Overview, Critical Assessment, and Conservation Implications of Koala Distribution and Abundance

ALISTAIR MELZER,* FRANK CARRICK,†, PETER MENKHORST,‡ DANIEL LUNNEY,§ AND BARBARA ST. JOHN**

*Koala Research Centre of Central Queensland, Central Queensland University, Rockhampton, QLD 4702, Australia, email a.melzer@cqu.edu.au
†Koala Study Centre, Department of Zoology, University of Queensland, QLD 4072, Australia
‡Flora and Fauna Branch, Department of Natural Resources and the Environment, P.O. Box 41, East Melbourne 3002, Australia
§New South Wales, National Parks and Wildlife Service, P.O. Box 1967, Hurstville, NSW 2220, Australia
**Department of Environment, Heritage and Aboriginal Affairs, P.O. Box 1047, Adelaide, SA 5001, Australia

Abstract: *Regional and national surveys provide a broadscale description of the koala's present distribution in Australia. A detailed understanding of its distribution is precluded, however, by past and continuing land clearing across large parts of the koala's range. Koala population density increased in some regions during the late 1800s and then declined dramatically in the early 1900s. The decline was associated with habitat loss, hunting, disease, fire, and drought. Declines are continuing in Queensland and New South Wales. In contrast, dense koala populations in habitat isolates in Victoria and South Australia are managed to reduce population size and browse damage. Current understanding of koala distribution and abundance suggests that the species does not meet Australian criteria as endangered or vulnerable fauna. Its conservation status needs to be reviewed, however, in light of the extensive land clearing in New South Wales and Queensland since the last (1980s) broadscale surveys. Consequently, we recommend that broadacre clearing be curtailed in New South Wales and Queensland and that regular, comprehensive, standardized, national koala surveys be undertaken. Given the fragmentation of koala habitat and regional differences in the status of the koala, we recommended that studies on regional variation in the koala be intensified and that koala ecology in fragmented and naturally restricted habitats be developed. More generally, the National Koala Conservation Strategy should be implemented.*

Visión General, Evaluación Crítica y Consecuencias para la Conservación de la Distribución y Abundancia del Koala

Resumen: *Los reconocimientos regionales y nacionales proveen una descripción amplia de la distribución actual del koala en Australia. Sin embargo, el reconocimiento detallado de su distribución ha sido impedido por prácticas de clareo actuales y del pasado en grandes extensiones del rango de distribución del koala. La densidad poblacional del koala incrementó en algunas regiones a finales del siglo dieciocho y disminuyó dramáticamente a comienzos del siglo diecinueve. Esta disminución estuvo asociada con la pérdida del hábitat, la caza, enfermedades, incendios y sequías. Esta disminución continúa en Queensland (QLD) y New South Wales (NSW). En contraste, las poblaciones densas de koalas en hábitats aislados en Victoria y Australia del Sur son manejadas para reducir el tamaño poblacional y el daño por ramoneo. El conocimiento actual de la distribución y abundancia del koala sugiere que la especie no reúne los criterios australianos para ser considerada como fauna amenazada o vulnerable. Sin embargo, este estado de conservación necesita ser revisado debido al clareo extensivo de tierras en NSW y QLD desde los últimos reconocimientos a gran escala realizados durante los años ochenta. Por consiguiente, recomendamos que se restrinja el clareo extendido de tierras en NSW y QLD, y que se lleven a cabo reconocimientos de koalas regulares, integrales y estandarizados a nivel nacional. Dada la fragmentación del hábitat del koala y las diferencias regionales en el estado de conservación del koala, recomendamos que se intensifiquen los estudios de la variación regional del koala y que se desarrollen estudios ecológicos del koala en hábitats fragmentados y naturalmente restringidos. En términos generales, se debe implementar la Estrategia Nacional de Conservación del Koala.*

Paper submitted August 23, 1999; revised manuscript accepted December 30, 1999.

Introduction

Koalas are folivorous arboreal marsupials that are naturally restricted to eastern Australian forests and woodlands that contain *Eucalyptus* species. They are protected in all states and territories. Koala conservation status is defined by separate legislation in each state and varies across the animal's range, reflecting regional differences in perceived threats to koalas and their habitat. In Queensland, the koala is listed as "common wildlife" under the Queensland Nature Conservation Act 1992; in New South Wales as "vulnerable" under the Threatened Species Conservation Act 1995; in South Australia as "rare" under the National Parks and Wildlife Act 1972. In Victoria the koala has no separate designation but is "protected wildlife" along with all native vertebrates under the Wildlife Act 1975.

The koala's range has declined since European settlement (e.g., for New South Wales, Phillips 1990; Reed & Lunney 1990; nationally, Martin & Handasyde 1995), and populations continue to decline in many areas (Maxwell et al. 1996; Australian and New Zealand Environment and Conservation Council [ANZECC] 1998). Nevertheless, koalas are widespread and locally abundant and not considered vulnerable or endangered under the commonwealth Endangered Species Protection Act 1992. Koalas are listed as near threatened in the National Action Plan for Monotremes and Marsupials—one category below vulnerable (Maxwell et al. 1996).

Some nongovernmental organizations have disagreed (Total Environment Centre 1983). In 1996 the Australian Koala Foundation (Maxwell et al. 1996) made unsuccessful submissions to the commonwealth government for *vulnerable* status under the Endangered Species Protection Act 1992. Australians For Animals (unpublished document) is seeking to have the koala included on the U.S. Endangered Species list. We examined current population size and distribution because an accurate assessment of conservation status depends on this information.

Koala Distribution and Abundance

Historic

The extent of the koala's range at the time of European contact has not been established accurately. The first recorded sighting was in 1798, and koalas were rarely reported up to about 1830 (Phillips 1990). Gould (1863) found the species difficult to locate and restricted to dense and tall *Eucalyptus* forests. By 1870 they were being sighted in lowland, open eucalypt forests and woodlands (Lee & Martin 1988; Phillips 1990).

By the 1890s the koala was common in much of its range (Phillips 1990). The apparent increase in regional population density may have been due either to expanding European settlement and the increasing visibility of koalas or to relief from Aboriginal hunting pressure. In Queensland at least, the removal of Aboriginal fire regimes in conjunction with European grazing and land-management practices (prior to the introduction of broadacre clearing) may have increased the extent and density of eucalypt forests and woodlands (Burrows 1996). This may have increased available habitat and perhaps facilitated the expansion of koala distribution and numbers.

The density of koalas in the 1890s supported an intensive hunting industry. Between 1890 and the early 1900s, several million skins were exported (Phillips 1990). Hunting, clearing, wildfire, and disease epidemics from the late 1880s through the early 1930s (Finlayson 1934; Parris 1948; Warneke 1978; Lunney & Leary 1988; Gordon et al. 1990*a*; Lunney et al. 1990; Phillips 1990; Gordon 1996) contributed to population crashes. A major reduction in distribution was apparent by the 1930s. In New South Wales, many populations were lost to extensive vegetation clearance before any records were taken, especially in the west and along the east coast (Reed & Lunney 1990) (e.g., the lower Hunter River was logged and cleared from 1801; (Knott et al. 1998). Lewis (1934) considered the koala exterminated in New South Wales, whereas Phillips (1990) estimated that there were "only hundreds" in that state in the late 1930s, "thousands in Victoria," and "ten thousand left in Queensland."

In Victoria, the hunting industry had collapsed by 1910 due to a scarcity of koalas, and by 1934 koala numbers in mainland Victoria were low—possibly <1000 animals (Lewis 1934, 1954; Lee & Martin 1988). Remnant populations possibly remained in the southwest, the Mornington Peninsula, and South Gippsland (Lewis 1934), including Wilsons Promontory (Kershaw 1906, 1934). In South Australia, koalas were extinct by the 1930s (Robinson 1978; Phillips 1990).

Current

Our contemporary understanding of koala populations comes from a series of surveys starting in the 1940s and a national survey undertaken in 1986. Distribution has been assessed by community reports of sightings (Kikkawa & Walter 1968; Campbell et al. 1979; Robinson et al. 1989; Phillips 1990; Reed et al. 1990; Menkhorst 1995; Lunney et al. 1996*a*, 1997; Patterson 1996), expert panels (Maxwell et al. 1996); intensive and systematic searches (Robinson 1978; Robinson et al. 1989; Menkhorst 1995), fecal pellet distribution (Phillips & Callaghan 1995; Munks et al. 1996; Sullivan 1998), combinations of community survey and fecal pellet surveys (Lunney et al. 1998, this issue), and call responses to taped calls and spotlighting (Jurskis & Potter 1997; Smith & Andrews 1997).

Various methods have been used to estimate koala population numbers and density, including inference from community surveys (Phillips 1990; Reed et al. 1990), transect counts (Morgan 1997), mark-resight estimates (Caughley & Sinclair 1994; Hasegawa 1995), and quadrat searches (White & Kunst 1990; Melzer 1995). Survey methods suited the purpose of each investigation and the difficulties in estimating the numbers of this cryptic animal.

Data regarding koala populations have been stored on regional (Queensland) or centralized (New South Wales, Victoria, and South Australia) databases maintained by the wildlife authorities in each state. In Victoria and South Australia, records are sufficient to allow analysis of changing koala distribution.

NATIONAL

Koalas occur in Queensland, New South Wales, the Australian Capital Territory, Victoria, and South Australia. There are no wild koalas in Western Australia, Tasmania, or the Northern Territory. They are most frequently sighted in southeast Queensland and northeast New South Wales (Phillips 1990). The highest densities (8.6–8.9 koalas/ha) are found in habitat fragments in Victoria (e.g., Mitchell 1990) and South Australia (B. S. J., personal observation), although low densities are also present (e.g., 0.7–1.6/ha, in Victoria [Hindell 1984]; <1/ha in South Australia [St. John, unpublished data]). In Queensland and New South Wales, population densities range from low (e.g., 0.01/ha in central Queensland [Melzer & Lamb 1994]; 0.006/ha in Eden, New South Wales [Jurskis & Potter 1997]) and moderate (e.g., 1–3/ha in central and southeast Queensland [Gordon et al. 1990*b*; Hasegawa 1995]) to high (4–8/ha in parts of northeast New South Wales [Gall 1980; Faulks 1990]).

Regional, state, and nationwide estimates of population size are few and inconsistent. The 1992 New South Wales koala population was estimated to be between 1,000 and 10,000 (Lunney et al. 1996*b*, 2000). The Australian Koala Foundation (Sharp 1995) put the national population at 45,000–80,000 koalas (25,000–50,000 in Queensland and 10,000 – 15,000 in both New South Wales and Victoria). This estimate contrasts sharply with estimates of 75,000–130,000 koalas for the Strathbogie Plateau Victoria alone (R. Martin, personal communication). Disagreement regarding the size of the national population has engendered a lack of confidence in figures that do not have a scientific basis.

QUEENSLAND

State-wide surveys were undertaken in the 1960s and 1970s by the Queensland Wildlife Preservation Society and in the 1980s as part of the National Koala Survey (Kikkawa & Walter 1968; Campbell et al. 1979; Patterson 1996). The former relied on the returns from primary schools, the National Parks and Wildlife Service, and the Forestry Department. Data for the National Koala Survey were collected through field surveys conducted close to human settlements by volunteer labor, the collation of incidental reports, and community surveys.

A comparison of the surveys by Kikkawa and Walter (1968), Campbell et al. (1979), and Patterson (1996) shows a range contraction in the north between 1967 and 1985 and in eastern central Queensland from St. Lawrence to Gladstone (Phillips 1990; Maxwell et al. 1996). Patterson (1996) attributed this loss to the broad-scale fragmentation of koala habitat across Queensland. Range reductions may have commenced before 1900 if anecdotal reports from Fraser Island are accepted (Phillips 1990).

Fecal pellet surveys have been used to estimate the distribution and relative density of koalas in the Prairie-Torrens Creek Alluvials Province of the Desert Uplands biogeographic region (Munks et al. 1996), Logan City in southeast Queensland (Pahl 1996), and the Mulgalands of southwest Queensland (Sullivan 1998). Near Mackay, M. Henry (personal communication) is using validated community records to assess the distribution of koalas in the Pioneer Valley. These refine the distribution maps of Patterson (1996) and Phillips (1990) and extend our knowledge of the species' western distribution.

In Queensland koalas are widely distributed and occur at high density in some places. They are found in moist coastal forests (Hasegawa 1995), in southern and central western subhumid woodlands (Gordon et al. 1990*a*; Melzer 1995), and in some of the eucalypt woodlands fringing watercourses in the semiarid west (Munks et al. 1996; Sullivan 1998). Koalas also occur on islands off the Queensland coast. The populations on North Stradbroke and Fraser (prior to 1900) Islands may have been natural, whereas those on Brampton, St. Bees, Newry, Rabbit, and Magnetic islands were introduced (Phillips 1990; Berck 1995).

NEW SOUTH WALES

As part of the National Koala Survey in 1986, New South Wales and the Australian Capital Territory undertook community-response surveys (Phillips 1990; Reed et al. 1990) supplemented by some limited field surveys (e.g., south-eastern forests) to determine distribution (Lunney et al. 1996*a*, 1997). A comparison of these surveys with historical data and surveys from 1949 and 1975 indicated that a range contraction and localized extinctions have occurred, particularly in southern and western parts of the state (Phillips 1990; Reed & Lunney 1990; Reed et al. 1990). The conclusion was that koalas have disappeared from about half their former range in New South Wales.

Koalas are patchily distributed in the northeast, adjacent parts of the Great Dividing Range, the eastern edge of the western plains and associated drainage lines, and

occasionally western New South Wales. They are now largely absent in the southern part of the state (Lunney & Leary 1988; Reed & Lunney 1990; Reed et al. 1990; Maxwell et al. 1996; Ellis et al. 1997; Lunney et al. 1997).

Direct census methods, such as spotlighting surveys (Jurskis & Potter 1997; Smith & Andrews 1997) and systematic searches, and indirect methods, such as the incidence of fecal pellets (Phillips & Callaghan 1995) and responses to taped calls, have provided detailed knowledge of local koala distribution. These data have been used to refine local distribution maps (e.g., Iluka in northern New South Wales [Lunney et al. 1996*a*] and Eden in southern New South Wales [Lunney et al. 1997]). To provide information for land-use planning, independent field and community surveys have been used to rank koala habitat from a geographical information system modeling procedure based on a detailed vegetation map (Lunney et al. 1998, this issue).

AUSTRALIAN CAPITAL TERRITORY AND VICTORIA

A koala population of low density survives in the Australian Capital Territory. It may have derived from koalas introduced from Victoria, escapees from Tidbinbilla Nature Reserve (Phillips 1990; ANZECC 1998), or immigration from New South Wales.

The koala's demise in Victoria was arrested by the translocation of several animals to Westernport Bay islands in the 1920s (Warneke 1978; Menkhorst 1995). These flourished, and the resulting overbrowsing of fodder trees prompted translocations to other islands and to the mainland (Menkhorst et al. 1998).

Systematic fauna surveys, particularly spotlighting of Crown Lands, have generated thousands of koala sightings. This information has been supplemented with sightings from the 1960s and data from the 1985–1987 National Koala Survey.

Current koala distribution approximates the hypothesized range at the time of European settlement (Warneke 1978; Martin 1989), but it is highly fragmented because of extensive clearing for pastoral and agricultural industries and is strongly influenced by past intensive population management. The translocation program has been successful, and populations derived from released animals have spread into the surrounding countryside. Koalas are widespread in coastal and lowland forests and woodlands across southern, central and northeastern areas, principally south of the 500-mm isohyet and below 700 m elevation (Menkhorst 1995), with some in the drier Riverina region along riparian forest corridors (Warneke 1978).

Dense populations have outstripped food resources, causing habitat damage, particularly in patches of coast manna gum (*Eucalyptus viminalis pryoriana*). Translocations have been used to alleviate severe browse damage (Menkhorst et al. 1998).

SOUTH AUSTRALIA

Coincident with the koala's disappearance from South Australia, animals were translocated from French Island in Victoria to Kangaroo Island in the 1920s. Koalas from Queensland, New South Wales, and Victoria were also introduced to the Mt. Lofty Ranges prior to the 1940s and subsequently were used to seed the Riverland koala population (Lindsay 1950; Robinson 1978). Koalas from Kangaroo Island were introduced to southern Eyre Peninsula in 1969 and reintroduced to their former range in the lower southeast (Robinson 1978). Koala distribution has been limited by the availability of suitable habitat, however, principally *Eucalyptus viminalis cygnetensis* and *E. v. viminalis* growing on fertile soils. In lower southeastern South Australia, clearing has reduced habitat. In the remaining areas, habitat was naturally limited by climatic and edaphic factors (Robinson 1978; Phillips 1990). Populations have expanded from the release sites to occupy all suitable habitat, and dispersing animals have been reported large distances from release sites (usually males, Robinson 1978), often in unsuitable habitats (e.g., *Casuarina* spp. and mallee associations) where they probably fail to establish.

The populations were sufficiently small and habitat sufficiently limited to permit intensive and systematic searches during the National Koala Survey. All were extant and breeding. The Mt. Lofty Ranges population had declined following wildlfires in 1983 (Robinson et al. 1989) and is now recovered substantially. These surveys revealed over-browsing in manna gum (*E. v. cygnetensis*) habitat on Kangaroo Island. In 1998 approximately 800 surgically sterilized koalas (vasectomy and tubal transection) were translocated from Kangaroo Island to lower southeastern South Australia. Sterile animals were used in the translocation to prevent a recurrence of population growth and subsequent overbrowsing at release sites.

Genotypic and Phenotypic Variation

Genotypic variation is recognized as important to biodiversity conservation under state and federal legislation and under formal biodiversity strategies. Morphological and genetic variation (probably clinal) occurs in koalas (Thomas 1923; Troughton 1935; Melzer 1995; Sherwin et al., this issue) but is insufficient to support subspecies classifications (Sherwin et al., this issue). Genetic variation in Victoria and South Australia koalas is low, reflecting the few individuals used to found the populations used in those states' translocation programs (Houlden et al. 1996). Regional variation is greatest in Queensland and New South Wales but is poorly understood. The conservation significance of losing regional variants during land clearing has not been studied but is discussed by Sherwin et al. in this issue.

Assessment of Distribution and Abundance

There are no nationally recognized standards for the assessment of koala numbers or distribution, and the techniques used suit the needs of individual projects. There are advantages and disadvantages associated with each method. For example, community-response survey results may be influenced by the distribution of roads and population centers (Ingram & Raven 1991). But when they are verified (e.g., through field survey and modeling with vegetation maps) and when broad conclusions are required [Lunney et al. 1997, 1998, this volume]), community-response surveys are effective and economical. Intensive, systematic searches yield detailed information about the distribution and density of local populations but have limited broadscale application. In South Australia and Victoria, habitat is limited, so intensive surveying is a viable method. Mark-resight estimates (Caughley & Sinclair 1994) have been used at replicated sites in a stratified sampling design to estimate koala numbers in the Cygnet River valley on Kangaroo Island, South Australia (B. St. J., personal observation). Broadscale application of the technique is precluded by time and logistical constraints. Census and density measures can be applied most usefully where an index of change over time is sought, as in detecting a decline in koala densities following large-scale fertility suppression in habitat isolates in Victoria or South Australia.

All regional and broadscale estimates of koala population size (e.g., Sharp 1995; R. W. Martin, personal communication) are derived by extrapolation from localized habitat densities. They rely on the assumption that there are similar habitat types elsewhere that can be identified and mapped and that contain the same density of koalas. Therefore, estimates tend to vary widely.

In Queensland, koala distribution, population size, and density are not well understood. Although Phillips (1990) and Patterson (1996) have described the extent of koala distribution, centralized and coordinated data collection would facilitate a better understanding of distribution, numbers, and changes over time. In New South Wales, the general extent of koala distribution is well understood. Variations in distribution and density occur within the koala's range, however. Intensive surveys (e.g., Lunney et al. 1997; Phillips & Callaghan 1995; Smith & Andrews 1997) are beginning to provide more quantitative data. Koala distribution appears to be best understood in Victoria and South Australia due to intensive management of koala populations and extensive monitoring and recording of incidental koala sightings.

Limits to Current Distribution and Abundance

The most significant threat to koala distribution and abundance is habitat loss, although drought, wildfire, disease, predation, and collisions with vehicles are also threats. These threats vary in intensity throughout the range of the koala and between years, so specific conclusions are difficult without further study.

Habitat Loss

Habitat destruction is the most significant threat to koalas (Reed & Lunney 1990; Maxwell et al. 1996; ANZECC 1998). There has been extensive clearing from the time of European settlement to the present (Wells et al. 1984; Sivertsen 1995), with *Eucalyptus* forest types suffering a 33–92% loss, depending on forest type (Graetz et al. 1995). Similarly, some *Acacia* landcover types (brigalow and mulga) known to support low-density koala populations (Melzer & Lamb 1994; Munks et al. 1996; Sullivan 1998) have suffered an 80–86% loss (Graetz et al. 1995).

Estimates of broadscale clearing of *Eucalyptus* landcover types may overestimate habitat loss because they include eucalypt communities beyond the natural range of the koala. Furthermore, koalas utilize the scattered trees left after clearing, at least until dieback or other influences claim the eucalypts within the vegetation remnant (Pahl et al. 1990). Nonetheless, estimates of clearing indicate direct loss of habitat and, by implication, koala populations (Pahl et al. 1990).

Glanznig (1995) reported that as much vegetation was cleared nationally from 1945 to 1995 as in the previous 150 years. In New South Wales, 25.7 million ha of forest or woodland, or 32% of the state, were ringbarked and partially cleared between 1893 and 1921 (Reed 1991). Clearing is continuing, with most occurring in Queensland and New South Wales. From 1983 to 1993 the estimated annual average clearing rate of native vegetation was 300,000 ha/year in Queensland and 150,000 ha/year in New South Wales (Glanznig 1995). Recent Queensland estimates place the current clearing rate in Queensland at approximately 262,000 ha/year (Queensland Department of Natural Resources 1997), most of which contains koala habitat. This ongoing habitat loss calls into question the distribution results of the 1986 National Koala Survey. Koala distribution has declined since the completion of the survey.

Clearing rates over the same period were approximately 7780 ha/year in Victoria and 9300 ha/year in South Australia. Most clearing has occurred in native grasslands and mallee associations. Only 14% (1385 ha) of vegetation cleared in South Australia since 1983 could be considered koala habitat. The current rate of destruction of native forest is low (Glanznig 1995), and less than 1220 ha of native vegetation has been cleared in South Australia since 1993. Thus, the loss of potential koala habitat in Victoria and South Australia is small, and the emphasis is now on restoration and rehabilitation of remnants, including management of overbrowsing by koalas.

Drought

Drought is normal, and from 1864 to 1995 there have been 10 major and 7 minor droughts (Bureau of Meteorology 1989, unpublished data). Droughts would be expected to affect koalas most severely in subhumid, semiarid, and highly seasonal environments (Phillips 1990). Defoliation of fodder trees under severe drought conditions may result in high mortality, although animals survive where fodder trees have access to adequate soil moisture (Gordon et al. 1988). In less extreme conditions, koala habitat and fodder selection may change in response to changes in leaf moisture content (Hindell 1984; Melzer 1995) in order to maintain physiological moisture balance (Ellis et al. 1995). Foliar nitrogen may limit koala distribution and abundance (Degabriele 1981). A reduction in foliar nitrogen and a consequent increase in polyphenolic antiherbivory compounds may result from subjecting eucalypts to drought, reducing fodder quality (Cork & Sanson 1990; Landsberg 1990). There has been no research on the distribution or status of koalas during drought.

Fire

Bushfires are also normal, often a consequence of drought (Bureau of Meteorology 1989; Phillips 1990), and they vary in frequency, extent, and intensity (Gill et al. 1981). Intense crown fires occur most frequently in the forests of southeastern Australia, where fuel loads are usually greater than in dry eucalypt forests and woodlands (Ashton 1981; Christensen et al. 1981). Fire frequencies in koala habitat vary from 1 to 5 years in Queensland, 3 to 15 years in coastal New South Wales and Victoria, and 5 to 20 years in South Australia, inland Victoria, and New South Wales (Cheney 1981), with serious bushfires occurring about every 13 years in southeastern Australia (Christensen et al. 1981). Crown fires pose direct and indirect threats to arboreal animals (Phillips 1990; Wilson 1994; Jurskis & Potter 1997). Direct effects include incineration and injury during the fire and burns from climbing smouldering trees. Indirect effects occur through loss of food in the post-fire period and through exposure to dog predation when animals are on the ground.

In 1983, wildfire in the Mt. Lofty Ranges (South Australia) resulted in local declines in koala populations, with no signs of recovery for about 5 years (Robinson et al. 1989; Phillips 1990). A 3000-ha wildfire in the Port Stephens area of New South Wales resulted in 46 deaths and 34 injuries from a known population of 134 koalas (D.L., unpublished data).

Low- or moderate-intensity fires can result in significant canopy scorch (Cheney 1981), removing fodder from those koalas not killed by fire. There is little information on how koalas survive such events and, widespread canopy scorching presumably results in starvation. Wildfires cause significant local reductions in koala populations, although these effects may be of short duration provided that some animals survive or are able to colonize from adjacent habitat (Tilley & Uebel 1990). Where that is not the case, fires and subsequent habitat loss or modification may have long-term effects on koala distribution and abundance (D.L., unpublished data; Phillips 1990).

Disease

Koalas are subject to a range of diseases (Jakob Hoff 1993), the most significant of which are those associated with *Chlamydia* spp. (ANZECC 1998). *Chlamydia* (recent DNA analyses implicate at least two species, *C. pecorum* and *C. pneumoniae*; Glassick et al. 1995) is associated with a range of symptoms, including eye infections and respiratory and urinary tract infections, and is capable of causing sterility in females. Chlamydiosis has been implicated in lowered reproductive rates in wild populations in Queensland and Victoria, although this did not appear to threaten the survival of the populations (Gordon et al. 1990*b*; Martin & Handasyde 1990). Chlamydial infection appears widespread in koala populations, and although infection rates may be high (McColl et al. 1984; Lee et al. 1988; Wiegler et al. 1988; Phillips 1990), symptoms of overt disease are commonly low (Wiegler et al. 1988; Phillips 1990; Ellis et al. 1993). There is circumstantial evidence (New South Wales and Queensland) that environmental stress such as urban and agricultural development (Brown et al. 1984; Ellis et al. 1993), nutritional stresses (Hume 1990), and overcrowding (Canfield 1990; Gordon et al. 1990*a*) may trigger overt chlamydiosis.

Predation

There is no information available on the significance of predation for koala populations. Research is needed as habitat is fragmented. Predators include domestic dogs (*Canis familiaris*), dingoes (*Canis lupus dingo*), Powerful Owls (*Ninox strenua*), Wedge-tailed Eagles (*Aquila audax*) and other raptors, and lace monitors (*Varanus varius*) (Lee & Martin 1988; Lunney et al. 1990; Phillips 1990; Jurskis & Potter 1997; A. M., personal observation). Dogs may be particularly important in urban areas (Lunney et al. 2000, unpublished data). Back-young, newly weaned, and/or injured koalas are probably most vulnerable to predation (Lee & Martin 1988).

Trends in Koala Distribution and Abundance

Koalas have suffered a >50% reduction in distribution and numbers since European settlement (Maxwell et al. 1996), with a 50–75% range reduction in New South

Wales alone (Reed et al. 1990; ANZECC 1998). Population decline has followed habitat loss, hunting, fire, drought, and disease. This decline will continue unless current clearing regimes change, especially in New South Wales and Queensland. In these states some genotypic variants of the koala may be lost before they are recognized or their conservation significance assessed (Sherwin et al., this issue). Survival of remnant koala populations will depend on the retention of drought refuges where fodder trees have access to adequate soil moisture. A comprehensive survey of koala and koala habitat distribution is needed to assess trends in New South Wales and Queensland and to provide a review of the conservation status of the koala in those states. In New South Wales, the planning provisions of state environmental planning policy no. 44, "koala habitat protection," provide a means of doing this on a shire-by-shire basis (Lunney et al. 1997, this issue). A koala recovery team has been set up under the New South Wales Threatened Species Conservation Act 1995.

Until population reduction through fertility suppression, combined with limited translocation, are widely imposed in South Australia, increased koala densities are expected on Kangaroo Island and in the Mt. Lofty Ranges. Elsewhere, koala numbers will probably be constrained by severely limited habitat (Riverland and Eyre Peninsula) or by managed infertility (lower southeastern South Australia). In Victoria, fertility suppression is being tested. Until the method is successfully implemented, translocations from overbrowsed habitat isolates are likely to continue and koala populations are likely to increase.

Despite New South Wales and Queensland population declines, the koala is still considered sufficiently abundant and widespread that it does not meet national criteria for listing as endangered or vulnerable (ANZECC 1998).

Recommendations

Our review agrees generally with the findings of the National Koala Conservation Strategy (ANZECC 1998), and we recommend that the strategy be implemented (three of the authors—P.M., D.L. and B. St. J.,—are members of the koala network that developed the strategy). The strategy's position on land clearing is inadequate, however, and we recommend that broadacre clearing in New South Wales and Queensland be curtailed. The New South Wales Native Vegetation Conservation Act 1998 should contribute to this aim. Further, the strategy does not address the detailed scientific issues discussed in this paper and thus does not sufficiently emphasise the importance of continuing research or examine the variation in conservation status or knowledge of koalas across their range. Consequently, we recommend that the following steps be taken:

(1) A review of the conservation status of the koala in Queensland, New South Wales, and nationally because of extensive broadacre clearing;
(2) a regular, comprehensive, national survey of koala and koala habitat distribution in key locations that accounts for biases in earlier surveys, uses standard methods, and updates state databases;
(3) intensified research into regional variation in the koala;
(4) consideration of habitat requirements of local koalas in land development proposals;
(5) investigation of the ecology of riparian and fragmented koala habitats by means of radiotracking and including studies of fire, drought, predation, and managed stream flows; and
(6) identification and protection of habitat used by koala during drought.

Acknowledgments

We acknowledge support from the Foundation for National Parks and Wildlife and the Central Queensland Koala Volunteers and assistance from the Earthwatch Institute, the National Parks Foundation of South Australia, the University of Adelaide, the Geographic Information Systems Division within New South Wales National Parks and Wildlife Service (koala sight data released July 1997), Wildlife Research and Monitoring within Environment Australian Capital Territory, Queensland Parks and Wildlife within the Environmental Protection Agency, and Central Queensland University's Electronic Media Unit. We thank members of the Victorian Koala Working Group and R. Melzer for helpful discussions.

Literature Cited

Ashton, D. H. 1981. Fire in tall open forests (wet sclerophyll forests). Pages 339–368 in A. M. Gill, R. H. Groves, and I. R. Noble, editors. Fire and the Australian biota. Australian Academy of Science, Canberra, Australian Capital Territory.

Australian and New Zealand Environment and Conservation Council (ANZECC). 1998. National koala conservation strategy. Environment Australia, Canberra, Australian Capital Territory.

Berck, L. 1995. St. Bees Island: its history, life-style and tales. Boolarong Press, Mackay, Queensland.

Brown, A. S., F. N. Carrick, G. Gordon, and K. Reynolds. 1984. The diagnosis and epidemiology of an infertility disease in the female koala *Phascolarctos cinereus* (Marsupialia). Veterinary Radiology **25:** 242–248.

Bureau of Meteorology. 1989. Drought in Australia. Bureau of Meteorology, Department of Administrative Affairs, Canberra, Australian Capital Territory.

Burrows, W. H. 1996. Queensland's grazed woodlands: an enormous anthropogenic carbon sink demanding recognition. Tropical Beef Centre, Queensland Department of Primary Industries, Rockhampton.

Campbell, P., R. Prentice, and P. McRae. 1979. Report on the 1977 koala survey. Wildlife in Australia **16(1):**2–6.

Canfield, P. J. 1990. Diseases affecting captive and free-living koalas

and their implications for management. Pages 36–38 in D. Lunney, C. Urquhart, and P. Reed, editors. Koala summit: managing koalas in New South Wales. New South Wales National Parks and Wildlife, Sydney.

Caughley, G., and A. R. E. Sinclair. 1994. Wildlife ecology and management. Blackwell Science, Cambridge, Massachusetts.

Cheney, N. P. 1981. Fire behaviour. Pages 151–175 in A.M. Gill, R.H. Groves, and I.R. Noble, editors. Fire and the Australian biota. Australian Academy of Science, Canberra, Australian Capital Territory.

Christensen, P., H. Recher, and J. Hoare. 1981. Responses of open forest to fire regimes. Pages 367–393 in A.M. Gill, R.H. Groves, and I. R. Noble, editors. Fire and the Australian biota. Australian Academy of Science, Canberra, Australian Capital Territory.

Cork, S. J., and G. D. Sanson. 1990. Digestion and nutrition in the koala: a review. Pages 129–144 in A. K. Lee, K. A. Handasyde, and G. D. Sanson, editors. Biology of the koala. Surrey Beatty and Sons, Chipping Norton, New South Wales.

Degabriele, R. 1981. A relative shortage of nitrogenous food in the ecology of the koala (*Phascolarctos cinereus*). Australian Journal of Ecology **6:**139–141.

Ellis, M., N. Shepperd, and K. Gall. 1997. Far western New South Wales occurrence of a koala *Phascolarctos cinereus.* Australian Zoologist **30(3):**327–328.

Ellis, W. A. H., A. A. Girjes, F. N. Carrick, and A. Melzer. 1993. Chlamydial infection in koalas under relatively little alienation pressure. Australian Veterinary Journal **70:**427–428.

Ellis, W. A. H., A. Melzer, B. Green, K. Newgrain, M. A. Hindell, and F.N. Carrick. 1995. Seasonal variation in water flux, field metabolic rate and food consumption of free-ranging koalas (*Phascolarctos cinereus*). Australian Journal of Zoology **43:**59–68.

Finlayson, H.H. 1934. On mammals from the Dawson and Fitzroy Valleys: central coast Queensland. Part II. Transactions of the Royal Society of South Australia **55:**218–231.

Gill, A. M., R. H. Groves, and I. R. Noble, editors. 1981. Fire and the Australian biota. Australian Academy of Science, Canberra, Australian Capital Territory.

Glanznig, A. 1995. Native vegetation clearance, habitat loss and biodiversity decline: an overview of recent native vegetation clearance in Australia and its implications for biodiversity. Biodiversity series, paper 6. Biodiversity Unit, Environment Australia, Canberra, Australian Capital Territory.

Glassick, T., P. Giffard, and P. Timms. 1995. Chlamydial infections in koalas: gene sequencing indicates that two separate chlamydial species are involved, *Chlamydia pecorum* and *Chlamydia pneumoniae.* Pages 154–162 in Proceedings on a conference on the status of the koala in 1995. Australian Koala Foundation, Brisbane, Queensland.

Gordon, G., editor. 1996. Koalas: research for management. Proceedings of the Brisbane Koala Symposium 1990. World Koala Research, Brisbane, Queensland.

Gordon, G., A. S. Brown, and P. Pulsford. 1988. A koala population crash during drought and heatwave conditions in south-western Queensland. Australian Journal of Ecology **13:**451–461.

Gordon, G., D. G. McGreevy, and B. C. Lawrie. 1990*a.* Koala populations in Queensland: major limiting factors. Pages 85–95 in A. K. Lee, K. A. Handasyde, and G. D. Sanson, editors. Biology of the koala. Surrey Beatty and Sons, Chipping Norton, New South Wales.

Gordon, G., D. G. McGreevy, and B. C. Lawrie. 1990*b.* Koala population turnover and male social organisation. Pages 189–192 in A. K. Lee, K. A. Handasyde, and G. D. Sanson, editors. Biology of the koala. Surrey Beatty and Sons, Chipping Norton, New South Wales.

Gould, J. 1863. The mammals of Australia. Taylor and Francis, London.

Graetz, R. D., M. A. Wilson, and S. K. Campbell. 1995. Landcover disturbance over the Australian continent: a contemporary assessment. Biodiversity series, paper 7. Biodiversity Unit, Environment Australia, Canberra, Australian Capital Territory.

Hasegawa, M. 1995. Habitat utilisation by koalas (*Phascolarctos cinereus*) at Point Halloran, Queensland. M.S. thesis. University of Queensland, St. Lucia, Brisbane.

Hindell, M. A. 1984. The feeding ecology of the koala, *Phascolarctos cinereus*, in a mixed *Eucalyptus* forest. M. S. thesis. Department of Zoology, Monash University, Melbourne, Victoria.

Houlden, B. A., P. R. England, A. C. Taylor, and W. D. Greville. 1996. Low genetic variabiliy of the koala, *Phascolarctos cinereus*, in southeastern Australia following a severe population bottleneck. Molecular Ecology **5:**269–281.

Hume, I. D. 1990. Biological basis for the vulnerability of koalas to habitat fragmentation. Pages 32–35 in D. Lunney, C. Urqhart, and P. Reed, editors. Koala summit: managing koalas in New South Wales. New South Wales National Parks and Wildlife Service, Hurstville, Sydney.

Ingram, G. J., and R. J. Raven. 1991. Introduction, Pages 5–14 in G. L. Ingram and R. J. Raven, editors. An atlas of Queensland's frogs, reptiles, birds and mammals. Board of Trustees, Queensland Museum, Brisbane.

Jakob Hoff, R. M. 1993. Diseases of free-living marsupials. Pages 276–280 in M. E. Fowler, editor. Zoo and wild animal medicine: current therapy. Saunders, Philadelphia.

Jurskis, V., and M. Potter. 1997. Koala surveys, ecology and conservation at Eden. Forest Research and Development Division, State Forests of New South Wales, Sydney.

Kershaw, J. A. 1906. Excursion to Wilson's Promontory: general zoology (except mollusca). Victorian Naturalist **22:**197–207.

Kikkawa, J. A., and M. Walter. 1968. Report on the koala survey. Wildlife in Australia **6:**100–103.

Knott, T., D. Lunney, J. Callaghan, and D. Coburn. 1998. An ecological history of koala habitat in Port Stephens Shire and lower Hunter on the central coast of New South Wales, 1801–1998. Pacific Conservation Biology **4:**354–368.

Landsberg, J. 1990. Dieback of rural eucalypts: the effects of stress on the nutritional quality of foliage. Australian Journal of Ecology **15(1):**97–108.

Lee, A., and R. Martin. 1988. The koala: a natural history. New South Wales University Press, Sydney.

Lee, A. K., R. W. Martin, and K. A. Handasyde. 1988. Research into Chlamydiosis in natural populations of the koala in Victoria, phases 1–3. Report. Australian National Parks and Wildlife Service, Melbourne, Victoria.

Lewis, F. 1934. The koala on Wilsons Promontory. Victorian Naturalist **51:**76–77.

Lewis, F. 1954. The rehabilitation of the koala in Victoria. Victorian Naturalist **70:**197–200.

Lindsay, H. A. 1950. Re-establishing the koala in South Australia. WildLife **12(6):**257–262.

Lunney, D., and T. Leary. 1988. The impact on native mammals of land-use changes and exotic species in the Bega District (New South Wales) since settlement. Australian Journal of Ecology **13:**67–92.

Lunney, D., C. A. Urquhart, and P. Reed, editors. 1990. Koala summit: managing koalas in New South Wales. New South Wales National Parks and Wildlife Service, Hurstville.

Lunney, D., A. Curtin, D. Ayers, H. G. Cogger, and C. R. Dickman. 1996*b*. An ecological approach to identifying the endangered fauna of New South Wales. Pacific Conservation Biology **2:**212–231.

Lunney, D., C. Moon, and A. Matthews. 1996*a.* A 1990 community based survey of the koala *Phascolarctos cinereus* population at Iluka in northern New South Wales. Pages 102–122 in G. Gordon, editor. Koalas: research for management. Proceedings of the Brisbane Koala Symposium, 1990. World Koala Research, Brisbane, Queensland.

Lunney, D., C. Esson, C. Moon, M. Ellis, and A. Matthews. 1997. A community-based survey of the koala, *Phascolarctos cinereus*, in the Eden Region of south-eastern New South Wales. Wildlife Research **24:**111–128.

Lunney, D., S. Phillips, J. Callaghan, and D. Coburn. 1998. Determining

the distribution of koala habitat across a shire as a basis for conservation: a case study from Port Stephens, New South Wales. Pacific Conservation Biology **4:**186–196.

Lunney, D., A. Curtin, D. Ayers, H. G. Cogger, C. R. Dickman, W. Maltz, and D. Fisher. 2000. The threatened and non-threatened vertebrate fauna of New South Wales. Environment and heritage monograph. New South Wales National Parks and Wildlife Service, Hurstville.

Martin, R. W. 1989. Draft management plan for the conservation of the koala (*Phascolarctos cinereus*) in Victoria. Arthur Rylah Institute for Environmental Research technical report series 99. Department of Conservation, Forests and Lands, Melbourne, Victoria.

Martin, R., and K. A. Handasyde. 1990. Population dynamics of the koala (*Phascolarctos cinereus*) in south-eastern Australia. Pages 75–84 in A. K. Lee, K. A. Handasyde, and G. D. Sanson, editors. Biology of the koala. Surrey Beatty and Sons, Chipping Norton, New South Wales.

Martin, R. W., and K. A. Handasyde. 1995. Family Phascolarctidae: koala. Pages 195–198 in R. Strahan, editor. The mammals of Australia. Reed Books, Chatswood, New South Wales.

Maxwell, S., A. A. Burbidge, and K. Morris. 1996. The 1996 action plan for Australian marsupials and monotremes. Project 500. for the IUCN/SSC Australasian Marsupial and Monotreme Specialist Group of the World Conservation Union/Species Survival Commission. Endangered Species Program, Environment Australia, Canberra, Australian Capital Territory.

McColl, K. A., R. W. Martin, L. J. Gleeson, K. A. Handasyde, and A. K. Lee. 1984. Chlamydia infection and infertility in the female koala (*Phascolarctos cinereus*). Veterinary Record **115:**655.

Melzer, A. 1995. Aspects of the ecology of the koala, *Phascolarctos cinereus* (Goldfuss, 1817), in the sub-humid woodlands of central Queensland. Ph.D. thesis. University of Queensland, St. Lucia, Brisbane.

Melzer, A., and D. Lamb. 1994. Low density populations of the koala (*Phascolarctos cinereus*) in central Queensland. Proceedings of the Royal Society of Queensland **104:**89–93.

Menkhorst, P. W., editor. 1995. Mammals of Victoria: distribution, ecology and conservation. Oxford University Press, Melbourne, Victoria.

Menkhorst, P., D. Middleton, and B. Walters. 1998. Managing overabundant koalas (*Phascolarctos cinereus*) in Victoria: a brief history and some potential new directions. Pages 19-29 in P. Cowan, editor. Managing marsupial abundance for conservation benefits. Cooperative Research Centre for Conservation and Management of Marsupials, Macquarie University, Sydney.

Mitchell, P. 1990. The home ranges and social activity of koalas: a quantitative analysis. Pages 171–187 in A. K. Lee, K. A. Handasyde, and G. D. Sanson, editors. Biology of the koala. Surrey Beatty and Sons, Chipping Norton, New South Wales.

Morgan, D. G. 1997. Tower Hill Game Reserve: koala population. Department of Natural Resources and Environment, Melbourne, Victoria.

Munks, S. A., R. Corkrey, and W. J. Foley. 1996. Characteristics of arboreal marsupial habitat in the semi-arid woodlands of northern Queensland. Wildlife Research **23:**185–195.

Pahl, L. 1996. Koala and bushland survey of west and central Logan City. Pages 82–92 in G. Gordon, editor. Koalas: research for management. Proceedings of the Brisbane koala symposium, 1990. World Koala Research, Brisbane, Queensland.

Pahl, L., F. R. Wylie, and R. Fisher 1990. Koala population decline associated with loss of habitat and suggested remedial strategies. Pages 39–47 in D. Lunney, C. Urqhart, and P. Reed, editors. Koala summit: managing koalas in New South Wales. New South Wales National Parks and Wildlife Service, Sydney.

Parris, H. S. 1948. Koalas on the lower Goulburn. Victorian Naturalist **64:**192–193.

Patterson, R. 1996. The distribution of koalas in Queensland, 1986–1989. Pages 75–81 in G. Gordon, editor. Koalas: research for management. Proceedings of the Brisbane koala symposium, 1990. World Koala Research, Brisbane, Queensland.

Phillips, B. 1990. Koalas: the little Australians we'd all hate to lose. Australian National Parks and Wildlife Service, Australian Government Publishing Service, Canberra, Australian Capital Territory.

Phillips, S., and J. Callaghan. 1995. Koala management study for Goonellabah and East Lismore. Draft report for public discussion prepared for Lismore City Council. The Australian Koala Foundation, Brisbane, Queensland.

Queensland Department of Natural Resources. 1997. Interim report. The statewide land cover and trees study (SLATS). Brisbane, Queensland.

Reed, P. C. 1991. An historical analysis of the changes to the forests and woodlands of New South Wales. Pages 393–406 in D. Lunney, editor. Conservation of Australia's forest fauna. Royal Zoological Society of New South Wales, Mosman.

Reed, P., and D. Lunney. 1990. Habitat loss: the key problem for the long-term survival of koalas in New South Wales. Pages 9–31 in D. Lunney, C.A. Urquhart, and P. Reed, editors. Koala summit: managing koalas in New South Wales. New South Wales National Parks and Wildlife Service, Hurstville.

Reed, P. C., D. Lunney, and P. Walker. 1990. A 1986–1987 survey of the koala *Phascolarctos cinereus* (Goldfuss) in New South Wales and an ecological interpretation of its distribution. Pages 55–74 in A. K. Lee, K. A. Handasyde, and G. D. Sanson, editors. Biology of the koala. Surrey Beatty and Sons, Chipping Norton, New South Wales.

Robinson, A. C.1978. The koala in South Australia. Pages 132–143 in T. J. Bergin, editor. The koala: proceedings of the Taronga symposium. The Zoological Parks Board of New South Wales, Sydney.

Robinson, A. C., R. Spark, and C. Halstead. 1989. The distribution and management of the koala in South Australia. South Australian Naturalist **64(1):**4–24.

Sharp, A. 1995. The koala book. David Bateman Ltd, Auckland, New Zealand.

Sivertsen, D. P. 1995. Habitat loss: its nature and effects (including case studies from New South Wales). Pages 29–42 in R. Bradstock, T. Auld, D. Keith, R. Kingsford, D. Lunney, and D. Sivertsen, editors. Conserving biodiversity: threats and solutions. Surrey Beatty and Sons, Chipping Norton, and National Parks and Wildlife Service, Hurstville, New South Wales.

Smith, A. P., and S. Andrews. 1997. Koala habitat, abundance and distribution in the Pine Creek study area. Report. State Forests of New South Wales, Coffs Harbour.

Sullivan, B. J. 1998. Low density population estimation using faecal pellet counts: koalas in the rangelands of south west Queensland. Ph.D. thesis. School of Natural and Rural Systems Management, University of Queensland, Gatton College, Gatton, Queensland.

Tilley, D., and K. Uebel. 1990. Observations of koala populations within the Sydney Water Board's Upper Nepean catchment area. Pages 81–84 in D. Lunney, C. Urqhart, and P. Reed, editors. Koala summit: managing koalas in New South Wales. New South Wales National Parks and Wildlife, Hurstville.

Thomas, O. 1923. On some Queensland Phalangeridae. Annals and Magazine of Natural History. **9:**246–250.

Total Environment Centre. 1983. Our wildlife in peril. A. H. and A. W. Reed Pty Ltd, Frenches Forest, New South Wales.

Troughton, E. 1935. The southern race of the koala. Australian Naturalist **9:**137–140.

Warneke, R. M. 1978. The status of the koala in Victoria. Pages 109–114 in T. J. Bergin, editor. The koala: proceedings of the Taronga symposium. Zoological Parks Board of New South Wales, Sydney.

Wells, K. F., N. H. Wood, and P. Laut. 1984. Loss of forests and woodlands in Australia: a summary by state, based on rural local government areas. Technical memorandum, 84/4. Commonwealth Scientific, Industrial, and Research Organization, Canberra, Australian Capital Territory.

White, N. A., and N. D. Kunst. 1990. Aspects of the ecology of the koala in south-eastern Queensland. Pages 109–116 in A. K. Lee, K. A.

Handasyde, and G. D. Sanson, editors. Biology of the koala. Surrey Beatty and Sons, Chipping Norton, New South Wales.

Wiegler, B. J., A. A. Girjes, N. A. White, N. D. Kunst, F. N. Carrick, and M. F. Lavin. 1988. The epidemiology of *Chlamydia psittaci* infection in a population of koalas (*Phascolarctos cinereus*) in south-east Queensland, Australia. Journal of Wildlife Diseases **24:**282–291.

Wilson, B. A. 1994. Fire effects on vertebrate fauna and implications for fire management and conservation. Pages 131–147 in Fire and biodiversity: the effects and effectiveness of fire management. Proceedings of the 1994 conference. Biodiversity series, paper 8. Biodiversity Unit, Department of Environment, Sport and Territories, Canberra, Australian Capital Territory.