MATSCHIE'S TREE KANGAROO (MARSUPIALIA: MACROPODIDAE, *DENDROLAGUS MATSCHIEI*) IN PAPUA NEW GUINEA: ESTIMATES OF POPULATION DENSITY AND LANDOWNER ACCOUNTS OF FOOD PLANTS AND NATURAL HISTORY

By

William Betz

Submitted for Degree of Master of Philosophy

School of Biological Sciences

University of Southampton

Biomedical Sciences Building

Bassett Crescent East

Southampton

SO16 7PX

Supervisor

C. Patrick Doncaster

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ABSTRACT

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MATSCHIE'S TREE KANGAROO (MARSUPIALIA: MACROPODIDAE, *DENDROLAGUS MATSCHIEI*) IN PAPUA NEW GUINEA: ESTIMATES OF POPULATION DENSITY AND LANDOWNER ACCOUNTS OF FOOD PLANTS AND NATURAL HISTORY

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Tree kangaroos (Marsupialia: Macropodidae, *Dendrolagus*) are some of the Australasian region's least known mammals. Basic questions concerning the population and conservation status of many species remain unanswered. However, there is sufficient anecdotal evidence of population decline and local extinctions to designate tree kangaroos as New Guinea's most endangered mammal group.

Tree kangaroo dung was sampled at four sites in Papua New Guinea (PNG). Distance sampling analysis was used to estimate tree kangaroo dung pellet densities for two of these sites. Pooled results for three trials at these sites give estimates of 51.2 - 109.8 pellets/ha for Matschie's tree kangaroo (*Dendrolagus matschiei*). Captive defecation rates for *D. matschiei* and three other tree kangaroo species were determined. Using this rate as well as a measured average pellet alteration time of approximately three days gave animal density estimates of 0.6-1.4 animals/hectare for the three trials. The precision of the density estimates is affected by uncertainties in the identification of tree kangaroo dung, by the equivalency of captive versus wild pellet production rates, and in the rate and constancy of dung decomposition. Possible solutions for these problems are discussed. The results indicate that distance sampling analysis of dung pellet counts shows promise at colder, higher altitude sites in New Guinea but may not be appropriate for hotter, lower elevation areas with high coprophagous arthropod populations.

Tree kangaroo food plants were documented. Food plants for Matschie's (*D. matschiei*), Doria's (*Dendrolagus dorianus*), and Goodfellow's (*Dendrolagus goodfellowi*) tree kangaroos were collected at two sites with the aid of landowners, and later identified by botanists in Papua New Guinea and Australia. The collections support Australian data that tree kangaroos are browsers, with the largest proportion of their diet coming from leaves and shoots from a wide variety of plants from at least 40 families for Matschie's, and 33 families for Goodfellow's and Doria's. Landowners from different areas of the country were in agreement that tree kangaroos favour eating leaves and stems of plants, with fruits and flowers comprising a relatively minor proportion of the animals' diets.

Additional information on tree kangaroo biology and conservation status was obtained through the use of formal and informal landowner interviews. Interview methodology was insufficient to produce many quantifiable results, but did give novel insights into tree kangaroo natural history, distribution, conservation status, and human utilisation. The interviewee responses indicate that the conservation status of the Matschie's tree kangaroo, *D. matschiei*, is perceived to have declined in recent decades, but this decline is not uniform. The current economic downturn in PNG may be encouraging overhunting in some areas as villagers search for ways to supplement their incomes. However, in other areas tree kangaroo numbers may be stable or increasing due to sociocultural and economic changes that have led to a decline in hunting intensity.

CONTENTS

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DECLARATION

The research for this thesis was undertaken as part of the work of the Tree Kangaroo Conservation Program (TKCP), which is directed by Dr. Lisa Dabek of the Roger Williams Park Zoo, Providence, Rhode Island, USA. The research has required several collaborators, and in some cases, such as landowner interviews by University of Papua New Guinea students, the author was not present when the data were collected.

The distance sampling results were produced and analysed by the author. Field assistance in the dung pellet counts came from Dr. Lisa Dabek; University of Papua New Guinea students Kasbeth Evei, Som Yalamu, Kepslok Kumilgo, Jeffrey Febi and the late Russell Terry; American volunteers Lisa Ware, Warren Lynch, John Williar, Dara Zirofsky, and Debra Williamson; and dozens of landowners from Keweng 1, Nomaneneng, and Maimafu villages. Consultations on distance sampling methods were held with Jeff Laake of the National Oceanic and Atmospheric Administration (Seattle, Washington, USA) and coauthor of the book *Distance Sampling*.

Tree kangaroo food plant collections were made by the author on the Huon Peninsula, and Queensland botanist Rigel Jensen at Crater Mountain. The collections were made with the assistance of landowners from Keweng 1 and Maimafu villages, with the most important informants being Manaono (Keweng 1) and Kaulovo (Maimafu). The Dendawang plant specimens were prepared by the author with the assistance of University of Papua New Guinea students Kasbeth Evei and Som Yalamu, and Keweng 1 landowner Watine Yauro. The Keweng 1 plants were identified by Dr. Wayne Takeuichi and Mr. Robert Kiapranis at the PNG National Herbarium in Lae, while the Crater Mountain specimens were identified by Rigel Jensen. All interpretations of the results were made by the author.

Landowner interviews were done by the author and by University of Papua New Guinea students Silas Wagi, Kasbeth Evei, Som Yalamu, and Kepslok Kumilgo, using an interview sheet prepared in consultation with the author and Dr. Dabek. The results of the interviews were interpretated by the author.

CHAPTER 1 INTRODUCTION

The island of New Guinea, along with northwest Amazonia, the Guyana Shield, and the Congo basin, is one of world's four remaining major tropical wilderness areas. These regions are the last strongholds of the tropical rainforests and are characterised by low human populations and large unbroken blocs of forest occupying more than 70% of the land area. They offer perhaps the last opportunity to conserve whole regions with a full range of biodiversity and complete ecological communities. The indigenous peoples that inhabit these areas are also crucial to the maintenance of human cultural diversity (Mittermeier et al., 1998).

New Guinea is divided politically into two approximately equal political units. The western half is the Indonesian province of Irian Jaya, recently renamed Papua, while the eastern portion is the independent nation of Papua New Guinea, henceforth referred to as PNG. Indonesia and PNG are both members of the group of 17 'Megadiversity' nations, which in aggregate are believed to account for 60 to 80% of the world's biodiversity (Mittermeier et al., 1997). The combination of New Guinea's biological wealth and its wilderness status makes it a global conservation priority (Dinerstein and Wikramanayake, 1993).

Although groups such as butterflies and birds are relatively well surveyed, much of New Guinea's biota remains little known. Tree kangaroos (*Dendrolagus*, Macropodidae, Marsupialia), perhaps the least studied genus of the entire Macropod family, are prime examples of this lack of knowledge (Beehler, 1991b). Two of the ten known species have only been described in the last 11 years, Scott's (*Dendrolagus scottae*) in 1990, and Dingiso (*Dendrolagus mbaiso*) in 1995, and it is possible that new taxa still await discovery (Flannery et al., 1995; Flannery and Seri, 1990).

From a zoological standpoint tree kangaroos are fascinating examples of evolutionary and anatomical readaptation to arboreal life and the demands of shifting from a grazing to a folivorous diet. From the conservation perspective tree kangaroos are charismatic mammals, which are highly suited to serve as 'flagship species' to raise awareness of the need to conserve New Guinea's rich forests and unique wildlife.

The objectives of this thesis are:

1. Estimate tree kangaroo population density. Knowledge of the conservation status of tree kangaroos is limited, in part by a lack of data on tree kangaroo populations and population densities. The thesis will investigate the feasibility of using dung pellet counts and distance sampling analysis to estimate population density for Matschie's tree kangaroos (*Dendrolagus matschiei*) at a site on the Huon Peninsula of northeastern PNG.
2. Document tree kangaroo food plants. Before larger questions on feeding ecology can be answered, descriptive information must be gathered on what tree kangaroos eat. Collections were made of food plants for three species of tree kangaroos: Matschie's (*D. matschiei*), Goodfellow's (*Dendrolagus goodfellowi*), and Doria's (*Dendrolagus dorianus*).
3. Document tree kangaroo conservation status through landowner interviews. Interviews with the people who live with (and hunt) tree kangaroos were used to learn more about tree kangaroo natural history, cultural significance, and conservation status.

Threats to biodiversity have now reached a point where ecological research projects should include a conservation component (Beehler, 1991a). The goal of the research for this thesis is not only to answer questions concerning tree kangaroo ecology, but also to serve as a catalyst for local landowners to designate new conservation areas to protect tree kangaroos and their habitats (Dabek and Betz, 2001).

CHAPTER 2 REVIEW OF THE LITERATURE ON TREE KANGAROOS

2.1 TREE KANGAROO CONSERVATION STATUS

2.1.1 Conservation concern

There are reasons for concern about the conservation status of tree kangaroos in New Guinea. All eight species found on the island face threats in the wild and one taxa, *Dendrolagus scottae*, may face imminent extinction. The survival of the two Australian tree kangaroo species is thought to be more assured, but they too face threats in the wild (Flannery et al., 1996; Newell, 1999a).

2.1.2 Threats

The primary threats to New Guinea tree kangaroo populations and taxa are overhunting and loss of habitat through deforestation or forest degradation. Underlying the deforestation and overhunting concerns is New Guinea's rapid population growth. Population growth rates in PNG are estimated at 2.2%/annum, and rates are higher, approximately 3%, in Irian Jaya (FAO, 1999; Government of Indonesia, 2000). Less than 10% of the PNG population are in wage employment, and over 80% of the populace still live in rural villages, and are dependent on the maintainence of healthy ecosystems for their subsistence (Filer and Sekhran, 1998). However, at present the human population in New Guinea is still relatively low, approximately 5 million (12 persons/km^2) for Papua New Guinea, 2 million (4.8 persons/km^2) for Irian Jaya, and natural forest cover is high. There is still time for adequate areas of tree kangaroo habitat to be preserved. Table 2.1 illustrates that while deforestation in PNG is currently occurring at a faster rate than the Solomon Islands, it is not occurring at the catastrophic pace seen in neighbouring Asian countries, especially the recent destruction in post-Suharto Indonesia (Jepson et al., 2001).

Table 2.1 Deforestation rates in Papua New Guinea and neighbouring nations (FAO, 1999)

Country	1995 Total Forest Area (km^2)	1995 Natural forest area (km^2)	1995 Natural Forest Area (% of total land area)	Annual deforestation rate 1990-1995 (km^2)	Annual deforestation rate 1990-1995(%)
PNG	369390	369090	81.5	1330	0.4
Solomon Islands	23890	23710	84.7	50	0.2
Indonesia	1097910	1036660	57.2	10840	1.0

Malaysia	154710	153710	46.8	4000	2.4
Philippines	67660	65630	22.0	2620	3.5

The greatest near-term threat to tree kangaroos is overhunting. Recent studies have shown that traditional hunting practices are often unsustainable and that even light hunting can reduce prey species populations by up to 75%, and heavy hunting by up to 95% (Redford, 1992). Tree kangaroo meat is highly prized, and the animals are prime targets for New Guinea hunters. The slow reproductive rate (see Section 2.5) of tree kangaroos makes them especially vulnerable to overhunting. Tree kangaroos have already been exterminated in many parts of New Guinea, and these zones of extinction will expand and increase in number so long as hunting continues at current rates and human populations continue to grow (Fitzgibbon et al., 2000; Flannery et al., 1996).

The second threat, habitat loss, can be divided into three types: loss of habitat due to resource industry development such as logging or mining, habitat destruction due to subsistence activities like agriculture, and climate induced habitat destruction.

The most destructive form of resource development in PNG is logging. Its deleterious effects upon Papua New Guinea's environment and political structures have been subject of great concern, both within and outside the country (Filer et al., 2000; Filer and Sekhran, 1998). However, while it damages forest structure, decreases overall biodiversity and causes great harm to watersheds, it is unclear that logging by itself immediately threatens the survival of larger mammals like tree kangaroos (Johns, 1997). Tree kangaroos appear to be capable of eating a wide variety of plants, and data from moderately logged forests in Australia indicate that they persist in selectively logged areas, albeit at lower levels (Laurance and Laurance, 1996), a finding also observed among folivorous primates in Malaysian forests (Johns, 1988). Tree kangaroos can consume the leaves and shoots of pioneer shrubs, trees and vines, which grow in profusion in newly logged areas and often are favoured by browsing and grazing mammals because of their relatively low toxin load (Coley, 1983; Whitmore, 1998). Furthermore New Guinea and tropical Australian forests routinely experience large-scale disruptions from natural forces like cyclones, earthquakes, landslides and volcanic eruptions, so it is possible that tree kangaroos are adapted to dealing with dramatic ecosystem disturbance (Johns, 1986; Whitmore, 1998). The primary threat that logging poses to tree kangaroos is that by building roads and tracks, loggers give greater access to the forest, both to locals and outsiders. This often leads to increased hunting pressure, as well as facilitating the establishment of new agricultural areas and new human settlements in previously uncultivated and uninhabited areas (Bennett and Robinson, 2000; Johns, 1993). Other development such as mining and oil exploration damage tree kangaroo habitat, and have had highly destructive impacts on watersheds, but the amount of forest destroyed is actually quite small when compared to logging. Like logging, the chief threat that they present to tree kangaroos is that they can open up previously remote areas to human entry.

A second source of deforestation is climatic events. The most recent example of this are the catastrophic forest fires that burned throughout New Guinea during the 1997-1998 ENSO (El Niño Southern Oscillation) droughts. In some areas persistent smoke kept airstrips closed for months, and crop failures led to the deaths of thousands of New Guineans in remote villages. In PNG, the deforestation and forest degradation caused by these fires is believed to have exceeded the total deforestation from all other causes since the country's independence was declared in 1975 (Filer and Sekhran, 1998). Large areas of upper montane and subalpine forest, the home of tree kangaroo species such as *D. dorianus*, *D. mbaiso*, and *D. matschiei* were destroyed in these fires (T. Flannery, pers.comm.). However, although the ENSO caused fires of 1997-1998 were especially destructive, events of equal severity have occurred in the historic past (Johns, 1986). On a more long-term scale habitat change from global warming is a potential threat to high altitude or restricted montane habitat taxa of tree kangaroos such as Scott's tree kangaroo (*Dendrolagus scottae*) and Dingiso (*Dendrolagus mbaiso*).

Deforestation through subsistence and small holder cash crop agriculture also present a threat to tree kangaroos, and without changes in practices will invariably lead to further reduction in tree kangaroo populations (Thomas, 1999). However, the impact of agricultural forest clearance is disputed. While it has been estimated that over 200,000 hectares are deforested for firewood or subsistence gardens each year in PNG, the percentage of area that is previously uncultivated land has been estimated to be only 3%. The horticultural response to increasing demand has been intensification within existing agricultural zones, rather than expansion into virgin forest (Filer, 1994; Filer and Sekhran, 1998). However, this pattern is not uniform; in certain areas such as the Telefomin region and the Torricelli Mountains of western PNG, cultivated areas have been expanding accompanied by rapid deforestation (T. Flannery, pers. comm.).

Whether the overall pattern of intensification instead of deforestation can be maintained as populations continue to expand is uncertain. While traditional farming practices in PNG may be sustainable at low population densities, they can become unsustainable as human numbers increase. The cycling of land from garden to regenerating forest is accelerated so that average soil fertility falls to a point where the forest does not regenerate and is replaced by grassland. These anthropogenic grasslands are subject to fire, both natural and man-made, so the habitat tends to persist, and now covers large areas of PNG's highland valleys. The search for firewood is also a major contributing factor to deforestation, and as human numbers increase, the area deforested by firewood collection inevitably widens (M. Murphy, pers. comm.).

2.1.3 Defining endangerment

Tables 2 and 3 illustrate two recent attempts to determine tree kangaroo conservation status. The first, by Tim Flannery (see Table 2.2), evaluates status by subspecies, while the second, produced by the Australasian Marsupial and Monotreme Specialist Group for the IUCN Red List of Threatened Animals (see Table 2.3) evaluates by species.

Table 2.2 Conservation Status of all tree kangaroo taxa (Flannery et al., 1996)

Subspecies	Common name	Status
Dendrolagus bennettianus	Bennett's tree kangaroo	Secure
Dendrolagus lumholtzi	Lumholtz's tree kangaroo	Secure
Dendrolagus inustus inustus	Grizzled tree kangaroo	Unknown
Dendrolagus inustus finschi	Finsch's tree kangaroo	Vulnerable
Dendrolagus ursinus	Vogelkop tree kangaroo	Vulnerable
Dendrolagus goodfellowi goodfellowi	Goodfellow's tree kangaroo	Unknown
Dendrolagus goodfellowi buergersi	Timboyok	Endangered
Dendrolagus goodfellowi pulcherrimus	Golden-mantled tree kangaroo	Critical
Dendrolagus spadix	Lowlands tree kangaroo	Unknown
Dendrolagus matschiei	Matschie's tree kangaroo	Endangered
Dendrolagus dorianus dorianus	Doria's tree kangaroo	Unknown

Subspecies	Common name	Status
Dendrolagus dorianus stellarum	Seri's tree kangaroo	Vulnerable
Dendrolagus dorianus notatus	Ifola	Endangered
Dendrolagus dorianus mayri	Mayr's tree kangaroo	Unknown
Dendrolagus scottae	Tenkile	Critical
Dendrolagus scottae subsp. Indet.	Fiwo	Vulnerable
Dendrolagus mbaiso	Dingiso	Vulnerable

Table 2.3 IUCN Red List conservation status of tree kangaroo species (Baile and Groombridge, 1996)

Subspecies	Common name	Status
Dendrolagus bennettianus	Bennett's tree kangaroo	Lower Risk/near threatened
Dendrolagus lumholtzi	Lumholtz's tree kangaroo	Lower Risk/near threatened
Dendrolagus inustus	Grizzled tree kangaroo	Data deficient
Dendrolagus ursinus	Vogelkop tree kangaroo	Data Deficient
Dendrolagus goodfellowi	Goodfellow's tree kangaroo	Endangered
Dendrolagus spadix	Lowlands tree kangaroo	Data Deficient
Dendrolagus matschiei	Matschie's tree kangaroo	Endangered
Dendrolagus dorianus	Doria's tree kangaroo	Vulnerable
Dendrolagus scottae	Scott's tree kangaroo	Endangered
Dendrolagus mbaiso	Dingiso	Data Deficient

The IUCN group made their determinations using the most current IUCN procedures (IUCN, 1994). Red List classification divides conservation status into 4 broad categories: Extinct, Threatened, Lower Risk, and Data Deficient. These are further divided into sub categories: Extinct and Extinct in the Wild; Critically Endangered, Endangered andVulnerable (for Threatened), Conservation Dependent, Near Threatened, and Least Concern for Lower Risk.These assesments were made in 1996 and have not been updated for the 2000 Red List. Flannery et al. (1996) use a simpler classification scheme which roughly correspond to the IUCN criteria, and divides conservation status into five categories: Extinct, Critical, Endangered, Vulnerable, and Secure, and in recognition of the meager state of knowledge of New Guinea mammal fauna, Unknown.

Regardless of methodological differences the existing conservation status analyses must be regarded as provisional and nonquantified. There have been no systematic countrywide attempts in PNG and Irian Jaya, let alone Australia, to determine population status of the different tree kangaroo species. Attempts have been made to determine the conservation status for *D. mbaiso* and are being made for *D. scottae*, both of which have restricted ranges.

In Australia the Tree Kangaroo and Mammal Group Inc. (TKMG) is now attempting to gather information on the population status of *D. lumholtzi*. Chapter 5 reports on work by the author and other researchers with the Tree Kangaroo Conservation Program to do the same for *D. matschiei* (Dabek and Betz, 1999; Dabek and Betz, 2001; Flannery et al., 1995; Flannery and Seri, 1990) (Schmidt et al., 2000).

Another problem facing tree kangaroo conservation assessment is that the taxonomy of genus *Dendrolagus* is poorly understood (see 2.5), and the number of species and subspecies is uncertain. An example of this taxonomic uncertainty is the status of Seri's tree kangaroo, *Dendrolagus dorianus stellarum*, which is known from the Star and Victor Emmanuel Mountains in western PNG, as well as the Snow (Sudirman) Mountains of Irian Jaya. Recent genetic comparisons between the PNG and Irian Jaya forms indicate that the subspecies may be comprised of two different taxa (Bowyer, 2000). Similar information deficiencies exist for the sub-topics affecting tree kangaroo conservation status, such as hunting levels and the effect of hunting on tree kangaroo populations, tree kangaroo habitat choice and effects of habitat conversion, tree kangaroo population densities (which this thesis will address), etc. Despite these qualifications there is little doubt that with the possible exception of long-beaked echidnas (*Zaglossus bruijnii*), tree kangaroos are the most endangered mammal group in PNG (Mittermeier et al., 1997).

2.1.4 Conservation status of Australian tree kangaroos

The conservation status of the Australian tree kangaroos is better known, and believed to be less worrisome than New Guinea species. In fact, despite population and distribution uncertainties, it is likely that the conservation status for *D. bennettianus* and *D. lumholtzi* has improved in the last few decades, but *D. lumholtzi* still faces significant threats in the wild. This improvement in conservation status is due to the near cessation of subsistence hunting of tree kangaroos by native Australians, especially since the 1960s. The difficulties in finding tree kangaroos experienced by nineteenth century explorers such as Carl Lumholtz, and more modern groups such as the 1949 Archbold Expedition, indicate that Australian tree kangaroos were much rarer and difficult to locate in the past than today. They were typically found only in the most remote and spiritually and/or physically dangerous areas such as sacred mountain peaks, or in intergroup boundary areas (Flannery et al., 1996).

Both *D. lumholtzi* and *D. bennettianus* are listed as Lower Risk/Near Threatened by the IUCN (1996), while Flannery et al. (1996) lists both species as Secure, which would probably correspond to Lower Risk/Least Concern on the IUCN lists. However, the two species still face threats, especially *D. lumholtzi* (Newell, 1999a). While Australia's landmark Wet Tropics World Heritage listing of its Northern Queensland rainforests has done much to conserve the range of *D. bennettianus*, it has limited value in protecting the known habitats of *D. lumholtzi*. Much of the species' current range lies on the Atherton Tablelands, where the forest is heavily fragmented and not protected by the World Heritage listing. The basaltic soil types that are most favoured by *D. lumholtzi* are also suitable for agricultural use, and much of this habitat has already been fragmented or destroyed. The remaining blocs are under a patchwork of private, Queensland state, and local government ownership with few restrictions on further forest clearance. The fragmentation of the Tableland forests obliges young tree kangaroos to disperse across open habitat where they are more at risk to predation by dogs, and to cross roads where they are endangered by automobiles and trucks. Several tree kangaroos are killed in this manner every year, and the effect of this mortality on the population is unknown. If Atherton Tablelands landowners do not maintain their timber holdings, or if traffic caused mortality increases then the population of *D. lumholtzi* could decline (Newell, 1999a; Schmidt et al., 2000).

2.2 REASONS FOR CONSERVING TREE KANGAROOS

There are four reasons for preserving tree kangaroos: ecological, aesthetic/cultural, utilitarian, and ethical/spiritual.

2.2.1 Ecological

From an evolutionary standpoint, tree kangaroos are interesting examples of convergent evolution. Like Australia, New Guinea has never had land connections with Asia, and thus many typical rainforest mammal groups such as primates have been unable to disperse to the island. In New Guinea tree kangaroos occupy the large arboreal folivore niche which in the forests of Asia, Africa, and Latin America are filled primarily by primates such as Howler monkeys (*Alouatta* spp.), or other folivores such as sloths (Bradypodidae) and red pandas (*Ailurus fulgens*). From a standpoint of maintaining ecosystem functions, tree kangaroos have not yet been shown to be keystone species for New Guinea and Australian forests. They are not major seed dispersers like Birds of Paradise (Paradiseae), or cassowaries (Casuariidae). They are not top predators like New Guinea Harpy Eagles (*Harpyopsis novaguinae*), nor are they crucial prey for these predators. However, New Guinea forest ecology is still poorly understood and tree kangaroos may yet be shown to be important for maintaining ecosystem health (Beehler, 1991b).

2.2.2 Aesthetic and cultural

Another reason for preserving tree kangaroos lies in their undoubted aesthetic and cultural appeal. This appeal makes tree kangaroos ideally suited for a conservation role as a 'flagship' species. Flagship species are charismatic species that people relate to in an emotionally positive way, and which can be used as a symbol for preserving entire habitats (Meffe and Carroll, 1997). Tree kangaroos are well suited for this role both for New Guinean as well as for Western audiences. For Westerners, the endearing appearance of tree kangaroos makes them ideal conservation ambassadors, and the seeming incongruity of a kangaroo that climbs trees undoubtedly contributes to their appeal.

New Guineans are drawn to the animals as well. Captured tree kangaroos are commonly kept as pets in villages. Tree kangaroo skins are frequently worn as adornments during 'singsings', traditional dances and ceremonies. The animals are admired for their strength and elusiveness and hunters view them as worthy foes. Men who succeed in killing tree kangaroos gain the respect of all in the village (Flannery et al., 1996). In some areas tree kangaroos are associated with powerful spirits, or are revered as ancestors, and they appear in traditional stories and myths (Flannery et al., 1995). Chapter 5 will give further examples of New Guinean cultural attitudes to tree kangaroos.

2.2.3 Utilitarian

Tree kangaroos are important prey for New Guinea hunters. Many New Guinea human populations subsist on low protein diets, and as the largest native land mammal in their habitat, tree kangaroos offer a welcome source of meat. Their pelts are also valued, especially in portions of the PNG Central Highlands, being used and traded for ceremonial purposes, but rarely for day to day clothing (Flannery et al., 1996). Thus tree kangaroos have monetary value and hunters in cash poor regions of the country are further attracted to hunting them because they can find ready buyers in the town and government station markets. Further findings on tree kangaroo hunting will be discussed in Chapter 5.

2.2.4 Ethical and spiritual

Many conservationists would argue that ultimately the most important reasons for conserving tree kangaroos are ethical and spiritual ones. In this view the power, or 'stewardship', that human beings possess to determine the fate of many of the Earth's ecosystems and species comes with a heavy responsibility (Baker, 1996). The recognition of the need to conserve and cherish the biosphere is seen as an objective that can partially bridge philosophical divides between religious and non-religious groups and other antithetical worldviews. Thus whether one approaches conservation from the viewpoint of evolutionary ecology or of traditional religions, all of nature (including tree kangaroos) is 'good', and deserves to be cherished and protected in its own right (Wilson, 1992).

2.3 METHODS OF CONSERVING TREE KANGAROOS

Conserving tree kangaroos and their habitat in New Guinea tree kangaroo is challenging. Significant obstacles exist in both Irian Jaya and PNG. I will confine my discussions to the problems in PNG.

2.3.1 Barriers to conservation in PNG

The major obstacle to forest and wildlife conservation in PNG is the fragmented and traditional nature of land ownership. Ninety-seven percent of the land in PNG is in customary ownership, and this is recognised and protected by the nation's constitution. Customary land is usually controlled by village-based clans, the members of which are keenly aware that the land is their primary source of wealth and security. Land ownership is normally passed down paternally, but men will often receive lesser ownership rights to land owned by their wives' and mothers' clans, thus complicating the picture further (Van Helden, 1998). Most New Guinea cultures are competitively egalitarian (at least for males) in their political structure, and this lack of defined hierarchy, combined with the complicated resource ownership pattern, makes gaining consensus for undertaking any large–scale group action very challenging. An additional impediment is that in many regions of the country, strong rivalries and even outright warfare, exists between neighbouring clans and villages. This makes conservation work at regional scales especially difficult. Even in peaceful areas interclan jealousies can develop if it is perceived that some clans are beginning to benefit more than others. This 'tall poppies' problem impairs conservation and development efforts and environmental groups must endeavour to avoid any hint or appearance of favouritism if they hope to succeed (Filer, 1994; Filer and Sekhran, 1998; Holzknecht, 1994).

Another obstacle to tree kangaroo and environmental conservation in PNG is that conservation awareness among rural New Guineans is often low. A common misconception held by many Western environmentalists and conservationists is that indigenous people such as New Guineans naturally have a more developed conservation ethic than the less rooted, less biophilic citizens of the developed world (Bulmer, 1982; Schaller, 2000). While it is true that the subsistence lifestyles and traditional knowledge of New Guineans often makes them very knowledgeable about local natural history, the notion that they are more likely to protect wildlife and forests is no longer true for many groups. Many rural Papua New Guineans are well aware of the material goods, comforts, and economic opportunities that they lack when compared with their town brethren or Westerners, and they are eager to get their share even if it means selling logging or mining rights (Van Helden, 1998). This eagerness to obtain 'development' is accompanied by an inability to foresee the consequences of large-scale resource extraction and unfettered human population growth. The lack of foresight is understandable – in many areas of New Guinea human populations have only begun to grow rapidly in the last one or two generations with the advent of improved medical care and reduction in tribal fighting. There is little cultural memory of deforestation or of exhaustion of natural resources (Filer and Sekhran, 1998).

Another reason for the lack of conservation awareness in PNG is that with the adoption of Christianity, the culture of many New Guineans has changed in ways that are, in the short-term, inimical to conservation. With their repudiation of 'devils' and 'spirits', churches in PNG have in many cases secularised their congregations' view of nature, and have thereby dramatically reduced the spiritual awe and fear that the forests and wildlife once engendered. Although attachment to ancestral land remains, the emphasis now in many areas is on how the land can be used to bring economic development to the clan or village. Conservation organisations or initiatives that do not respond to this thirst for development are destined to fail (Ericho, 1999; Van Helden, 1998).

One problem that often stymies conservation efforts in PNG is the differing temporal scales of villagers leading a subsistence life compared to outside conservationists and their funding organisations. It takes time to win wholehearted local acceptance of conservation aims, and the time required often seems excessive to the visiting workers and even more so to their funding organisations. The temptation for conservationists is to move forward and achieve 'results' quickly. Initially this may seem possible because landowners will often be enthusiastic and reluctant to express reservations. Only later, as the true costs and benefits of conservation initiatives to local lifestyles become apparent, will problems and opposition surface. The need for local people to fully understand and agree with the goals and demands of conservation actions has led some PNG environmental groups to emphasise an 'isi isi', (easy easy) approach, which to the outside observer can appear to be frustratingly slow (Ellis, 1997; Orsak, 1999a).

Although PNG is a signatory to most major international conservation treaties such as the Convention on International Trade of Endangered Species (CITES), the government finds it difficult to seriously enforce these laws, at least domestically. The problem again is that the government is reluctant to interfere in the actions of landowners on their own land. There is a thriving internal market in bird plumes and mammal furs for use in ceremonial costumes and regalia, and live and dead tree kangaroos are commonly sold in town markets, despite the fact that they are classified as protected fauna under PNG law (Kula and George, 1996). The country's recent economic difficulties have forced the PNG Office of Environment and Conservation (OEC) to make many of its officers redundant, and to close some of its provincial offices, thereby making effective enforcement even more difficult (Ellis, 1997).

2.3.2 Practical actions required

The customary ownership of land in PNG makes the establishment of government owned reserves and parks unfeasible. There is virtually no state-owned land, and it is difficult to persuade landowners to relinquish ownership of lands suitable for conservation. The conservation approach that has been developed in PNG is the Wildlife Management Area, or WMA, in which landowners designate certain areas as conservation zones, then petition the government to legally recognise their decision (Seri, 1992). The procedure is as follows:

- Customary landowners inform government of wildlife problems.
- Discussions are held between landowners and government field officers.
- A final meeting is held to decide boundaries, committee members, and regulations.
- A report is made by field officer to the Wildlife Division of the Office of Environment and Conservation.
- The Department of Lands prepares a legal boundaries description.
- The Legislative Counsel prepares a declaration which includes boundaries, landowner committee members and the name of the area.
- Declaration is made to the Government Printer for printing in National Gazette.
- A Statutory Instrument is signed by Minister for Environment and Conservation.
- The Statutory Instrument is submitted to National Executive Council for information.
- The Governor General approves Statutory Instrument.

The declaration of an area as a WMA provides some protection for wildlife, andd therefore WMA status balances conservation needs with the requirement to maintain traditional control. WMA's also serve as frameworks for landowners and non-government organisations (NGOs) to establish Integrated Conservation and Development (ICAD) projects which seek to combine conservation goals with sustainable local economic and social development (Ellis, 1997). However, WMA's are still vulnerable to development pressures. Legally WMA designation only protects the wildlife of an area – it does not protect the forest or subterranean resources, and thus petroleum, forestry and mining companies can legally approach the landowners and government for permission to operate. This has meant that even well established WMAs such as Crater Mountain are now threatened by large-scale mining and logging. A more recently developed designation called a Conservation Area offers greater protection, by safeguarding the land as well as the wildlife. However, no Conservation Areas have yet been established, so the legal strength of the classification has not been tested. Conservation Area designation does not maintain full landowner control and ownership over the conserved land - it makes landowners and government co-managers of the area. When given the choice, clans and villages have always chosen the WMA option (Ellis, 1997).

As stated above, the preferred regional conservation project model in PNG is integrated conservation and development, or ICAD. The ICAD concept is promoted as the best way to conserve forests and biodiversity while meeting the legitimate economic aspirations of landowners. ICAD projects endeavour to serve their constituents in several ways. An example of this multifaceted approach can be seen in the efforts of the Research and Conservation Foundation of Papua New Guinea (RCF) in the Crater Mountain WMA. Crater Mountain is a very large (247,000 ha) reserve, which encompasses portions of three provinces: Gulf, Simbu, and Eastern Highlands. The reserve ranges in altitude from 80-3100 m, and encompasses habitats ranging from lowland swamp to upper montane rainforest. The area is sparsely populated with the semi-nomadic Pawaian speakers inhabiting the lowlands, and sedentary Gimi speakers living in the highlands. Landowners in Crater Mountain have designated thousands of hectares of land as no-hunting zones. In return, RCF and its donors have encouraged economic development by organising and supporting the following activities:

- **Scientific Research.** Biological research is encouraged in the WMA and RCF has been successful in attracting scientists. RCF monitors the research, and, in consultation with local landowner committees, establishes and enforces land use fees and payment structures for carriers and local field assistants. It also attempts to explain to villagers what researchers are doing and what they hope to accomplish, even going so far as to take landowner delegations on tours of the national museum and herbarium to show them where biological samples collected have been taken and stored.

- **Artifact Sales.** RCF supports the sales of local handicrafts. Artisans produce their work, then quote a price to the village artifact sales board. Board members arrange the sale of the item at that price either in the artifact centre in the village itself, or more typically in towns at hotels and art shops.
- **Ecotourism.** Guesthouses have been built in the three main villages within the reserve, and links are being established with travel companies with the hope that activities such as trekking and birdwatching can be encouraged.
- **Spice Plantations.** Contacts have been made with spice companies to establish smallholder vanilla and capsicum plantations in the lowland villages in the reserve. This is important because up to now lowlanders have had no high value cash-crops.
- **Schools.** RCF has helped to establish village community schools throughout the reserve, and has helped to place US Peace Corps volunteers into some of the communities to help teach in schools and to work on other development projects.
- **Water Supplies.** RCF has assisted villagers within the WMA in acquiring water supply systems.

However, the emphasis placed on economic incentives in ICAD projects has been criticised. One concern is that the emphasis on sustainable development leads to a 'handout' mentality among villagers and raises undue economic expectations. This invariably leads to landowner disappointment and resentment because the short term economic return of sustainable enterprises usually cannot compete on a purely monetary basis with other development such as commercial logging. Orsak (1999b) states that proponents of the ICAD paradigm often oversell the monetary returns of these projects at the expense of emphasising conservation awareness development and training. His warnings are perhaps best exemplified by the Lak ICAD in Southern New Ireland which was launched in 1993 as part of the Global Environment Facility (GEF) funded Biodiversity and Conservation and Resource Management Programme (BCRMP). The BCRMP was developed in the aftermath of the

1992 Rio Global Environment Conference. Despite the dedication of its volunteers, extensive consultation with landowners, and sizeable financial resources, the Lak ICAD was unable to win the consent of the landowners to choose sustainable logging and conservation over the quick money of industrial logging (Ellis, 1997; Orsak, 1999b).

One way for ICAD projects to deal with the problem of perceived economic noncompetitiveness is to leave the large-scale development to someone else. By tying their work to existing development projects, environmental organisations can concentrate on developing a conservation consciousness among landowners and developing sustainable economic enterprises, which will be better, appreciated by the landowners when the higher incomes from intensive resource extraction are finished. This strategy is being pursued in PNG by the World Wide Fund for Nature (WWF) in partnership with Chevron Petroleum in the Kikori Basin of PNG's Southern Highlands and Gulf Provinces. WWF has agreed to work with Chevron to help manage the environment within Chevron's 2.3 million ha operations area, which includes much of the range of *D. spadix*, as well as populations of *D. goodfellowi* and *D. dorianus*.

The partnership means that WWF is not under pressure to deliver large-scale development - Chevron has assumed the responsibility of building the roads, schools, and health centres that local landowners demand. In addition, Chevron polices the area. Hunting and large-scale logging are not allowed within Chevron's work areas. WWF can thus concentrate on raising conservation awareness, developing WMAs within the area, and starting eco-enterprises such as a certified forestry operation. In turn, Chevron has attempted to minimise the environmental effects of its operation, with the result that the forests surrounding its drill sites and pipeline are some of the most wildlife rich in PNG. The experience of WWF and Chevron shows that some forms of large - scale resource extraction are possible without environmental devastation, and it provides a perhaps more fruitful model of NGO – multinational corporation relations (Diamond, 1999; WWF South Pacific Program, 2000).

A final method that conservation groups in PNG have chosen to advance their objectives is to link their activities to existing local institutions. The primary institutions for this in PNG are the nation's churches. Churches are one of the few unifying forces in New Guinea, and church leaders command respect and hold some power within their communities. Environmental NGOs such as Christians for Environmental Stewardship (CES) are trying to meld modern conservation messages with Biblical teachings and to spread these integrated messages to landowners. The approach of working closely with church leaders is now being tested by the Bismarck-Ramu ICAD project in Madang Province. This project is part of the same Global Environment Facility BCRMP project as the failed Lak ICAD, and it is attempting to apply the lessons gathered from the mistakes in the Lak project. One of the changes made was a strong emphasis on working with local churches and church leaders (Ellis, 1997). The Tree Kangaroo Conservation Program is also pursuing this strategy, albeit less formally, with church leaders in the YUS local government area of the Huon Peninsula (see 2.4.2).

Despite the various methods attempted and lessons learned, conservationists working in PNG must reconcile themselves to the fact that the landowners decide whether conservation practices are followed. The dependence on local interest and goodwill and the lack of legal instruments to enforce conservation agreements means that any conservation area is potentially impermanent (Van Helden, 1998).

2.3.3 How to increase awareness of value (local and international)

There are ongoing efforts, both within and outside of PNG to raise awareness of conservation of the country's wildlife and ecosystems. One commonly hears and reads about the need to protect PNG's forests and coral reefs in the nation's media. The PNG Office of Environment and Conservation (OEC) has authored several public service conservation messages that are regularly broadcast on provincial radio stations. Environmental themes are frequently discussed in newspapers such as the English language *Post-Courier*, or the Tok Pisin (Neo-Melanesian pidgin, PNG's lingua franca) *Wantok Nius*. However, discussions of the need to protect rare or endangered species are less frequent. For example, the problems of overhunting game or overharvesting fish or turtle eggs are rarely mentioned. In addition, conservation messages often do not reach the villages. Many conservation groups are now attempting to change this. For example, RCF is now planning on producing a Tok Pisin newsletter for distribution to villagers in the Crater Mountain WMA (Research and Conservation Foundation, 2000). The newsletter will contain articles about conservation topics as well as reports about ongoing scientific research and eco-enterprises within the reserve. RCF already produces an English language newsletter called *Singaut*, which is distributed to subscribers within and outside of PNG.

Thanks to the growth of the World Wide Web it is often easier for PNG conservation NGOs to reach international audiences than it is to communicate with landowners in the remote villages found in conservation areas. Although PNG is not as 'wired' as developed nations, it does have commercial Internet Service Providers and NGOs such as the Village Development Trust (VDT, http:// www.global.net.pg/vdt) can publicise their activities with minimal effort.

2.4 THE TREE KANGAROO CONSERVATION PROGRAM

The research for this thesis was done under the auspices of the Tree Kangaroo Conservation Program, or TKCP, an integrated conservation, research, and education project working in PNG (Dabek and Betz, 2001).

2.4.1 History

The TKCP is part of the American Zoo and Aquarium Association's (AZA) Tree Kangaroo Species Survival Plan (TK-SSP). It has worked in PNG since 1996, under the direction of Dr. Lisa Dabek, Director of Conservation and Research at the Roger Williams Park Zoo in Providence, Rhode Island, USA. Most of this work is carried out on the central Huon Peninsula in the YUS local government area of the Kabwum Electoral District (Morobe Province).

2.4.2 Aims

The primary goal of the TKCP is to promote the preservation of tree kangaroos and their rainforest habitat in PNG. The project seeks to educate villagers about the uniqueness and the global significance of tree kangaroos and their habitat, and the importance of managing the animals and habitat for the future. It is hoped that through these efforts landowners will eventually organise clan-based associations to co-operatively manage their land as a WMA, or perhaps as a Conservation Area. Clans that elect to join this effort will determine how much of their own land they will demarcate as wilderness zones with no hunting or timber cutting allowed. The establishment of no-hunting zones has been shown to be an effective method of preserving wildlife (Joshi and Gadgil, 1991). The efforts to establish clan declared conservation areas do not eliminate the requirement to learn about the animals' conservation status and natural history. This is being accomplished through an active research project (see below), while the need to raise community conservation awareness and literacy levels is being met through a conservation education project.

2.4.3 Research

Matschie's tree kangaroo dung pellet counts have been conducted at field sites in the YUS local government area and Nomaneneng regions of the Huon Peninsula, and in the Crater Mountain WMA in Eastern Highlands Province. Data from these surveys were sufficient to estimate tree kangaroo densities at two sites using distance sampling. These results will be discussed in detail in Chapter 3. The surveys have been led by the author and/or by Kasbeth Evei, a recent University of Papua New Guinea (UPNG) graduate who was trained by the author. Faecal samples from these surveys have been collected to be used in future genetic studies.

Successful tests of both Global Positioning System (GPS) as well as conventional VHF radiocollars have been performed. The next step is to develop safe low stress methods of capturing tree kangaroos for collaring. The method currently being investigated is live trapping using large baited box traps. Kasbeth Evei is testing trapping methods in collaboration with Steve Lapidge, a doctoral candidate from the University of Sydney.

Trailmaster™ wildlife monitoring and camera systems have been used to photograph tree kangaroos and other native mammals and birds at Huon and Crater Mountain sites.

Landowner identified tree kangaroo food plants have been collected and identified. The Huon Peninsula specimens were collected by the author and identified by Dr. Wayne Takeuchi (Botanical Research Institute of Texas) at the PNG National Herbarium while the Crater Mountain specimens were collected and identified by Queensland botanists Rigel Jensen and Steve McKenna, based on a initial list recorded by the author. The results from these collections will be discussed in Chapter 4.

Landowner interviews have being conducted at several villages on the Huon Peninsula by UPNG students. These interviews give insight into tree kangaroo natural history, local hunting practices and changes in tree kangaroo populations over time, as well as cultural beliefs about the species. Most of the interviews have been conducted by former UPNG student Som Yalamu, based on an interview template developed by the author in consultation with project director Dabek, and Yalamu. Information and conclusions gathered from these interviews will be discussed in Chapter 5.

2.4.4 Conservation

In their conversations with landowners TKCP workers have been forthright about the need for clans to not act hastily, and to honestly evaluate how much land clans require to satisfy current resource needs. This approach has allowed a local conservation consensus to develop. A written agreement was signed in 1999 by TKCP representatives and one landowner clan from Keweng 1 village on the Huon Peninsula, formally recognising a field site as a research/conservation area, setting wages for local field assistants, and guaranteeing scientist access to clan lands. Similar verbal agreements were reached with the other two clans in the Keweng 1 in 2000, and written agreements will be signed with these clans in 2001. These agreements represent the first step towards establishing a WMA on the Huon Peninsula.

Meetings were held with a PNG Member of Parliament, the Honourable Ginson Saonu (Kabwum District) about future prospects for the establishment of a WMA in the YUS local government area of his district on the Huon Peninsula. The YUS local government council passed a resolution in support of the program's activities and for the establishment of a conservation area. The governmental support encouraged the TKCP to extend conservation efforts to other villages in the YUS region. A walking tour was made of part of the YUS region in 2000 during which conservation pledges of more than 9000 ha were made by clans in four villages. Land pledges made by other clans in 2001 have since expanded this area to at least 20,000 hectares.

2.4.5 Education

The TKCP is attempting to encourage a stronger conservation ethos among the landowners of the YUS local government area. A key to this effort is conservation education in local schools. However, the remote schools in the YUS region are beset by teacher shortages and lack of government support and funding. Conservation education cannot succeed unless more teachers are hired, and the schools are strengthened and given support to accomplish their basic educational goals.

The TKCP's conservation education component is led by Debra Williamson, a middle school teacher from Federal Way, Washington State, USA. The goal of the education component is to first aid YUS local government area schools in developing basic literacy, then to introduce teachers and students to conservation concepts through targeted curricula. The TKCP is assisting community (primary) schools in the YUS local government area by donating school supplies, text and library books; by working with local teachers on incorporating conservation education curricula; and by establishing school exchanges between YUS and American schools. Collaborative efforts with the YUS local government have begun to help deal with the chronic teacher shortages by funding teacher training for qualified YUS students.

2.5 TREE KANGAROO BIOGEOGRAPHY, EVOLUTION, AND TAXONOMY

2.5.1 Distribution and physical description of tree kangaroos

The biogeography of Australian tree kangaroo species is fairly well known, but much less so for the New Guinea species. Australia is home to two species of tree kangaroos: Bennett's (*D. bennettianus*) and Lumholtz's (*D. lumholtzi*). Both species are found in the tropical rainforests of northern Queensland. *Dendrolagus bennettianus* occurs north of the Daintree

River to Mt. Amos, and from the coast westward to the Mt. Windsor Tablelands. *Dendrolagus lumholtzi* occurs in forests south of the range of *D.bennettianus*, primarily in the mountain forests of the Atherton Tablelands immediately to the west of Cairns, although its distribution once extended down to the coast (Newell, 1999a).

According to the most accepted taxonomy (Flannery et al., 1995) New Guinea is home to at least eight species of *Dendrolagus*. They are listed below along with recognised subspecies and approximate geographic ranges according to Flannery et al (1996), with relevant revisions. Three species are relatively widespread while the ranges of the other five are more restricted (see Appendix 2 for maps of New Guinea tree kangaroo distributions). Further details of the pelage and other physical characteristics of tree kangaroo species can be found in Table 2.4 below.

1. ***Dendrolagus inustus*** (Grizzled tree kangaroo). *Dendrolagus inustus* is found in the northern lowlands and Vogelkop (Birds-head) and Bomberai Peninsulas of Irian Jaya, and also occurs in the northern lowlands of Papua New Guinea (see Fig. 1, Appendix 2). It is primarily found in lowland and hill forest. There are two subspecies: *D. inustus finschi* and *D. inustus inustus*. *Dendrolagus inustus finschi* is confined to the northern lowlands of New Guinea from the Van Rees Mountains and Yapen Island in Irian Jaya eastward to Wewak, just west of the mouth of the Sepik River in PNG, while *D.inustus inustus* occurs on the the Vogelkop, Bomberai, and Wandammen Peninsula in Irian Jaya.
2. ***Dendrolagus ursinus*** (Vogelkop tree kangaroo). *Dendrolagus ursinus* is endemic to western Irian Jaya, occurring on the Vogelkop and Bomberai Peninsulas as well as east along the southern coast of the 'Birds-Neck' isthmus as far as Etna Bay (see Fig. 4, Appendix 2). Throughout most of this area it occurs sympatrically with *D. inustus inustus* in hill forests as low as 800 m, but its range extends to higher altitude montane forests (2500 m), and it is less common at lower altitudes than *D. inustus*.
3. ***Dendrolagus goodfellowi*** (Goodfellow's tree kangaroo). The distribution of *D. goodfellowi* is centred on the New Guinea central cordillera, but it also extends north

to some of the island's outlying ranges (see Fig. 2, Appendix 2). Recent findings indicate that a tree kangaroo similar, if not the same as *D. goodfellowi* occurred on Irian Jaya's Bird's Head Peninsula as recently as the Quaternary (Aplin et al., 1999). *Dendrolagus goodfellowi* occurs primarily in lower to mid-montane rainforest, especially in *Castanopsis* (oak) - rich forests, from 500-2680 m. It is found at lower elevations than *D. dorianus* although there is usually a zone of altitudinal sympatry. There are three recognised subspecies of *D. goodfellowi.* The critically endangered *D. goodfellowi pulcherrimus* occurs in the Bewani and Torricelli Mountains of the North Coastal Ranges, and there are reports that *D. goodfellowi pulcherrimus* or perhaps another undescribed *D. goodfellowi* subspecies occurs in the Foya and Van Rees Mountains of northern Irian Jaya. If this still undescribed population is *D. goodfellowi pulcherrimus* then the conservation status of the species may have to be revised. The other two subspecies – *D. goodfellowi goodfellowi* and *D. goodfellowi buerguersi* - are confined to the central cordillera of PNG. *Dendrolagus goodfellowi goodfellowi* occurs on the southeast peninsula, primarily in the Owen Stanley and Bowutu Mountains, while *D. goodfellowi buergersi* occupies the mountains to the west, terminating near the Irian Jaya border. It remains unknown from the central cordillera west of the Irian Jaya border.

4. ***Dendrolagus spadix*** (Lowland tree kangaroo). This species, which some researchers have previously considered to be con-specific with *D. goodfellowi* and *D. matschiei,* is confined to the lowlands of southern PNG, from the forests just to the east of Lake Murray eastwards to at least the Purari River (see Fig. 2, Appendix 2). The biology of *D. spadix* is poorly understood but it is not known to occur in areas with significant human populations and it is said to prefer limestone karst areas, especially the Great Papuan Plateau, from near sea-level to 800 m.
5. ***Dendrolagus matschiei*** (Huon, or Matschie's tree kangaroo). This species (which some researchers have considered to be conspecific with *D. goodfellowi* and *D. spadix)* is endemic to the Finisterre, Saruwaged, Cromwell, and Rawlinson Mountains of the Huon Peninsula of northeast PNG (see Fig. 2, Appendix 2). It also occurs in the

mountains of nearby two offshore islands: Umboi and New Britain. Umboi and New Britain have never ever had any terrestrial connection to New Guinea, so their *D. matschiei* populations are probably introduced. *Dendrolagus matschiei* is the only tree kangaroo in its range, and it is the only tree kangaroo species in PNG that occurs on offshore islands. It is monophyletic, and lives in lower montane to subalpine forest (1500-3300 m) although some researchers place the lower altitude at 1000 m. The altitudinal distribution of *D. matschiei* will be discussed further in Chapter 5.

6. ***Dendrolagus dorianus*** (Doria's tree kangaroo). *Dendrolagus dorianus* is found in the mid-montane and upper montane forests of New Guinea's central cordillera and one outlying range (see Fig. 3, Appendix 2). It was formerly known only from the PNG portion of the central cordillera, until it was discovered in Irian Jaya in 1994. Although *D. dorianus* has been found at altitudes as low as 500 m, it is commonly encountered much higher, where it favours mossy mid to upper montane forests. Where its geographic range overlaps with *D. goodfellowi*, *D. dorianus* is found at a higher altitude than *D. goodfellowi*, with some altitudinal sympatry in mid-montane forest. There are four subspecies of *D. dorianus*. Three are confined to the central cordillera, while one occurs in an outlying range. *Dendrolagus dorianus dorianus* is found in southeast PNG in the Owen Stanley Mountains. *Dendrolagus dorianus notatus* occurs in the PNG Central Highlands, from the Wau area west to the Strickland River. *Dendrolagus dorianus stellarum* is found from the Victor Emmanuel Range (just east of the Strickland River) westwards into Irian Jaya at least as far as the Wissel (Paniai) Lakes. *Dendrolagus dorianus mayri* is the only subspecies known to occur beyond the central cordillera. It is found in the coastal Wondiwoi Mountains of Irian Jaya, and is only known from one specimen making it the least known of the tree kangaroo taxa.
7. ***Dendrolagus scottae*** (Scott's tree kangaroo, Tenkile and Fiwo). This species has the most restricted range of any tree kangaroo, occurring only in the northern coastal ranges of PNG (see Fig 4, Appendix 2). There are two forms: the nominate form, 'Tenkile' (*D. scottae*), known only from the slopes of Mount Somoro in the Torricelli

Mountains, and 'Fiwo' (*D. scottae* subsp. indet.), which occurs on Mt. Menawa in the Bewani Mountains near the Irian Jaya border. The total known range of these two taxa is no more than 100 km^2, and their phylogenetic relationship is unclear. Tenkile and Fiwo favour mossy forest, from 1200 m to the summits of their respective peaks at 1500 m and 2000 m.

8. ***Dendrolagus mbaiso*** (Dingiso). This is the most recently recognised species, only described in 1995 (See Fig 4, Appendix 2). It appears to be confined to the Snow (Sudirman) Mountains of Irian Jaya at altitudes as low as 2700 m, but primarily above 3200 m, up to treeline at 4200 m. It favours steep, rocky terrain, in elfin forest or scrub.

Table 2.4 Tree kangaroo pelage adapted from Flannery et al. (1996)

Taxa	Pelage	Other distinguishing characters
D. bennettianus	Lower back and hind limbs gray, belly and chest dark gray/black, shoulders reddish.	Large (up to 14 kg). Prominent tuft of hair at base of tail.
D. lumholtzi	Back gray, belly and chest cream, face dark grey, pale forehead band (adults only)	Small (5-7kg). Tuft of hair at base of tail.
D. inustus inustus	Back gray, belly light-grey or cream. Forehead gray or brown.	Large (up to 17kg). Ears point to the side. Large callosity at base of tail.
D. inustus finschi	Back gray, belly light-grey or cream. Forehead black.	Large. Ears point to the side. Large callosity at base of tail.
D. ursinus	Back, limbs, and tail black. Tip of tail white to cream. Chest and belly light brown. Cheeks white to red.	Tufted ears.
D. goodfellowi goodfellowi	Two yellow stripes on lower back. Tail yellow with brown bands. Back and face brown. Forearms yellow with some darker hairs.	Distinguished from *D. goodfellowi buergersi* by larger size (>9kg).
D. goodfellowi buergersi	Two yellow stripes on lower back. Tail yellow with brown bands. Back and face brown. Forearms yellow with no darker hairs	Distinguished from *D. goodfellowi goodfellowi* by smaller size (<9kg).
D. goodfellowi pulcherrimus	Two yellow stripes on lower back. Tail dark brown with white bands. Upper back and shoulders yellow. Lower back brown. Face pinkish, ear margins white.	

Taxa	Pelage	Other distinguishing characters
D. spadix	Chestnut fur, lighter on belly. Occasionally has yellow ring at base of tail.	Fur is short and thin.
D. matschiei	Back chestnut to dark brown. Belly yellow. Tail yellow without markings. Distinctive white/yellow markings on face and ears.	
D. dorianus dorianus	Uniformly brown in colour. Yellow patch on upper surface of base of tail.	Distinguished from *D. dorianus notatus* by larger size.
D. dorianus notatus	Uniformly brown in colour. Yellow ring around base of tail.	Distinguished from *D. dorianus dorianus* by smaller size.
D. dorianus stellarum	Fur brown with some grey 'frosted hairs' on back, limbs , and tail. Tail has yellowish tinge.	Distinguished from *D. dorianus notatus* by heavy grey 'frosting'.
D. dorianus mayri	Torso fur brown, limb and tail base fur reddish with some grey 'frosted hairs' on back, limbs, and tail.	
D. scottae, Tenkile	Black fur on back, brown on limbs and belly with yellow patch on upper surface of base of the tail.	Strong body odour. Distinguished from Fiwo (*D. scottae* sp. indet.) by its larger size (9 - 11.5 kg).
D. scottae sp. indet., Fiwo	Black fur on back, brown on limbs and belly with yellow patch on upper surface of base of the tail.	Distinguished from Tenkile (*D. scottae)* by its smaller size (6.7-9.5 kg).
D. mbaiso	Black fur on back. Belly fur white. White 'star' on forehead and band around muzzle	Shortest tail of any tree kangaroo

2.5.2 Evolution of tree kangaroos

The evolutionary history of tree kangaroos is as poorly understood as their natural history. Fossil evidence indicates that they evolved relatively recently, and perhaps surprisingly, that they may have originated in southeastern Australia. The earliest known tree kangaroo fossils are tooth fragments found near Hamilton, Victoria. They have been dated to roughly 4 million years ago and came from animals that were small, roughly the size of today's *D. lumholtzi*. The earliest fossil of a more complete skeleton are the 2 million year old remains of a giant tree kangaroo named *Bohra paulae* which was found in the Cathedral Caves near Wellington, New South Wales. This animal was twice as large as any living *Dendrolagus*, and this along with its anatomical distinctiveness is what led its discoverers to place it in a new genus. No tree kangaroo remains of similar age are known from Queensland, or from

New Guinea. Whether radiation occurred in Pliocene southern Australian tree kangaroos in the same manner that one sees in today's New Guinea is unknown, as is the existence of tree kangaroos on New Guinea at that time (Flannery et al., 1996; Flannery and Szalay, 1984).

New Guinea's mammalian fossil record is not extensive. This is due in large part to the island's geological youth and tectonic dynamism. In the case of tree kangaroos a further difficulty is the rarity of fossil deposits from montane ecosystems, which based on current distributions, are the ecosystems where tree kangaroo radiation has been most extensive. The oldest mammalian fossil site known for New Guinea is the 3.1 million years old Otibanda formation. The Otibanda fauna is dominated by Diprotodonts (an extinct group of herbivorous marsupials) and forest wallabies (*Protemnodon* spp.). There is no evidence of tree kangaroos. However, the fauna was most likely a lowland one, and perhaps unsuited for tree kangaroos. The earliest New Guinean tree kangaroo fossils are much younger. They were excavated from the Nombe Rock Shelter in PNG, and are of Holocene age having been dated to approximately 24,000 to 14,000 years ago. These animals are very similar to today's *D. dorianus* but were appreciably larger in size, perhaps indicating that hunting pressure has led to the 'dwarfing' of present day animals (Flannery et al., 1996; Marshall and Corrruccini, 1978).

In the absence of fossils, researchers have had to turn to molecular evidence for clues to tree kangaroo phylogeny and evolution. Aplin (1993) has compared the serum albumin relationships of Australian and New Guinea mammals. He postulates three migration and dispersion time periods when Australian mammals colonised New Guinea. The first, at 20 million years ago, saw the arrival of the bandicoots (Peroryctidae) and Cuscus (Phalangerinae). The second, at 10-12 million years ago, saw the arrival of many of the ringtail possums (Pseudocheirids), trioks/long-tailed possums (Dactylopsilines), forest wallabies (*Dorcopsis*), and some of the predatory Dasyuridae. The final event took place approximately 4.7-2.7 million years ago and saw the arrival of *Dendrolagus* and the remaining Dasyurids. One striking fact about this dispersion is the limited set of marsupial families and lineages within each family that were able to establish themselves in New Guinea. This was despite the fact that New Guinea and Australia have been connected several times since the early Miocene. Flannery (1996) has attributed this to the island's geologic history. New Guinea has undergone very rapid tectonic evolution since the beginning of the Miocene, as Pacific island arcs collided with the Australian plate and new mountain ranges arose. During this time New Guinea was not a single geologic entity, but rather a shifting combination of colliding terranes and young mountain ranges and islands. Given the dynamic tectonic conditions dispersion would have been difficult and nascent mammalian faunas could have been subject to stochastic extinctions (Aplin et al., 1993; Flannery, 1996; Pigram and Davies, 1987).

Therefore, based on current evidence it appears that tree kangaroos arose approximately 4 million years ago in the Pliocene forests of southeastern Australia (which were as temperate then as they are today) then dispersed north into Queensland and New Guinea where they radiated further. Tree kangaroos are now extinct in Southern Australia. They are believed to have died out there as forests retreated during drying episodes associated with Quaternary glaciation. Whether the vegetational changes associated with this drying was sufficient to render the animals extinct or whether it was associated with other causes, such as predation by human hunters, is not known. (Dodson, 1989; Flannery et al., 1996).

Evolution and evolution may have and may still be occurring at a rapid rate in tree kangaroos. One recent DNA hybridisation study of the evolution of the marsupial lineages places the divergence between *D. inustus* with *D. matschiei* and *D. dorianus* at only 1.99 million years before present, and the split between *D. matschiei* and *D. dorianus* at 1.33 million years (Kirsch et al., 1997). There is also evidence that present day tree kangaroo taxa are evolving and diverging. This can be seen especially in *D. dorianus*. Matthew Kawei of the University of PNG (1989) examined the distinctiveness of two subspecies of *D. dorianus* (*D. dorianus dorianus* and *D. dorianus notatus*) by comparing skull and pelage characteristics of the two subspecies. The skulls of *D. dorianus dorianus* were found to be significantly (10%) longer and wider than *D. dorianus notatus* skulls. Pelage differences were also noted; for example, tail colour is uniform in all specimens of *D. dorianus dorianus* but exhibit striking individual variation in *D. dorianus notatus*. The known ranges of the two taxa meet in southeastern PNG but do not overlap (Kawei, 1989). The differences between the two taxa that Kawei's results documented are supported by the observations of Phillip Leahy, who has a captive collection *of D. dorianus* with individuals from both subspecies at his farm in Zenag, Morobe Province. Flannery et al. (1996) report that Leahy has observed that individuals from *D. dorianus notatus* will not breed with individuals from *D. dorianus dorianus*, and Leahy has since confirmed these observations to the author. The genetic distinctiveness of different taxa of *D. dorianus* has also been highlighted in a study by Jocelyn Bowyer of MacQuarie University. Bowyer's (2000) comparisons of mitochondrial cytochrome B gene sequences of various species of tree kangaroos have shown greater average sequence divergence between *D. dorianus stellarum* and *D. dorianus notatus* (6.5%) than between *D. goodfellowi* and *D. matschiei* (4.8%). A further surprising result from this study was the very large sequence divergence within one subspecies, *D. dorianus stellarum.* The divergence between specimens from Tembagapura, Irian Jaya at the western edge of the taxa's range and a specimen collected at the eastern edge near Telefomin, PNG was 6.9%. Thus based on anatomical, behavioural and genetic data it is entirely possible that at least some of the subspecies of *D. dorianus* are in fact full species and in the case of *D. dorianus stellarum*, further taxonomic division maybe required (Bowyer, 2000).

The differentiation of *D. dorianus* populations has occurred despite the fact that the ranges of the different taxa are virtually contiguous (except for the isolated *D. dorianus mayri* of the Wondiwoi Mountains in northern Irian Jaya), with few geographic barriers that separate one form from another. This pattern of east-west geographic differentiation of central cordilleran taxa is also seen in New Guinea birds, especially among the birds of paradise, another dynamic, relatively recently evolved vertebrate group. Central cordilleran Birds of Paradise have evolved into 'species complexes', with closely related species within the complex replacing one another as one moves west to east along the cordillera, and with daughter subspecies and species evolving after dispersing to the outlying ranges (Frith and Beehler, 1998). Jared Diamond (1972) has posited a mechanism which he calls the 'drop-out phenomenon', in which stochastic local extinctions of poorly dispersing species could break up and isolate contiguous populations and thus allow evolutionary divergence to occur. It is possible that similar events have triggered differentiation in the Doria's complex (Diamond, 1972).

2.5.3 Tree kangaroo taxonomy

This thesis has used Flannery et al.'s (1996) classification of tree kangaroo taxa (see Table 2.5), which divides tree kangaroos into ten species and 17 subspecies. An earlier phylogeny by Groves (1982), developed before the discovery of *D. scottae* and *D. mbaiso*, is more conservative, grouping *D. matschiei*, *D. goodfellowi*, and *D. spadix* as as one species (*D. matschiei*). Flannery disputes this, asserting that *D. spadix* and *D. goodfellowi buergersi* are allopatric across a broad range with no known hybrids (Flannery et al., 1996). In the case of *D. matschiei* and *D. goodfellowi*, Groves acknowledges that there are significant differences in the relative tail-lengths and the forelimb to hindlimb ratios in the two taxa.

Table 2.5 Tree kangaroo taxa (Flannery et al., 1996)

Species	Subspecies
Dendrolagus lumholtzi	
Dendrolagus bennettianus	
Dendrolagus inustus	*Dendrolagus inustus inustus*
	Dendrolagus inustus finschi
Dendrolagus ursinus	
Dendrolagus matschiei	
Dendrolagus goodfellowi	*Dendrolagus goodfellowi goodfellowi*
	Dendrolagus goodfellowi buergersi
	Dendrolagus goodfellowi pulcherrimus
Dendrolagus spadix	
Dendrolagus scottae	*Dendrolagus scottae*
	Dendrolagus scottae subsp. indet.
Dendrolagus mbaiso	
Dendrolagus dorianus	*Dendrolagus dorianus notatus*
	Dendrolagus dorianus stellarum
	Dendrolagus dorianus dorianus
	Dendrolagus dorianus mayri

Bowyer's (2000) genetic analysis by supports Flannery's more liberal classification. The results of Bowyers' examination of tree kangaroo mitochondrial cytochrome B gene sequences shows a 4.8% divergence between *D. goodfellowi*, *D. spadix*, and *D. matschiei*, equivalent to the divergence seen between *D. lumholtzi* and *D. bennettianus* (Bowyer, 2000; Groves, 1982).

Groves (1982) hypothesised that tree kangaroos shared a common ancestor with forest wallabies (*Dorcopsis* and *Dorcopsulus*) of New Guinea, with the implication that tree kangaroos evolved in New Guinea before dispersing to Australia. However, more recent serum immunological and DNA hybridisation studies have shown that tree kangaroos are most closely related to present-day rock wallabies (*Petrogale* and *Petrodorcas*), with a estimated divergence date of 7.19 million years ago. This date is more in accord with the fossil evidence that tree kangaroos originated in Australia, then dispersed to New Guinea (Baverstock et al., 1989; Kirsch et al., 1995; Kirsch et al., 1997).

Both Flannery et al. (1995) and Groves (1982) divide tree kangaroos into two groups, primitive and derived. The primitive group consists of the two Australian species *D. bennettianus* and *D. lumholtzi*, and one New Guinea species, *D. inustus*. The derived group includes the other New Guinea species. The derived group can be further divided into the Goodfellow's, and Doria's species complexes, with *D.ursinus* remaining as the most primitive member of the group. *Dendrolagus ursinus* is confined to the Vogelkop Peninsula of western Irian Jaya, perhaps indicating that the derived group evolved there. The Goodfellow's complex is comprised of *D. goodfellowi*, *D. matschiei*, and *D. spadix*. The Doria's complex includes the various *D.dorianus* taxa, *D. scottae*, and perhaps *D. mbaiso* (Flannery et al., 1996). Table 2.6 lists the primary anatomical differences between the two groups.

Table 2.6 Anatomical comparisons of 'primitive' and 'derived' tree kangaroos (Flannery et al., 1996)

Character	Primitive	Derived
Foot-Length	Long	Short
Ankle facet	Transverse calcaneal-astragal facet	Diagonal calcaneal-astragal facet
Fourth Toe Length	Fourth toe much longer than fifth	Fourth toe just longer than fifth
Toe pad	No crease on pad under last two phalanges of the toes	Crease on pad under last two phalanges of toes
Tibia-fibula contact	Extensive contact between the lower portions of the tibia and fibula	Very little contact between the tibia and the fibula
Tibia/Femur Ratio	Long tibia relative to femur	Short tibia relative to femur
Gait preference	More often hops than walks, even in tree tops	Walks more often than hops.
Location of hair whorl	Behind shoulders	Centre of back (*D. goodfellowi, D. matschiei*) Root of tail (*D. dorianus, D. scottae*)

More recent research by Iwaniuk et al (1998) has revealed another difference between the two groups. Comparisons of captive *D. lumholtzi* and *D. matschiei* highlighted differences in forepaw anatomy between the two species, as well as differences in the preferred methods used to grasp objects. Both species can grasp objects using one forepaw in a 'whole hand' grasp, where the object is grasped between the claws and the palmar pad. However, *D. matschiei* is more likely to use this technique while *D. lumholtzi* favours a 'scissor grasp', where objects (usually leaves) are held between the third and second digits. The interpretation of this result is that *D. lumholtzi* uses the scissor grasp more often because it is more of an obligate folivore than *D. matschiei*, whose diet is said to possibly include some frugivory. However, it could also be argued that whole hand grasping is a more derived characteristic than scissor grasping, and that the derived group of tree kangaroos show adaptations to make this more possible. This is supported by the fact that although all tree kangaroos have longer claws and larger palmar pads compared to those of other macropods, there are also significant differences between the different tree kangaroo species. *Dendrolagus lumholtzi*, a member of the primitive group, has shorter claws, longer digits, and a shorter, less differentiated palmar pad in comparison to *D. matschiei*, a member of the derived group. In other words, *D. lumholtzi* forepaws are more similar to that of other macropods than to *D. matschiei*. Although suggestive, further interspecies comparisons need to be undertaken before grasping behaviour can be shown to be a differentiating factor between the primitive and derived groups (Flannery et al., 1996; Iwaniuk et al., 1998).

It is interesting that the primitive group consists only of the Australian and a single lowland New Guinea species. This agrees with the hypothesis that tree kangaroos originated in Australia, dispersed to the lowlands of New Guinea, then into the island's mountains where they radiated further. Many of the adaptations in the derived group, like the shortened tibia/femur ratio, the shortened and broadened foot, and the change in gait preference, are indicative of a further shift to arboreal existence. One question is why the one representative of the primitive group found in New Guinea, *D. inustus*, is confined to the western and northern lowlands of the island. One would expect that the ancestral New Guinea populations crossed over a land-bridge between present day Australia and southern New Guinea sometime during a glacial maxima, but the only species of tree kangaroo known from the southern lowlands, *D. spadix*, is a member of the derived group. A possible explanation is that New Guinea has experienced several dry periods during Pleistocene glacial maxima, when lowland rainforest on the island was reduced to relict patches in the north and west. During these periods southern New Guinea was covered by grassland and mixed savanna, and any ancestral 'primitive' tree kangaroos could have gone extinct at this time (Flannery et al., 1996; Maynes, 1989).

However, the recent results from Bowers' (2000) genetic studies have shown that the dualistic division of tree kangaroos into primitive and derived groups maybe overly simplistic. Bowers' sequencing of the cytochrome B gene in tree kangaroo mitochondrial DNA (all species with the exception of *D. ursinus* and *D. scottae*) indicates that *D. inustus* is more closely related to other New Guinean species than to its fellow primitive group members in Australia, *D. bennettianus* and *D. lumholtzi*. In addition, the results show that the Doria's complex (not including *D. mbaiso*) is very distinct from the other New Guinea species, and may have diverged earlier. The Goodfellow's complex (*D. goodfellowi*, *D. spadix*, and *D. matschiei*) is distinct as well. The relationships between these two groups and *D. inustus* and *D. mbaiso* are not clear. As discussed above the Doria's complex shows very high inter- and intra-taxa diversity. This suggests that the Doria's lineage may have split from the ancestral New Guinea tree kangaroo stock before *D. inustus*, thus raising the possibility that genetically *D. dorianus* is not a part of the same derived group as the Goodfellow's complex, *D. ursinus*, or even *D. mbaiso* (Bowyer, 2000).

2.6 TREE KANGAROO NATURAL HISTORY

2.6.1 Anatomy and physiology

The ancestors of kangaroos were small, arboreal, and possum-like. As Australia dried during the late Oligocene and early Miocene, the ancestral macropods became terrestrial and adapted to life on the grasslands. Their hindlimbs and feet grew longer, their ankles became laterally inflexible, their tails rigidified, and their jaw and teeth structure adapted to grazing. Tree kangaroos have reversed this course. They have returned to the trees, and now show a number of adaptations, or readaptions to arboreal life, including shortened, broadened feet that can move independently (walk), a more flexible ankle joint, a more mobile, less muscular tail, shortened hind limbs, longer, more powerful, and dextrous forelimbs, greater stereoscopic vision, a reduction in overall muscle mass, and a relocated hair whorl. These changes in the macropod body plan allow tree kangaroos to walk (instead of just hop), climb tree trunks, move about in the canopy, grasp branches and leaves to feed, and to rest comfortably in the tree tops (Flannery et al., 1996; Grand, 1990).

The tree kangaroo's transition to a more folivorous, 'browsing' diet has led to modifications in their teeth morphology. The premolars are enlarged, sharp (for shearing thick stems), and high- crowned and thus also suited for puncturing and shredding leaves. The molars are low-crowned (and thus not suited for extensive grinding) but have sharp ridges suitable for further dissecting leaves (Flannery et al., 1996; Sanson, 1989). Rainforest leaves are lower in energy and significantly higher in toxins than grasses, and tree kangaroos have partially modified their digestive organs to deal with the challenges of leaf eating in varying degrees. Lumholtz's tree kangaroo shows the least adaptation and the derived group of tree kangaroos, especially the Doria's species complex, and *D. mbaiso* in particular, show the greatest adaptation with greatly enlarged guts. The gut of *D. mbaiso* makes up nearly 50% of the animal's body weight (Flannery et al., 1996). The large gut of tree kangaroos serves an additional purpose in that it makes them better at processing more fibrous plant foods than smaller folivores such as ringtail possums (Pseudocheiridae). Studies in Australia have confirmed that tree kangaroos eat leaves and stems with a higher fibre content than those consumed by possums (Procter-Gray, 1990).

The reduced energy inherent in the folivorous diet has led tree kangaroos to make another physiological adaptation, lowering their metabolic rate. An example of this can be seen in *D. matschiei*, which has a basal resting metabolism only 70% of the red kangaroo (*Macropus rufus*), despite the fact that average body mass of *D. matschiei* is less than half that of *M. rufus*. *Dendrolagus matschiei* metabolism is significantly lower (84%), than the value expected for like-sized marsupials and only 55% of the value for a like-sized placental mammal. (Flannery et al., 1996; McNab, 1988). In contrast to most mammals, *D. matschiei* can maintain a constant core temperature while lowering their metabolism as ambient temperatures drop. Their metabolic rates show a two-fold reduction, from 0.205 cm^3 $O^2/g{\bullet}h$ at 27° C, to 0.088 cm^3 $O^2/g{\bullet}h$ at 7° C, and this lowered rate holds steady as the temperature continues to fall, before rising again at temperatures below 2° C. The metabolic rate reduction is accomplished by progressively restricting blood flow to the skin and limbs, which cools these areas and lowers thermal conductivity. A number of other arboreal folivores, such as the red panda (*Ailurus fulgens*) show a similar metabolic pattern. Reduced metabolism at lower temperature maybe a conservation measure as part of a low energy survival strategy (McNab, 1988).

It is not known if tree kangaroo basal metabolism varies from species to species, but captive *D. inustus* are active for longer periods of time than *D. dorianus*, perhaps indicating differing metabolic rates. One explanation for this difference is that lowland species such as *D. inustus* would not face low temperatures in the wild, especially early in the morning and late in the afternoon. Thus *D. inustus* would not need to conserve energy (through lowered metabolic rates) to the same degree as montane species such as *D. dorianus* (Flannery et al., 1996; McNab, 1988).

2.6.2 Reproductive biology

The distinctiveness of tree kangaroos extends to their reproductive biology. Unlike other macropods, tree kangaroos do not exhibit embryonic diapause, a mechanism which female kangaroos use to delay the development of an embryo during droughts and other stressful conditions. Instead the tree kangaroo reproductive cycle seems to be more reflective of the groups low metabolic rate strategy. Matschie's tree kangaroos have an oestrous cycle of 54-55 days, approximately two lunar months, one of the longest of any marsupial (Dabek, 1994). Typical kangaroos have much shorter oestrous cycles, for example 35 days in red kangaroos (*Macropus rufus*). Matschie's tree kangaroo has a gestation period of 44-45 days, which is the longest known for any marsupial. Most kangaroos have a gestation period of a little over a month, for example 31-32 days in yellow-footed rock wallabies (*Petrogale xanthopus*). Tree kangaroo joeys also develop more slowly than most other macropods, although the difference is not as pronounced as the difference in oestrous cycles and in gestation time (Strahan, 1995).

Like other marsupials, tree kangaroo joeys are born in an immature state. After birth they must crawl into their mother's pouch and attach themselves to the teat. In Matschie's tree kangaroos this normally takes about 2.5 minutes. They first venture out from the pouch at six months and leave permanently at nine to ten months. They remain 'at foot' for several months afterward, leaving their mother sometime between one to two years, with female joeys tending to remain with their mother for longer periods of time. Births are spaced 12 to 18 months apart. Female tree kangaroos reach sexual maturity at three years of age, males at approximately two years. (Dabek, 1994; Flannery et al., 1996; Strahan, 1995).

2.6.3 Social behaviour

There is little observational data on tree kangaroo social behaviour in wild New Guinea populations, but Australian studies indicate that Lumholtz's and Bennett's tree kangaroos are less social than terrestrial kangaroos. Both females and males are solitary. The only long-term social relationship is the one between a mother and her joeys. Female tree kangaroos avoid contact with each other, but males will fight, presumably over access to females. Females have been reported to occasionally gather together with their joeys, and males and females have been shown to form temporary 'consort relationships' which last for up to two days when the female is in oestrous, but these relationships are short-term in nature (Flannery et al., 1996; Procter-Gray, 1985).

The relatively low level of social behaviour seen in Australian tree kangaroos has been observed in captive studies of one New Guinea species, *D. matschiei* (Hutchins et al., 1991). However there is other evidence that some of the New Guinea tree kangaroos maybe more social than Australian species and that sociability may vary between species. Evidence for interspecies variation can be seen the marked difference in average sexual dimorphism among the species, with the ratio of male/female bodyweight ranging from 1.3-1.5 in *D. inustus*, *D. bennettianus*, and *D. scottae*, to 0.9-1.0 in *D. matschiei* and *D. goodfellowi*. Some species such as *D. goodfellowi* and *D. matschiei* have distinctive and individual facial and fur markings that may serve a social purpose: white marks on the face for *D. matschiei*, and tail rings for *D. goodfellowi*. *Dendrolagus scottae* and *D. dorianus* also have distinctive social characters. *Dendrolagus dorianus* and *D. scottae* have the smallest relative testicle size, which combined with pronounced sexual dimorphism supports the possibility that dominant males have sole mating rights with females in their territories or social groups. The two species also have strong body odours, which maybe used for sexual and/or social cues. Hunters report that Fiwo, the undescribed population of *D. scottae*, will occasionally gather in mixed sex groups of up to six individuals, while captive *D. dorianus* are reported to live in 'one male groups', with a single dominant male having sole mating rights with several females (as in gorillas). Adults in these groups are relatively social and will even play with each other and juveniles. (Flannery et al., 1996; Flannery and Seri, 1990).

Another potential influence on tree kangaroo social behaviour is human hunting pressure. As noted above, Fiwo (*D. scottae* sp. indet.), which lives in an area of low human population and low hunting pressure, is reputed to be quite sociable. However, the other form of *D. scottae*, Tenkile, is said to be solitary. Tenkile's circumscribed range is surrounded by several human settlements and is under intense hunting pressure, and it is possible that one response to this pressure is for animals to avoid congregating. A similar reason for solitary behaviour among *D. inustus* is given by hunters who report that males from that species avoid proximity to females with joeys (Flannery et al., 1996).

2.6.4 Feeding ecology

Tree kangaroos are adapted to a 'browsing' feeding style and thus have dentition that are effective at cutting thick stems, puncturing leaves and grinding plant matter (Sanson, 1989). Their large gut allows them to process more fibrous plant foods than smaller folivores such as ringtail possums (Pseudocheiridae), which has been confirmed by researchers working with Australian tree kangaroos (Procter-Gray, 1990). Australian tree kangaroos are known to eat leaves, shoots, and vines from several species of plants, but food plant data are minimal for most New Guinea species. For example, there is no information on the wild diets for any *D. dorianus* taxa. A captured juvenile female *D. scottae* was observed to eat vines from genus

Scaveola and Tetracera, as well as leaves from *Asplenium* spp. ferns. The animal did not eat large amounts of any one species, a behaviour characteristic of arboreal folivores (Glander, 1977). Both *D. inustus* and *D. ursinus* are said to prefer leaves but will also ingest fruit (primarily figs) and flowers as well. *Dendrolagus goodfellowi* also appears to be at least partially frugivorous. Animals have been observed eating fig fruits in captive settings and seeds have been found in a wild caught specimen's caecum. On the other hand, *D. mbaiso* appears to be a near obligate folivore, and its gut size reflects this; the digestive system comprises up to half of the animal's bodyweight (Flannery et al., 1996; Flannery and Seri, 1990). Chapter 4 will report new findings on the diets of *D. matschiei*, *D. goodfellowi buergersi*, and *D. dorianus notatus*.

An additional dietary capability that some New Guinea species may possess is carnivory, although this behaviour has never been observed in the wild. The behaviour seems to be most common in *D. matschiei* and *D. goodfellowi*, although captive *D. inustus finschi* are known to eat boiled eggs and mealworms (but to reject chicken meat). In one case a captive *D. matschiei* even captured and ate a Nicobar Pigeon (*Caloenas nicobarica*), and captive *D. matschiei* and *D. goodfellowi buergersi* are said to relish chickens and eggs. Carnivory has not been noted in other species (Flannery et al., 1996; Steenberg, 1984).

The feeding data for Australian species is more complete. Elizabeth Procter-Gray (1985) recorded 75 observations of *D. lumholtzi* feeding. In 74 of those instances the animal was feeding on leaves, and 90% of the leaves were mature. Gut contents of a captured *D. lumholtzi* revealed nothing but leaves. More recent observers have recorded *D. lumholtzi* eating some fruit and flowers, but leaves still comprise more than 90% of the diet. Mature tropical forest leaves are high in secondary defensive compounds. In order to distribute the toxin load, Lumholtz's tree kangaroo might be expected to follow the dietary strategies of other arboreal folivores such as Howler monkeys (*Aloutta* spp.) and eat small portions from a wide variety of food plants (Glander, 1977). This appears to be the case. *Dendrolagus lumholtzi* is known to eat at least 70 species of plants from 39 families. Common species consumed by *D. lumholtzi* include ribbonwood (*Idiospermum* spp.), milky pine (*Alstonia scholaris*), milk bush (*Neisosperma poweri*), white apple (*Syzygium forte ssp. forte*), pepper vines (*Piper* spp.), figs (*Ficus obliqua*, *Ficus superba*), umbrella tree (*Schefflera actinophylla*), and nutmeg (*Myristica insipida*). *Dendrolagus bennettianus* is also primarily folivorous, but its diet appears to include more fruit than *D. lumholtzi*, with the fruits of Australian olive (*Olea paniculata*) and various fig species (Moraceae) being favoured (Flannery et al., 1996; Procter-Gray, 1990; Tree Kangaroo and Mammal Group, 2000).

2.6.5 Activity, movement patterns, and home ranges

Tree kangaroos are less active than other kangaroos. Procter-Gray and Ganslosser (1986) found that based on 428 hours of observation, *D. lumholtzi* spend 61% of their time asleep/resting, and even when awake were active (feeding, moving, grooming, interacting socially) only 10% of the time. This lack of activity is probably due to the animals' lowered metabolic rate that is in turn reflective of the greater digestive demands of a folivorous diet. The same pattern of extended inactivity to allow digestion is seen in other arboreal folivores such as Howler monkeys (*Aloutta* spp.) which spend 63 to 79% of their time resting (Crockett and Eisenberg, 1987; Flannery et al., 1996; Procter-Gray and Ganslosser, 1986).

Daily movement patterns are fairly well known for the Australian species. *Dendrolagus bennettianus* is nocturnal, commencing its feeding rounds roughly two hours after sunset. This behaviour exists despite the fact that *D. bennettianus*, like other tree kangaroos, is not fully adapted for nocturnalism, because it lacks the *tapetum lucidum* cell layer in its retinas which nocturnal mammals such as possums and cats use to improve night vision. *Dendrolagus lumholtzi* has not been shown to have any significant pattern to its feeding or other non-rest periods, but it is more likely to change locations during the night (Flannery et al., 1996; Martin, 1996; Procter-Gray and Ganslosser, 1986).

In contrast to the Australian tree kangaroos, most New Guinea species are crepuscular or diurnal. Fischer (1992) radiotracked a *D. dorianus notatus* and documented that it was most active between 07:00-11:00 and 16:00-20:00, and never active between 20:00 and 07:00. In captivity *D. goodfellowi buergersi* appears to be crepuscular, but some wild populations near human populations are said to be nocturnal, perhaps an adaptation to hunting pressure. *Dendrolagus ursinus* is essentially diurnal in captivity. A radiotracked *D. scottae* showed a crepuscular or diurnal activity pattern, and both *D. inustus inustus* and *D. dorianus dorianus* are reported to be crepuscular in captivity (Flannery et al., 1996).

Laurance (1990) found that *D. lumholtzi*'s nocturnal activity was unaffected by precipitation, but Fischer's (1992) radiotracking of *D. dorianus notatus* as well as Flannery's (1990) radiotracking of a single *D. scottae* indicate that the animals are less active during rainy periods. This agrees with McNab's (1988) data on *D. matschiei*'s metabolic response to lowered temperature, which shows that the animals lower metabolic rates (and therefore activity and movement capability) with lowered temperatures. Seasonal movement patterns of tree kangaroos are not well documented, but Torricelli Mountain hunters report that during rainy periods tree kangaroos will move out of gullies and up onto ridge-tops (Flannery et al., 1996; Laurance, 1990; McNab, 1988). Further information on tree kangaroo activity patterns can be found in Chapter 5.

Australian studies indicate that tree kangaroos have home ranges. Female tree kangaroos are sedentary, inhabiting small non-overlapping home ranges. Male home ranges are larger, overlapping with several female home ranges, and males are more mobile, often entering other males' ranges. Procter-Grey (1990) recorded average female and male home ranges of 1.8 ha and 4.8 ha, for *D. lumholtzi* living in fragmented forest. *Dendrolagus lumholtzi* appear to be strongly attached to their home ranges. Newell (1999b) has documented how animals refused to leave their home ranges even after their forested habitat had been clear-felled. *Dendrolagus bennettianus* female home ranges have been measured at 5.5 to 10 ha for females and 3.8 to 29.8 ha for males, with young and post reproductive males occupying smaller home ranges. Overall density has been estimated to be approximately 0.3 animals/ha (Martin, 1993). Attempts to determine home ranges of New Guinea species have met with little success with the exception of a single reading of approximately 25 ha for a *D. matschiei* of unrecorded sex (Flannery et al., 1996; Procter-Gray, 1990; Stirling, 1991).

2.6.6 Predation and predator avoidance

During the Pliocene and Pleistocene the chief predator of tree kangaroos were probably the now extinct 'marsupial wolves' or 'Tasmanian tigers' (*Thylacinus* spp.) which ranged over most of Australia and New Guinea. Another extinct Australian predator which may have killed tree kangaroos were the marsupial 'lions', *Thylacaleo* spp., whose limb structure suggests that they were capable of climbing trees. If so, these leopard-sized predators would have presented a real threat to tree kangaroos (Wroe et al., 1999). Martin (1996) speculates that the threat of *Thylacaleo* could have led to the development of tree kangaroos 'great leap' escape strategies (see below). Although current day Australian and New Guinean rainforests do not have any native large mammalian predators, tree kangaroos still face predatory threats in the wild. In Australia the chief threat to tree kangaroos comes from dingos and feral dogs, as well as large pythons such as Amesthytine Pythons (*Morelia amethistina*), which have been observed to eat Bennet's tree kangaroos (Martin, 1995; Martin, 1996).

In New Guinea, the primary predator of tree kangaroos is man, or more accurately, the human-dog partnership. It is this combination that threatens the survival of tree kangaroos on the island. Other possible tree kangaroo predators include Amethystine Pythons in lowland habitats and the New Guinea Harpy Eagle (*Harpyopsis novaeguineae*) in both lowland and montane forests. Harpy Eagles are known to kill possums, giant rats, forest wallabies and small pigs. They should be capable of killing tree kangaroos, especially joeys. Landowners in the Telefomin region of western PNG state that the eagles do kill tree kangaroo joeys but this remains undocumented in the wild (Coates, 1985; Flannery, 1998). It is also possible that tree kangaroos living at lower elevations, such as *D. inustus* and *D. spadix*, are preyed upon occasionally by large monitor lizards (Varanideae). One of these lizards, Salvadori's Monitor (*Varanus salvadorii*), is partially arboreal and is known to reach lengths in excess of 3 m. Its hunting habitats are poorly known, but it does feed on small mammals, and it is possible that it could kill young tree kangaroos (Bennett, 1999).

Tree kangaroos possess defences against predators. When cornered they are effective fighters, able to use their strong, clawed fore-limbs and projecting incisors to inflict grievous wounds on both canine and human foes. Many hunters (and their dogs) bear scars from run-ins with the animals (Flannery et al., 1996). If a tree kangaroo wishes to escape from a tree it will resort to the 'great leap', where the animal jumps to the ground from heights of up to 23 meters, and then attempts to escape with high speed hopping like other kangaroos. This unique behaviour is possible because of the robustness of the marsupial pelvic architecture (including bone extensions called epipubes which extend forward and down from the pubic bones and help support the viscera), whose strength in females is not compromised by the need for a large birth canal, and by the heightened strength of the tree kangaroo femur (Barbour, 1977; Flannery et al., 1996).

As stated previously tree kangaroos are known for their elusiveness. Martin (1996) and others have attributed this to sustained human hunting pressure, and he gives human hunting pressure as the explanation for why Bennett's tree kangaroo may have evolved dark fur on its belly and chest - as a means of avoiding detection by human hunters on the ground. Martin (1996) has also hypothesised that tree kangaroos may be more intelligent than other marsupials (based on higher encephalization ratios) and thus more able to modify their behaviour to deal with the human threat. Another example of tree kangaroo adaptation to human hunting pressure is the adoption of nocturnal activity patterns by some *D. goodfellowi* populations in the PNG highlands (Flannery et al., 1996).

Additional evidence that tree kangaroos' cryptic behaviour may be an evolved or learned response to human disturbance and predation comes from natural history observations in regions with no history of human hunting. In such areas tree kangaroos do not hide from human beings. The evidence for this comes from Jared Diamond's 1979, 1981 and 1993 ornithological survey expeditions to the uninhabited Foya and van Rees Mountains in northern Irian Jaya, where he also observed tree kangaroos (probably *D. goodfellowi*) and other mammals. Diamond (1981) reported that he was able to approach within 10 meters of a tree kangaroo without it making any attempt to flee. Diamond's experiences suggest that much of tree kangaroo 'invisibility' is a behavioural adaptation to human hunting pressure. Another example of tree kangaroo naiveté in the absence of human predation is the behaviour of *D. mbaiso*. Hunters report that the animal can be captured on the ground by simply walking up to it and slipping a looped vine around its head, or by luring it into reach with tempting leaves. Dingiso only occurs in rough, broken terrain at high altitudes in Irian Jaya's Snow (Sudirman) Mountains. Its fearlessness indicates that it may have limited or only recent experience with human hunters (Diamond, 1981; Diamond et al., 1999; Flannery, 1993; Flannery et al., 1995).

Like other regions of the world, the Australasian region experienced a wave of extinctions at the close of the Pleistocene epoch. The extinctions roughly coincide with the arrival of the first *Homo sapiens sapiens*. This has led observers such as Diamond (1989) and Flannery (1994) to argue that the arrival of modern humans in 'new lands' such as Australasia, was the primary cause for the extinction of the megafauna, such as the large herbivorous Diprontodontids, which were common in both Australia and New Guinea. Recent discoveries have tightened the temporal link between human arrival in Australasia and megafaunal extinction, and it now appears that most of the Australasian mammalian megafauna went extinct because of human hunting or human caused disruption of native ecosystems (Roberts et al., 2001).

Although tree kangaroos managed to escape extinction at the close of the Pleistocene, there is evidence that their average size declined, a phenomenon called 'time dwarfing'. Like the Pleistocene extinctions, time dwarfing is attributed to the impact of human hunters. The remains of a *D. dorianus* found at Noibano Rock Shelter in PNG have teeth approximately 12% longer than present day animals, indicating an animal 30% heavier than today's. The effects of time dwarfing can also be seen in a number of extant Australian marsupial species such as the agile wallaby (*Macropus agilis*), the eastern grey kangaroo (*Macropus giganteus*), and the Tasmanian devil (*Sarcophilus harrisii*), all of which have experienced body size reductions of 20-30% over the last 40,000 years (Flannery, 1994; Marshall and Corrruccini, 1978).

2.7 PREVIOUS FIELD RESEARCH ON TREE KANGAROOS

The history of tree kangaroo field research is not lengthy. The earliest scientific description of a tree kangaroo was of *Dendrolagus ursinus* by Dutch scientist Coenraad Jacob Temminck in 1836. The other species were first described in the following order:

- *Dendrolagus inustus*: 1840, Müller
- *Dendrolagus dorianus*: 1883, Ramsay
- *Dendrolagus lumholtzi*: 1884, Collett
- *Dendrolagus bennettianus*: 1887, De Vis

- *Dendrolagus matschiei*: 1907, Förster & Rothschild
- *Dendrolagus goodfellowi*: 1908, Thomas
- *Dendrolagus spadix*: 1936, Troughton & Le Souef
- *Dendrolagus scottae*: 1990, Flannery & Seri
- *Dendrolagus mbaiso*: 1995, Flannery, Boeadi & Szalay

The chronology of discovery and description of tree kangaroo species roughly follows the course of exploration and colonisation in Australia and New Guinea. Thus the description of *D. ursinus* and *D. inustus* correspond with the first Dutch attempts to establish permanent settlements in western New Guinea, *D. dorianus* with the establishment of the British colony on the southeast coast of the island, *D. lumholtzi* and *D. bennettianus* with the first scientific explorations of the northern Queensland rainforests, *D. matschiei* and *D. goodfellowi* with further explorations of the near coastal mountains of the Huon Peninsula and the Owen Stanley Mountains, and *D. spadix* with the first European foot patrols of the Great Papuan Plateau in southern New Guinea. However, these initial inventories of New Guinea's fauna were incomplete, and scientists often did not work closely with knowledgeable local informants, so *D. mbaiso* and *D. scottae* remained unknown until the late 1980s. Today there are still areas of New Guinea that are poorly known to outsiders, especially in Irian Jaya, and it is possible that unknown tree kangaroo taxa remain to be discovered in these areas (Flannery et al., 1996; Sekhran and Miller, 1994; Supriatna et al., 1999).

Long-term field-studies of tree kangaroos did not begin until the 1980s when Procter-Grey (1986) began her work on *D. lumholtzi* and Martin (1996) studied *D. bennettianus*. Their work in Australia was extended in the 1990s by the research of Graeme Newell (1999a) on *D. lumholtzi* in the mid-90s, and the data collection of the Tree Kangaroo and Mammal Group Inc. up to the present day (Schmidt et al., 2000).

In New Guinea, Flannery and Seri (1990) discovered Seri's tree kangaroo (*D. dorianus stellarum*) in 1987, followed by the Tenkile (*D. scottae*) in 1988, and the Fiwo (*D. scottae* sp. Indet.) in 1989. The discovery of *D. scottae* led to a period of intensive research on that species and the discovery of *D. goodfellowi pulcherrimus* in the North Coast Ranges in the early 90s. During this period, Fisher and Austad (1992) radiotracked a *D. dorianus notatus* at

Mt. Stolle in the Western Highlands of PNG, and Liam Stirling (1991) led an Oxford University expedition to radiotrack *D. matschiei* in 1991. Flannery, Boeadi, and Szalay (1995) discovered Dingiso (*D. mbaiso*) in 1994, and did some field studies on the animal in that year and in 1995-1996. The most extensive and long-term studies of tree kangaroos have been those of Procter-Grey, Martin, Newell, and the Tree Kangaroo and Mammal Group of Atherton Tablelands Inc. on the Australian species; Flannery on Tenkile and Dingiso; and the work of the Tree Kangaroo Conservation Program on *D. matschiei*, and to a lesser extent *D. goodfellowi* and *D. dorianus* (Dabek and Betz, 2001). The Australian researchers managed to obtain home range sizes, and to identify some of the food plants. Flannery was unable to obtain home ranges for Tenkile, but he did determine the species' conservation status, and documented some food plants and seasonal movement patterns. Stirling's work suffered from limited field time but he did manage to obtain one tentative home range (Flannery et al., 1996).

All tree kangaroo field researchers have been hampered by the animals' cryptic behaviour, and in the case of the New Guinea by the difficult field conditions and terrain which characterise the island. In addition, Procter-Gray, Martin and Flannery recognise an 'observer effect', where the researcher's presence causes the animals to change their behaviour (Flannery et al., 1996; Procter-Gray and Ganslosser, 1986).

It is clear that there is a need for long-term research on virtually all topics of New Guinea tree kangaroo biology. Perhaps the most important from a conservation standpoint is determining tree kangaroo population status. Chapter 3 will report the results and discuss the efficacy of using distance sampling analysis of tree kangaroo dung pellet counts to estimate local population densities.

Another topic is tree kangaroo feeding ecology. The present state of knowledge is rudimentary with little information on what plants New Guinea tree kangaroos actually eat. In the absence of direct observation, one source of information is the traditional knowledge of New Guinea's people who have lived in intimate association with the island's plants and wildlife for thousands of years and whose knowledge of tree kangaroo feeding ecology is only partially tapped. Chapter 4 will give landowner information on food plants eaten by Matschie's, Goodfellow's, and Doria's tree kangaroos.

The traditional knowledge of landowners extends to other aspects of tree kangaroo biology besides feeding ecology, and landowners are also potentially useful sources of information on tree kangaroo conservation status. Chapter 5 will report results and evaluate the effectiveness of landowner interviews by the author and UPNG students to determine the conservation status of Matschie's tree kangaroos, as well as document traditional knowledge of Matschie's, Doria's and Goodfellow's tree kangaroos' natural history.

CHAPTER 3 ESTIMATION OF NEW GUINEA TREE KANGAROO POPULATION DENSITIES USING DISTANCE SAMPLING ANALYSIS OF DUNG PELLET COUNTS

3.1 INTRODUCTION

New Guinea's tree kangaroos (Marsupialia: Macropodidae, *Dendrolagus* spp.) are considered to be the most endangered group of mammals on the island [(Mittermeier et al., 1997); see also Sect. 2.1.2 herein]. In many areas, the animals are now rare or locally extinct, and some taxa, such as Scott's tree kangaroo (*Dendrolagus scottae*), face imminent extinction (Flannery et al., 1996). However, there are little quantifiable data on tree kangaroo populations, and there are no estimates of population density. The number of tree kangaroos a unit area of New Guinea forest can support remains unknown, and data are necessary in order to estimate species populations, conservation status, and habitat requirements in order to plan protection efforts. This chapter reports results that begin to address this question, and evaluates the utility of the method used, distance sampling analysis of dung pellet counts from point transects.

The objectives for this chapter are to:

1. Report on attempts to estimate tree kangaroo dung pellet densities from four different sites in PNG.
2. Estimate tree kangaroo densities for those sites where sufficient observations of pellets were made.
3. Discuss the utility of the methods employed, and suggest possible alternatives or solutions to problems encountered.

Tree kangaroos are cryptic and it is difficult to estimate populations or densities by counting the animals themselves. The author has only observed four wild tree kangaroos (and only two without using dogs), in approximately 50 weeks of field work over five field seasons in PNG, an experience that is not atypical [(Beehler, 1991a); see 2.7]. It is relatively easy to locate tree kangaroos with hunting dogs, but that approach is undesirable for two reasons. The first is that it presents excessive risk to the tree kangaroos, either from stress or self-inflicted injuries sustained while under pursuit, or from the bites of dogs. The second is that it alters the behaviour of the tree kangaroos, either by chasing them out of the area or by inducing them to hide in the treetops, which makes accurate population estimates difficult to achieve (Flannery, 1998).

The concerns over tree kangaroo safety and the desire to minimise effects on their behaviour led to an attempt to estimate their populations indirectly. Dung pellets were chosen as the best marker for tree kangaroos because of their abundance and because they are sufficiently distinctive to be identifiable. Additional reasons for collecting pellets were the potential opportunities that they offer for genetic research as well as for the identification of tree kangaroo food plants. Other markers that were considered and rejected were feeding sites, because of the inability of the researchers and local informants to distinguish between the feeding sites of tree kangaroos and that of other mammals, and claw marks and tracks because they were too infrequently encountered to produce good population estimates.

Tree kangaroo dung pellet counts were undertaken and density estimates were made using point transect distance sampling. Other pellet sampling methods were considered but were rejected as being unsuitable for field conditions and/or limited in their effectiveness. One technique considered was strip transects, in which searchers walk along a transect line and locate objects within a set distance, or strip width, of the line. However, in order for strip transects to produce accurate estimates, all objects, in this case tree kangaroo dung pellets, within the strip width must be observed, a near impossibility given the difficulty of the terrain and thickness of vegetation that characterises many New Guinea montane habitats. In addition, the use of strip transects does little to assist efforts to characterise the vegetation and habitats of a given area (Sutherland, 1996).

A second technique considered was sample plots, which have been used in Australia to count dung pellets for various species of macropods (Johnson and Jarman, 1987; Vernes, 1999). Unlike strip transects, the use of sample plots allows habitats to be characterised, and doesn't require observers to search while walking through the field area. The method is suitable in Australia because the groundcover in many of the forests is not prohibitively thick and pellets are easily located (L. Dabek, pers. comm.). However, sample plots, like strip transects, are unsuited for conditions in montane New Guinea, because the thick undergrowth often precludes observing all pellets in the plot. By contrast, distance sampling using point transects allows accurate estimation even in areas where the difficulty of making observations precludes all objects (dung pellets) from being observed. It also allows the full variety of habitats to be sampled and described (Buckland et al., 1993; Sutherland, 1996).

Another reason for choosing distance sampling is that the technique is more resistant to differences in observer capability. Distance sampling, unlike strip transects and sample plots, allows observers with different skill levels (different observational ability) to calculate similar results so long as the following conditions are met:

- All objects close to the line or point are detected, or the detection probability, g(x), at the point can be assumed to be 1. If it is not possible to detect all observations, the rate of missed observations must be known, so that the value of g(x) can be recalculated.
- Accurate measurements of horizontal distances are made from the sample point or line to the observation.
- Sufficient observations are made. Distance sampling normally requires a minimum of 60 to 80 observations to produce significant results.

Distance sampling is usually performed using one of two methods: line or point transects. The two approaches can be considered to be outgrowths of strip transect and variable circular plot surveys respectively (Buckland et al., 1993). Line transects require an observer/observers to walk along a marked line and record horizontal distances and radial angles to objects as they are encountered. It is the preferred method for counting most animals, and can be used for a counting a wide variety of readily visible wildlife (O'Brien and Kinnaird, 2000). It allows all observations made within the transect area to be recorded, providing that measurements are made to the point where an animal is first encountered or 'flushed'. It can also be used to estimate the population of immobile wildlife markers such as gorillas sleeping nests or elephant dung (Barnes et al., 1997b; Hall et al., 1998).

The second distance sampling method is point transects, in which observers search at designated survey points arrayed at fixed distances along a series of transect lines. Point transects are the preferred method for estimating many bird populations (Walker and Cahill, 2000), and are also preferable in areas that are difficult to traverse (and therefore adequately survey), with the proviso that observations made between survey points along transect lines can not be recorded (Buckland et al., 1993).

The author tested the line transect method during a pilot study in 1996 at the Dendawang field site (see site description below). He was unable to observe tree kangaroos and found that the line transect method was unsuitable for locating tree kangaroo dung pellets, because of the difficulty of searching while moving through thickly vegetated and uneven terrain. These problems led to a switch to a point transect method in 1997. The point transect method was suitable but other problems more specific to New Guinea field conditions delayed the successful implementation of the technique. The 1997 surveys were problematic because the drought caused by the strong ENSO (El Niño Southern Oscillation) climatic event caused anomalous field conditions, and a landowner dispute between two villages led to the loss of a field site. This loss of the field site was remedied in 1998 by the identification of the Sibidak field site (see description below), but the disappearance of a local child near Dendawang led to disruption of the site and fieldwork, as villagers searched for the lost child. Searchers repeatedly entered the transect area with dogs thereby comprising the integrity of the site. Not until 1999 did fieldwork proceed smoothly at Sibidak and Dendawang and useful results were achieved in that year and in 2000. The success of fieldwork in 1999 and 2000 was due in large part to the decision of Keweng 1 villagers to fully involve themselves in the research by learning distance sampling techniques and assisting the author with surveys.

The two other sites, Semia and Tomongan (see descriptions below) were established in 1998 and 1999 respectively. Tomongan was surveyed in October 1999, while Semia was surveyed in December of 1999.

3.2 METHODS

3.2.1 Study areas

Distance sampling was undertaken at four field sites in PNG. The first site covering approximately 39 ha was located in an area called Dendawang (S 6^{0}04.84' E 146^{0}34.32'). The second site covering approximately 23 ha was in an area called Sibidak, (S6^{0}04.29 E 146^{0}33.62'), separated from Dendawang by a narrow valley. The two sites were located in the upper Bunum River valley of the eastern Finisterre Mountains of the Huon Peninsula, approximately 20 km south of the government station of Teptep. Altitudes at the two sites ranged from 2300 to 2600 m. Vegetation at the two sites is similar and consists of mid-montane forest with thick undergrowth. The area experiences frequent disturbances (landslides, blow-downs) so there are large areas of regenerating forest and successional areas dominated by ferns and shrubs. Common canopy trees include *Dacrydium* (Podocarpaceae), *Astronidium* (Melastomaceae), *Litsea* (Lauraceae), *Mallotus* (Euphorbiaceae), *Caldcluvia* and *Weinmannia* (Cunoniaceae) with *Dacrydium* appearing to be more common than in most other New Guinea sites of similar altitude. Common subcanopy trees include *Symplocus* (Symplocaceae), *Astronidium* (Melastomaceae), *Prunus* (Rosaceae), *Dendrocnide* (Urticaceae), *Schizomeria* (Cunoniaceae), and *Pandanus* (Pandanaceae) (Steve Mckenna, pers. comm.). The area is habitat for Matschie's tree kangaroo, *Dendrolagus matschiei*, which is the sole tree kangaroo species found on the Huon Peninsula. A total of 52 transect lines (32 Dendawang, 20 in Sibidak), and 961 survey points (609 in Dendawang, 352 in Sibidak), have been established. The area is owned by landowners from the Jang and Umbewa clans from the village of Keweng 1.

The third site, also in *Dendrolagus matschiei* habitat, is called Tomongan. It lies on the ridge-crest of Kwaimkwaim Mountain (S 6^{0}20.09' E 147^{0}18.21'), in the Cromwell Mountains of the eastern Huon Peninsula. It is near the upper Mongi River, approximately 11 km north-northwest of the village of Nomaneneng, and covers an area of approximately 18 ha at altitudes ranging from 2400 to 2600 m. The site is steeper than Dendawang and Sibidak, and the forest at this site is taller and more closed, with lower proportions of *Dacrydium* and a higher proportion of *Podocarpus* and *Libocedrus*. The site has 295 sampling points on 15 transect lines. It is owned by landowners from the village of Nomaneneng.

The fourth area, called Semia, is just south of the upper Je River on the slopes of Kolevotai Mountain in the Crater Mountain Wildlife Management Area (S 6^{0}34.73' E 145^{0}00.59'). It covers an area of approximately 70 ha at altitudes ranging from 1400 to 2150 m. It is inhabited by two species of tree kangaroos, *Dendrolagus goodfellowi buergersi*, and

Dendrolagus dorianus notatus. The Semia site has 40 transect lines and 655 sample points. It is owned by landowners from the village of Maimafu.

The four sites were surveyed between July 1999 and August 2000. However, only the Dendawang and Sibidak sites produced sufficient tree kangaroo dung observations to enable statistically significant density estimations.

3.2.2 Dung collection and distance sampling

Transect lines were cut at right angles from a baseline at measured 50 m intervals from a random starting point. Distance sampling allows regular grids to be used so long as the grid is placed randomly over the study area. Survey points were marked along these lines at 15 m intervals. Lines varied in length from 10 to 32 survey points with the majority containing 15 to 20 points (~225-300 m). No allowance was made for slopes in measuring between lines and points, but slope angles were recorded with a clinometer to be used to determine horizontal line and point spacing by trigonometry, so that area measurements for the sites could be calculated. Points were marked by labelled flagging tape tied to a pole.

The area surrounding the survey points was searched for tree kangaroo and other mammal dung pellets by two person observer teams with a third person occasionally present to record data. The search time was four minutes per point as timed by a digital wristwatch with a countdown timer. Searching was performed in a manner consistent with distance sampling practice, with observers making their greatest search effort at or near the point followed by progressively more distant semicircular searches around the point. Pellets encountered after the search period or while walking between the survey points were not recorded. Horizontal measurements were made from the survey point to each pellet found, or if a cluster of pellets, to the centre of the cluster. Slope angles were recorded (for later trigonometric conversions) where excessive slopes made horizontal measurements unfeasible. The numbers of pellets in clusters were recorded, as were pellet characteristics: age, colour, fibrousness, substrate, and evidence of decay. Linear measurements were made on all tree kangaroo pellets, fresh as well as decomposed, and fresh samples were collected and stored in 90% ethanol for future genetic and dietary studies.

Although all tree kangaroo pellet observations and their distances to the survey points were measured, only the observations of fresh pellets were used in density calculation. This was because landowners were not confident that they could distinguish between older pellets of tree kangaroos and those of the New Guinea pademelon (*Thylogale browni*), another macropod inhabiting the site. Typically, fresh tree kangaroo dung pellets were firm and olive-green in colour with a slightly shiny surface, while old dung tended to be brown, dull surfaced, and in various stages of decay due to rain, fungal growth, and dung beetles. Fresh pademelon dung pellets tended to be softer, less strongly segmented, more cylindrical in cross-section, darker green in colour, and smaller in diameter than tree kangaroo dung pellets. Landowners attributed these differences in pellet size and morphology to the smaller average body size of pademelons, and to pademelons favouring more succulent and less fibrous vegetation than tree kangaroos.

Qualitative habitat characteristics (slope, canopy height and closure, undergrowth thickness, presence/absence of deadfalls and surface water) were recorded at each point to check for possible correlation with dung location. Maximum search distance varied from point to point in proportion to the thickness of the vegetation: from less than two meters for areas with thick undergrowth, to as much as seven meters at flat, sparsely vegetated points.

Initially all data recording were done by project scientists, volunteers, and UPNG students, while landowners only assisted in searching for the dung. However, in July 1999, representatives from the Umbewa and Jang Clans of the village of Keweng 1 (the owners of the Dendawang and Sibidak field sites) were trained in measurement techniques, sample preparation and data entry. They successfully surveyed the Dendawang and Sibidak field sites in January 2000, and again in August 2000 under the supervision of the author and UPNG student Kasbeth Evei. The training and deployment of local observer teams allowed the 961 points at Dendawang and Sibidak to be surveyed in two (Sibidak) to four to five (Dendawang) days. Sample gathering would typically begin the afternoon of or the morning after the arrival of the survey team. This was important because it minimised the 'observer effect', where the presence of human beings in an area causes tree kangaroos to modify their behaviour [(Flannery et al., 1996); see 2.7]. An additional reason for employing landowners to do the surveys was to build local support for conservation, a result that has been observed with other locally-based wildlife surveys (Marks, 1994).

Data were analysed using the program DISTANCE (Thomas et al., 1998). Horizontal distance measurements for all fresh tree kangaroo pellet clusters, and the number of pellets per cluster, were entered into the program. Density estimates were made to a 95 % confidence level using minimum AIC (Aikake Information Criteria) to choose from the best model (Uniform, Half Normal, Hazard Rate, Negative Exponential) and adjustment terms (cosine, simple polynomial, hermite polynomial) with no truncation of measurements. Data from the Dendawang and Sibidak sites were pooled; this was possible because in both 1999 and 2000 the sites gave similar density estimates when calculated alone. The dung pellet density estimates were then divided by the captive tree kangaroo pellet production rate and measured pellet alteration time (see below) to produce an estimated animal density. Other statistical analyses for captive dung production, dung alteration time and correlation were calculated with Microsoft Excel and Statview.

3.2.3 Determination of pellet production rates for captive tree kangaroos

Captive tree kangaroo faecal production rates were measured during a six-day study at the Zenag captive facility at Zenag, Morobe Province. Daily pellet production was monitored for 18 individuals of four species: seven *D. matschiei*, seven *D. goodfellowi*, three *D. dorianus*, and one *D. inustus*. The Zenag tree kangaroos were held in roofed earthen floor pens separated by wire chain-link walls. They were fed twice a day with a mixture of wild and cultivated vegetation, usually a mixture of stems and leaves from wild *Piper* spp., *Secchium edule* (a vine used as a vegetable throughout New Guinea), and sweet potato (*Ipomea batatas*) cuttings and tubers. Pellets were counted twice a day, at approximately 07:00 hrs local time and again at 15:00 hrs, just before the animals were fed, and pellets found were removed from the pens. Pellet clusters were not counted, because the density of pellets in the pens as well as the displacement of pellets by animal movements made cluster identification problematic. The study may have been biased towards adult animals – only three of the 18 animals were joeys (one *D. goodfellowi* and two *D. matschiei*). Table 3.1 shows that deposition rates varied from 26 pellets/animal/day for *D. matschiei* to 44 pellets/animal/day for the single *D. inustus*.

Table 3.1 Average daily dung pellet production rates of captive tree kangaroos at Zenag, PNG

Species	No. of animals	No. of days	No. of pellets	Daily rate per animal (pellets/dy)	95% confidence interval (pellets/dy)	Standard deviation (pellets/dy)
D. inustus	1	6	262	43.6	N.A.	± 7.4
D. goodfellowi	7	6	1468	35	± 6.9	± 7.5
D. dorianus	3	6	600	33.3	± 11.5	± 4.6
D. matschiei	7	6	1093	26.0	± 4.6	± 5.0

3.2.4 Determination of dung pellet alteration rate

Attempts to estimate wildlife density via dung pellet counts usually include separate studies to determine dung disappearance rates. Tree kangaroos normally share their habitat with pademelons (*Thylogale* spp.), forest wallabies that overlap with tree kangaroos in body mass (Flannery, 1995). Pademelon dung pellets can be confused with tree kangaroo pellets, especially if the pellets are old or decaying. In order to avoid this confusion, this study restricted itself to new or 'fresh' tree kangaroo dung pellets (see 3.3.4 for further discussion), and thus determining the disappearance rate of tree kangaroo pellets became less important than the quantifying the 'alteration rate' (from 'fresh' to 'old') of pellets. Faecal alteration rates were observed in August-September of 2000 at the Dendawang field site. Thirty new tree kangaroo pellets were monitored over a one week period. Fifteen pellets were placed in closed forest and 15 in an open clearing. Five pellets from each area were placed in protected areas, such as the undersides of logs. The pellets were examined daily and rated for colour, consistency, moisture, presence/absence of fungus and insects, and most importantly for subjective age. Subjective age was determined by landowners involved in the dung sampling work; typically the transition from fresh to old was reflected by a change in pellet morphology from intact to fragmented, olive-green to brown or black, and shiny to dull. The results, as shown in Table 3.2, are consistent with landowner estimates of a three-day alteration time from 'fresh' to 'old'. As expected, dung pellets placed in protected areas inside the forest stayed fresh longer than pellets in exposed open areas, but the difference (0.8 days) was less than one day.

Table 3.2 Alteration times ('fresh' to 'old', in days) of *Dendrolagus matschiei* dung pellets at Dendawang field site, 26 August to 1 September 2000 (mean, 95% confidence interval and standard deviation from 30 samples)

Locations	Number of samples	Average days 'fresh'	95% confidence interval (days)	Standard Deviation (days)
Exposed Forest	10	3	± 0.3	0.5
Protected Forest	5	3.6	± 0.6	0.5
Exposed Open	10	2.8	± 0.3	0.4
Protected Open	5	3.2	± 0.6	0.5
All	30	3.1	± 0.2	0.5

3.3 RESULTS AND DISCUSSION

Distance sampling analysis of dung sampling from the Dendawang and Sibidak field sites indicate high Matschie's tree kangaroo densities from the upper Bunum River valley of the Huon Peninsula. Surveys from the Semia and Tomongan sites did not produce sufficient dung pellet observations to allow the calculation of statistically significant density estimates.

3.3.1 Abundance estimates at the Dendawang and Sibidak field sites

The results of distance sampling analysis of the dung sampling results (see Tables 3.3 and 3.4) from the Dendawang and Sibidak study sites indicate high *D. matschiei* densities in the upper Bunum River Valley.

Table 3.3. *Dendrolagus matschiei* dung pellet density estimates, 95% confidence limits (CL), and encounter rates for combined Dendawang and Sibidak sites (961 survey points)

Survey Date	Density (pellets/ha)	Lower CL density (pellets/ha)	Upper CL density (pelllets/ha)	Number of observations	Encounter rate (observations/pt)
7/99	109. 8	68.2	176.7	70	0.073
1/00	51.3	33.5	78.4	77	0.080
8/00	88.1	58.9	131.9	86	0.089

Table 3.4 Combined Dendawang and Sibidak *D. matschiei* animal density estimates

Survey Date	Dung density (pellets/ha)	Mean dung production rate (pellets/animal/dy)	Average dung alteration time (days)	Tree kangaroo density (animals/ha)	95% confidence interval (animals/ha)
7/99	109.8	26.0 ± 4.6	3.1 ± 0.6	1.4	± 0.7
1/00	51.3	26.0 ± 4.6	3.1 ± 0.6	0.6	± 0.3
8/00	88.1	26.0 ± 4.6	3.1 ± 0.6	1.1	± 0.5

The average density for the three trials was approximately 1 animal/ha. This is roughly equivalent to the density implied by the average home range of 0.87 ha/animal for six *D. lumholtzi* (five female, one male) recorded by Newell (1999b) in a small habitat fragment on the Atherton Tablelands in Queensland, and comparable to the density implied by the average home range of 1.8 ha/animal for three female and 4.8 ha for one male *D. lumholtzi* in a larger fragment on the Tablelands recorded by Procter-Gray (1990). It is denser than the abundance of 0.3 animals/ha calculated for *D. bennettianus* by Roger Martin (1993). The calculated density for Dendawang and Sibidak *D. matschiei* are much higher however, than the density indicated by the estimated home range of 25 ha for a *D. matschiei* radio-tracked by Stirling (1991). However, Stirling's animal could have been male (the sex was not recorded), which in Australian studies have been shown to have larger home ranges that encompass the home ranges of several females. The animal's movement pattern could also have been effected by post-capture stress, or by the presence of the trackers themselves (Flannery et al., 1996).

3.3.2 Abundance estimates from the Semia field site

The November 1999 survey at the Semia field site in Crater Mountain recorded fewer dung pellet observations than the surveys at the Dendawang and Sibidak sites. The presence of tree kangaroo dung pellets was correlated to altitude: although 19 *D. dorianus notatus* pellet observations were made at the higher elevation survey points between 1800 and 2100 m, *D. goodfellowi buergersi* pellets were nearly absent (three observations) at the lower elevation points of the study site. Only one observation was made below 1500 m. It is unlikely that tree kangaroos could have been driven or hunted out from the area. Local informants assured the author that no hunting had occurred at the site, and a *D. goodfellowi buergersi* had been photographed in the area during the previous year by UPNG student Kasbeth Evei. Furthermore, the absence of tree kangaroo dung pellets extended to other types of mammal dung, with no cuscus, wallaby, or rat dung pellets observed on the lower elevation transects, indicating that other factors besides hunting were responsible.

The most likely explanation for the lack of dung pellets at the lower altitudes of the Semia is a higher rate of faecal disappearance. The higher rate can be explained by three factors.

The first is that average temperatures are higher at the Semia site than at the Huon sites: 18-19^0 C at 1500 m at Semia versus 12-13^0 C at the 2400 m at Dendawang and Sibidak. The second is that precipitation is higher at Semia than at Dendawang and Sibidak; the Crater Mountain area is one of the wettest in New Guinea with annual rainfall in excess of 6 m versus approximately 3-4 m at the Huon sites (Barry, 1980). Average rainfall at the Semia site over a 13 day period in December 1999 was 17.1 mm/day, whereas average rainfall over a 19 day period in October 1999 at the Tomongan site on the eastern Huon Peninsula was 9.2 mm/day. Higher temperatures and heavier precipitation would lead to faster fungal and bacterial growth, and would also increase the rate of physical weathering of pellets, such that during heavy rains some of the softer pellets could be dissolved or washed away.

The third factor for the faster pellet disappearance rate at Semia was the obvious difference between the arthropod faunas of the Semia and the Huon sites. Terrestrial ants are abundant at Semia while the Huon sites have none visible on the forest floor at the survey altitudes of 2300-2600 m. The activities of the ants and dung beetles meant that pellet decomposition studies were not possible at the lower elevations (1400-1600 m) of the Semia site – there were no pellets observed. Fresh *D. dorianus notatus* pellets collected at 1900 m and placed on leaf litter at 1500 m were broken up and carried away by dung beetles and ants within nine hours.

Rapid faecal pellet breakdown and disappearance was a problem also encountered by Johnson and Jarman (1987) when studying red-necked wallabies (*Macropus rufogriseus banksianus*) and eastern gray kangaroos (*Macropus giganteus*) in mixed grassland-sclerophyll forest habitats in New South Wales. Pellet counts were not feasible during the warm, moist Austral autumn (April-June) because of the high rate of faecal disappearance, with 62% of the pellets gone within two days, and the highly variable rate of pellet disappearance (28.2% disappearance in long grass versus 62.1% in open areas). Because of these difficulties, Johnson and Jarman elected not to estimate populations for the Austral Autumn and to confine their calculations to the dry Austral winter period (June-August) only.

Dung pellet surveys will be repeated at the Semia site. If difficulties in locating pellets continue, then the use of dung pellet counts to estimate *D. goodfellowi buergersi* populations at lower elevations at Semia and at other sites will have to be reconsidered.

3.3.3 Abundance estimate from the Tomongan field site

The Tomongan site did not have the problem of excessively fast dung pellet decay that was observed at the Semia site. Like Dendawang and Sibidak, Tomongan temperatures were cool (7-20^{0}C) and coprophagous insect populations were sufficiently low to ensure that dung disappearance was not an important factor in density determination. Nevertheless, like Semia the number of pellet observations at Tomongan was insufficient for calculating significant density estimates (see Table 3.5). However, the observed pellet cluster encounter rates indicate that the pellet density at Tomongan could well be lower than that of Dendawang and Sibidak.

Table 3.5 *Dendrolagus matschiei* dung pellet density estimates and encounter rates for the Tomongan field site (295 points, confidence limit 95%)

Survey date	Pellet Density (pellets/ha)	Lower CL density (pellets/ha)	Upper CL density (pellets/ha)	Number of observtions	Encounter rate (observations/pt)
10/99	16.8	3.6	78.3	7	0.024

Dendawang and Sibidak together have 961 survey points. The 1999 and 2000 surveys at these sights produced 70, 77, and 86 fresh dung pellet cluster observations respectively, giving an average encounter rate of 0.081 observations/point. Only seven fresh dung cluster observations were made on Tomongan's 295 points, giving an encounter rate of 0.024 observations/point. If the 335% difference in dung encounter rates reflect real differences in tree kangaroo density between the two areas, then the Tomongan site may not be suitable for distance sampling. The number of points at Tomongan would have to be increased roughly tenfold (to 2-3000 points), or the results of multiple surveys would have to be pooled, in order to obtain the minimum number (60 to 80) of observations that distance sampling typically requires to achieve significant results. This would be prohibitively time consuming, unless very large observer crews were deployed (Buckland et al., 1993).

There could be several causes for the low encounter rates at Tomongan. One factor was the time constraints of the 1999 survey, which only allowed three weeks for developing and surveying the site. Because of this limitation, the dung pellet surveys were done a week after cutting the transect lines and marking the survey points. This may not have been sufficient time for any tree kangaroos present to resume normal activities. Another potential cause for the difference in encounter rates between Tomongan and Dendawang-Sibidak is differences in habitat. The Dendawang and Sibidak forests have less continuous canopies and a thicker understory than the forest at Tomongan (see 3.3.5). The greater luxuriance of terrestrial vegetation at Dendawang and Sibidak may provide more food and cover, and therefore allows denser tree kangaroo populations than at Tomongan. Finally, differences in hunting pressure must also be considered. Tree kangaroos are still being hunted at Tomongan whereas hunting at the clan-protected Dendawang and Sibidak sites ceased with the start of field studies in the area in 1996. The Tomongan population density could be depressed because of this hunting, or perhaps hunting has made tree kangaroos more wary.

3.3.4 Uncertainties in the density estimates and possible solutions

There are several uncertainties that could bias the tree kangaroo density estimates. Most of these would lead to an overestimate of animal abundance. The exception to this is the possibility that the dung pellet population was not fully sampled. Dung pellets were sought on the ground, or near the ground on boulder tops, logs or fallen trees. It was not possible to survey the forest mid-stage and canopy and thus the full three-dimensional environment that tree kangaroos inhabit could not be examined. Tree kangaroos spend many hours resting and feeding above ground [(Procter-Gray and Ganslosser, 1986); see 2.6.5]. Some tree kangaroo faeces could be deposited and remain in the treetops, for example on the large epiphytic mats found on many of the branches of larger trees, and therefore the complete population of tree kangaroo dung may not be sampled. This is particularly problematic if any arboreal pellets lie directly above (are horizontally on or close to the point) the survey point(s) because this would violate a key requirement of distance sampling, namely that g(x), the probability of detection, must be equal to 1 at the point, and very close to 1 near it (Buckland et al., 1993).

Several factors could produce an overestimation of tree kangaroo numbers. The first is that the dung pellet production rates of wild tree kangaroos may be higher than that of captive animals. Studies of red-necked wallabies (*Macropus rufogriseus banksianus*) and eastern grey wallabies (*Macropus giganteus*) have shown that pellet production rates estimated from captive animals are typically lower (up to 300%) than that of wild animals (Johnson et al., 1987). This discrepancy may be due to differences between wild and captive diets and activity patterns. In a recent Australian study, a captive wild-born *D. lumholtzi* fed a diet of known tree kangaroo food plants defecated at a rate of 96 pellets/day, much higher than the Zenag animals that were fed a mixture of wild and cultivated foods (K. Coombes, pers. comm.). It is thus possible that the defecation rates calculated from the Zenag study are an underestimate, and the Dendawang and Sibidak animal densities have been overestimated. A possible method to reduce this uncertainty would be to repeat the captive defecation study at Zenag solely with known wild food plants which would better mimic conditions in the wild.

Another potential cause of density uncertainty is misidentification of pellets. The landowners that work on the surveys are experienced hunters. They are accustomed to examining fresh faeces from killed animals, but they acknowledge that smaller tree kangaroo dung pellets are not always distinguishable from those of the New Guinea pademelon, *Thylogale browni*, and to a lesser degree the small dorcopsis, *Dorcopsulus vanheurni*. This overlap in appearance and size of macropod dung is not unique to New Guinea. It has also been noted by Australian researchers studying *D. lumholtzi* in habitats shared with the red-legged pademelon (*Thylogale stigmatica*) (S. Phillips, pers. comm.), and in habitats shared by the Parma's wallaby (*Macropus parma*) and the red-necked pademelon (*Thylogale thetis*) (Read and Fox, 1989).

Huon Peninsula landowners are confident that they can determine the identity of fresh dung pellets, but are less sure when evaluating older pellets. Thus the problem of pellet identification has an additional consequence in that it leads to reliance on fresh dung. It would be preferable to include older pellets in pellet density studies because pellet disappearance time estimates are less subjective than 'fresh' to 'old' alteration time estimates. In addition, the emphasis on fresh dung results in fewer observations and therefore less precision in dung density estimates. A potential solution for this problem is to identify the species by microscopic examination of associated hairs (swallowed during grooming) found in pellets. Hairs would be removed from the faeces, examined under a microscope, and compared with reference samples from tree kangaroo and pademelon (Brunner and Comam, 1974).

The final source of uncertainty is dung pellet decomposition times. Although the results of the August 2000 pellet alteration study at Dendawang supported landowner assertions of a three day alteration time, it is not possible to extend this finding to other sites. Pellet decomposition and alteration times are highly variable due to the effects of rainfall, temperature, sunlight exposure, arthropod (primarily dung beetle, termite and ant) activity, and dietary composition (White, 1993). The uncertainty is greater during periods of wet weather, because microclimate induced differences in faecal decay are accentuated. Australian researchers have acknowledged this concern with rainy season sampling and in some cases have chosen not to sample macropod dung during wet periods (Johnson and Jarman, 1987; Vernes, 1999). This strategy is appropriate in the more seasonal climates of Australian habitats with their predictable dry seasons. It is less practical for New Guinea montane rainforest habitats where the climate is normally wet, in which pronounced dry seasons occur in some years and not in others, and in which short dry periods can occur during any month. Given that weather cannot be relied on, and that during wet periods the dung decay rate may vary according to microhabitat, it will be very difficult to determine a single dung decay rate. Like previous studies with African forest elephants (Barnes et al., 1997a), long term decomposition or alteration time studies for tree kangaroo dung will have to be undertaken at a variety of altitudes and in a variety of rainfall regimes before there are sufficient data to make predictions of decay rates. Until those studies are performed, short-term decomposition/alteration studies will probably be required at every site, and indeed may have to be undertaken with each survey.

One solution to pellet decay uncertainty would be to remove all pellets from the survey points first, then wait a predetermined time before beginning pellet counts. This removes the imprecision of estimating dung decomposition rates, and if the fallow time is short there will be no concerns with some of dung being too altered to identify. In previous field seasons there were not enough field personnel to attempt this, but with the successful training of landowners from Keweng 1, it is possible the check the survey points at the Sibidak and Dendawang sites in four to five days. However, this method would not work if local tree kangaroos react negatively to human presence (by hiding in the trees or fleeing the area after the first survey), or if the disturbance to vegetation caused by the searchers kept animals from approaching survey points during the time period between surveys. Results from a second round of sampling undertaken in August 2000 at the Sibidak site indicate that this is the case. Although the animals did not leave the area, fewer pellet observations were made and virtually all observations were made at distances greater than four meters, indicating that the tree kangaroos were avoiding the survey points.

3.3.5 Habitat comparisons and correlation with pellet locations

One of the advantages of using a point transect methodology for dung pellet counts is the opportunity that it gives to characterise habitat. Unlike the continuous nature of line transects, the discrete nature of point transects allows generalisations about habitat to be made, and thus allows different sites to be compared. If continued for several years, it can also be used to track or calculate rates of habitat change and disturbance. More immediately the ability to characterise habitat gives an opportunity to look for correlations between habitat and pellet locations.

Observers rated each survey point for gradient, canopy closure, and undergrowth. Ratings were tri-level. Thus for gradient, observers graded points as flat ($0\text{-}5^0$), sloping ($5\text{-}25^0$), or steep ($>25^0$), for canopy closure observers graded points as closed, partially closed, and open, and for undergrowth observers graded points as having sparse, moderate, or thick undergrowth. Additional factors noted included undergrowth constituents such as ferns, shrubs, herbaceous (non-woody) plants, and vines, presence/absence of fallen trees, and presence/absence of surface water.

The ratings allow some generalisations and comparisons to be made about habitat in different field sites. Tomongan survey points are steeper, more close canopied, and have less undergrowth than do points at Dendawang and Sibidak. Table 3.6 lists gradient, canopy, and undergrowth characteristics for the Dendawang, Sibidak, and Tomongan field sites.

Table 3.6 Habitat characteristic proportions for three Huon Peninsula research sites.

Character/subcharacter		Saruwaged Mts. sites			Cromwell Mts.
		Sibidak (352 points)	Dendawang (609 points)	Dendawang/Sibidak combined (961 points)	Tomongan (295 points)
Gradient proportions (No. of points)	Flat	0.236 (83)	0.338 (206)	0.301 (289)	0.122 (36)
	Sloping	0.648 (228)	0.484 (295)	0.544 (523)	0.553 (163)
	Steep	0.116 (41)	0.177 (108)	0.155 (149)	0.325 (96)
Canopy cover proportions (No. of points)	Open	0.099 (35)	0.126 (77)	0.117 (112)	0.020 (6)
	Partial	0.622 (219)	0.567 (345)	0.587 (564)	0.129 (38)
	Closed	0.278 (98)	0.307 (187)	0.297 (285)	0.851 (251)
Undergrowth proportions (No. of points)	Sparse	0.159 (56)	0.138 (84)	0.146 (140)	0.546 (161)
	Moderate	0.52 (183)	0.432 (263)	0.464 (446)	0.261 (77)
	Thick	0.321 (113)	0.430 (262	0.390 (375)	0.193 (57)

There were insufficient pellets observed at Tomongan to allow for dung-habitat correlation to be evaluated. However, the 233 dung observations (at 176 points) made at Dendawang and Sibidak during three surveys in July 1999, January 2000, and August 2000 allow an analysis to be made of whether dung deposition is correlated to gradient, canopy closure, or undergrowth level. Table 3.8 lists the habitat subcharacteristic ratios of Dendawang and Sibidak's combined 961 points and then for the 176 points with dung observations and the 785 points where dung was not found.

Table 3.8 Habitat sub-characteristic proportions for points with and without dung at the combined Dendawang and Sibidak sites from pooled results of three surveys in 1999 and 2000.

Habitat character	Subcharacter	All points (961 pts)	Dung points (176 pts)	Non dung points (785 pts)
Gradient proportions (No. of points)	Flat	0.307 (289)	0.318 (56)	0.297 (233)
	Sloping	0.544 (523)	0.540 (95)	0.545 (428)
	Steep	0.155 (149)	0.142 (25)	0.158 (124)
Canopy cover proportions (No. of points)	Open	0.117 (112)	0.125 (22)	0.115 (90)
	Partial	0.587 (564)	0.557 (98)	0.594 (466)
	Closed	0.297 (285)	0.318 (56)	0.292 (229)
Undergrowth proportions (No. of points)	Sparse	0.146 (140)	0.142 (25)	0.148 (116)
	Moderate	0.464 (446)	0.483 (85)	0.460 (361)
	Thick	0.390 (375)	0.375 (66)	0.392 (308)

Pellets were observed more frequently at points that were flat, and less often at points that were rated as sloping or steep. Pellets were also more abundant in open areas. This would indicate that perhaps ease of searching is a contributor to pellet discovery, but this trend is not consistent for the rest of the canopy subcategories and for the undergrowth category. For example, searchers were more likely to locate pellets at closed canopy than at partial canopy points, and sparse undergrowth points were less likely to have pellets, moderate more, and thick less. However, none of these differences appear to be significant. Table 3.9 shows that differences in the χ^2 (chi-square) contingency table results for the three habitat characteristics of dung and nondung points do not indicate that the presence or absence of dung depends on any of the three.

Table 3.9 χ^2 test results for contingency tables of habitat correlations for points with and without *D. matschiei* dung observations (null hypothesis: dung values ≠ no dung values).

	Gradient	Canopy Closure	Undergrowth
Chi-square	0.461	0.804	0.308
Chi-square p-value	0.794	0.669	0.857
Degrees of freedom	2	2	2
Critical value (α=0.05)	5.991	5.991	5.991
Critical value (α=0.25)	2.773	2.773	2.773

Even if α is made less stringent (i.e. α=0.25) the χ^2 test still does not show any strong correlation for any habitat character, and thus any influence of habitat on searching efficacy or on dung location is probably small. This finding agrees with local landowner beliefs (see Chapter 5) that tree kangaroo movements are non-patterned and that the animals do not favour any habitat over another.

3.4 CONCLUSION

3.4.1 *Dendrolagus matschiei* density estimates using dung pellet counts

The *D. matschiei* dung pellet counts have produced the first density estimate for any species of New Guinea tree kangaroos. Density estimates of *D. matschiei* dung pellets from the pooled Sibidak and Dendawang field sites range from approximately 51 to 110 'fresh' pellets/ha. Dividing these figures by the alteration time of approximately three days and a captive deposition rate of approximately 26 pellets/animal/day gives an estimated 0.6-1.4 animals/ha, or 60-140 animals/km^2, with an average of approximately 1 animal/ha, or 100 animals/km^2. This is a high density but it is not exceptional for arboreal folivores.

Dendrolagus matschiei at Dendawang and Sibidak is found at five-fold lower densities than the approximately 500 animals/km^2 recorded for three toed sloths (*Bradypus* spp.), and three-fold lower than the 300 animals/km^2 for red colobus monkeys (*Piliocolubus* spp.). However it is roughly three to four- fold higher than the 26-31 animals/km^2 recorded for Mantled howler monkeys, (*Aloutta pallattia*) and 33 animals/km^2 estimated for Bennett's tree kangaroo (Kingdon, 1997; Kricher, 1997; Martin, 1993; Mittermeier, 1998).

There are uncertainties that could bias the *D. matschiei* density estimates. The calculated density could be an underestimate due to the possibility that the sampled pellet population is not complete because the forest canopy has not being surveyed. However, other uncertainties, chiefly a possible underestimate of average daily faecal pellet production rate, make it possible that this figure is an overestimate. For example, if the true wild rate is not 26 pellets/day but rather is closer to the 96 pellets/day measured in *D. lumholtzi* (K. Coombes, pers. comm.), then estimated *D. matschiei* density would be reduced to approximately 30 animals/km^2. This would be similar to the figure of 0.3 animal/ha calculated for the Australian species *D. bennetti* (Martin, 1993).

Whether the dung pellet densities observed at Dendawang and Sibidak are representative for densities in other portions of *D. matschiei*'s range is unknown. An initial survey at the Tomongan site in the Cromwell Mountains did not produce sufficient observations to produce significant density estimates that could be compared with the densities estimated for the Dendawang and Sibidak sites. However, the low dung pellet encounter rates at Tomongan indicate that tree kangaroo densities at this site could be lower, possibly because of habitat differences or from hunting pressure. Additional points must be added and further surveys need to be made at this and other sites. This may show that the Dendawang and Sibidak densities are unusually high compared to densities found in other portions of *D. matschiei*'s range.

The habitat ratings enables rough gradient, canopy closures, and undergrowth values to be tallied at each survey point, thus allowing different study sites to be compared. It also allowed an examination of correlation between habitat and dung locations. Data from the Dendawang and Sibidak sites indicate that areas where tree kangaroo dung are found are not significantly different from the overall habitat characteristics of the site. This agrees with the statements of Keweng 1 landowners that tree kangaroos do not follow predictable paths and do not have favoured habitat types. It will need to be compared with future results from the Tomongan site in the Eastern Huon, where landowners state that *D. matschiei* favour certain trees for sleeping and feeding, and may spend more time in steep inaccessible areas (see Chapter 5 for further discussion).

3.4.2 Limitations of dung pellet counts for New Guinea tree kangaroo density estimates

The results of the 1999 and 2000 surveys indicate that distance sampling analysis of pellet counts can be a useful method for estimating tree kangaroo abundance. However, the large number of points required to make sufficient pellet observations necessitates a fairly large work force in order that areas can be surveyed quickly and potential 'observer effects' minimised. If dung density is too low, such as at the Tomongan site, then the number of points required for sufficient pellet observations maybe too high for all but the largest survey crews. As stated above it is unclear whether Dendawang and Sibidak densities are representative of densities for other populations of *D. matschiei*. If the normal densities are lower then pellet counts may prove to be of limited value.

A further concern is that dung sampling maybe problematic at lower elevations where higher temperatures, precipitation and arthropod populations hasten dung decomposition and disappearance, as shown by the very low numbers of pellets found at the Semia site. Continued low mammal pellet counts at this and other sites would indicate that the use of dung as a marker to estimate tree kangaroo and other mammal species abundance is not suitable for high rainfall lowland to lower montane New Guinea forests.

Finally, it must be noted that the dung sampling results from Dendawang and Sibidak densities may not be typical. Interviews with Keweng 1 landowners indicate that these sites were known to be rich in tree kangaroos, and in the past supported high levels of hunting. At the time of the survey the sites had not been hunted for four (Dendawang) and six (Sibidak) years respectively. This combination of favourable habitat and reduced hunting pressure could be uncommon for the rest of the species' range. Therefore attempts to extrapolate species population or conservation status from the density figures are probably premature and must be treated with caution, particularly because landowner interviews indicate that many *D. matschiei* populations have declined (see 5.3.2).

CHAPTER 4 DOCUMENTATION OF TREE KANGAROO FOOD PLANTS

4.1 INTRODUCTION

New Guinea's tree kangaroos (Marsupialia: Macropodidae, *Dendrolagus* spp.) are perhaps the island's most threatened mammal group. Basic knowledge of their natural history, which is critical to their conservation, is lacking (Beehler, 1991b). One area of ignorance is feeding ecology. Tree kangaroos have dentition that is suited for a browsing feeding style, and the ten known species possess gut morphologies that show varying levels of adaptation to a mostly folivorous diet [(Flannery et al., 1996; Sanson, 1989); see 2.6.1]. Previous research has shown that Australian tree kangaroos eat a wide variety of plant species [(Flannery et al., 1996; Tree Kangaroo and Mammal Group, 2000); see 2.6.4]. The diet of New Guinea tree kangaroos is believed to be similarly diverse, but data to support this are lacking. There has been no concerted effort to determine the full range of New Guinea tree kangaroo diets (Flannery et al., 1996). This is due in part to the extreme difficulty of directly observing the animals in the wild. However, traditional New Guinea cultures have been shown to possess extensive knowledge about native wildlife and its natural history (Diamond and Bishop, 1999; Flannery, 1998). Traditional knowledge can contribute to scientific understanding (Bulmer, 1982; Hill et al., 1982), but biologists often fail to use these indigenous biological databanks.

In an initial effort to document New Guinea tree kangaroo diets knowledgeable landowners, typically older experienced hunters, were asked to identify food plants for three tree kangaroo taxa: Matschie's (*Dendrolagus matschiei*), Goodfellow's (*Dendrolagus goodfellowi buergersi*), and Doria's (*Dendrolagus dorianus notatus*). The wild diets of the three species are almost completely unknown with only limited data (less than ten species) recorded for *D. goodfellowi*, and none for *D. matschiei* and *D. dorianus* [(Flannery et al., 1996); see 2.6.4]. While the native plant lists are anecdotal, they provide a useful starting point for future research using more direct methods.

4.2 METHODS

Landowners from the village of Keweng 1 (YUS Local Government Area, Morobe Province, Huon Peninsula) assisted the author in identifying, collecting, and photographing Matschie's tree kangaroo (*D. matschiei*) food plants at the Dendawang fieldsite (S. $6^0$04.84' E. $146^0$34.32', altitude 2400 m). Collections were made in an altitude range of 2300 to 2600 m in July and August of 1997, and again in September of 1998. Plants were identified and gathered by landowners with extensive tree kangaroo hunting and captive rearing experience. For some of the specimens, landowners also provided information on which portions of the plant are consumed by *D. matschiei*. The specimens were later identified to family and/or genus and species level at the PNG National Herbarium in Lae by Dr. Wayne Takeuchi and Mr. Robert Kiapranis. Identification and collection of Goodfellow's and Doria's tree kangaroo food plants were made in the Crater Mountain Wildlife Management Area by Australian botanists Rigel Jensen and Steve McKenna and landowners from the village of Maimafu at the TKCP's Semia field site (S. $6^0$34.73' E. $145^0$00.59') in February 1999. These collections were based on an initial list prepared by the author and landowners from Maimafu in 1996 and 1997. The Semia collections, like those from Dendawang, were made with the assistance of older landowners with experience hunting tree kangaroos, and a full grasp of traditional botanical and zoological knowledge. Semia collections were made at altitudes from 1400 to 2150 m, with most of the collecting effort concentrated at the lower altitudes. A key element in the collecting method used at Semia and at Dendawang was to allow the landowners to walk in the forest and find the plants themselves. The superiority of these informal, discovery based methods has been noted by other ethnobiological researchers in New Guinea (Diamond and Bishop, 1999).

4.3 RESULTS

Over 100 specimens of tree kangaroo food plants were collected at the Dendawang site. However, some of the specimens were duplicates, infertile or otherwise unsuitable for identification, which reduced the total of identified plants to 91. A further 70 plants were obtained at the Semia site. Tables 4.1 and 4.2 lists the plants collected and identified for the two sites. The collections are not complete - additional species continue to be noted by landowners at the both sites, and further collections will need to be made.

Table 4.1 *Dendrolagus matschiei* food plants, as identified by Keweng 1 landowners. Collected by the author and identified by Dr. Wayne Takeuchi and Mr. Robert Kiapranis, PNG National Herbarium.

Family	Genus_Species	Local Name	Portion eaten (not incl. roots)	Type
Lycopodiaceae	*Palhinhaea cernua*	Ngongnong	growing tip	club moss
Lycopodiaceae	*Lycopodium*	Gongong	growing tip	club moss
Adiantaceae	*Adiantum*	Gesong monong	young fronds/stems	fern
Aspleniaceae	*Asplenium*	Tenakwan	young fronds	fern
Aspleniaceae	*Asplenium*	Gasin gaman	young fronds	fern
Blechnaceae	*Blechnum*	Bungwak monong	young fronds	fern
Blechnaceae	*Blechnum*	Bungwak	young fronds	fern
Dennstaedtiaceae	*Histiopteris*	Soham gaman	all	fern
Dryopteridaceae	*Arachniodes aristata*	Damna monong		fern
Dryopteridaceae	*Dicksonia*	Gesinalok	young fronds, stems	fern
Lindsaea group	*Lindsaea*	Gesinalok		fern
Marattiaceae	*Marattia*	Num	heads, new stems/fronds	fern
Polypodiaceae	*Belvisia*	Dobaljok	young fronds, stems	fern
Polypodiaceae	*Goniophlebium*	Gesinalok		fern
Polypodiaceae	*Goniophlebium*	Gaisinalok		fern
Polypodiaceae	*Goniophlebium*	Chekuluk	young fronds	fern
Pteridaceae	*Pteris cf. pacifica*	Gesinalok		fern
Vittariaceae	*Antrophyum*	Dobaljok monong	young fronds, Stems	fern
Actinidiaceae	*Saurauia*	Jambangaman	flowers, new leaves/shoots	tree
Actinidiaceae	*Saurauia*	Gulawan		tree
Actinidiaceae	*Saurauia*	Gulawan monong		tree
Actinidiaceae	*Saurauia*	Yesit		tree
Actinidiaceae	*Saurauia*			tree/shrub
Apiaceae		Pabapalok	all	herb
Araceae	*Rhaphidophora*	Tabeng		vine
Asteraceae	*Blumea*	Kuak madeb		herb
Asteraceae	*Olearia*	Gan		tree
Asteraceae		Onganang	all (when young)	herb
Asteraceae		Kuak	all	herb
Asteraceae		Nupteban		vine
Balsaminaceae	*Impatiens hawkeri*	Kaljang kuak	all	herb
Begoniaceae	*Begonia*	Manungan monong	all	hemiepiphyte
Begoniaceae	*Begonia*			shrub
Begoniaceae	*Begonia*	Manungan monong	all	epiphyte
Campanulaceae	*Peracarpa carnosa*	Nawong		hemiepiphyte
Celastraceae	*Perrottetia alpestris*	Sindap		tree
Coriariaceae	*Coriaria papuana*	Amanaman		small tree/shrub
Cyperaceae	*cf. Fimbristylis*	Tapmang		grass
Cyperaceae	*Gahnia*	Nadangit monong		grass
Equisetaceae	*Equisetum ramosissimum*	Nalong		horsetail
Ericaceae	*Dimorphanthera*	Dabum	young shoots	vine

Family	Genus_Species	Local Name	Portion eaten (not incl. roots)	Type
Ericaceae	*Diplycosia*	Arinarin monong	young branches leaves and fruit	epiphytic shrub
Ericaceae	*Rhododendron*	Kabibifjab		vine
Ericaceae	*Vaccinium*	Kondankgaman		tree/shrub
Ericaceae		Kondankgaman monong	new (red) stems, leaves, shoots	tree
Gesneriaceae	*Cyrtandra*			herb
Gesneriaceae	*Cyrtandra aff. erectiloba*	Mndak mndak monong	leaves, shoots, sometimes stem	herb
Haloragidaceae	*Gunnera macrophylla*	Katenam		herb
Lamiaceae		Bamamakuak		herb
Loganiaceae	*Fagraea*	Bi		tree
Melastomataceae	*Medinilla*	Parung parung		shrub
Monimiaceae	*Levieria*	Mok	young stems and leaves	tree
Myrsinaceae	*Myrsine leucantha*	Jumjum madeb		tree
Myrsinaceae	*Rapanea*	Arinarin	young stems/leaves	epiphyte
Orchidaceae	*Dendrobium*	Nengneng monong	all	epiphyte
Orchidaceae	*Dendrobium*	Nengneng monong	all	epiphyte
Orchidaceae	*Dendrobium vexillarius*	Nengneng	all	epiphyte
Orchidaceae	*Epiblastus*	Nengneng	all	herb
Orchidaceae	*Epiblastus*			epiphyte
Orchidaceae	*Spathoglottis*	Gakgak monong		herb
Orchidaceae	*Spathoglottis*			herb
Orchidaceae	*Liparis* sect. *Distichon*	Klapgamanjab	new leaves/shoots	herb
Orchidaceae		Nengneng gaman		epiphyte
Orchidaceae		Nawong	new shoots	epiphyte
Orchidaceae		Nengneng	all	epiphyte
Pandanaceae	*Freycinetia*	Saki	fruit & growing portion of stem	hemiepiphyte
Pandanaceae	*Freycinetia*	Saubsaub		epiphyte
Pandanaceae	*Freycinetia augustifolia*	Saubsaub monong		hemiepiphyte
Piperaceae	*Piper*	Magalan	young stem	tree
Piperaceae	*Piper*	Bamadawak	stems & leaves	vine
Poaceae		Tapmang	young stems	grass
Poaceae		Kwengkweng	young portions	hemiepiphyte
Podocarpaceae	*Dacrydium*	Kwetumak	fruit	tree
Polygonaceae	*Polygonum*	Amanaman	all	hemiepiphyte
Polygonaceae	*Polygonum*	Dowan Duwan	stem/leaves	vine
Rosaceae	*Rubus*	Tapmat gaman	all	vine
Rosaceae	*Rubus moluccana*	Tapmat monong		shrub
Rubiaceae	*Psychotria*	Temudt	new stems and unopened leaves	tree
Rubiaceae	*Timonius*	Kisikngang		tree
Solanaceae	*Solanum*	Babp	young stems/leaves	tree
Urticaceae	*cf. Cypholophus*	Kakat	young stems, leaves	shrub
Urticaceae	*Elatostema*	Gwang monong		herb
Urticaceae	*Elatostema*	Deyk madep	all above middle of stem	herb
Urticaceae	*Elatostema*	Deyk	all	shrub
Urticaceae		Gwang		herb

Family	Genus_Species	Local Name	Portion eaten (not incl. roots)	Type
Urticaceae		Pungpung		herb
Urticaceae		Kakapbam	young stems, closed leaves	shrub
Urticaceae				vine
Zingiberaceae	*Pleuranthodium*	Jodal	young shoot/ Inner stem	herb
Zingiberaceae	*Riedelia*	Jodal Monong	young shoot/ Inner stem	herb
Zingiberaceae	*Riedelia*			herb
Zingiberaceae	*Riedelia*	Jodal	inner stem, growing tip	epiphyte

Table 4.2 *Dendrolagus dorianus notatus* and *Dendrolagus goodfellow buergersi* food plants from Semia field site. Identified by Maimafu landowners. Collected and identified by Rigel Jensen.

Family	Genus_species	Tree Kangaroo	Local Name	Comments
Blechnaceae	*Blechnum*	Both	Bararoparo	terrestrial fern to 50cm
Cyatheaceae	*Cyathea*	Both	Muleya	tree fern, red prickly crown, trunk 1.6m, fronds to 3.4m
Cyatheaceae		Both	Bagayabi	stout tree fern, fronds to 1.8m
Cyatheaceae		Both	Miru 1	slender tree fern, fronds to 1.5m
Cyatheaceae		Both	Bagada	stout tree fern 1.5m, fronds to 2.2m
Cyatheaceae		Both	Kilembeya	stout tree fern 4m, fronds to 1.8m
Cyatheaceae		Both	Miru 2	stout tree fern 3m, fronds to 1.6m
Marattiaceae		Both	Habi	terrestrial fern with no trunk, fronds to 1.8m.
Apiaceae	*Hydrocotyle*	Both	Holiyau	creeping herb to 10cm, flowers white, fruit black/red
Araceae		Goodfellow's	Kaboda	herb to 60cm. fruit red, underside of leaf purple.
Araliaceae		Both	Ekari	scrambling shrub/vine, flowers purple/pink, fruit. orange.
Araliaceae	*Schefflera*	Both	Ekari	terrestrial shrub to 3m
Balsaminaceae	*Impatiens*	Both	Usiasimeto	herb to 80cm, flowers white, zygomorphic
Begoniaceae	*Begonia*	Both	Abada	herb 50cm flowers pink
Begoniaceae	*Begonia*	Both	Abaya	herb 60cm, flowers white
Begoniaceae	*Begonia*	Both	Abaya 1	herb 40cm
Caprifoliaceae	*Sambucus*	Both	Agise	shrub
Cunoniaceae		Both	Kukali	subcanopy tree flowers white/green
Cyperaceae		Both	Huru	small sedge
Ericaceae		Both	Hari	treetop vine, immature fruit.green
Ericaceae		Both	Kalikalimo	epiphytic creeper, flowers maroon, tips white
Euphorbiaceae	*Omalanthus novo-guineensis*	Goodfellow's	Kolave	small tree in disturbed areas, 8m
Gesneriaceae		Both		small shrub, flowers red
Grossulariaceae	*Polyosma*	Both	Fikiya	shrub/small tree
Loganiaceae	*Neuburgia corynocarpa*	Both	Hibida	canopy tree to 30m, fruit white/cream
Loranthaceae/ Santalaceae?		Both	Kalikalumo	parasitic vine
Melastomataceae		Both		shrub 1.2m, flowers pink

Family	Genus_species	Tree Kangaroo	Local Name	Comments
Melastomataceae		Both		shrub 1.2m, fruit purple
Melastomataceae		Both	Aleneda	shrub 90cm, flowers white, fruit purple/black.
Melastomataceae		Goodfellow's	Alineda	
Melastomataceae		Both	Kimu 1	shrub 5m
Monimiaceae	*Palmeria*	Both	Naga	scrambling vine, infertile
Monimiaceae	*Palmeria*	Both	Yamogi Naga 1	scrambling vine
Monimiaceae	*Palmeria*	Both	Yamogi Naga 2	scrambling vine
Moraceae	*Ficus*	Both	Lape	seedlings, infertile
Moraceae	*Ficus*	Both	Mariha	small tree, infertile
Myrsinaceae	*Rapanea*	Both	Mame	shrub/small tree infertile
Myrtaceae		Both	Nabu	sapling 4m, infertile
Pandanaceae	*Freycinetia*	Both	Fugera	root clinger, infertile
Pandanaceae	*Freycinetia*	Both	Oeno	root clinger, fruit reddish
Piperaceae	*Piper*	Both	Huju	glabrous shrub to 5-6m, flowers white
Piperaceae	*Piper*	Both	Kangareva 1	shrub 3m, flowers white
Piperaceae	*Piper*	Both	Kangareva 2	shrub 4m, fruit almost black
Piperaceae	*Piper*	Both	Kikifalea	shrub to 3m, flowers white, fruit orange.
Piperaceae	*Piper*	Both	Obamora	root clinging vine, flowers white
Piperaceae	*Piper*	Both	Obamora	small vine, flowers white
Pittosporaceae	*Pittosporum*	Both	Mino	subcanopy tree, 12m, frt. red, immature frt. brown
Pittosporaceae	*Pittosporum*	Both	Mowa	shrub infertile
Poaceae		Both	Nimikaitaiyoni	short grass, to 12cm
Podocarpaceae	*Podocarpus nerifolius*	Both	Aloho	canopy tree to 30m
Rosaceae	*Rubus*	Both	Habakida	Scrambling vine, fruit red
Rosaceae	*Rubus*	Both	Hakuiyoni	small shrub, flrs. white, fruit red
Rubiaceae		Both	Inareba	
Rubiaceae		Both	Inareba 2	shrub 6m, immature fruit white
Rubiaceae		Both	Ubida	shrub to 2m
Rubiaceae		Both	Unu Aba Raga	vine
Rubiaceae	*Gardenia*	Goodfellow's	Hanu	shrub/small tree, flowers yellow, fragrant
Rubiaceae	*Morinda*	Both	Asa Naga	vine, flowers yellow
Rubiaceae	*Ophiorhisa*	Both		herb to 70cm, flowers white, fruit green/purple
Rubiaceae	*Timonius*	Both	Hubida	shrub 4m, fruit maroon/purple
Theaceae	*Ternstroemia*	Both	Polo	tree flower buds, dehiscent fruit with reddish seeds.
Urticaceae		Both	Kigitora	shrub to 4m, flowers. whitish/cream
Urticaceae		Both	Lagale	shrub/small tree, flowers white/cream
Urticaceae		Both	Sibu	shrub 1.5m
Winteraceae	*Tasmannia*	Both	Fokia	understory tree flowers white, immature fruit
Zingiberaceae		Both	Abiruru	pendulous epiphytic ginger to 1.5m, flowers red/yellow
Zingiberaceae		Both	Falao	epiphytic ginger to 1.2m, flowers. red
Zingiberaceae		Both	Nansan	terrestrial ginger 1m, flowers white/red

Family	Genus_species	Tree Kangaroo	Local Name	Comments
Zingiberaceae		Both	Nansandya	terrestrial ginger 1.2m, flowers maroon/white fruit purple/black
Zingiberaceae	*Riedelia*	Both	Lupu Falau	terrestrial ginger, flowers yellow/red

The Dendawang and Semia landowners that assisted the author and Rigel Jensen believe that Matschie's, Doria's, and Goodfellow's tree kangaroos eat a wide variety of plants from several families. They are partial to ferns from several families, climbing Pandans, (*Freycinetia* spp., Pandanaceae), various gingers (Zingiberaceae) especially species from genus *Riedelia*, peppers (Piperaceae), vines and shrubs from *Rubus* (Rosaceae), and trees from *Timonius* (Rubiaceae). The Dendawang landowners also identified orchids (Orchidaceae) as an important component of tree kangaroo diets but this family was not identified by any of the Semia landowners.

The Semia and Dendawang field sites are home to different species of tree kangaroos: *D. goodfellowi buergersi* and *D. dorianus notatus* at Semia, *D. matschiei* at Dendawang. The two sites are at different altitudes (1500 m versus 2400 m), and in different biogeographical zones (Huon Peninsula versus Eastern Highlands), and are thus home to different plant communities. Nevertheless, the tree kangaroo food plant lists from Semia and the Dendawang field sites show some similarities at the family level, with 21 shared families. Similarities at the generic level were not as pronounced, with ten shared genera, but this discrepancy may be partially due to incomplete identification. Table 4.3 lists the shared food plant families and genera for the two sites.

Table 4.3 Shared Families and Genera of *Dendrolagus matschiei*, *Dendrolagus goodfellowi*, and *Dendrolagus dorianus* food plants between the Dendawang and Semia field sites.

Shared Families	Shared Genera
Apiaceae	
Araceae	
Balsaminaceae	*Impatiens*
Begoniaceae	*Begonia*
Blechnaceae	*Blechnum*
Cyperaceae	
Ericaceae	
Gesneriaceae	
Loganiaceae	
Marrattiaceae	*Marrattia*
Melastomaceae	
Monimiaceae	
Myrsinaceae	*Rapanea*
Pandanaceae	*Freycinetia*

Shared Families	Shared Genera
Piperaceae	*Piper*
Poaceae	
Podocarpaceae	
Rosaceae	*Rubus*
Rubiaceae	*Timonius*
Urticaceae	
Zingiberaceae	*Riedelia*

The Dendawang landowners stated that the diet of *D. matschiei* is primarily composed of stems and leaves. The animals will eat some flowers and some fruits, but these are not an important part of their diet. Of the 50 plant species for which information was gathered, only three species (6%) were said to have fruit consumed by *D. matschiei*, and in only one case (*Dacrydium* spp.) was fruit the sole portion of the plant consumed. Flowers were said to be a more prominent part of the *D. matschiei* diet, with the animals eating the blossoms of seven species (14%), primarily Orchidaceae (six species), but flowers were never the sole portion of the plant consumed. The Dendawang landowners also stated that *D. matschiei* chooses younger or less mature plants or plant portions for over 60% (32 of the 50) food plants described. This tendency agrees with what is known of arboreal folivore diets, but which does not agree with data for some Australian species (see 4.4.1 below).

4.4 DISCUSSION

4.4.1 Dietary diversity and plant portion composition

In terms of plant part preferences (leaves and stems over fruits and flowers) the diet of *D. matschiei* is not dissimilar to published accounts of the diets of *D. lumholtzi*. However, landowners stressed that *D. matschiei* prefer to eat immature, young or growing portions of stems or leaves. The mature plants or plant parts that were eaten tended to be succulent herbaceous species, and not mature leaves or other parts from trees or shrubs. Consumption of mature leaves, especially mature tree leaves, was virtually unmentioned by the landowners. This conflicts with Australian data for Lumholtz's tree kangaroo whose observed diet consists of more than 80% mature leaves (Procter-Gray, 1985). With its emphasis on immature and young foliage, *D. matschiei*'s dietary choices more closely resemble that of other folivores such as the mantled howler monkey (*Aloutta palliata*), which has a diet composed of 19.4% mature leaves, 44.2% new leaves, 12.5% fruit, 18.2% flowers, and 5.7% leaf petioles (Glander, 1977).

Whether the *D. goodfellowi buergersi* and *D. dorianus notatus* that inhabit the Semia site show a similar preference for young and immature plants is not yet certain. Jensen did not obtain information on which portions of plants were eaten by tree kangaroos, but in informal conversations with the author Semia and other Maimafu landowners have stated that both Doria's and Goodfellow's prefer to eat immature leaves and stems of plants.

The flowering plants that New Guinea tree kangaroos consume possess varying levels of toxicity. Some families, such as Zingiberaceae, Orchidaceae (except for alkaloids) and Pandanaceae (except for Calcium oxalate) are relatively non-toxic. However, most of the other families possess appreciable amounts of secondary compounds. For example, Piperaceae typically have high levels of alkaloids, while Haloragidaceae are usually cyanogenic. Three families, Balsaminaceae, Pandanaceae, and Rubiaceae, typically possess leaves which contain calcium oxalate, a known skin and mouth irritant. Tree kangaroos are said to consume all portions of the Balsaminaceae, but only the fruit and immature portions of leaves of Pandanaceae, and only immature leaves of Rubiaceae (Watson and Dallwitz, 1992).

4.4.2 Interspecies comparisons

There are little data on wild tree kangaroo diets in New Guinea. Food plants which the *D. matschiei* of Dendawang share with *D. mbaiso* and *D. scottae* include ferns (such as *Blechnum* and *Asplenium*), and vines from the pepper (Piperaceae) family. The Semia populations of *D. goodfellowi buergersi* and *D. dorianus notatus* eat figs (Moraceae), which are also known food plants for wild *D. goodfellowi pulcherimmus*, *D. bennettianus*, and captive *D. ursinus* [(Flannery et al., 1996; Tree Kangaroo and Mammal Group, 2000); see 2.6.4]. Two tree kangaroo food plants have been identified by every group of landowners that the author has visited. They are the herbaceous *Impatiens hawkeri* (Balsaminaceae) that grow in moist areas of the forest and on stream banks, and the large *Marratia* spp. (Marratiaceae) terrestrial ferns, that are a prominent constituent of the understory of mid-montane forests.

When excluding the culturally restricted list of the Cromwell Mountain landowners (see 5.3.6) more similarities between the diets of *D. matschiei* and *D. goodfellowi buergersi* and *D. dorianus notatus* are revealed, for example in the consumption of *Riedelia* (Zingiberaceae), *Timonius* (Rubiaceae), *Piper* (Piperaceae), terrestrial ferns such as genus *Blechnum* (Blechnaceae), and grasses (Cyperaceae and Poaceae).

However, there are some differences in the food plant lists from Semia and Dendawang. The most obvious is the identification of orchids (Orchidaceae) as important tree kangaroo food plants by Dendawang landowners and not by the Semia landowners, or indeed by any previous studies on any tree kangaroo species (Flannery et al., 1996; Tree Kangaroo and Mammal Group, 2000). Orchidaceae is the largest plant family in New Guinea, with over 3000 known species, and orchids account for much of the plant diversity in epiphyte-rich montane forests such as the ones found at Semia and Dendawang (Mittermeier et al., 1997). There is no doubt that *D. matschiei* are capable of eating Orchidaceae – the author has observed captive animals consuming the stems of the epiphytic orchids with apparent relish, and landowners from other portions of the Huon, such as the upper Urawa river valley, have also stated that *D. matschiei* eat orchids. Whether *D. dorianus* or *D. goodfellowi* will eat orchids is unknown, as is orchid consumption by wild populations of any other species. Given the Semia landowners' extensive knowledge of tree kangaroo diets, their failure to include Orchidaceae among the food plant list for *D. dorianus notatus* and *D. goodfellowi buergersi* is surprising. Further interviews are necessary to resolve this discrepancy.

Another important tree kangaroo plant family identified for the first time was Zingiberaceae (gingers). Although gingers are not as large a family as orchids (approximately 200 species in New Guinea), they are perhaps equally prominent, especially in the forest understory. Like orchids they are typically low in toxins, which may make them more attractive to tree kangaroos (Watson and Dallwitz, 1992).

4.4.3 Site specificity in tree kangaroo diets

It is important to stress that the plant lists and the plant part proportions of tree kangaroo diets from Dendawang and Semia are habitat and altitude specific. It is possible that the composition of tree kangaroo diets may vary with location, soil type and altitude in conjunction with changes in the resource base, and plant collections will need to be made at a variety of locations to capture the full spectrum of tree kangaroo diets. For example, when the author visited *D. matschiei* habitat at 2000-2500 m with landowners from Kotet and Towet villages (approximately 35 km ESE from Dendawang), he was shown ten tree kangaroo food plant species that were on the Dendawang list, and ten that were not. Invariably the plants that were not shared with the Dendawang list were species not found at Dendawang, as confirmed by accompanying Dendawang landowners. For example, the Kotet landowners said that *D. matschiei* consumes the fruit of a fig (Moraceae) which the Dendawang landowners stated does not occur on their land. On another occasion Towet landowners showed the author *Tom* trees, provisionally identified as *Carpodetus* spp., Saxifragaceae (S. McKenna, pers. comm.) which were clearly being used by tree kangaroos (heavily scratched trunks with abundant faeces at the base), and stated that *D. matschiei* eat the leaves of the species. The accompanying Dendawang landowner was certain that the species does not occur at Dendawang, and was unsure whether it is found at lower altitude forests down valley from that site. The species has since been observed in the Dendawang region. It was found in forests approximately four km southwest and 500 m lower than the field site. Accompanying landowners from the village of Kesan identified it as a tree kangaroo food plant.

The identification of a fig as a tree kangaroo food plant by Kotet and not by Dendawang landowners is interesting because it suggests that the relative proportions of plant parts in *D. matschiei* diets may not be fixed. Matschie's tree kangaroo has a wide altitude range (1500-3300 m), from lower montane forests to tree-line, and different populations live in different habitats with different vegetative resources. It is the only tree kangaroo that occurs on the Huon Peninsula, and thus occupies a wider ecological niche than most New Guinea tree kangaroos which typically share their mountain ranges with one or two other species (Flannery et al., 1996). For example, most of the PNG Central Cordillera is occupied by two species: *D. goodfellowi* and *D. dorianus*. *Dendrolagus goodfellowi* occurs at lower altitudes and *D. dorianus* at higher with a limited zone of sympatry. Wild *D. goodfellowi* are known to consume figs, while *D. dorianus* may prefer ferns and leaves to fruit (Flannery, 1995). It seems possible that *D. matschiei* at lower altitudes may show a more *goodfellowi*-like diet (consume a higher proportion of fruit), in conjunction with the greater fruit resources found in lower elevation forests, while high altitude *D. matschiei* would have a more obligately folivorous diet.

4.5 CONCLUSION

There is little existing literature on New Guinea tree kangaroo diets in the wild, so interspecies comparisons are difficult to make at this time. However, the Semia and Dendawang landowner information about tree kangaroo food plants agree with previous Australian data that tree kangaroos prefer to eat many species of plants, with leaves and stems being the principal constituents of the diet. This is typical of the more generalist arboreal folivores [(Montgomery, 1978); see 2.6.4], and is probably related to the need for the animals to deal with the high levels of secondary compounds commonly found in leaves and stems of tropical plants. According to Dendawang landowners Matschie's tree kangaroos take the additional step of concentrating on young and immature leaves and stems which are typically less toxic and more nutritious (Coley, 1983; Hladik, 1975). This strategy has been observed in other arboreal folivores such as mantled howler monkeys (*Aloutta palliata*) [(Milton, 1980); see 2.6.4].

The plant lists from the Dendawang and Semia sites are not complete and further collecting is necessary. However, even if the full list from these two sites is known, there will still be a need for collections from other areas in order to approximate the complete plant menu for tree kangaroos diets. It would not be surprising if *D. matschiei*, *D. goodfellowi buergersi*, and *D. dorianus notatus* each eat hundreds of species. It is also possible that the composition of tree kangaroo diets varies in conjunction with altitudinal or habitat based resource variation, especially for species like *D. matschiei* that occupy a wide ecological niche. For example, fruit such as figs may form a greater proportion of *D. matschiei* diets at lower altitudes, while comprising a very small proportion or none of the diet at higher altitudes.

The large number of plant species eaten by New Guinea tree kangaroos, and their preference for young or immature plants and plant parts suggests that they are well adapted to the frequent ecosystem disturbances that effect New Guinea's habitats [(Hovius et al., 1998; Johns, 1986); see 2.1.2]. The regrowth from these disturbances would probably be lower in toxins, contain more nutrients than mature plants, and thus be more suitable for tree kangaroos (Hladik, 1975; Whitmore, 1998); see 2.1.2]. Therefore habitat change and alteration due to natural (landslides, fires, etc) and human (selective logging) agents are probably not as great a threat to tree kangaroos as overhunting.

CHAPTER 5 NEW GUINEA LANDOWNER ACCOUNTS OF TREE KANGAROO NATURAL HISTORY AND CONSERVATION STATUS

5.1 INTRODUCTION

Knowledge about wild New Guinea tree kangaroos (Marsupialia: Macropodidae, *Dendrolagus*) is limited. Basic questions concerning the animals' natural history and conservation status remain unanswered (Flannery et al., 1996). Human beings have been present on New Guinea for more than 40000 years (Groube et al., 1986) and New Guinea cultures often possess profound knowledge about the animals and plants which share their land as well as about the characteristics of these organisms (Bulmer, 1982; Diamond, 1966).

With over 1000 languages New Guinea is the richest linguistic region on earth. The linguistic diversity is fractal in nature, with differences at even the smallest scales, and the linguistic diversity is associated with equivalent cultural variety. Therefore, any attempts to document traditional knowledge in New Guinea must proceed with the recognition that the the effort will only capture a portion of the true richness extant. For example, the Yupno language, spoken by roughly 6-7000 people on the central Huon Peninsula, is itself divided into at least nine dialects (Wurm and Hattori, 1981). The dialects are as different as the 'common language' that divides English speaking countries from one another. The author's experience is that adjacent Yupno speaking villages will often have very different names for common objects and wildlife. For example a visitor walking from the Teptep government station to the village of Keweng 1 will pass through four intervening villages and will hear three different words used for Matschie's tree kangaroo (*Dangwitgaman*, *Tongap*, *Klapgaman*), and three different words for the sweet potato, the staple crop of the region. One explanation for this intra-language diversity is that the inhabitants of adjacent villages can often trace their ancestors to very different portions of the Huon and even to offshore islands. Thus neighboring villages often have very different histories and vestiges of past cultures and languages can still be seen today.

Ethnobiology, the study of the relationships of plants and animals with human cultures, has much to offer to traditional biology. Researchers working in New Guinea and other areas have documented that indigenous knowledge can be scientifically accurate, give novel biological and ecological insights and even be used to augment other types of research, such as remote sensing studies of forest habitat types (Dumbacher et al., 1992; Shepard Jr. et al., 2001). However, ethnobiologists have also shown that indigenous knowledge does not consistently agree with scientific outlooks. Indigenous knowledge is often part of an integrated system of knowledge that incorporates cultural and spiritual beliefs and explanations for the natural world (Berlin, 1992). These influences can often lead to statements about nature which are manifestly not 'real' such as cases where non-poisonous lizards and snakes are believed to be poisonous (Goodman and Hobbs, 1994). Indigenous cultures may also use different methods or criteria for classification than scientists do. These methods, often based on the utility of the organism, maybe logical and consistent but incompatible with that of scientific classifications. In some cases, concordance with scientific thinking is variable depending on the level of taxa. Thus genera are often more 'scientifically' defined than higher (Family), or lower (species, subspecies) taxa (Berlin, 1992).

Finally, native cultures and individuals vary in their biological proficiency. Many cultures have biological knowledge that is directly related to the perceptual or utilitarian 'salience' of the given organism to the culture's beliefs and subsistence needs (Berlin, 1992). However some cultures appear to have a depth of knowledge which exceeds what is required for subsistence, and reflects a genuine curiosity about the ecosystems in which they live. Examples of this can be seen in cultures such as the Ketengban of New Guinea and the Matsigenka and Matses of Peru. They have been shown to possess encyclopedic knowledge of avian behaviour and taxonomy, the ability to make sharper distinctions between species and subspecies of *Cecropia* than all but the most knowledgeable western botanists, and the analytical acumen to correlate mammal occurrence with dozens of defined forest types (Diamond and Bishop, 1999; Fleck and Harder, 2000; Shepard Jr. et al., 2001).

Ethnobiological research has often focussed on topics such as ethnobotany, folk taxonomy, hunting patterns, and cross-cultural comparative research (such as the question of the reality of biological species). However, indigenous knowledge of vertebrate biology and behaviour has received less attention. Ethnozoologies of tribal groups are relatively rare, both from the past and in the present, with notable exceptions like Bulmer and Majnep's work on the Kalam people's ethnoornithology and Rea's account of the Piman's ethnomammalogy (Majnep and Bulmer, 1977; Rea, 1998).

Tree kangaroos are good subjects for ethnobiological-based enquiry because their cryptic nature makes them difficult to research in the field, and much of their biology remains unknown. Present day New Guineans have an intimate association with the animals – they are a favourite food item, their pelts and fur are used for decorations in ceremonial performances, and orphaned animals are often kept as pets in villages (Flannery et al., 1996). The author and his coworkers with the Tree Kangaroo Conservation Program (TKCP) have attempted to document some of this aboriginal knowledge using landowner interviews in the hope that the interviews will give new insights into tree kangaroo biology as well as an approximation of the animals' conservation status. An additional goal of the interviews is to learn more about cultural attitudes towards the animals in order to help evaluate the effectiveness and appropriateness of conservation efforts in the region.

Finally, the landowner interviews not only seek to conserve tree kangaroos, but the knowledge which rural New Guineans have about them. Indigenous ethnobiological knowledge is perhaps even more threatened than the biodiversity and ecosystems upon which it is based, and PNG is no exception to this trend. As traditional cultures change and become more enmeshed in national cultures and the global marketplace, learning priorities shift and the perceived value of their traditional biological knowledge begins to decline. Efforts to conserve this irreplaceable information are urgently needed (Diamond and Bishop, 1999; Nettle and Romaine, 2000).

5.2 METHODS

Ethnobiological research often depends on surveying or interviewing subjects to record indigenous knowledge. Two methods of interviewing were used for this study. The first was flexible – questioning was unstructured and took place as a part of free flowing conversation around the campfire, or while walking in the forest. This method used both informal and unstructured interviewing. Informal interviewing is defined as being 'characterized by a total lack of structure and control', while unstructured interviews are said to be 'based on a clear plan that you keep constantly in mind, but are characterized by a minimum of control over people's responses' (Bernard, 2002). The advantage of the flexible approach is that it leads to unpredicted novel insights, and often it allows landowners to reveal knowledge in a way that is more culturally appropriate. It is also opportunistic and does not require setting aside discrete blocs of time. It is highly suited for use with informants which will be interviewed more than once (Bernard, 2002). This method has been used by researchers such as Goodman and Hobbs (1994) to investigate indigenous knowledge of reptiles among Khushmann Ma'aza Bedouins in Egygpt's Eastern Desert. The author used this method with Maimafu landowners in the Crater Mountain WMA, and Keweng 1, Teptep, Ronji, Yawan, Kotet, Towet, Indagen, and Nomaneneng landowners on the Huon Peninsula (see maps in Appendix 1, Figures 1 and 2).

The second, more formal procedure was interviews with individuals or small groups of landowners by Biology or Environmental Sciences students from the University of Papua New Guinea (UPNG). In this method the students used a mixture of unstructured interviewing and semistructed interviewing. Semistructured interviewing, like unstructured interviewing, allows free responses by informants, but also uses an interview guide, typically a list of questions and topics to focus conversations (Bernard, 2002). Semistructured interviewing is commonly used in ethnobiological studies, for example by Wang et al (2000) to record indigenous bamboo classifications and conservation strategies in Yunnan Province, China.

A final technique, structured interviewing was not used in this study. This method requires that the interview structure remain constant for each informant – that the informants be exposed to the same questions in the same order (Bernard, 2002). Although useful for quantifying results, the technique was not used because of the lack of flexibility that it gave to the student interviewers.

The UPNG students were given the task of formal landowner interviews (instead of the author) for two reasons. The first was that one of the missions of the TKCP is to provide research and training opportunities to local university students. Landowner interviewing was considered to be a good choice for the students because the work can be performed independently and does not require much equipment or the presence of the project scientists. The second reason for entrusting the interviewing to UPNG students was that it was thought that landowners would be more comfortable speaking with fellow New Guineans than to foreigners and therefore more likely to give complete and truthful answers. The author's experience is that UPNG students are more attuned to the thinking and feelings of the landowners than foreign researchers are. The students have often grown up in a village environment themselves and despite linguistic and ethnological differences are culturally more similar to landowners than outsiders. Students are also more knowledgeable of Tok Pisin (neo-Melanesian Pidgin, PNG's *lingua franca*) and therefore more capable of distinguishing subtleties of meaning than their less fluent overseas counterparts. Lastly the presence of overseas visitors often causes concern and suspicion among landowners who will sometimes refuse to give interviews or give false answers to queries. Landowners will often suspect that the foreign researcher has a hidden agenda (i.e. prospecting for minerals) that has brought him or her to the area. It was hoped that the UPNG students would not face the same levels of mistrust.

The list of interview questions was developed by the author in consultation with UPNG students and TKCP director Dr. Lisa Dabek (see Appendix 3). The questions were divided into four topics: tree kangaroo natural history, hunting practices and hunting rates, tree kangaroo conservation status, and cultural and spiritual beliefs pertaining to tree kangaroos. However, students were encouraged to use their own initiative and to add or delete questions where appropriate. Students were not given training in unstructured and semistructured interviewing techniques (such as probing and phased assertions) which are used to obtain more information and to assess the acccuracy of replies from informants (Bernard, 2002).

The majority of the interviews were carried out by UPNG student Som Yalamu, with additional interviews undertaken by Silas Wagi, Kepslok Kumilgo and Kasbeth Evei. Wagi was a student in environmental sciences while Yalamu, Kumilgo and Evei were students in biology. All of the formal interviews were carried out on the Huon Peninsula villages near Matschie's tree kangaroo (*Dendrolagus matschiei*) habitat. Insights gained on the natural history of Doria's and Goodfellow's tree kangaroos (*Dendrolagus dorianus notatus* and *Dendrolagus goodfellowi buergersi*) in the Crater Mountain WMA came solely from informal conversations.

5.3 *DENDROLAGUS MATSCHIEI* INFORMATION

5.3.1 *Dendrolagus matsciei* distribution

The altitudinal range of *D. matschiei* extends from the edge of the subalpine grasslands at 3200-3400 m, downwards as low as: 1500 m (Bulum River valley, eastern Huon), 1600 m (upper Urawa River Valley, Central Huon), and 1900 m (Upper Bunum River Valley, Western Huon). In the heavily hunted Teptep region, *D. matschiei* no longer occurs below 2400 m. This altitude range conflicts with the most recent published figure of 1000-3300 m (Flannery, 1995). However, the published data may include information about the altitudinal distribution of *D. matschiei* on Umboi Island as well as the Rawlinson Mountains of the southeastern Huon Peninsula. The smaller area and height of these island and outlying ranges would give them lowered and compressed vegetation zones (the 'Massenerhebung' effect) in comparison to the more massive Cromwell, Saruwaged, and Finisterre Ranges where the author and the UPNG students have worked (Whitmore, 1998).

Although tree kangaroos do not live above tree line, landowners in the Saruwaged and Finisterre Mountains stated that the animals will venture onto the subalpine grasslands that lie above the forested zone for short periods to feed on grasses, disperse, or simply warm themselves in the sun. The author has observed tree kangaroo dung pellets in grasslands just beyond the edge of the subalpine forest, and on 24 October 2000 observed a male *D. matschiei* in subalpine grasslands at approximately 3850 m in the western Saruwaged Range above Kotet village. However, landowners from the Cromwell Mountain region did not agree that tree kangaroos feed in grasslands, stating that tree kangaroos confine themselves to forested areas.

Similarly, tree kangaroos are said to occasionally visit lower altitudes, presumably while dispersing. Landowners in Dakanom, a village approximately ten kilometers northeast of Teptep, showed the author a captive male *D. matschiei* which they had caught as it crossed a foot path at approximately 1200 m altitude. More surprisingly, landowners at Ronji, a remote coastal settlement located near the mouth of the Yupno River on the north shore of the Huon, stated that they had killed tree kangaroos at altitudes of no more than 200 m near the edge of the coastal forest. However, this assertion was challenged by neighboring hunters from the inland village of Koripon as well as by accompanying Keweng 1 landowners, who stated that the lowland regions were simply too hot for tree kangaroos to visit.

When asked about tree kangaroo distribution, Huon Peninsula landowners will sometimes mark tree kangaroo habitat by identifying it with the habitat of another animal or plant. Thus Keweng 1 hunters associate the animals with 'cold' forest where the *Karuka* tree, *Pandanus jiulianetti*, an edible nut bearing Pandanaceae, is found and say that the animal is not found where *Marita (Pandanus conoideus)*, a Pandanaceae with a large red edible fruit is prevalent. *P. conoideus* rarely grows above 1700 m (Kocher Schmid, 1991). Teptep landowners associate *D. matschiei* occurrence with the presence of *Libocedrus* trees, which are common in the upper montane forests above 2800 m. Animals that Keweng 1 landowners associate with the presence of *D. matschiei* are montane birds such as the Crested berry-pecker, *Paramythia montium*, which typically ranges from about 2150 m-timberline, or the Blue-capped Ifrita, *Ifrita kowaldi,* which normally occurs from 2000 to 2900 m (Beehler and Pratt, 1986).

5.3.2 *Dendrolagus matsciei* conservation status

Most Huon Peninsula landowners (25 of 32) who expressed an opinion on *D. matschiei* conservation status believe that the range of *D. matschiei* has contracted and the population found in village bordering forests has declined, often in conjunction with the status of the forests themselves. The area most affected by this was the Bulum River valley in the eastern Huon, where tree kangaroos have disappeared (along with primary forest) from the lower part of the valley in living memory. Tree kangaroo numbers have declined precipitously in the Teptep area where tree kangaroos are rarely found in suitable mid-montane forest, and the mountains immediately to the north of the Yupno River gorge, where *D. matschei* is locally extinct. However, the interviews revealed that there are still regions where the animals are found in good numbers, such as the more remote regions of the Cromwell Mountains, the Finisterre Mountains near Nankina, and the western Saruwaged Mountains near Yawan and the villages upriver from Yalumet. These are areas that have traditional hunting taboos that block human use, or are too rugged, remote, or cold for local hunters. The number of areas that have hunting taboos is still quite high. Only 16 landowners from seven villages stated that there were no longer any forbidden areas, whereas 39 landowners from 20 villages revealed that taboo areas still exist.

An exception to the trend of only forbidden and far off forests having plentiful tree kangaroo populations was observed in the forests owned by Keweng 1 landowners at the headwaters of the Bunum River. These forests are partially open for hunting and can be reached in three to four hours from the village but according to the landowners (and distance sampling results reported in Chapter 3) still maintain plentiful populations of tree kangaroos. Keweng 1 has a population of roughly 600, which makes it a large village for the region. A few other landowners spoke of having hunting areas close to the village, but these areas were normally found near villages with smaller populations.

5.3.3 *Dendrolagus matsciei* hunting techniques and hunting taboos

The biggest change in the hunting practices in PNG in recent decades has been the widespread adoption of shotguns by landowners in several parts of the country. In many areas the use of shotguns has had a dramatic and negative impact on wildlife populations especially on prized prey such as Crowned Pigeons (*Goura* spp.), black-spotted cuscus (*Spilocuscus rufoniger*) and tree kangaroos (Beehler, 1991a; Flannery, 1995). However, with the exception of two reports from landowners in the Nankina and Isan areas, shotguns are not used in the Huon villages that the author and the UPNG students have visited. One landowner from the YUS village of Worin (near Sapmanga) stated that he had used a gun in the past but gave it up when he realised that firearms scare the game away. This was a common reason given for the continued use of bow and arrows and other traditional hunting methods. Any remaining shotgun hunting in the Huon can be expected to decline further in the future, because the PNG government has restricted the sale of shotgun cartridges in an effort to reduce law and order problems (Filer and Sekhran, 1998). Virtually all hunters interviewed only hunt tree kangaroos with dogs and bow and arrows, with 56 of 58 landowners stating that dogs are always used for hunting. Other traditional hunting methods have disappeared or are disappearing. For example, several landowners in the Cromwell areas of the eastern Huon, one from the upper Urawa valley (western Saruwaged), and one from the Teptep region stated that deadfall and pit traps were formerly used to capture tree kangaroos. Their use has been discontinued because modern day hunters do not spend as much time in the forest as their fathers' generation, and therefore cannot check the traps on a regular basis. Tree kangaroo hunting was said to be an exclusively male activity. However, one elderly landowner from the village of Gomdan in the Finisterre Range described a lost method of hunting tree kangaroos, where men and women would hunt together with women singing and making loud noises to drive tree kangaroos to the men who would surround and kill the animals.

Hunting is attempted more frequently during the dry season, which in most parts of the Huon occurs from May to September. Twelve of 18 landowners who expressed an opinion on this topic said that tree kangaroos were easier to catch during this time, mainly because the animals spend more time in the ground, are less dispersed in the forest and closer to streams, and also because the weather is more favourable for hunting. This is especially true for longer hunting trips to remote areas that are too deep in the forest (Cromwell Mountains) or too high (Finisterre Mountains) for hunters to withstand the damp cold associated with rain. For example, Cromwell Mountain landowners from the village of Indagen said that their furthest hunting grounds are only hunted during the driest years. Not surprisingly, these areas were also said to have the highest density of tree kangaroos.

Virtually all the Huon Peninsula landowners interviewed are members of the Evangelical Lutheran Church of Papua New Guinea (ELC). ELC doctrine typically discourages the continuation of pre-Christian spiritual taboos, but taboo hunting areas are still recognised by 39 out of 55 landowners that answered this question. These areas are considered to be physically and/or spiritually dangerous for outsiders to enter. Landowners from other villages, such as Nomaneneng, told the author that although they no longer recognise taboo areas, there are still forests that they are reluctant to enter because of a lack of ancestral knowledge and trails of the area. The author has observed the same phenomenon among Yupno speaking villagers of Keweng 1, and the reluctance of Yupno language group landowners to deviate from known paths in the forest has been documented in formal anthropological studies (Wassman, 1994; Wassman, 1997). Similarly, Yawan villagers in the upper Urawa River valley own blocs of forest that they will not enter because of their lack of traditional knowledge of the area.

Matschie's tree kangaroos are a valued commodity and are still sold in local as well as town markets. In areas with low incomes, especially in those villages that are too high or too remote from markets to grow coffee (the primary cash crop of highlands New Guinea), the money from the sale of tree kangaroos is an inducement to hunt. Dead tree kangaroos are typically sold for 3 to 10 Kina in local markets and 10 to 20 Kina in town markets (1 Kina = ~£0.19). Live tree kangaroos are typically sold for 50 to 100 Kina in the town markets. However the commercial aspect of *D. matschiei* hunting does not seem to be heavily developed in the areas that the author or the other interviewers have visited. There was no evidence observed of systematic and intensive commercial hunting of tree kangaroos like that which has decimated wildlife such as the Babirusa (*Babyrousa babyrussa*) in Sulawesi, for example (Clayton et al., 1997).

Most landowners interviewed believe human populations and their impact on the Huon Peninsula environment have increased substantially in recent decades. However, in some of the villages visited by the author and the UPNG students, landowners also stated that the per capita frequency and intensity of hunting has diminished or is diminishing. Elders in these villages will lament that the younger generation of men seem less interested in hunting and spending time in the forest, and will point to the youngsters' interest in town life, as well as increased demands of church, community and commercial activities as the cause.

The reduction in per capita hunting activity is associated with a decline in skilled hunting dogs, which then contributes to a further reduction in hunting intensity. Virtually all hunters interviewed stress the importance of having good hunting dogs towards successful tree kangaroo hunting, a fact which the author and other researchers have observed personally

(Flannery et al., 1996). Good hunting dogs are nearly uncontrollable if they detect tree kangaroo scent, and will tirelessly pursue their prey. Traditional training practices, usually involving a mixture of magic spells and feeding the dogs certain plants, are still used by the most serious hunters to produce these dogs, as are other traditional methods of preparing the dogs for the hunt. However, hunters believe that good training is not enough, that a dog must have the right mix of inborn aggression, intelligence, and tenacity to be a good hunter. Unfortunately, these qualities also make the dogs difficult to keep in the village. Good dogs have to hunt frequently otherwise they will express their natural aggression by attacking other dogs or by killing chickens. In either case, the dog's owner must typically pay compensation to the aggrieved party. If he is unable to pay, he will be required to kill his dog, or others will do so. Mambawe Manauno, one of the author's chief informants and collaborators, experienced this in 1998, when his best hunting dog was killed by fellow villagers who were angered by the dog's attacks on their chickens.

Hunters from the Cromwell Mountain village of Indagen told the author that the pattern of a dog's pursuit lets them know in advance what species their dog is chasing. For example, when pursued *D.matschiei* will typically flee directly downhill, often after leaping downwards from a tree. A *D. matschiei* observed by the author in 1996 escaped in this manner, leaping first from an approximately six meter high branch and then hopping down-slope through thick vegetation. Pursuing dogs were unable to catch the animal. Tree kangaroos are said not to concern themselves with the thickness of vegetation and thus the noise of a fleeing tree kangaroo is easily distinguishable. Tree kangaroos crash through vegetation, unlike fleeing New Guinea pademelons (*Thylogale browni*) or small dorcopsis (*Dorcopsulus vanheurni*), which tend to escape on existing game trails when pursued. The Indagen landowners noted that tree kangaroos will often try to escape from dogs by fleeing through thickets of *Dendrocnide* (Urticaceae), whose leaves and stems are equipped with fine (and toxic) siliceous hairs that are intensely irritating to the paws and snouts of dogs. In November 1996 the author observed hunting dogs suffering in the aftermath of one of these encounters while searching for tree kangaroos with Indagen village landowners in the Cromwell Mountains.

5.3.4 *Dendrolagus matsciei* Non human tree kangaroo predators

Matschie's tree kangaroos live at altitudes that are too high for the large Amesthytine Pythons (*Morelia amethistina)* that are known to kill *D. bennettianus* in Australia. However, they maybe threatened by an equally imposing predator: the New Guinea Harpy Eagle (*Harpyopsis novaeguineae*). Landowners in the Yawan area (Urawa River valley) believe that *H. novaeguineae* are the major natural predators of *D. matschiei*. The Yawan statements about Harpy Eagles agree with those of landowners near Telefomin in western PNG, who believe that the birds can kill young tree kangaroos [(Flannery, 1998); see 2.6.6]. The Yawan landowners also believe that wild, or 'singing' dogs, are tree kangaroo predators, particularly at higher altitudes on the edges of the subalpine grasslands, where the dogs are most abundant. This supports speculations that New Guinea singing dogs are capable of killing high altitude dwelling Doria's tree kangaroos, and agrees with Australian observations that dingos and feral dogs kill Bennett's and Lumholtz's tree kangaroos [(Newell, 1999a); see 2.6.6]. Landowners in other portions of the Huon agree that wild/feral dogs kill tree kangaroos, but although agreeing with the possibility, they do not 'know' that Harpy eagles do.

5.3.5 *Dendrolagus matsciei* activity patterns

Huon Peninsula landowners believe that *D. matschiei* is crepuscular or diurnal. Only eight landowners stated that the animal was active at night, while 62 landowners stated *D. matschiei* is only active during the predawn to dusk time periods. Eight landowners stated that *D. matschiei* sleeps during the day, while 53 stated that the animals sleep at night. However, 18 of the 53 who stated that *D. matschiei* sleeps at night added that that the animals also sleep and rest during the 'hot' (middle) portion of the day.

Bulum River landowners interviewed by UPNG student Kepslok Kumilgo stated that *D. matschiei* is crepuscular, while landowners in the Teptep, Keweng, and Nankina areas are divided between those who thought that *D. matschiei* is truly crepuscular and others who say that the animal is diurnal. Landowners interviewed by the author in the upper Urawa River villages of Yawan, Kotet, and Towet state that *D. matschiei* is diurnal but with a resting or sleeping period from late morning to mid afternoon. The author has encountered two animals in the wild, and the activities of the animals lend support to both the diurnal and the crepuscular arguments. The first animal was found at approximately 09:50 local time on October 23, 1999 at the Tomongan field site. The animal was lying on a branch approximately 10m above the ground. Its sex could not be determined because its genital area was obscured. It appeared to be sleeping, although it would periodically (approximately once every 5 minutes) shake its head to disperse biting insects. It was observed for approximately one hour and did not move from its perch. A second *D. matschiei* was encountered on October 24, 2000 at approximately 10:00 local time in the western Saruwaged Mountains, near the village of Kotet. This animal, a male, was walking in subalpine grassland at an altitude of approximately 3850 m. The nearest forest was several hundred meters away, so it may have been dispersing.

Almost all of the claims for *D. matschiei* nocturnal behaviour came from landowners from the Kabwum area of the eastern Huon, and four from one village, Musep. They were joined by one landowner from Gorgiok in the YUS region, and one from Gomdan (in the Nankina region). It is possible that *D. matschiei*, like *D. goodfellowi*, can adopt nocturnal activity patterns as a response to hunting pressure [(Flannery et al., 1996); see 2.6.6], but it is unknown whether tree kangaroos in the Musep area are being hunted more intensively than other areas.

There is geographical disagreement as to whether tree kangaroos have specific trees that they return to in order to sleep or rest. Landowners in the Nomaneneng and Indagen area of the eastern Huon believe that they do. Nomaneneng landowners say that these trees tend to be located in steep gullies where the animal can escape downslope if threatened. Landowners in the Yawan region of the upper Urawa River drainage do not believe that tree kangaroos have specific trees that they use for sleeping but rather that the animals prefer to feed in certain *Tom* (provisionally identified as *Carpodetus* spp., Saxifragaceae) trees. Landowners from the upper Yupno River village of Keweng 1 believe that the animals do not favour specific trees, although they say an animal will occasionally use a particular tree for a few days. The landowners comments agree with the author's field experiences in their respective areas.

During five field seasons he has never seen an obvious resting or feeding tree at the Dendawang and Sibidak field sites belonging to Keweng 1 clans, but has seen such trees within hours or days of entering forests in the Indagen and Nomaneneng areas, as well as heavily used *Tom* trees in the Yawan area. The differences in tree usage patterns maybe an indication of behavioural variation between different populations of *D. matschiei*, and this maybe due to habitat variation. Another interpretation is that the less predictable behaviour of Dendawang and Sibidak *D. matschiei* could be an adaptation to high levels of hunting in the past (T. Flannery pers. comm.). The two sites are not hunted currently, but were used by hunters regularly before the TKCP's arrival in 1996.

A majority of landowners (12 of 16) believe that *D. matschiei* is less active during rainy periods, and less likely to leave the trees and move about on the ground. This agrees with results from studies of the Tenkile (*D. scottae*) and *D. dorianus* [(Flannery et al., 1996); see 2.6.5]. Landowners also stated that dry seasons cause *D. matschiei* to spend more time in cool areas or near water sources, while wet seasons lead them to disperse more evenly throughout the forest.

5.3.6 *Dendrolagus matsciei* social behaviour

Captive *D. matschiei* have been shown to be relatively solitary with the only strong social bond being the one between mother and joey [(Hutchins et al., 1991); see 2.6.3]. The results of the landowner interviews partially support this, while giving an indication that social behaviour may vary between hunted and unhunted areas. Twentynine of the 46 Huon Peninsula landowners interviewed state that tree kangaroos are normally seen alone, or in the case of females, with the joey. The other 17 landowners stated that *D. matschiei* will assemble to look after joeys, or to feed in favoured trees. One landowner from Keweng 1 told the author that he once encountered five adult animals feeding together with one joey on a grass and shrub covered landslide chute. Three landowners stated that tree kangaroo social behaviour varies with hunting pressure: in low hunting or taboo areas the animals will form groups, while in hunted areas they are essentially solitary. This increased level of sociability in less hunted areas has also been reported for other species of New Guinea tree kangaroos [(Flannery et al., 1996); see 2.6.4].

5.3.7 *Dendrolagus matsciei* food plants

Chapter 4 reported that landowners from Keweng 1 village in the YUS local government area of the central Huon Peninsula believe that *D. matschiei* eat a wide variety of food plants, and helped the author collect 91 species of plants at the Dendawang field site. The landowners also stated that tree kangaroos do not eat too much of any particular kind of plant before moving on to another species. This agrees with behaviours observed in other folivore species such as the Red Colobus monkeys (Colobidae, *Piliocolobus* spp.) [(Kingdon, 1997); see 2.6.4]. Landowner interviews by UPNG student Som Yalamu in other villages in the YUS local government area and in the Nankina region to the west reveal similar results. However, Yalamu's results are unlikely to be complete. He was not able to accompany any of the landowners to their forest holdings and thus was not able to collect the plants that the villagers listed. The author's experience is that landowners will not identify as many food plants when interviewed in a village setting as they will when walking through the forest with the plants at hand. For example the author documented 20 species of *D. matschiei* food plant species by asking accompanying landowners from Kotet village (Urawa River drainage) to point out tree kangaroo food plants while ascending from the village to the crest of the western Saruwaged Mountains. This method of recording indigenous knoledge through direct observation may be more suitable than sedentary interviewing for recording landowner knowledge of food plants, and agrees with other ethnobiological studies (Diamond and Bishop, 1999).

However, the belief that Matschie's tree kangaroos eat a wide variety of food plants is not universal on the Huon Peninsula. Landowners from the Kabwum and Nomaneneng area of the Cromwell Mountain region believe that the animal eat no more than seven kinds of plants. This belief is localised: other landowners living in the Bulum River drainage, east of Nomaneneng, believe that *D. matschiei* eat several species of plants, concentrating primarily on young shoots, vines, and ferns. This may indicate that the Kabwum and Nomaneneng landowners, who also share the belief in a supernatural form of tree kangaroo (see 5.3.7) have a predominantly culturally influenced understanding of tree kangaroo dietary preferences. Another explanation for this restricted list is that the landowners may only be listing the dominnt or most common plants in the *D. matschiei* diet.

Another fundamental geographical disagreement in *D. matschiei* diets is whether they eat grasses. Finisterre and western Saruwaged Mountains landowners believe that tree kangaroos will venture out of the forest for short distances to feed on fresh leaves and stems of grasses in subalpine grasslands or landslide areas. Keweng 1 landowners have shown the author grass covered landslide areas where they say tree kangaroos will come to graze grasses and shrubs. Tree kangaroo faeces were prominent at these sites. Similarly landowners from Towet and Yawan in the upper Urawa River valley gorge state that they often observe *D. matschiei* feeding at approximately 1600-1800 m on steep grass-covered slopes below the 2200 m high rim of the gorge. The tree kangaroos use of grass covered areas is also attributed to a need to 'sunbathe' or 'warm the skin' in the early hours of morning. The author has observed captive *D. matschiei* eating grass inside an enclosure at a hotel in the coastal town of Lae, so it is possible that grasses and sedges make up a portion of wild Matschie's tree kangaroo diets. However, eastern Huon Peninsula landowners from Indagen and Ogeranang disagree with this, stating that tree kangaroos are confined to forests, and do not eat grasses nor visit grasslands or meadows.

No landowner interviewed mentioned carnivorous behaviour among tree kangaroos, although this behaviour has been observed in captive *D. goodfellowi* and *D. matschiei* [(Steenberg, 1984); see 2.6.4]. This suggests that carnivory does not occur or is very rare in the wild, perhaps only taking place in the forest canopy beyond human view.

5.3.8 Types of *Dendrolagus matschiei*

Ethnobiologists have observed that while indigenous peoples' species classifications often agree well with scientific taxonomies (especially at the generic level), cultures will often further subdivide species into 'folk-specific' and 'varietal' forms, which may not agree with scientifically recognised breeds and subspecies (Atran, 1999; Diamond, 1966). Most (43 of 52) of the Huon Peninsula landowners interviewed believe that there are types, or varietals of *D. matschiei.* The division of the animals into different forms appears to be based on biological as well as cultural/spiritual classifications.

An example of a cultural distinction is the belief held by landowners in the Keweng villages that there are two distinct types of *D. matschiei*: the *paljik kalan* ('thin tail') and *paljik pok* ('fat tail'). Landowners insist that the two forms do not interbreed, and there are no intermediates. The two forms were said to be sympatric, occurring together in all *D. matschiei* habitats. The *paljik kalan* is said to have a long thin tail and a long rangy body, while the *paljik pok* is said to have a short, fat or thick body as well as a shorter thicker tail. When asked to mark these lengths with their hands, Keweng landowners marked a body length of 63.5 cm for *paljik kalan*, 53.3cm for *paljik pok* and tail distance of 71.1 cm for *paljik kalan*, 63.5cm for *paljik pok.* These measurements are likely to be incorrect because the landowneres gave tail measurements that are appreciably longer than body lengths, a trait which has not yet been observed in *D. matschiei* (Flannery et al., 1996). *Paljik pok* are said to have a larger gut than that of *paljik kalan*, and their faeces are larger as well. Thus when identifying dung pellets for distance sampling studies (see Chapter 3), landowners would classify the pellet as belonging to either *paljik kalan* or *paljik pok.*

The Keweng landowners bifurcation of taxa into varietals extends to other taxa besides *D. matschiei.* They make similar tail size-based distinctions for other mammals such as New Guinea pademelon (*Thylogale browni*) and body size distinctions for mountain cuscus (*Phalanger carmelitae*), indicating that the *paljik kalan* and *paljik pok* varietals are likely to be part of a larger cultural pattern. Similar size based tree kangaroo varietals are recognised by landowners in other parts of the Huon - landowners in the Nankina area recognise thin and fat-tailed forms of tree kangaroos, but they also state that a third, possibly intermediate form of tree kangaroo exists. Dualistic folk taxonomies on the basis of size have also been observed among the Kalam/Karam people of the Kaironk valley of the Western Highlands of PNG (Bulmer and Menzies, 1972).

A more biologically probable distinction that is made by Keweng landowners is between tree kangaroos which live in the elfin, subalpine forest found at altitudes of approximately

3000 m and above on mountain-tops, and those living in the taller mid-montane forest found at lower altitudes. Accounts of lighter furred high altitude *D. matschiei* were also received from landowners from the village of Kotet in the upper Urawa River region. Unlike the *paljik kalan* and *paljik pok* these high altitude forms are unnamed, and Keweng landowners state that the high and low altitude classifications are unrelated to the *paljik pok* and *paljik kalan* distinctions. The high altitude forms are said to be lighter in pelage, having a 'blond' appearance, while the animals found in the lower forests are darker and browner in colour. A lighter coloured animal, similar to the high altitude description was seen by the author on 14 August 1996 at 3150 m, while one matching the lower altitude form was seen on August 24, 1996 at an altitude of 2600 m. Keweng landowner opinion is divided as to whether these pelage differences are permanent. Captive *D. matschiei* have been observed to become lighter furred, a change which has been attributed to nutritional deficiencies (Flannery et al., 1996). It is possible that sub-alpine tree kangaroos do not have access to the same diverse diets that lower altitude forms do, thereby resulting in nutritional deficiencies. Another explanation could be that lighter coloured fur is a result of higher exposure to solar radiation.

Landowners from the Kabwum and Ogeranang region of the eastern Huon recognise two types of tree kangaroos. The primary form is called *Sivam* in the Konge language spoken in the Kabwum area, and *Pesuhk* in the Bulum language spoken by the people of Ogeranang and Nomaneneng. It is the normal 'red' furred *D. matschiei*, the form commonly encountered and killed by hunters. A second form is the *Dagikorep*, which among Nomaneneng and Indagen landowers is regarded as a supernatural being. They believe that it is the 'mother of all mammals' – capable of reproducing itself or normal *Sivam* or *Pesuhk*. Hunters and dogs encounter it rarely, and interact with it at their peril. Landowners from villages neighboring Indagen acknowledge the existence of the *Dagikorep* but see it as just a darker, 'blacker' tree kangaoo that can be hunted and killed just like *Sivam*. A third form, called *Siksik*, is recognised by some landowners near Ogeranang in the Bulum River Valley. It is red furred but has prominent black stripes on its flanks, and is much larger than the *Pesuhk*.

The belief in a spiritually powerful and dangerous form of tree kangaroo maybe more widespread in the Huon than than just the Cromwell Mountain region. Landowners in Kotet, a village near the headwaters of the Urawa River in the western Saruwaged Mountains, believe in a tree kangaroo that they called *Sombe*. It was described as being longer tailed and bodied than the normal tree kangaroo form. Like the *Dagikorep*, the *Sombe* is believed to be dangerous to hunters and their dogs, and hunters are forbidden to kill them. The belief in a supernatural tree kangaroo that Kotet landowners share with the Indagen and Nomaneneng landowners is an example of the interchange of words and beliefs between language groups that has occurred on the Huon Peninsula.

5.4 *DENDROLAGUS DORIANUS* AND *DENDROLAGUS GOODFELLOWI* INFORMATION

5.4.1 *Dendforlagus dorianus* and *Dendrolagus goodfellowi* distribution

In the Maimafu region *D. goodfellowi buergersi* and *D. dorianus notatus* are altitudinally allopatric with a zone of sympatry. *Dendroalagus dorianus notatus* is found primarily from the tops of the highest peaks at over 3000 m down to approximately 1700 m, while *D. goodfellowi buergersi* ranges up to elevations of 2200 m. However, the altitude zones are not fixed. Perhaps a better guide is habitat. Crater Mountain landowners state that *D. dorianus notatus* favours low-statured forest found on mountain ridgetops and in steep slopes and landslide areas, while *D. goodfellowi buergersi* is most common in tall close-canopied lower to mid-montane forest. At the Semia field site, *D. goodfellowi buergersi* is restricted to altitudes below 1800m, and *D. dorianus notatus* was found from the summit at 2100m down to approximately 1600m.

5.4.2 *Dendrolagus dorianus* and *Dendorlagus goodfellown* hunting and hunting taboos

Previous studies of wildlife consumption in areas with religious taboos have documented that wildlife in these areas can be more abundant than in neighboring areas that lack religious proscriptions against hunting (Bennett and Robinson, 2000). The land owned by clans in Maimafu, a village in the northern portion of the Crater Mountain WMA, is becoming a de-facto protected area for tree kangaroos and other mammals. This is because of the success of the Seventh Day Adventist Church (SDA) in missionising residents of the area. PNG SDA church doctrine classifies all native New Guinea mammals (including tree kangaroos) as unclean and church members are forbidden to eat them. Tree kangaroo hunting has declined in Maimafu, being practised now almost exclusively by older landowners who have not fully embraced SDA church teachings (the SDA church did not enter the Maimafu area until the 1970s). Skilled hunting dogs are becoming rare. In 1996 the author was told that only five good hunting dogs were left in the region, and the trends have not reversed since then. One would expect that tree kangaroo populations there will continue to increase provided that outsiders can be kept from hunting on Maimafu lands. The decline in hunting in Maimafu as well as the previously mentioned Huon Peninsula community of Towet, suggests that mammal populations could also be increasing in other SDA controlled regions, and that conservationists should consider targeting SDA communities in PNG.

The remaining Maimafu hunters confirmed that tree kangaroo hunting is done primarily with dogs and bow and arrow. *Dendrolagus dorianus notatus* was said to be fairly simple to catch. It is not particularly fast or agile, so dogs can overcome it on the ground and it is easy to shoot if it tries to climb the low trees that occur in its habitat. Its only defence is the cold weather, thick vegetation, and steep, sometimes precipitous terrain of its upper montane habitat, which makes human and canine pursuit difficult. However, *D. goodfellowi buergersi* is said to be more difficult to catch because of its greater speed and agility. Hunters must first locate a tree where the animal is resting, then cut and pile vegetation to make a fence around the tree. The hunters and dogs then surround the tree, while one hunter climbs the tree or one adjacent to it until he gets in position to shoot the animal. When the animal falls/jumps to the ground, the hunters and dogs must move quickly to catch it before it escapes over the fence.

5.4.3 *Dendforlagus dorianus* and *Dendrolagus goodfellowi* activity patterns

According to Maimafu landowners both *D. goodfellowi buergersi* and *D. dorianus notatus* are diurnal. This agrees with previous radiotracking results for *D. dorianus notatus* [(Fischer and Austad, 1992); see 2.6.5].

5.4.4 *Dendforlagus dorianus* and *Dendrolagus goodfellowi* food plants

Both *D. dorianus notatus* and *D. goodfellowi buergersi* are said to eat a large number of plant species. Chapter 4 lists the 70 plants collected and identified by Rigel Jensen at the

TKCP's Semia field site. This list is not complete however, as it only contains plants that occur between 1400 m and 2150 m. During a visit to Crater Mountain in 1996, landowners showed the author upper montane forest plants that they said are consumed by *D. dorianus notatus*. One of these high altitude food plants was a *Rhododendron* spp. (Ericaceae). The mature leaves of Rhododendrons often contain grayonotoxins, which are known to be toxic to ruminants such as cattle, sheep, and goats (Goetz et al., 2000). Whether grayonotoxins have a similar effect on *D. dorianus notatus* is unclear, but it is suggestive that landowners stated that *D. dorianus notatus* only eat the young leaves and shoots of *Rhododendron.* A strategy of consuming immature leaves and shoots is consistent with attempts to avoid toxins and to increase nutrient intake [(Hladik, 1975; Opler, 1975); see 2.6.1 and 2.6.4].

5.4.5 *Dendforlagus dorianus* and *Dendrolagus goodfellowi* social behaviour

Goodfellow's tree kangaroo is thought to be one of the more social tree kangaroos, and the statements of Maimafu landowners supported this [(Flannery et al., 1996);see 2.6.3]. Semia field site landowners said that *D. goodfellowi buergersi* will meet in groups of three to four animals at certain trees in April-May. The favoured tree for this is the *Hibia* tree, *Neuburgia corynocarpa var. coryncarpa* (Loganiaceae). In 1997 the author was shown one of these trees at the Semia field site. The bark of the tree was heavily scratched by tree kangaroo claws and decayed faeces surrounded its base. A *D. goodfellowi buergersi* was photographed at base of the tree in January 1999 by UPNG student Kasbeth Evei using a remotely triggered camera.

The Maimafu landowners did not discuss any social behaviour among *D. dorianus notatus*. Captive *D. dorianus* have been observed to be quite social, forming family groups headed by a dominant male [(Flannery et al., 1996); see 2.6.3].

5.4.6 *Dendforlagus dorianus* and *Dendrolagus goodfellowi* - miscellaneous natural history

Semia fieldsite landowners stated that *D. goodfellowi buergersi* will drink 'salt water' at a (presumed) brine pool or salt/mineral lick. The Maimafu landowners say that the pool is attractive to several other species of mammals and birds as well. This is the second account of a New Guinea tree kangaroo seeking out mineral and/or salt rich water to drink or ground to eat. The first report of the use of brine pools by tree kangaroos, also for *D. goodfellowi buergersi*, was recorded by Bulmer and Menzies (1972). No other native Australasian mammal is known to visit mineral licks (Klaus and Schmid, 1998). Salt rich springs are known from the Baliem River gorge region in the central cordillera of Irian Jaya, and are used by the indigenous people there to acquire salt (NaCl). It is unknown if native mammals use these pools as well.

Four Maimafu landowners say that *D. dorianus notatus* 'washes its hands' or 'makes fire' with moss after feeding. The animal is said to clean its muzzle with its paws/wrists, before wiping them vigorously on moss. Maimafu landowners showed the author several piles of disturbed vegetation that were attributed to this behaviour on the summit ridge of Crater Mountain (3100 m).

5.5 DISCUSSION

5.5.1 Evaluation of the interview method

The greatest difficulty encountered during the interviews was landowner distrust. The student interviewers reported that landowners often expressed anxiety about the motives of the TKCP and/or the interviewers. Questions about tree kangaroo natural history and regional conservation status were usually answered, but many landowners were afraid to speak honestly about hunting, and perhaps about deeper cultural attitudes towards tree kangaroos. Many of the landowners were under the mistaken impression that the students had law enforcement powers or would report them to the police for killing tree kangaroos. This was despite repeated assurances by the students that they were merely seeking information and that there is no law in PNG forbidding the hunting of tree kangaroos for subsistence. Therefore, the expectation that landowners would be more forthcoming to PNG students was only partially true. Future interviews in new areas may need to be more limited in scope, perhaps concentrating on general questions about tree kangaroo natural history and local conservation status, with some non-'incriminating' questions about hunting practices.

Detailed interviews concerning hunting practices, hunting levels and cultural beliefs may only be productive in areas where landowners trust the TKCP's motives, and may have to be done by trained local interviewers, rather than by outsiders. An additional reason for using local interviewers is that their knowledge of local languages would enable clearer questions and replies, because of the greater precision of using local languages rather than Tok Pisin (Majnep, 1982).

The problems of overcoming landowner distrust meant that the student's work would have been difficult regardless of the methodology used. However, in retrospect it is also clear that the methodology had flaws. The first was that the UPNG students were not given training in proper interview techniques before they began their work. A second problem was that the interview sheet was not structured in a way that the same questions could have been asked in different forms in different times during a given interview. This would have been useful to obtain more truthful and accurate answers. Another mistake was that students were allowed to make their own data-sheets, which often were not consistent. The author was thus unable to determine if missing responses to questions from the interview sheet were due to a lack of response by the informant or by the interviewer not asking a given question. This lack of consistency hampered any effort to quantify the interview results, as did a lack of a design for codeable responses (Bernard, 2002).

A final observation was that landowners were often more comfortable when interviewed as a group. The animated discussions that these mass interviews engendered led to more complete, nuanced and considered answers as unsatisfactory replies were swiftly challenged, debated, and sometimes edited or rejected by the group. Future interviews will use this technique, in addition to single informant interviews.

Despite the methodological shortcomings, the landowners interviews were valuable. They gave insights about tree kangaroo natural history, hunting practices, tree kangaroo distribution, and conservation status, and to a lesser degree information about the culture significance of tree kangaroos. Indeed the very informality of much of the interviews was advantageous because they assisted in building rapport with informants and uncovering new topics of enquiry that might not have been discovered using more rigorous methods (Bernard, 2002).

5.5.2 *Dendrolagus matschiei* conservation status

The interviews with Huon Peninsula landowners gave useful information concerning the conservation status of Matschie's tree kangaroos. The most important insight is that in most of the areas visited by the author and other TKCP workers is that the perceived conservation status of *D. matschiei* has declined. If the trends observed in these areas hold for the rest of Matschie's range then the species is indeed Threatened or Endangered [(Baile and Groombridge, 1996); see 2.1.3].

The species faces continued threat from hunting. Tree kangaroo populations have declined in several areas with many hunters reporting reduced capture rates compared with the past. However, the decline in populations is probably not uniform, because in a few areas hunting has diminished, and it is possible that *D. matschiei* populations will increase in those areas. In addition, there are still isolated or forbidden blocs of forest that are not hunted by humans and which serve as refugia for the species.

Habitat loss is a problem in several areas, due to human population growth and associated activities, especially human caused fires. Human populations are growing rapidly in the mountains of the Huon Peninsula. For example, during the ten year span between the 1990 and 2000 national census the human population in the YUS Local Government Area grew from approximately 6500 to approximately 9500 (D. Ogate, pers. comm.). Part of this increase may be an artefact of an incomplete census in 1990, but all observers interviewed by the author stated that populations are increasing rapidly. Although logging and mining are not a major factor in montane regions of the Huon as yet, they remain potential threats as shown by proposals to log forests in some of the best portions of the species range, such as the uninhabited montane forests of the Cromwell Mountains (Johns, 1993).

5.5.3 *Dendrolagus matschiei* natural history

Huon Peninsula landowners state that *D. matschiei* is crepuscular or diurnal. *Dendrolagus matschiei* are probably less active during rainy periods and more active on the ground during dry sunny periods. The animals can occur as low as 1500 m, and disperse at least as low as 1200 m, but they favour 'cold' forests above 2-2400 m, up to tree-line (3200-3400 m), and will disperse across the highest mountains (to at least 3800 m). Landowners confirm that the species has a varied diet, (primarily of leaves and shoots) from a large number of plant species, including grasses and sedges, although this is disputed by Cromwell Mountain landowners who believe that the *D. matschiei* menu is restricted to no more than seven species and does not include grasses.

There is also regional disagreement on the use of specific trees for feeding or resting/sleeping. Landowners in the Cromwell and western Saruwaged Mountains believe that tree kangaroos visit certain trees repeatedly and were able to show these trees to the author. Landowners in the eastern Finisterre Mountains believe that *D. matschiei* do not have preferred trees for feeding or sleeping, and the author has never seen a heavily scratched tree in the region. The disagreement and the evidence that the author has observed indicate that there may be some regional variation in *D. matschiei* activity and movement patterns.

Dendrolagus matschiei found in elfin upper montane forest at high altitudes are reputed to be more lightly colored than the darker furred animals found in mid-montane forests. Other forms of *D. matschiei* recognised by landowners are probably cultural varietals. Thus the fat-tailed *paljik pok* and thin-tailed *paljik kalan* forms of Keweng 1 and other Yupno speaking villages are likely to be part of a multispecies size-based classification system, while the supernatural *Dagikorep* and *Sombe* of the Cromwell and western Saruwaged Mountains may reflect the strong place that tree kangaroos hold in traditional spiritual beliefs.

5.5.4 *Dendrolagus goodfellowi* and *Dendrolagus dorianus* information from the Maimafu region of the Crater Mountain WMA

Dendrolagus goodfellowi buergersi and *D. dorianus notatus* populations maybe increasing in the Maimafu region of the Crater Mountain WMA. This is because most villagers in the Maimafu area have accepted Seventh Day Adventist (SDA) church teachings that prohibit the hunting and consumption of native mammals. The remaining hunters in Maimafu hunt tree kangaroos in the traditional manner with dogs and bow and arrows. They state that *D. dorianus notatus* is easier to catch than *D. goodfellowi buergersi* chiefly because of the latter taxa's speed and elusiveness when under pursuit.

Both *D. goodfellowi buergersi* and *D. dorianus notatus* are diurnal. They eat a large number of food plants. *Dendrolagus goodfellowi buergersi* will occasionally gather in groups of 3-4 animals to feed on the leaves of *Neuburgia corynocarpa var. coryncarpa* (Loganiaceae), a tree which can heights of greater than 30 m. Favoured trees are heavily scratched and ringed by tree kangaroo faeces at their bases. *Dendrolagus goodfellowi buergersi* is also said to drink 'salt water' at certain muddy areas.

CHAPTER 6 GENERAL CONCLUSIONS

6.1 INTRODUCTION

Chapter 1 listed the following goals for this thesis:

1. Estimate tree kangaroo population density using distance sampling analyses of dung pellet counts.
2. Document tree kangaroo food plants.
3. Document tree kangaroo conservation status and natural history through landowner interviews.

Sections two through four of this chapter will summarise the results obtained for each of these topics and an evaluation of the degree to which each goal was met. This will be followed by a discussion of the conservation implications of, as well as the conservation actions that have resulted, from this research and its associated conservation program, and finally by suggestions for further research to address short-comings in the existing research and to suggest new approaches.

6.2 MATSCHIE'S TREE KANGAROO POPULATION DENSITY ESTIMATES

The first stated goal (see Chapter 1, page 2) of this thesis was to estimate tree kangaroo population density and to evaluate the feasibility of using dung pellet counts and distance sampling analysis to estimate population density for Matschie's tree kangaroos (*Dendrolagus matschiei*). The goal was fulfilled, albeit with significant uncertainties in dung depostion, and alteration rates. This thesis reported the first density estimate for a New Guinea tree kangaroo species, Matschie's tree kangaroo (*Dendrolagus matschiei*). The estimate of roughly one animal/ha is similar to abundance measured for Lumholtz's tree kangaroo (*D. lumholtzi*) and roughly three fold higher than Bennett's tree kangaroo (*D. bennettianus*) in Australia [(Martin, 1993; Newell, 1999b); see 2.6.5]. It confirms that Matschie's tree kangaroos, like other arboreal folivores such as sloths and folivorous monkeys, can occur at high densities in suitable habitat where hunting pressure is low [(Kingdon, 1997; Kricher, 1997); see 3.4.1]. However this density figure has not been duplicated at another site. Dung pellet encounter rates from the hunted Tomongan site were one third of those at Dendawang and Sibidak, and it is possible that the Dendawang and Sibidak results are atypically high for most areas of its range.

The tree kangaroo density estimates were derived from dung pellet counts, and like previous pellet count studies of Australian macropods, have significant uncertainties. Chief among these is determining the average dung pellet production rate. The dung pellet production rate for *D. matschiei* measured for this study was approximately 26 pellets/day/animal for captive animals fed a diet partially composed of human crops. However, an Australian study done with a single *D. lumholtzi* fed a diet of known wild food plants produced a much higher rate of 96 pellets/day [(K. Coombes, pers. comm.); see 3.3.4]. If this higher defecation rate estimate is used, then the calculated Matschie's tree kangaroo density would be reduced to approximately 0.27 animals/ha, or 27 animals/km^2, a rate similar to like-sized folivorous monkeys such as the mantled howler monkey (*Aloutta palliata*) (Mittermeier, 1998).

Additional uncertainties include possible confusion of tree kangaroo and New Guinea pademelon (*Thylogale browni*) dung pellets, and possible miscalculation of dung alteration times. These uncertainties are less problematic because the New Guineans assisting the author are experienced hunters and have experience evaluating the morphological differences between the faeces of the two species, while the pellet alteration rate has been measured in the environment where the animals live. A final uncertainty is over the proportion of the tree kangaroo dung pellet population that has actually been sampled. Tree kangaroos spend significant amounts of time in the trees and it is quite possible that if they defecate in the trees not all pellets that they produce will reach the ground. Unfortunately, extensive canopy sampling was not feasible for this study and the faecal sample pool maybe incomplete, thus leading to a possible underestimate of tree kangaroo dung pellet densities (and tree kangaroo populations).

6.3 TREE KANGAROO FOOD PLANTS

The second goal of this thesis (see Chapter 1, page 2) was to document tree kangaroo food plants by gathering descriptive information on the food plants of three species of New

Guinea tree kangaroos. This was achieved but it is likely that the list represents a beginning, and not the final word on the diets of the three tree kangaroo taxa in question (*Dendrolagus matschei*, *Dendrolagus goodfellowi buergersi*, and *Dendrolagus dorianus notatus*). Collections need to be repeated with the same and different landowners, at different altitudes and different forest types within each taxa's range before the descriptive ethnobiologically based approach can have achieved its potential.

Landowner knowledge was recorded, and collections were made of the diet of Matschie's, Doria's, and Goodfellow's tree kangaroos. Observational data for Lumholtz's tree kangaroo as well as evidence from previous work in New Guinea [(Flannery et al., 1996); see 2.6.4] indicated that tree kangaroos follow the typical arboreal folivore pattern of consuming many species of plants. Although anecdotal, the landowner information on tree kangaroo food plants provides support for this hypothesis. Most knowledgeable Huon Peninsula landowners interviewed stated that *D. matschiei* has a wide and varied diet consisting of plants from several families. Extensive collections made with the assistance of landowners from the village of Keweng 1 produced 91 species, from 40 families. Similar results (70 species from 37 families) were obtained by Rigel Jensen and Maimafu landowners for food plant collections for Goodfellow's (*D. goodfellowi buergersi*) and Doria's (*D. dorianus notatus*) tree kangaroos at the Semia site in the Crater Mountain Wildlife Management Area. It should be noted that the Huon and Crater Mountain lists are not complete and it will be necessary to make further collections of plants that landowners have recently identified. Nevertheless, the pattern of many food plant species from a wide variety of families is clear.

Landowners confirmed that tree kangaroos exhibit another typically arboreal folivorous trait in that the animals not only eat a wide variety of food plants but also do not consume large amounts of any one species. This behaviour is likely a response to the need to deal with digesting toxic secondary compounds which are found in high abundance in the leaves of tropical plants [(Glander, 1977; Milton, 1980); see 2.6.4].

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6.4 LANDOWNER INTERVIEWS

The third goal of the thesis (see Chapter 1, page 2) was to document tree kangaroo conservation status, natural history, and cultural significance through landowner interviews by New Guinean university students. Due to a lack of methodological rigour, geographic and personnel limitations and difficulties in gaining landowner trust, this goal was not as well realised as the first two goals. Nevertheless the approach of surveying landowners shows promise, and useful information was obtained.

The interviews indicate that populations of *D. matschiei* have declined in the last generation. The declines have paralleled the rapidly increasing human populations, the conversion of forest to grassland and crop land, and more recently, the destruction and/or degradation of habitat due to human caused fires accentuated by severe El Nino Seasonal Oscillation (ENSO) induced droughts. This evidence indicates that the species is threatened or endangered thus supporting the published conservation status [(Baile and Groombridge, 1996; Flannery et al., 1996); see 2.1.3]. However, the declines in tree kangaroo populations have not been uniform: some areas remain too remote or are forbidden to human entry, and in those areas tree kangaroos are still plentiful. In at least one area, Towet village in the upper Urawa River, *D. matschiei* populations are probably increasing because of religious proscriptions against hunting and consuming native mammals.

Over hunting is probably the greatest immediate threat to tree kangaroos (see 2.1.2), and hunting has been largely responsible for the decline in *D. matschiei* populations on the Huon. However, while confirming that hunting pressure is heavy throughout much of *D. matschiei*'s range, the landowner interviews for this study also documented that a decline in per capita hunting activity has occurred or is occurring in some villages. Young men in these villages are hunting at a lower frequency than previous generations of hunters. This trend coincides with the relative ease of travel to the towns, and the development of local institutions as well as alternative forms of recreation such as football. The contradictory trends of rising human populations and rising habitat degradation versus local decreases in human hunting intensity makes it difficult to generalise about future trends for *D. matschiei* populations and also offer some hope that further decline is not inevitable.

The interviews revealed that landowner knowledge of *D. matschiei* natural history agrees with much of what has already been learned in captive studies. The animals are crepuscular to diurnal, are essentially solitary and reproduce slowly. They are less active during rainy periods, and spend more time on the ground during dry periods. They range in altitude from approximately 1500 m to treeline at 3300 m. However, tree kangaroos will occasionally be found higher, to the summits (3850 m) of the high peaks of the Saruwaged and Finisterre ranges, and lower than this range, to at least as low as 1200 m. The pelage of *D. matschiei* may vary with altitude, with individuals found in upper montane and subalpine zones possessing lighter and more yellow fur than individuals in the middle montane forests. This could be due to nutritional deficiencies from a more limited diet, a result that has been observed in captive animals [(Flannery et al., 1996); see 2.6]. Other 'varietal' *D. matschiei* forms identified appear to be cultural constructs.

Although many traditional beliefs have been lost or discarded in the aftermath of widespread missionisation, it is clear that Matschie's tree kangaroo remain culturally significant to Huon Peninsula landowners. On a material level tree kangaroo tails and pelts are still used by groups throughout the region as adornment during ceremonial occasions. On a spiritual level some ancestral beliefs remain, with the most interesting example being the belief professed in some communities bordering the Cromwell Mountains and in the western Saruwaged Mountains in a supernatural tree kangaroo called *Dagikorep* or *Sombe*. This form appears to embody a maternal and/or forest guardian force in its ability to restock the bush with more tree kangaroos, and other wildlife. This form also serves as a representation for dangerous spiritual forces thought to be present in the forest, in that it is dangerous to encounter, and a hunter who does so will commonly become lost.

Information about *D. dorianus notatus* and *D. goodfellowi buergersi* was obtained during informal conversations with landowners from Maimafu in the Crater Mountain WMA. Both species are said to be diurnal or crepuscular. This agrees with previous information [(Fischer and Austad, 1992; Flannery et al., 1996); see 2.6.5]. *Dendrolagus dorianus notatus* is associated with high altitude forests but will reach lower altitudes in areas with steep terrain and/or where short-statured forest are found. *Dendrolagus goodfellowi buergersi* is associated with less precipitous terrain and with tall close canopied lower and mid montane forests. When found on the same mountain, such as the TKCP's Semia field site, the animals will share a limited zone of sympatry. The captive evidence of greater activity among *D. goodfellowi* versus *D. dorianus* is mirrored in the statements by Maimafu landowners that the speed and agility of Goodfellow's makes them much more difficult to catch than Doria's. Doria's is said to live in single male dominated groups in captivity but Maimafu landowners did not know of this. However, they did agree that *D. goodfellowi buergersi* is more sociable with up to three to four animals gathering to feed in *Neubergia corynocarpa* trees. Perhaps the most interesting behaviour reported by the landowners is that Goodfellow's tree kangaroos visit brine pools or mineral licks, a behaviour only noted on one previous study (Bulmer and Menzies, 1972). If confirmed, this would be the first known instance of this behaviour in Australasian marsupials [(Klaus and Schmid, 1998); see 5.4.6].

6.5 CONSERVATION IMPLICATIONS

The distance sampling results reported in Chapter 3 (see 3.3.1) indicate that *D. matschiei* can occur at high densities, and therefore that the habitat requirements of the species are not overly large. It is possible that *D. matschiei* densities can approach 100/km2, and likely that they can exceed 27/km^2, at least in mid montane forest with no hunting pressure. A suitably chosen area of 25-100 km^2 would probably contain a reproductively viable population of the animals provided that they could be completely protected from hunting. Hunting pressures can rapidly reduce tree kangaroo populations to levels that would require much larger forested areas for the animals to persist [(Redford, 1992); see 2.1.2]. Protecting and managing such large areas would be difficult because of the divided nature of land ownership in the Huon Peninsula, and PNG in general [(Holzknecht, 1994); see 2.3.1]

The combination of *D. matschiei*'s potential for high densities, its vulnerability to hunting pressure, and the pattern of land ownership in its range suggests that a potential method of ensuring the species' survival would be to establish a network of relatively small clan-owned reserves. These reserves would need to be fully protected with no hunting or other resource extraction allowed. Clans would only demarcate part of their lands, and the intervening forests would be maintained as hunting/subsistence use areas for human populations and as corridors for genetic interchange for tree kangaroos (and other wildlife). This method of establishing a network of small reserves has been observed in other traditional societies and has been shown to be an effective method for conserving wildlife while allowing sustainable hunting [(Joshi and Gadgil, 1991); see 2.4.2]. This strategy is particularly effective when reserves are numerous and well distributed throughout the habitat. This allows mixing of populations to occur and maximises populations outside of the reserves.

Hunting outside the reserves does not need to be discouraged but perhaps does need to be moderated, preferably by local government laws. This is particularily important for dealing with individuals or clans that tresspass on other clan's lands. Indeed this is one of the prime reasons given by landowners for supporting formal conservation efforts.

In order for the clan-based conservation strategy to be successful, workers will need to identify landowners and clans that have a sincere interest in conservation, and intensive efforts will need to be made to engage them. Landowners and clans that are not interested in conservation should not be pressured to participate, although they may join later. 'Engaging' clans will require using an ICAD strategy of facilitating local economic and social development, while a conservation ethos is inculcated in landowners that they will internalise and which will outlast the conservation project's lifetime. This will take time and an *isi isi* ('easy easy') approach will be necessary [(Ellis, 1997; Orsak, 1999a); see 2.3.1]

The core of this conservation ethic will need to be tied to existing Christian (and/or appropriate traditional beliefs), where the biblical concept of humanity's role and duty as stewards, rather than destroyers, of nature is stressed. A secondary rationale for conservation will be the concept of clan conservation area or areas as wildlife and resource banks that will guarantee that future generations will be able to obtain the same wildlife and plant resources as their parents. Finally, the establishment of conservation areas will be presented as being an integral part of broader efforts to improve landowner livelihoods through sustainable developments in agriculture, education, health, etc. It is hoped that conservation projects can help foster, and in turn benefit from, improved regional cooperation, especially if larger interclan landowner groups are formed to manage conservation areas. Once formed the same groups could conceivably work together to accomplish other development objectives in the area.

Successful conservation of *D. matschiei* will benefit other species as well. The network of small clan-based reserves may not be sufficiently large and/or contiguous to guarantee protection to reproductively self-sustaining populations of nomadic/highly mobile species or those with large habitat requirements, such as the New Guinea Harpy Eagle (*Harpyopsis novaeguineae*). However, they should be sufficient to protect much of the resident fauna, including New Guinea conservation priorities such as the long beaked echidna (*Zaglossus bruijni*), and Huon Peninsula endemics such as the Huon Astrapia Bird of Paradise (*Astrapia rothschildi*) and the Spangled Honeyeater (*Melipotes ater*). The example of clans protecting mid to upper montane habitats containing tree kangaroos may serve to inspire other Huon Peninsula landowners at lower altitudes to conserve areas which contain their own endemic 'flagship' species, such as the Emperor Bird of Paradise (*Paradisaea guilielmi*) or the Wahnes' Parotia Bird of Paradise (*Parotia wahnesi*). This objective maybe realised; at the time of completion of this thesis landowners in the Yupno River valley were considering establishing conservation areas in lowland and hill-forest areas (see 2.4.4).

Paramount to the success of any conservation project in PNG is the realisation that landowners must feel that they are in control of the process. Initially this may not fully be the case, but as they become familiar with conservation arguments they must be encouraged to not merely tolerate, but to take leadership roles in projects that are taking place on their lands. They alone must determine what areas of land that will be set aside for protection, and they must assume responsibility for maintaining the protected status of the lands that they set aside.

6.6 SUGGESTIONS FOR FUTURE RESEARCH

6.6.1 Distance sampling

The distance sampling research described in Chapter 3 produced density estimates for *D. matschiei* at the Dendawang and Sibidak field sites. However, this result is subject to uncertainties, which future research should seek to reduce or resolve. Research could also attempt to gather more data on *D. matschiei* densities by obtaining densities at other areas. Finally future distance sampling research could be aimed at other species. Thus suggested research might include:

- Studies at different sites and attempt further censuses at existing sites like Tomongan to obtain a broader perspective of *D. matschiei* densities.
- Further dung alteration studies. Alteration rates need to be quantified for different altitudes and rainfall levels as has been done for African elephants.
- Further surveys at the Semia site and perhaps at other sites to determine feasibility of dung sampling at lower altitudes.
- Verification of tree kangaroo dung pellet identifications by examining hairs swallowed during grooming, and determination of error rates for identification.
- Radiotelemetry studies of tree kangaroos at or near field sites to determine home ranges as a cross-check to the density figures obtained from distance sampling.
- Density studies using dung pellet counts and distance sampling analysis for other tree kangaroo species. The Critically Endangered *D. scottae* is a potential subject.

6.6.2 Food plants

Chapter 4 listed and discussed New Guinea landowner identified food plants for *D. matschiei*, *D. goodfellowi buergersi*, and *D. dorianus notatus*. Although descriptive and anecdotal, these lists represent the first extensive food plant information ever gathered for New Guinea tree kangaroos. Future research could aim to finish recording landowner knowledge at existing sites, record landowner information from new areas, and attempt to confirm landowner statements through direct observation of wild tree kangaroos. Thus suggested future research might include:

- Further plant collections at Dendawang and Semia sites to gather the complete tree kangaroo food plant menu for those areas. The interviews would include further questions about what portions of plants are eaten.
- Working with landowners from other clans or villages to collect tree kangaroo food plant at new sites, especially at different altitudes and/or different forest types to begin to document full diversity of food plants.
- Determine tree kangaroo diets by analysis of plant fragments in tree kangaroo faeces.
- Nutritional and chemical analysis of tree kangaroo food plants, especially favoured plants such as *Marratia* spp. (Marattiaceae), *Impatiens hawkerii* (Balsaminaceae), *Neuburgia corynocarpa* (Loganiaceae), and *Tom* (*Caropdetus* spp., Saxifragaceae).
- Direct observaton of the feeding behaviour of radio-collared tree kangaroos as a cross-check to the landowner plant lists.

6.6.3 Landowner interviews

Landowner interviews have produced useful information concerning the natural history of *D. matschiei*, *D. goodfellowi buergersi* and *D. dorianus notatus*. The interviews have also given insight into the conservation status of *D. matschiei* as well as providing some information about the cultural significance of tree kangaroos and tree kangaroo hunting practices. The interviews should be continued. However, the interview methodology may have to be revised to assuage landowner concerns with perhaps less emphasis on direct questions about hunting and more emphasis on natural history and the perceived conservation status of tree kangaroos. Thus suggested future research might include:

- Continue interviews in new areas of the Huon Peninsula where *D. matschiei* occurs. The long-term goal would be to visit communities throughout the entirety of the species range.
- Perform more detailed interviews in regions where the Tree Kangaroo Conservation Program's (TKCP) activities and goals are better understood by landowners. These interviews would attempt to achieve greater depth concerning the more sensitive topics such as hunting rates and cultural beliefs concerning tree kangaroos.

- Hire and train local landowners to be interviewers. This might lower levels of distrust and may also give greater insight into traditional knowledge of the area, while allowing more interviews to be performed and a larger area to be covered. The use of more complex local languages may also clearer results compared with interviews which use the simpler *lingua franca* Tok Pisin (Bulmer, 1982).
- Accompany landowners to neighboring forests and ask them to identify food plants and give local names. Plants could be photographed, and compared with the existing Dendawang list.
- Give greater emphasis to group interviews to achieve more accurate and complete answers.
- Continue interviews with Maimafu and other Crater Mountain landowners on *D. goodfellowi buergersi* and *D. dorianus notatus*.

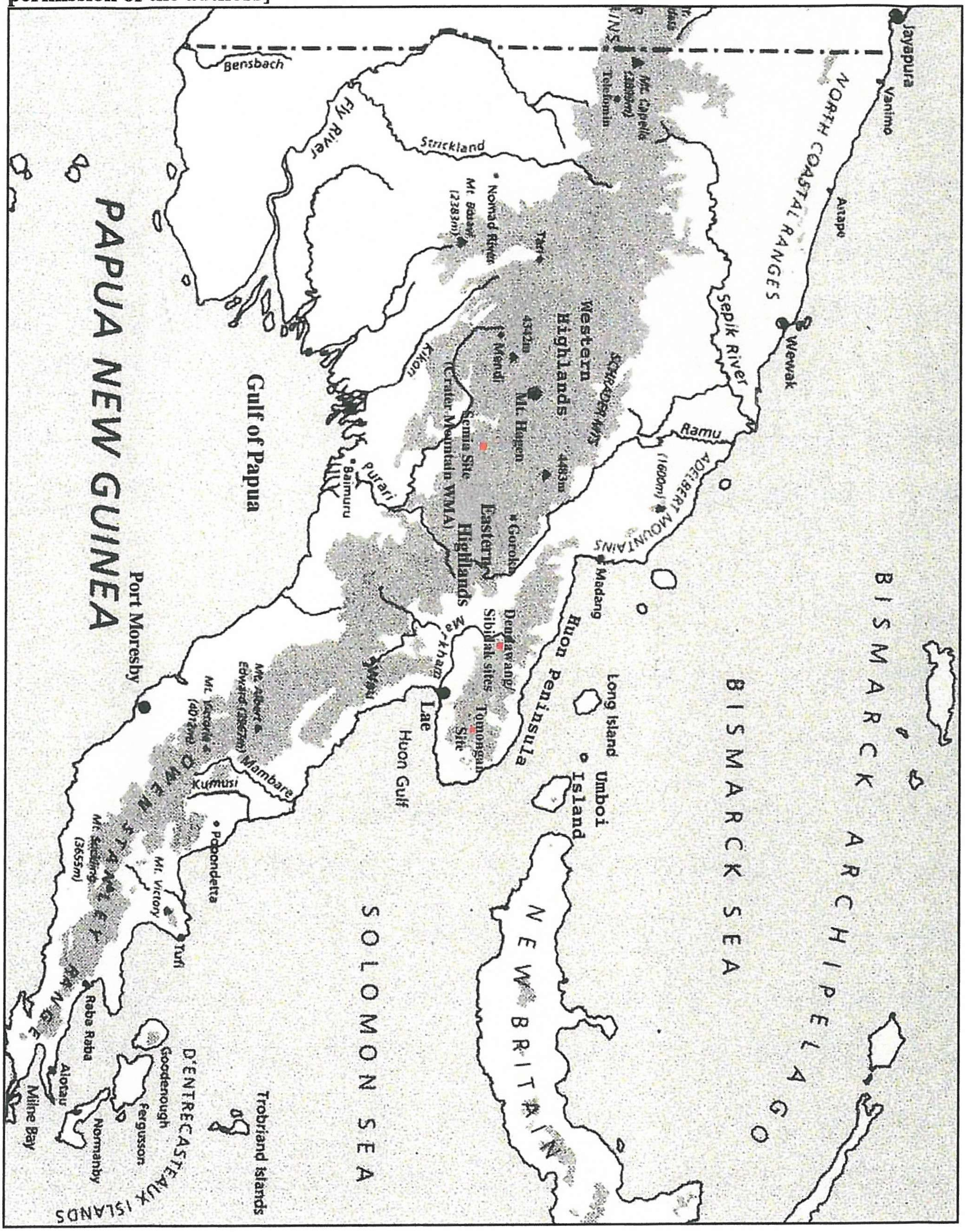
6.6.4 Other research

Other research techniques should be attempted to improve knowledge of tree kangaroos. One avenue that shows promise is reintroduction studies. Research in Australia has revealed that captive-born macropods, such as yellow-footed rock-wallabies (*Petrogale xanthopus*) are capable of rapid adjustment to wild conditions provided that levels of exotic predation are not high, and animals are not competing with exotic herbivores for food (Lapidge, 2000; Short et al., 1992). Australian macropods are typically faced with both problems because of the presence of introduced predators such as foxes (*Vulpes vulpes*) and introduced herbivores such as goats (*Capra hircus*) and rabbits (*Oryctolagus cuniculus*). Eradication programs of these introduced species are necessary before reintroduction of native mammals can commence. This would be unnecessary in New Guinea; tree kangaroos would face limited predation threats and no competition from introduced species, and therefore could be ideal subjects for reintroduction.

Reintroduction is obviously useful for conservation purposes, especially for Critically Endangered taxa such as *D. goodfellowi pulcherrimus* and *D. scottae*, whose unassisted survival is not assured [(IUCN, 1994); see 2.1.3]. It also offers opportunities for learning about tree kangaroo activity patterns, home ranges, feeding ecology, and physiology. This is because captive animals can be 'trap-trained' before their release. The animals will continue to enter these traps when returned to the wild, thus giving researchers a safe, relatively non-stressful way to capture animals for study. In addition, the animals' habituation to humans will make them easier to track through radio-telemetry and perhaps more easy to observe directly thus allowing natural history observations to be made (Lapidge, 2001).

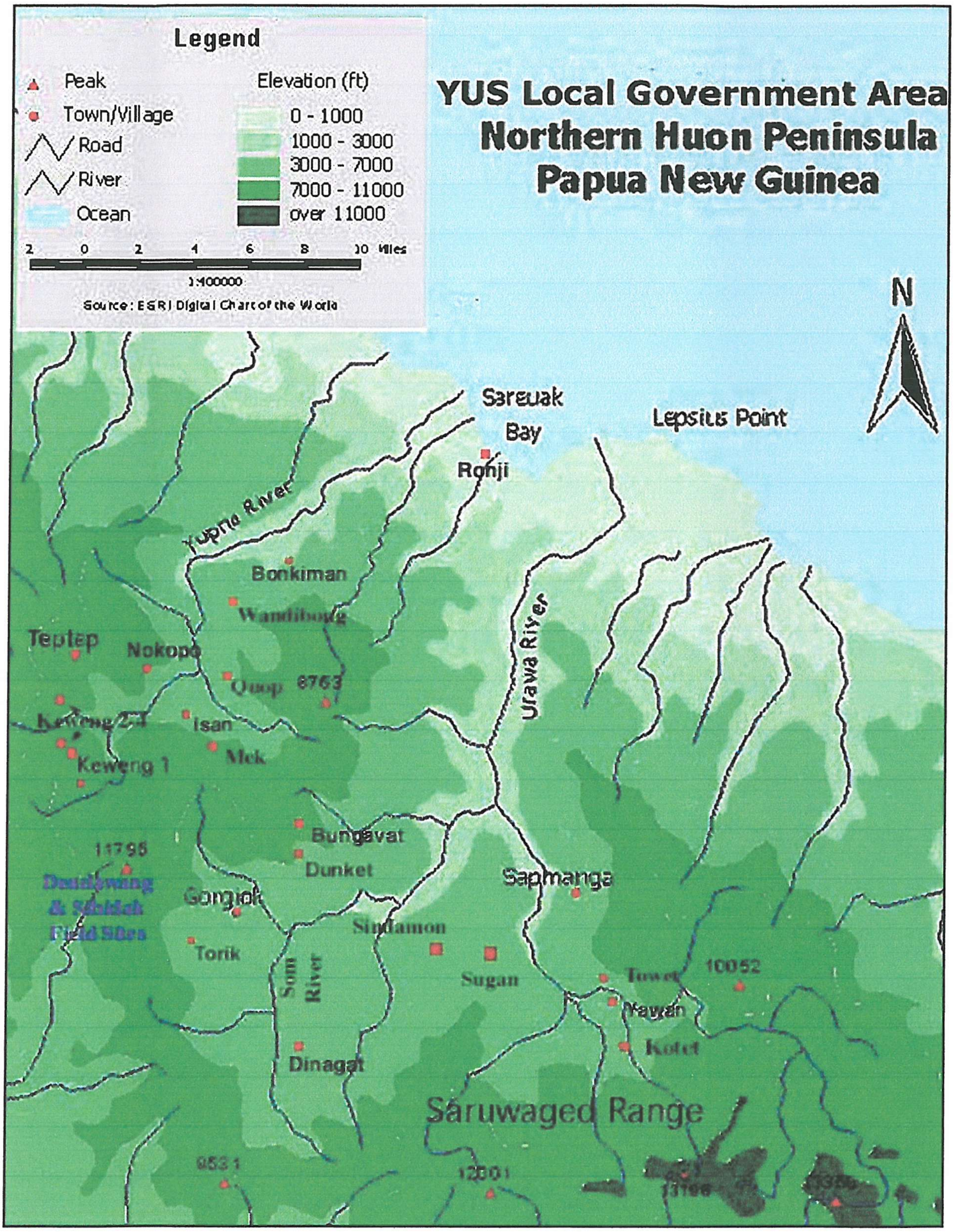
APPENDIX 1: MAPS

Figure 1. Map of Papua New Guinea [modified from Beehler et al. (1986), used with permission of the authors]



APPENDIX 1: MAPS

Figure 2. Map of YUS Local Government Area, Morobe Province, PNG (prepared by Jim Pugh and modified by the author, used with permission)



APPENDIX 2. DISTRIBUTION MAPS OF NEW GUINEA TREE KANGAROOS [modified from Beehler et al. (1986), used with permission of authors.]

Fig. 1 Approximate distribution of *D. inustus*

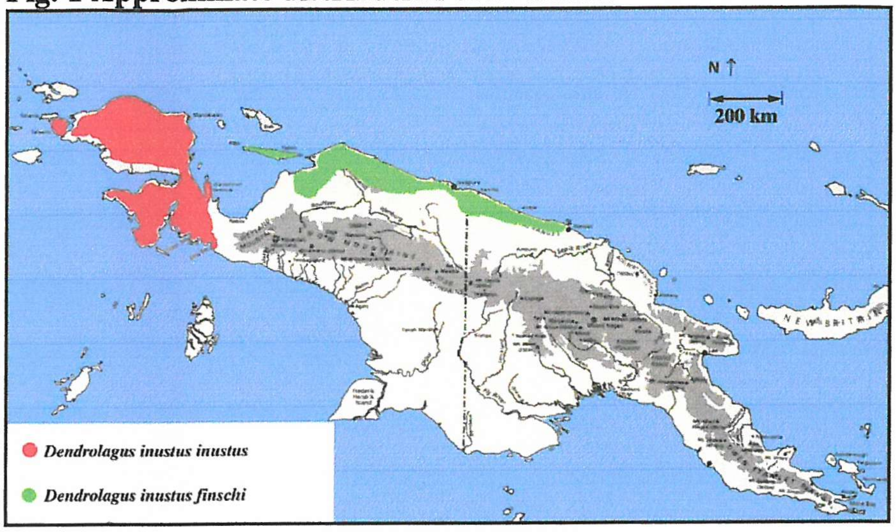


Fig. 2 Approximate distribution of *D. goodfellowi*, *D. spadix*, and *D. matschiei*

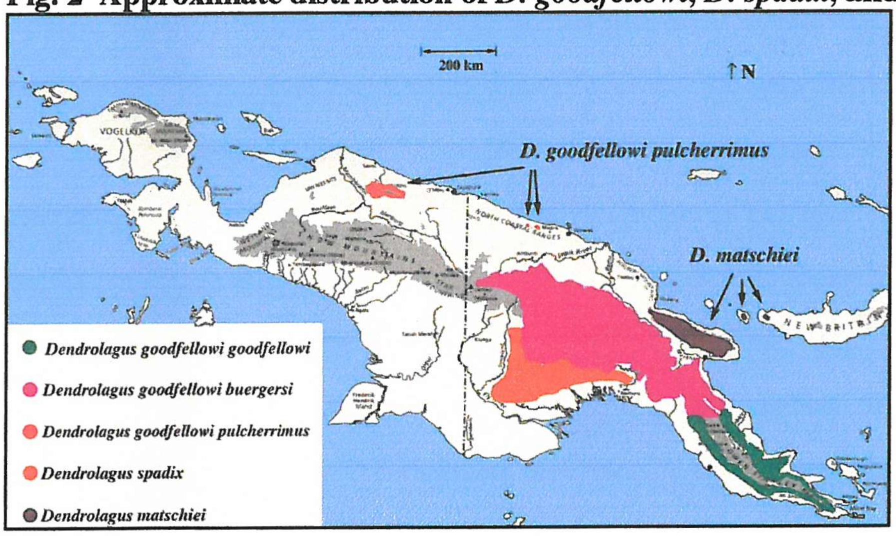
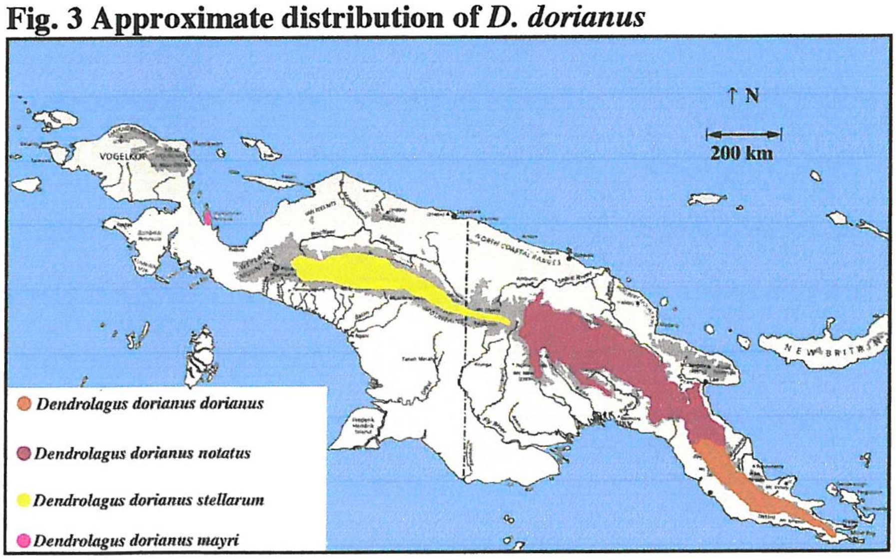
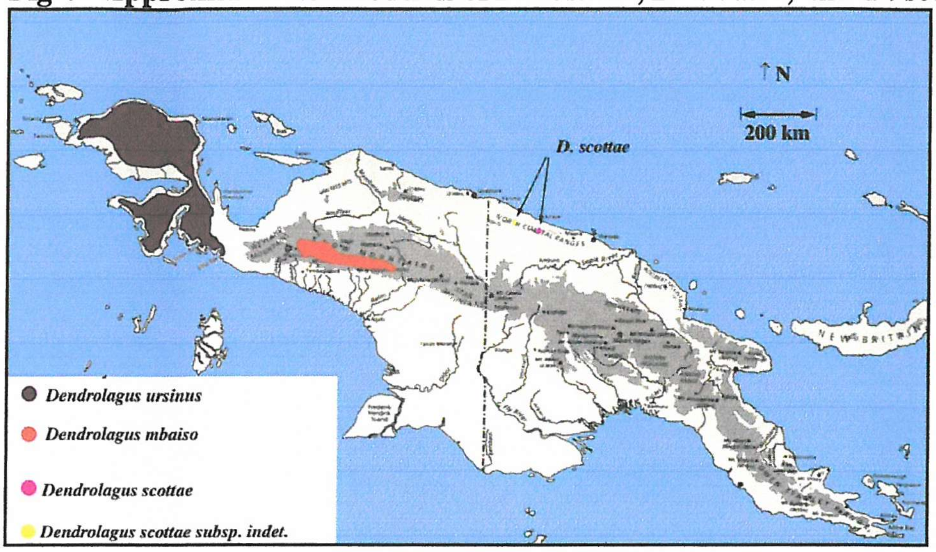


Fig. 3 Approximate distribution of *D. dorianus*



APPENDIX 2. DISTRIBUTION MAPS OF NEW GUINEA TREE KANGAROOS KANGAROOS [modified from Beehler et al. (1986), used with permission of authors.]

Fig 4. Approximate distribution of *D. ursinus*, *D. mbaiso*, and *D. scottae*



APPENDIX 3. LIST OF LANDOWNER INTERVIEW QUESTIONS

Hunter Questions

1. Describe the type (forest, grassland) of land you own. What is the local name or names for your land. How long does it take you to walk across it (how big is it?). Who owns the bush that borders yours? Do you have any problems with people tresspassing on your land and hunting without your permission?
2. What do the tree kangaroos look like (colour, size)? Do they look like any on the poster? Are all tree kangaroos on your land the same or is there more than one type? If yes – are the different types found in the same or different areas?
3. Where do the tree kangaroos live? In forests only or in grasslands and other open areas? Up high, near the tops of mountains, in the mountain forests, in the lowland forests?
4. What do tree kangaroos eat? Do they ever eat ground (clay) or drink "saltwater"?
5. When are they most active (dawn, morning, midday, afternoon, dusk, night)? When is the best time to see them? When do they sleep?
6. Do tree kangaroos like to come to the ground? When? Where do they spend the most time: on ground, or in the trees?
7. Do weather conditions (rain, sun) affect tree kangaroo activity or how they divide their time between the ground and the trees?
8. Do you have tree kangaroos on your land? Do you ever see them? How often do you see tree kangaroos? When do you see them? Do you see them alone or in groups? Do you often see female tree kangaroos with joeys? With more than one joey?
9. Do you hunt? What kinds of mammals and birds do you hunt? Are there any mammals/birds that you **can't** (it is forbidden to) hunt? If yes: why?
10. Do you ever hunt tree kangaroos? Have you ever killed a tree kangaroo? When was the last time you killed one? How many did you kill? How many have you killed in your life? Is there anything else besides man and dogs which hunts tree kangaroos?
11. How often do you go hunting? Do you use dogs? Every time? Do you use bow and arrows? Traps? Guns? Which do you use to kill tree kangaroos? How do you hunt tree kangaroos? Do you ever chop down the tree that they are sitting in to kill them?

12. How far away (days, hours) do you have to walk to go hunting? How far do you have to walk to hunt tree kangaroos?
13. Are you always successful when you hunt tree kangaroos (do you always find and kill one)?
14. Do people in this area sell tree kangaroos? If yes: live or dead or both? For how much (live or dead)? Have you ever sold a tree kangaroo? Who buys tree kangaroos (live or dead)? Where are tree kangaroos sold (locally or in towns)? If they are sold in towns is the price different than the local price?
15. Do the neighboring villages hunt tree kangaroos? Are there any villages/clans who don't hunt tree kangaroos. If yes: why?
16. When you were a boy how often did your father go out hunting? Did he go hunting more less than you do now? Did he hunt tree kangaroos? How often did he kill them? How far did he have to go to find them? Closer or further than you have to go now?
17. Are there any places where you **don't** hunt? Why?
18. Are there any places where you **can't** (it is forbidden to) hunt? Why?
19. Did there used to be places where you or you father did not or could not hunt? Do you hunt there now? If yes: why can you hunt there now?

Elders

9. What was the bush like when you were young? What is it like now? Has it changed since you were a young man, and if so how?
10. Did you see tree kangaroos when you were young? Did you hunt them? If yes: how did you hunt them? How many did you kill? How often? How often? Did you ever sell them? Live or dead?
11. Did there used to be places where you did not hunt? If yes: why? Do people hunt there now? If yes: why?
12. Did there used to be places where it was forbidden to hunt? If yes: why? Do people hunt there now? If yes: why?
13. Have there been any changes in the location or abundance of tree kangaroos in your lifetime? If yes: how has it changed?
14. Have there been any changes in your lifetime in the way people hunt tree kangaroos? If yes: how has it changed?
15. What do tree kangaroos look like (colour, size)? Do they look like any on the poster? Are all the tree kangaroos the same or is there more than one type? If yes: describe the different types. Are the different types found in the same or different areas?
16. Where do tree kangaroos live? In forests only or in grasslands/open areas as well? Near the top of the mountains, in the mountain forests, in the lowland forests?
17. What do tree kangaroos eat? Do they ever eat ground (clay) or drink 'saltwater'?
18. When are they most active (dawn, morning, midday, afternoon, dusk, night)? When is the best time to see them? When do they sleep?
19. Do tree kangaroos like to come to the ground? When? Where do they spend more time: on the ground, or in the trees?
20. Do weather conditions (rain, sun) affect tree kangaroo activity or how they divide their time between the trees and the ground?
21. Are there any animals (besides men and dogs) which hunt tree kangaroos?
22. Do you know any ancestral stories about tree kangaroos?

23. Do you or other people in your village make any objects from tree kangaroo furs or skin?

If yes: what do you use them for?

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