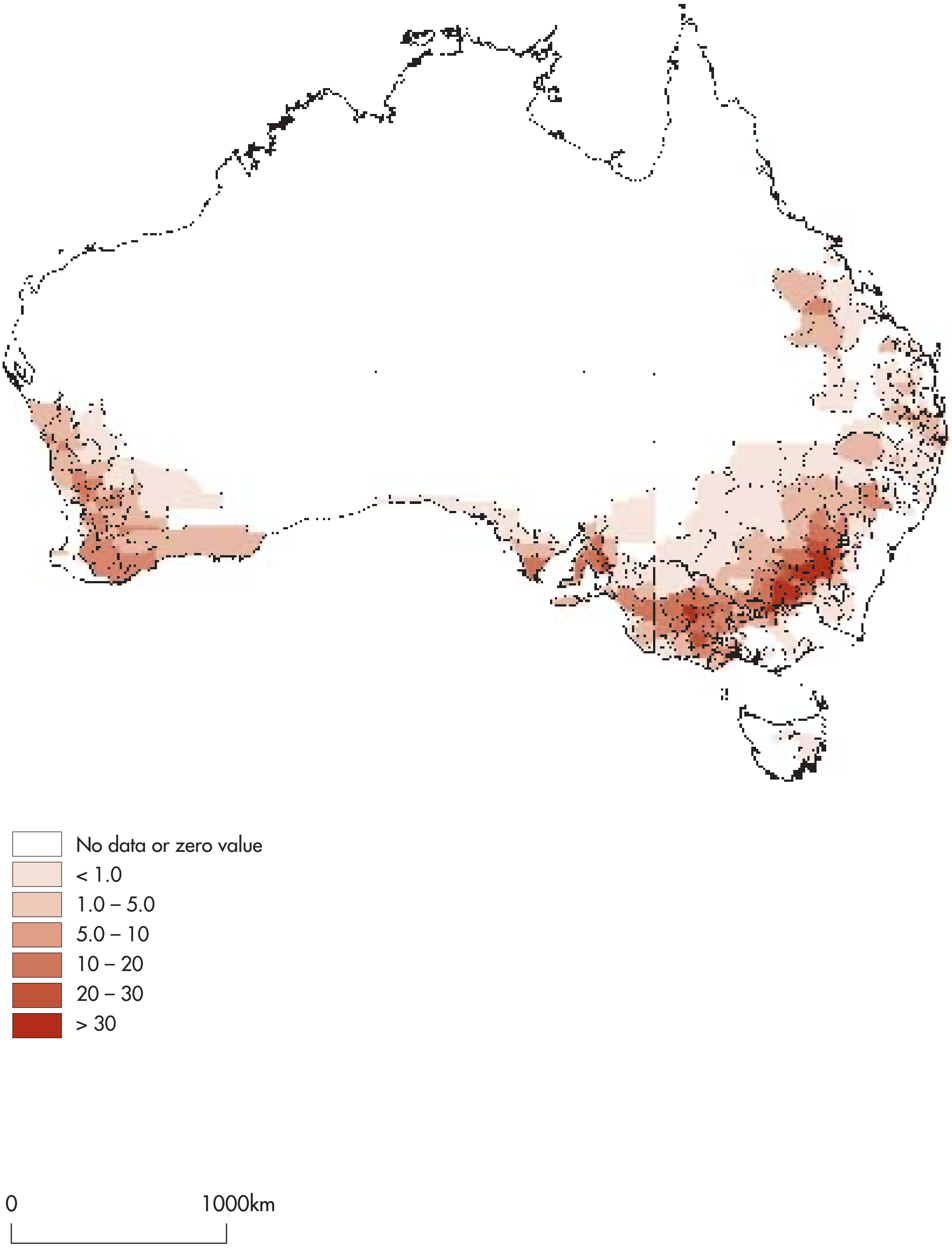
# Eggs ($ value/hectare)



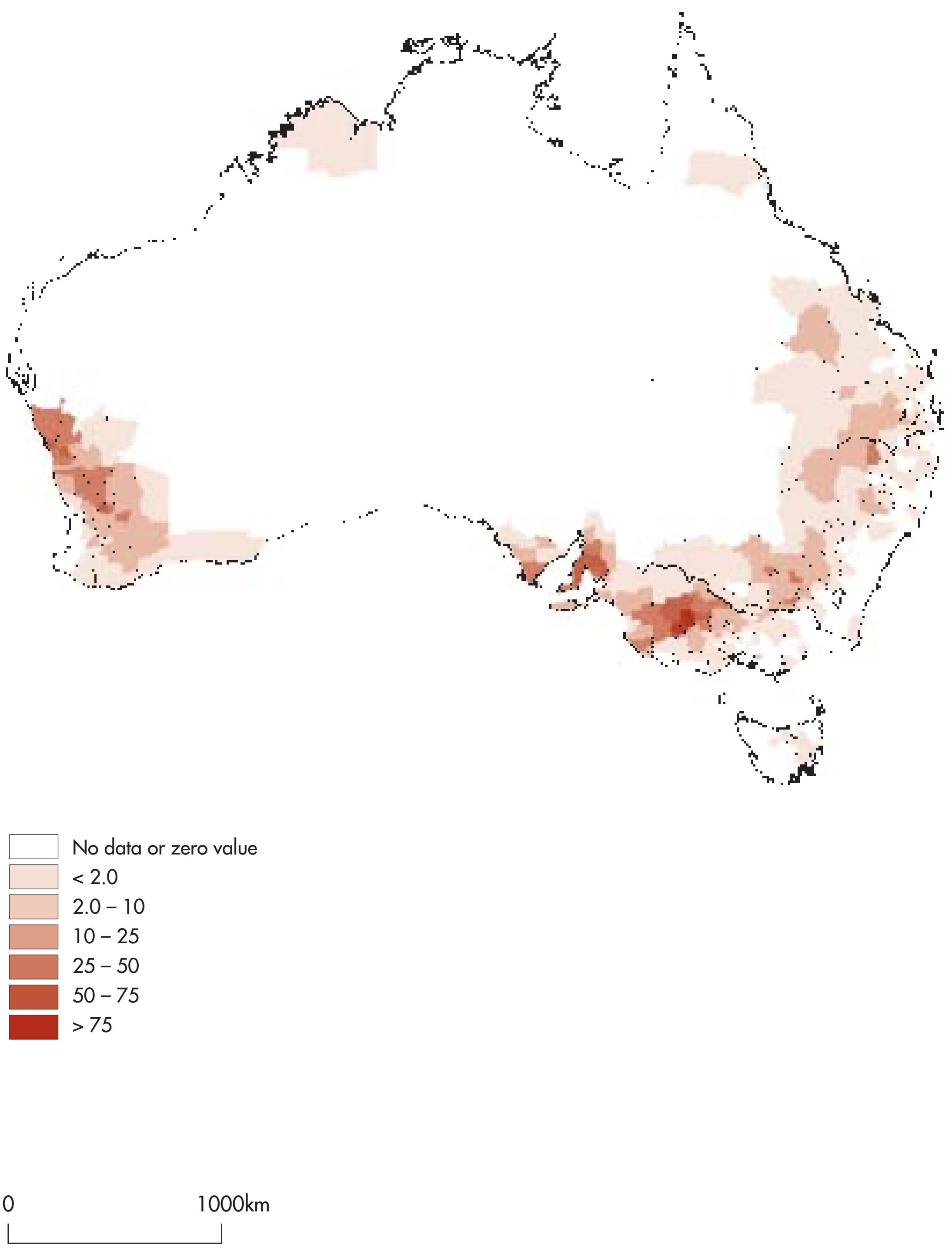
# Cotton ($ value/hectare)



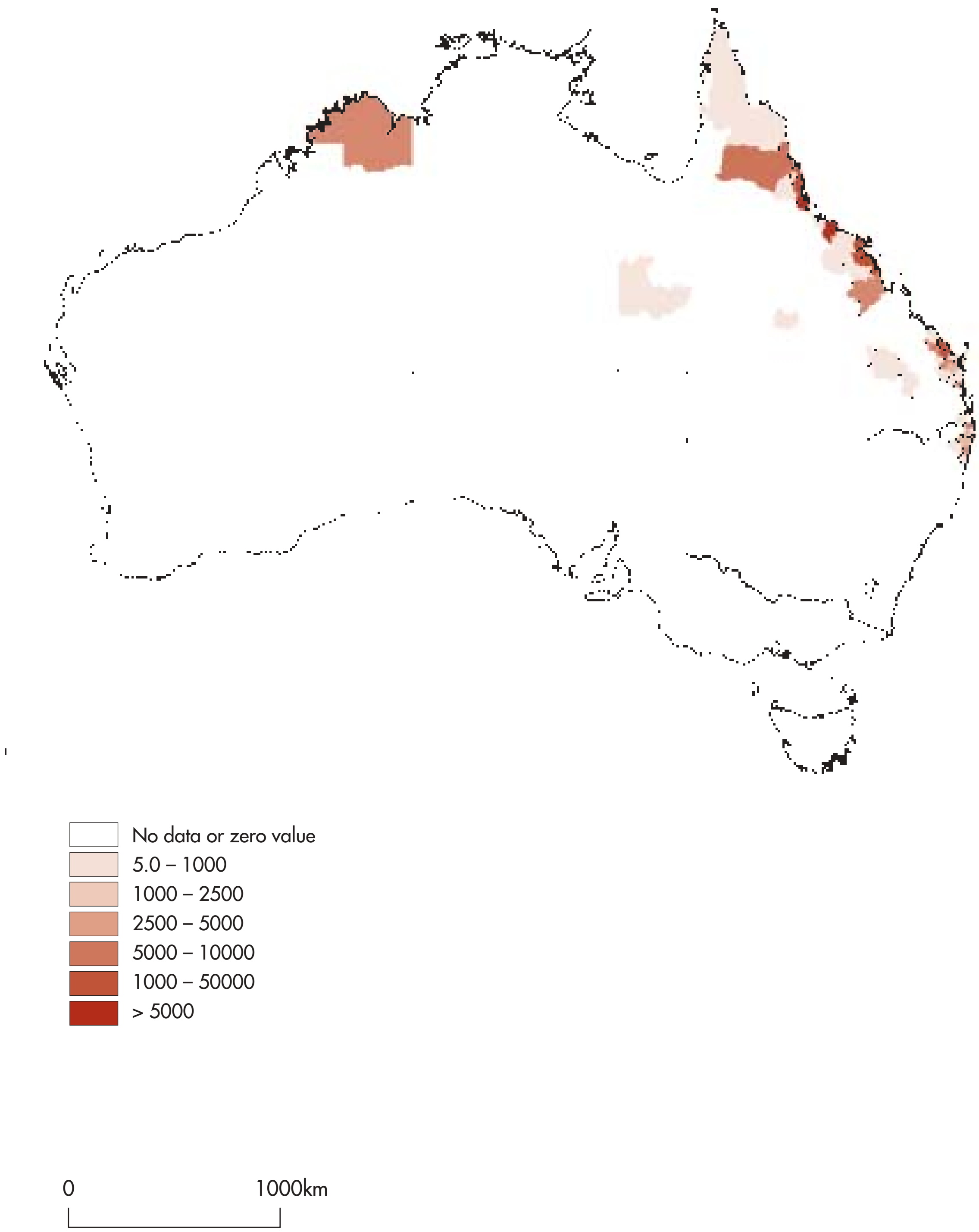
# Oilseeds ($ value/hectare)



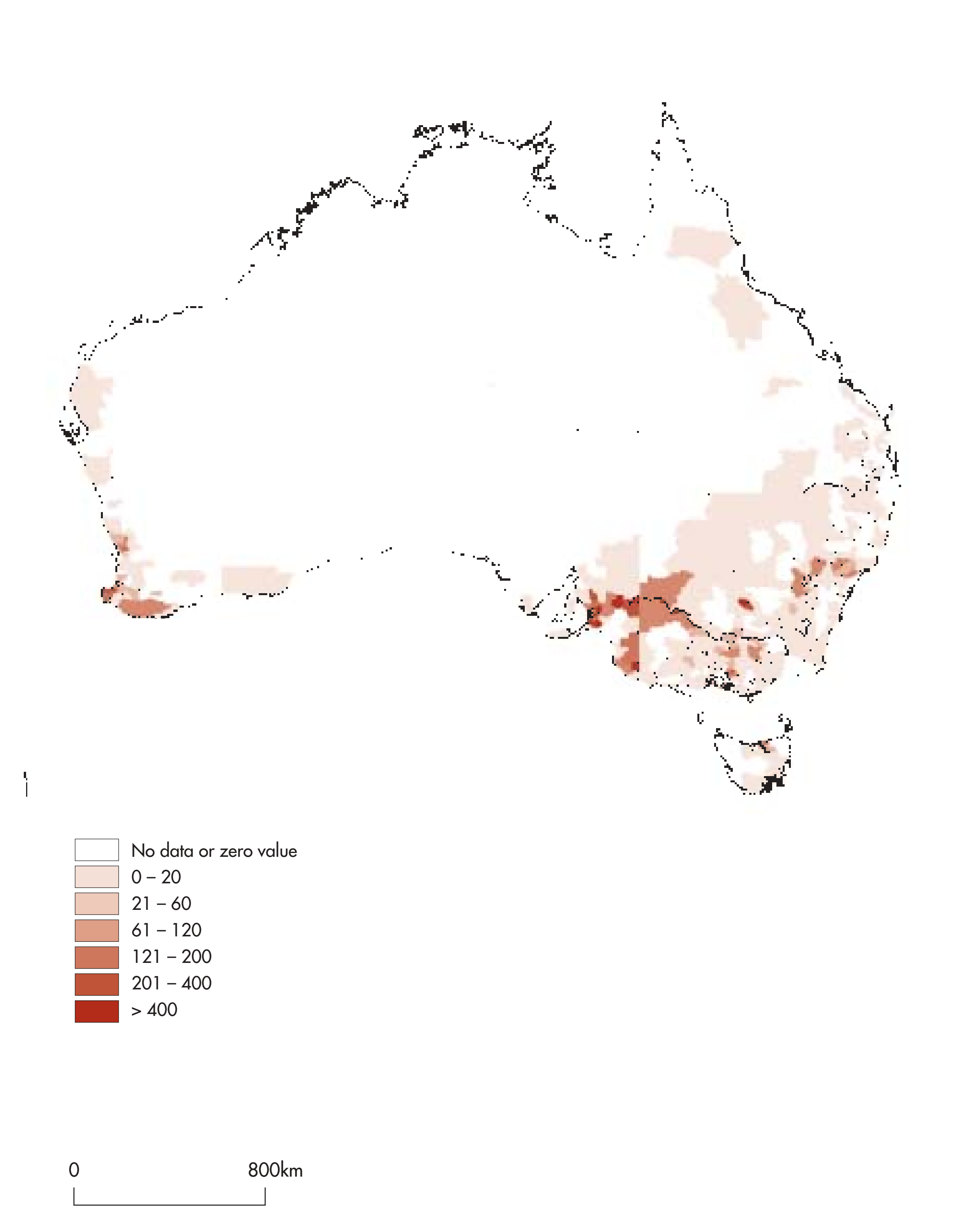
# Legumes for grain ($ value/hectare)



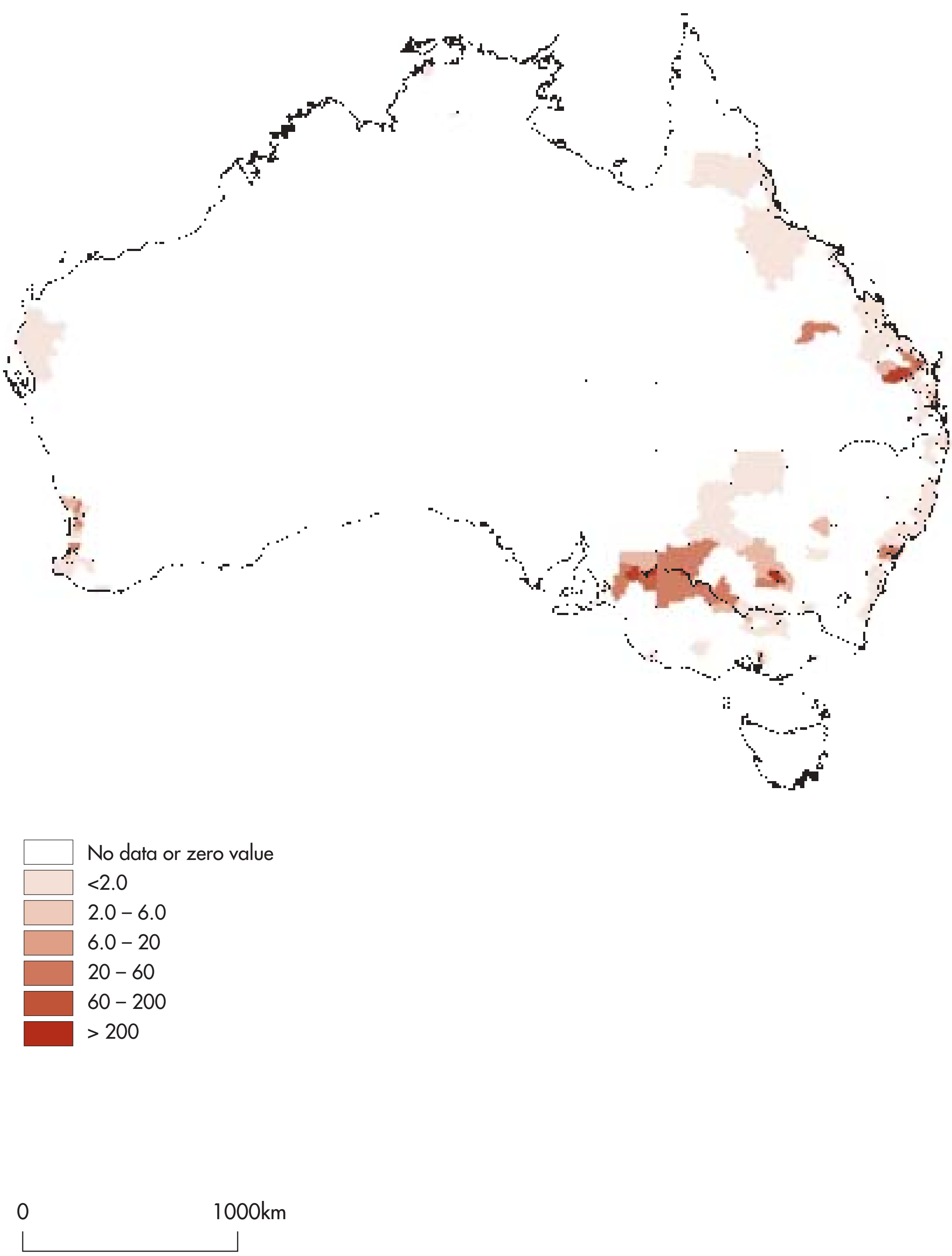
# Sugarcane (hectares grown)



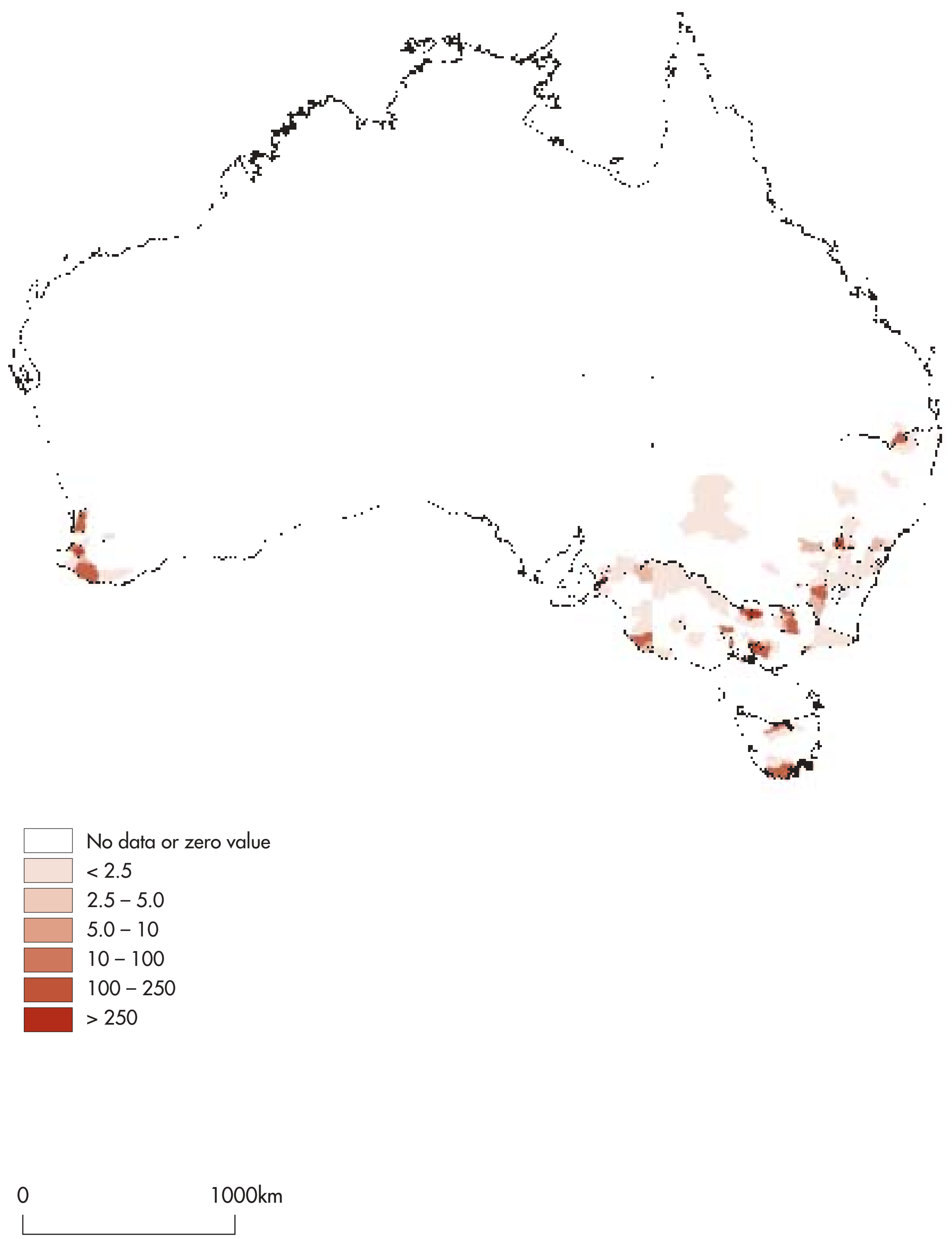
# Grapes for wine ($ value/hectare)



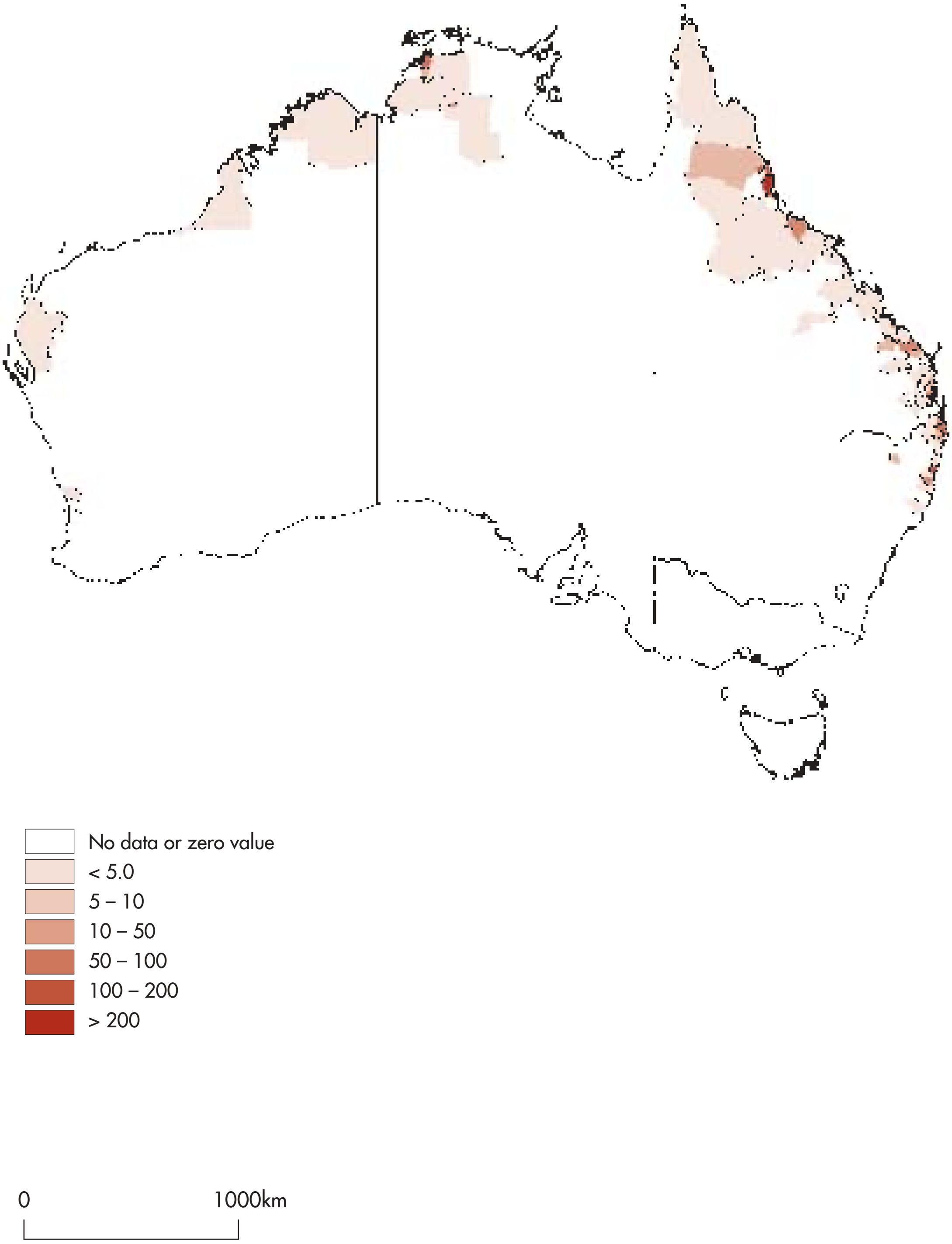
## Citrus ($ value/hectare)



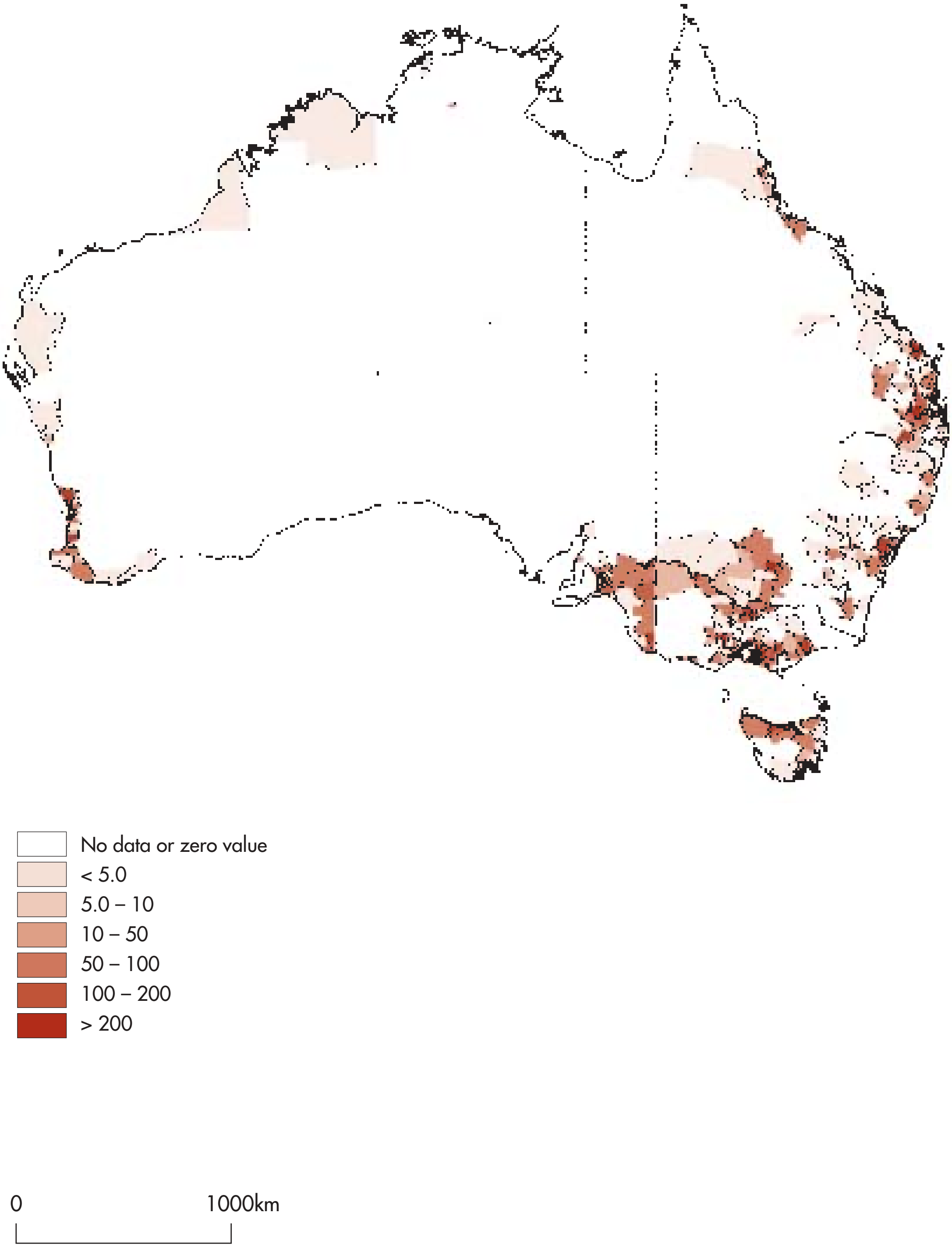
# Pome fruit ($ value/hectare)



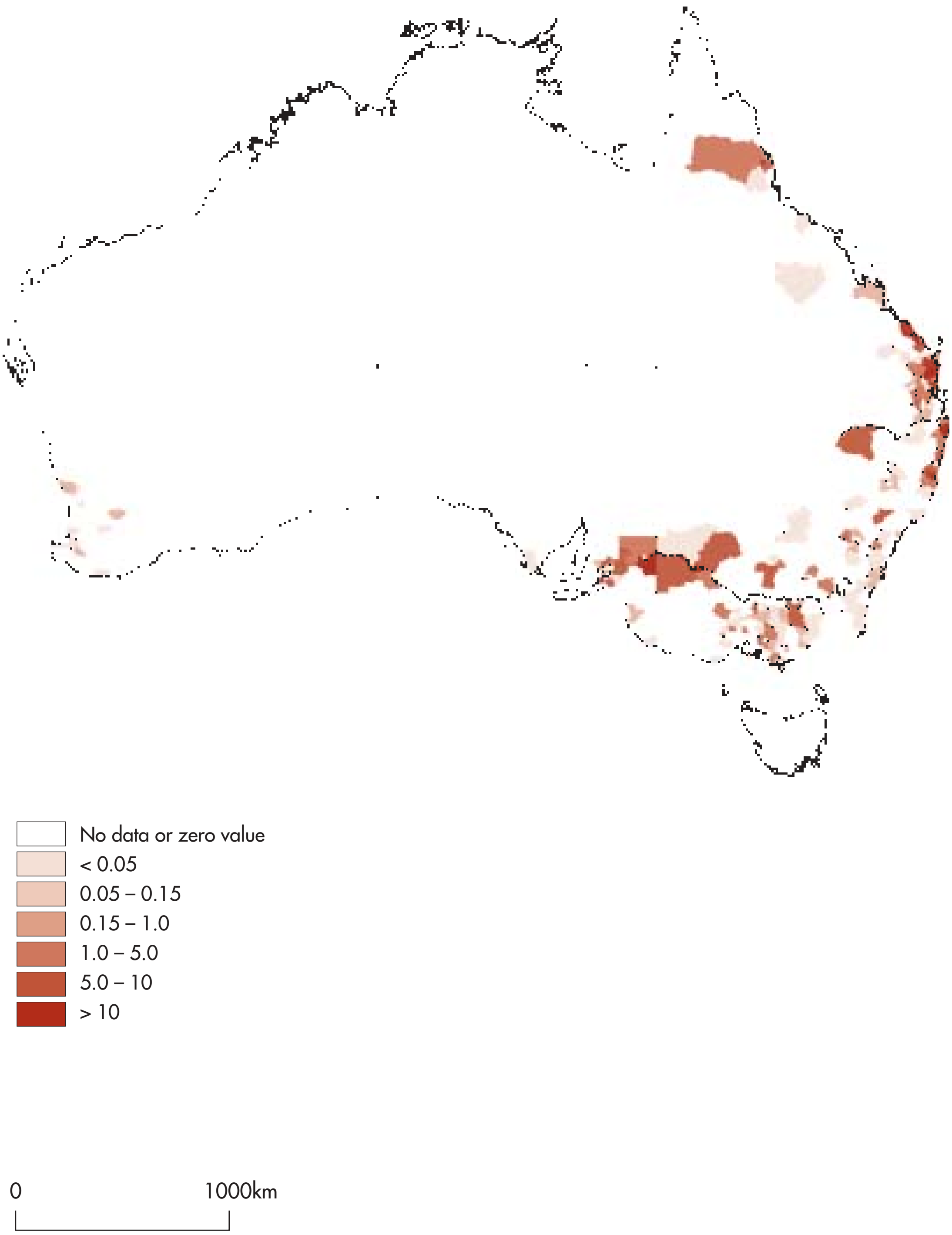
# Mangoes and bananas ($ value/hectare)



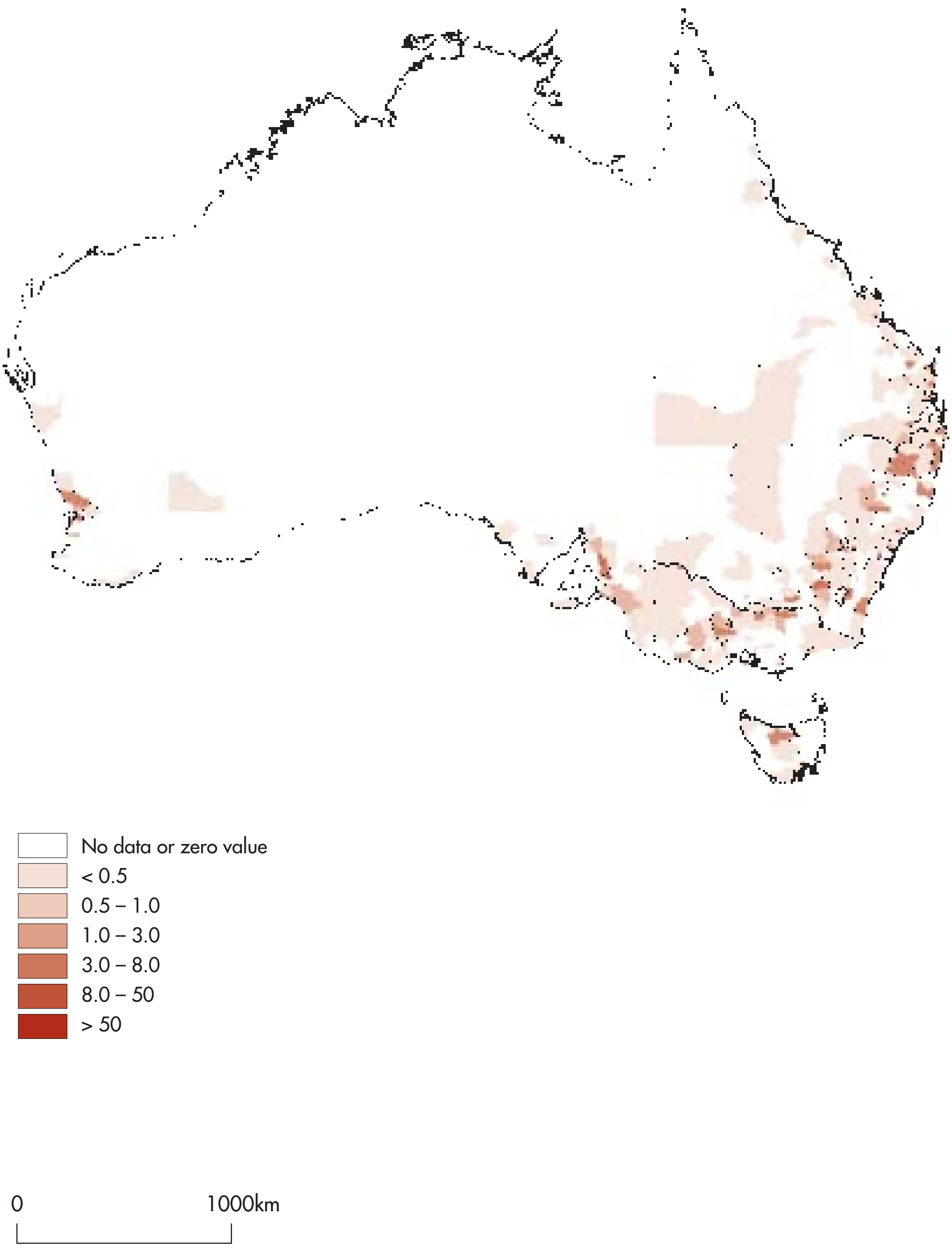
# Vegetables ($ value/hectare)



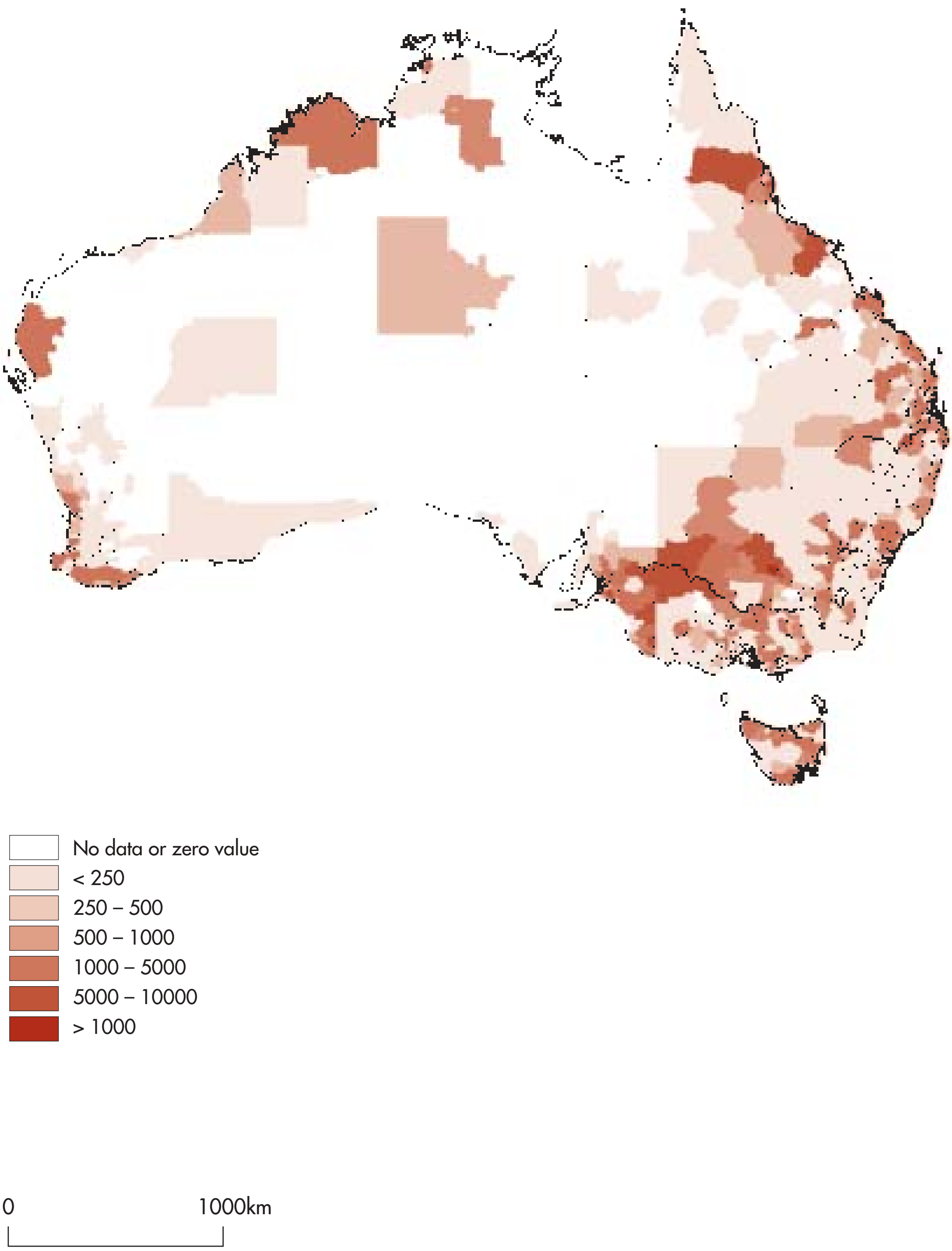
# Nuts ($ value/hectare)



# Honey ($ value/hectare)



# Horticulture (hectares grown)



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