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ECOLOGY AND POPULATION VIABILITY ANALYSIS

OF THE SOUTHERN CASSOWARY

Casuarius casuarius johnsonii

MISSION BEACH, NORTH QUEENSLAND

Thesis submitted by

Leslie Allan Moore

April 2003

Thesis submitted for the research Degree of Masters of Science in Zoology within the School of Tropical Biology, James Cook University of North Queensland

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Abstract

This thesis investigates the endangered cassowary population at Mission Beach, north Queensland, and examines the problems associated with determining the population size and density of this keystone species. Using the results of an intensive field survey, it explores the conservation implications of small population size, population demography, densities and distribution, the impacts of identified threatening processes, and the probability of persistence of the population over timeframes of 100 years and 500 years.

The examination and analysis of the factors that place this iconic population at risk of extinction were addressed using population viability analysis. Data resulting from the field survey of the Mission Beach area and augmented by information from previous studies were used to drive the modelling process in this PVA. The analyses assessed the interactive affects on the fate of the population of factors such as the availability of existing cassowary habitat; population size; carrying capacity; population age and sex structure; reproduction and survival; age-sex specific mortalities; adult mortality rates; immigration; genetic influences; and catastrophes.

Population ecology

The Mission Beach cassowary study area was intensively surveyed on foot between June 1 and December 16, 2000. The primary field survey objective was to accurately locate, measure, and map all cassowary sign *ie* footprints, bird sightings, droppings, vocalisations, feet stamping. A total of 101.66 km^2 of rainforest was searched resulting in 345.8 kilometres of search transects and the location of 4729 cassowary sign (sightings, footprints, droppings, vocalisations). The total search effort used in the analyses amounted to 582.54 hours.

The field survey located 110 cassowaries in the study area, approximately 49 of which were adults. This is 27-37% of the maximum number of adults previously estimated for the Mission Beach area. Of the 49 adult cassowaries identified within the Mission Beach study area, 25 were identified as males, 19 as females, and two adult birds were of unknown status. Three other birds, although inadequately sighted, are believed to be

adult males. The available cassowary habitat surveyed at Mission Beach currently appears fully occupied, supporting at least 79 independent cassowaries (49 adults, 28 subadults, and 2 unknowns).

The sex ratio of the Mission Beach cassowary population was 1.47 males to 1 female, greater than that found in the strictly polyandrous emu *ie* 1.26 males to 1 female. Although characteristic of a polyandrous species, the strongly biased adult male to female ratio may be of concern given the small population size and relatively high mortality of the Mission Beach cassowaries. The relative scarcity of females indicates that the males as caregivers should not be the limiting sex *ie* the availability of adult females is likely to be a limiting factor in cassowary population dynamics.

A total of 16 males *ie* 61.5 % of known males (n=25) were recorded escorting 31 chicks. Chick ages ranged from a few weeks to >8 months old, with the majority of new chicks appearing in September 2000. Regular sightings of males foraging prior to being seen with newly hatched young indicate that not all incubating males sit without eating throughout the incubation period.

There was evidence of a widespread distribution of subadults throughout existing adult cassowary home ranges, with twenty-eight subadults located during the survey. The data indicate that subadults maintained home ranges, with most individuals recorded using the same area continually for the entire field program *ie* 6 months. This behavioural feature has not been recorded previously due to the lack of comprehensive field surveys using methodology appropriate for gathering demographic data.

A regression found no relationship between cassowary sign *per se* and the number of birds using an area. This finding confirms that the number of cassowaries in an area cannot be inferred by a simple count of droppings *ie* cassowary density is <u>not</u> related to dropping count.

The mean Indicative Home Range (*ie* each bird's home range at the time of the study and an approximation of its foraging activities over a number of preceding weeks or months) of adult females was 2.13 km^2, while males maintained a slightly smaller IHR of 2.06 km^2. There is an indication that breeding males have an increased area requirement than non-breeding males. Although this relationship was not quite statistically significant, possibly due to the small size of the sample, it has important management implications and needs to be investigated further.

The population density of adult cassowaries for the Mission Beach area was 1 adult per 2.09km^2 *ie* 0.48 adults/1km^2, almost half the density of adult birds previously calculated for the Lacy's Creek catchment, and one-sixth the density estimated by Bentrupperbaumer for Kennedy Bay area and coastal areas of Mission Beach. Overall population density of independent birds *ie* adults and subadults and excluding chicks, was 1 bird per 1.29 km^2 *ie* 0.78 birds/km^2. The density of subadults in the Mission Beach area was 1 subadult per 3.63km^2 *ie* 0.28 subadults/km^2. A population density of *Casuarius casuarius* subadults either in the Wet Tropics or New Guinea has not been possible previous to this study.

The practice of surveying small areas at Mission Beach has led to constant over-estimates of cassowary population density. The study results indicate that at a scale of 1km^2 or less there is little or no chance of reflecting true cassowary densities. Depending on the resolution required and the environmental parameters of the target area, it is considered that a sample plot between 5-15km^2 may be necessary to reflect the true cassowary density.

It was found that apart from four adult birds in the Kennedy Bay section of the Hull River National Park, there is no permanent coastal cassowary population at Mission Beach. Field surveys showed that the majority of birds classified in previous work as coastal birds live in the hinterland while making occasional or seasonal use of the coastal areas, thus inflating the earlier population numbers

The current Mission Beach cassowary habitat zones are flawed in their location and\or relevance to the true distribution of Mission Beach cassowary population. The results of this study were used to review the habitat zoning, and recommended that Important Cassowary Habitat Zone, Potentially Critical/Important Habitat Zone, and Natural Corridor/Habitat Zone, be upgraded Critical Cassowary Habitat.

Continued clearing threatens the already tenuous connectivity existing in the Mt. Mackay to Tully Heads Linkage (almost broken) and Mt. Caruchan to Meunga Creek

Linkage of the Wet Tropics Coastal Wildlife Corridors. If connectivity is broken in either of these areas, it will remove the opportunity for cassowary movement in and out of the Mission Beach area, and will permanently isolate the population.

This field study confirmed the presence of 22 cassowary road-crossing points in the 23.6 kilometres of roads between El Arish-Mission Beach and Tully-Mission Beach Roads. It was found that the road crossings were currently being used by approximately 70% of the adult cassowary population of Mission Beach.

Population viability analysis

Baseline PVA simulation modelling, which used a range of mortality rates, breeding cycles, presence and absence of catastrophes, and inbreeding effects, indicates that the Mission Beach cassowary population is in deterministic decline. Under all scenarios but that of Low mortality (considered to be improbable mortality rates), the extinction of the Mission Beach cassowary population appears virtually certain, with a predicted mean time to extinction between 37 to 70 years. Overall, the analyses reveal there is a strong chance that the population may become extinct within the 100 years projection period under most simulated models, with probabilities of extinction ranging from 68% – 99.8%.

Stochastic growth rates in most simulations generally remained strongly negative, although at a slightly higher rate than deterministic growth rate. The small differences between the two rates demonstrate that stochastic influences are outweighed as a threat to population persistence by the severity of the deterministic decline.

It appears that the critical factor for the survival of the cassowaries at Mission Beach is either the preservation of effective immigration from other cassowary populations, or the supplementation of the population with at least four "foreign" birds a year. However, to <u>maintain</u> the current population size of approximately 79 independent birds requires augmenting the population by at least six birds per year (3 males and 3 females <4 years old).

The analyses showed that although the population is predicted to persist for a greater period of time if adult mortality can be kept to 1-2% (≥1 adult/year), the predicted cassowary population size still decreased by 32.7% (at 33% breeding) over 100 years. This finding suggests that the effects of inbreeding depression *ie* deleterious alleles and/or other genetic impacts, will play a significant role in the decline of the Mission Beach cassowary population in the absence of immigration.

Genetic diversity of the Mission Beach population dropped significantly even when input parameters kept the population relatively stable. Heterozygosity reduced to between 61% and 85%, and inbreeding depression increased markedly from about 30 years onwards, varying little with decreased adult mortality.

It appears that catastrophes may have a profound impact on the viability of the cassowary population, doubling the probability of extinction under Moderate mortality rates from 35% to 68%.

Mission Beach has only a small population of cassowaries, and a small population can die out entirely by chance even when its members are healthy and the environment favourable. When a population becomes small, isolated, and localised, chance events can become so important as to dominate the long-term dynamics and fate of a population. The small isolated population of cassowaries at Mission Beach, therefore, would appear to face an uncertain future.

Acknowledgments

I have been extremely anxious about the plight of cassowaries since my field survey of the Wet Tropics in 1988, which first established the conservation status and distribution of the species in north Queensland. The results of that work clearly indicated that the species was declining in many areas, with continuing reductions noticeable even over the last decade. The recognised cassowary areas of Innisfail and Kuranda are now in immediate danger of losing their local populations, with the number of surviving adults down to single figures. Similarly, extinction is imminent for the southern-most population of cassowaries in north Queensland (and the world), at Paluma Range just north of Townsville. The loss of this southern population will result in a significant reduction in the geographic range of the species.

Mission Beach has not escaped this downward trend. Known for many years for birds both within the forest and visiting suburban roads and houses, its cassowary population is declining due to road deaths, dog attacks, disease and increased clearing and development leading to fragmentation and habitat loss. I was concerned that more accurate and comprehensive data than was currently at hand be made available to form a sound foundation for any future management strategies and recovery plans. This study, therefore, was designed in consultation with Community for Coastal and Cassowary Conservation (C4), to obtain accurate information on the true population number and distribution and demography of the Mission Beach cassowary population.

My sincere thanks go, therefore, to the Community for Coastal and Cassowary Conservation for sourcing the funding to support the field research at Mission Beach. This committed group has always played a pivotal role in the protection of cassowaries, not just at Mission Beach but also in the Wet Tropics generally. Particular gratitude is expressed to Mary Ritchie of C4, whose personal dedication to conservation, along with her drive to protect the cassowary, was instrumental in initiating the survey work at Mission Beach. Her unfailing friendship and belief in my work often kept a leech-ridden and leg-weary cassowary researcher going. The Mission Beach project itself was made possible by a grant to C4 from the Wet Tropics Management Authority.

I am very grateful to the unique institution that is James Cook University at Townsville, both for their environmental inspiration and unflagging confidence in my work. My supervisors, Dr Chris Johnson and Professor Richard Pearson, were a constant source of encouragement, information, and friendship. They contributed significantly to making this research both enjoyable and productive.

I would also like to express my deep respect for the fraternity of PVA and endangered species people worldwide, including the staff of the Conservation Breeding Specialist Group (CBSG). Many of these dedicated people generously shared their research experiences and responded to my confused email ramblings with kind words and support. Additionally, as I am sure is the case with many other endangered species zoologists involved in researching and/or managing threatened species, I have immense admiration for Robert Lacy, the author of the VORTEX population viability analysis program. His ongoing commitment to conservation biology serves both as motivation and an inspiration to those of us endeavouring to preserve threatened and endangered species.

Using population viability modelling in my research has changed me from being a little sceptical of the usefulness of PVA (which, like most, came from ignorance of the process), to being an enthusiastic advocate of its use in appropriate circumstances. Unfortunately, given the rate at which the natural landscape is being fragmented, thus creating isolated and often small populations of plants and animals, the role of PVA in the assessment and management of viable populations of threatened species in the wild will increasingly become more critical. It is hoped, therefore, that this population viability study on the endangered cassowaries of Mission Beach will join with similar studies to assist those wildlife managers and researchers faced with the task of conserving our declining biodiversity.

Finally, special thanks go to my wife, Nicole, and son Nicholas, who put up with my long absences in the field and my distracted behaviour during the writing of this thesis.

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CHAPTER 1

INTRODUCTION AND AIMS OF THE STUDY

1.1 Thesis structure

Chapters 1-5 of this thesis outline the known ecology of cassowaries at Mission Beach north Queensland and elsewhere, and present the methodology and results of the six-month field survey carried out from June to December 2000. Also addressed are the conservation implications of small population size, population demography, densities and distribution, and the impacts of identified threatening processes at Mission Beach. Past studies and surveys conducted at Mission Beach are reviewed, and the current Cassowary Habitat Zoning for the area is examined.

Chapters 6-7 comprise a Population Viability Analysis of the Mission Beach cassowary population using the VORTEX version 8.42 computer program (Lacy and Kreeger 1992; Lacy 1993, 2002). The PVA analyses assessed the interactive affects on the fate of the population of factors such as the availability of existing cassowary habitat; population size; carrying capacity; population age and sex structure; reproduction and survival; age-sex specific mortalities; adult mortality rates; immigration; genetic influences; and natural catastrophes. In this PVA, population and demographic data resulting from the field survey of the Mission Beach area and augmented by information from previous studies were used to drive the modelling process.

Chapter 8 presents a Discussion of the results of the cassowary survey and subsequent Population Viability Analysis of the Mission Beach cassowary population. Also addressed are the current Cassowary Habitat Zones for the area, and recommendations are given for Zone changes to more appropriately reflect the results of this study.

Chapter 9 brings the thesis to a close with the Conclusion, a short set of comments on the prognosis for the Mission Beach cassowary population based on the survey results and analyses, and the simulation modelling of the cassowary population using the VORTEX Population Viability Analysis software package.

1.2 Background to the Mission Beach cassowary study

Mission Beach has been known for many years for its cassowary population, both within the forest and visiting suburban roads and houses. This has earned the region a significant reputation as a natural wildlife area and has provided visitors and locals alike with an opportunity to view these unique birds at close quarters. Mission Beach therefore, has become synonymous with cassowaries and this has contributed to its commercial success and natural life style image.

Previous work done in the area, however, suggested that cassowary numbers are declining (Crome and Moore 1988, 1990; Bentrupperbaumer 1988, Crome and Bentrupperbaumer 1992, 1993; Moore 1998a, 1999e-h, 2000a-b). Factors implicated in this decline include road deaths, dog attacks, disease and increased clearing and development leading to fragmentation and removal of habitat. During the period 1986-2000 (excluding 1989-1990 for which no records were kept), 62 cassowary deaths were recorded at Mission Beach (Community for Coastal and Cassowary Conservation (C4) *pers. comm.*), an average death rate of 4-5 birds per year. Of these deaths, one bird was shot; six died from disease (*Mycobacterium spp*., *Aspergillosis spp*., *Salmonella spp*., *Pasteurella spp*., acute nephritis, and severe liver damage [Moore 2000a-b]); 13 were killed by dogs; and 42 died as a result of being struck by vehicles.

1.2.1 Population size

Unfortunately, past cassowary population figures for the Mission Beach area comprise rough approximations only and are primarily based on ad hoc sightings and a number of small area surveys. Consequently, estimates of the adult cassowary population at Mission Beach vary considerably, from 134-180 adult birds (Crome and Bentrupperbaumer 1991, 1992; Goosem 1992) to less than 52 adult birds (Moore 1998). Such uncertainty in population estimates makes it impossible to establish either the scale of any population decline or the viability of the remaining population.

The world is changing rapidly for the cassowaries of Mission Beach and the development of appropriate and effective conservation strategies requires accurate information on the true population number, and the distribution and demography of the local population. There is a need to document the ways in which habitat loss, environmental uncertainty, demographic stochasticity, and other threatening processes may interact to influence extinction probabilities and population persistence for the species. The use of Population Viability Analysis (PVA) to estimate the probability of persistence of populations over time is one way this may be achieved (Soule 1987).

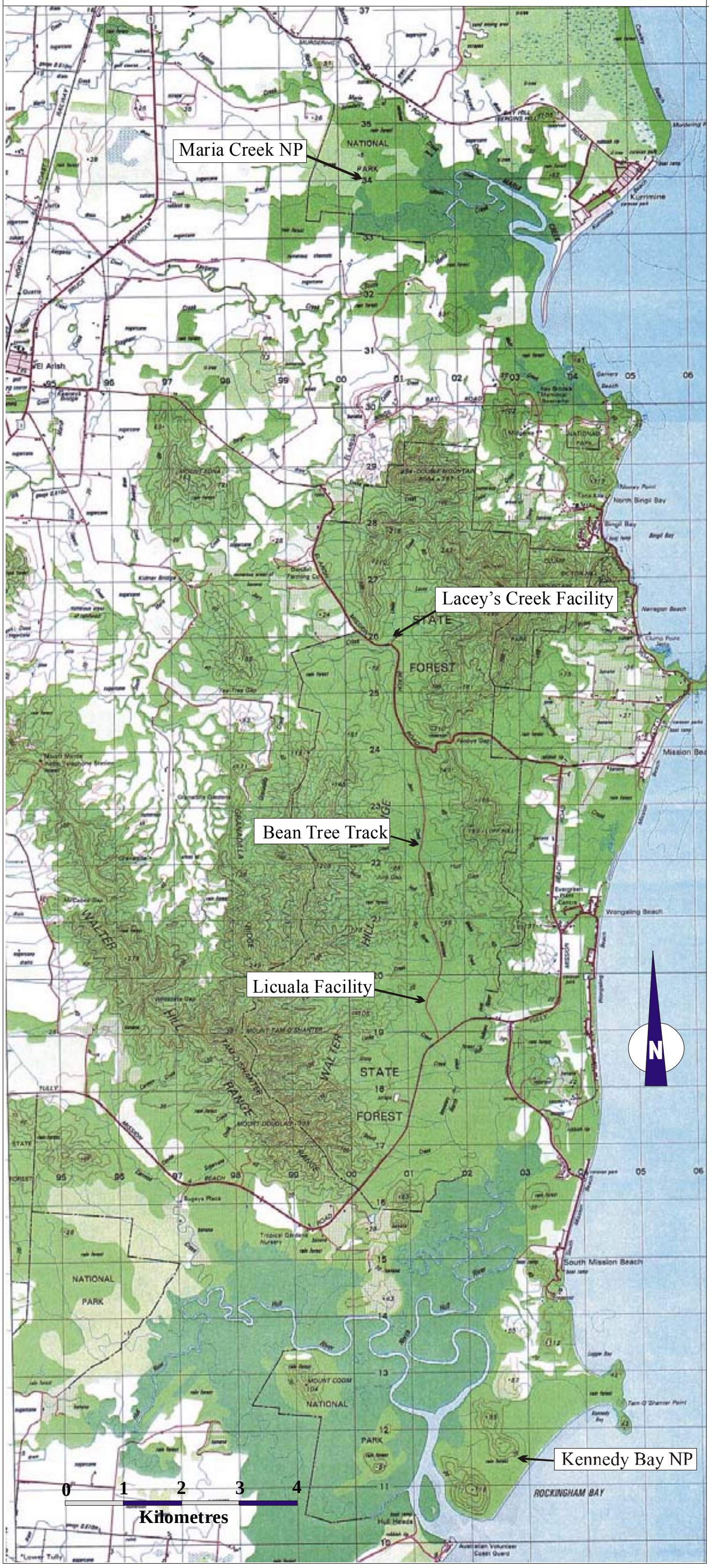
1.2.2 Population viability analyses

Population Viability Analyses can be used to guide research programs, develop conservation strategies, and inform decision and policy making for both endangered and non-endangered species (Clark *et al* 1991; Lindenmayer *et al* 1993; Boyce 1997; Rolls and Taylor 1997; Shaffer 1993). PVA can be particularly valuable when viewed in the context of adaptive management, as it pulls together all available data to build a simulation model that constitutes a synthesis of our current understanding of the population (Lindenmayer *et al* 1993, *1995*).

The amount of information required for an effective PVA is considerable, however, and in practice data are often not available for many variables, particularly demographic variables such as population size, age structure, sex ratio, life history traits, habitat quality and availability (Reed *et al* 1998). To obtain these demographic data for the population modelling of the Mission Beach cassowaries, a comprehensive field survey of the Mission Beach cassowary population was conducted from 1 June – 15 December 2000.

Figure 1.1

Mission Beach Cassowary Survey Area
June - December 2000



Source: Les Moore 2001

1.3 Aims of the study

The primary aims of the Mission Beach study were to:

- conduct a cassowary survey of Mission Beach to identify individual adult cassowaries within the Mission Beach management area;
- determine Indicative Home Ranges of individual adult and subadult cassowaries (*ie* each bird's home range at the time of the study and an approximation of its foraging activities over a number of preceding weeks or months);
- develop a demographic profile of the Mission Beach cassowary population with particular regard to number and distribution of subadults; and
- model the probability of extinction of the Mission Beach cassowary population using Population Viability Analyses (PVA).

This thesis, therefore, details the results of that study and the conservation and management questions subsequently explored by Population and Viability Analysis modelling.

1.4 Site description

1.4.1 Location of study area

The study area covers about 130km^2 (Figure 1.1) and is centred on Mission Beach, approximately 120 kilometres south of Cairns and approximately twenty kilometres east of Tully. The area surveyed in this study lies across two boundaries, those of the Johnstone and Cardwell Shires, and extends from Maria Creek National Park in the north, to the mouth of the Hull River in the south; the western arm of the Walter Hill Range delineates the westernmost section of the survey area.

1.4.2 Topography and landform

The Mission Beach study area comprises four main topographic units:

1. Lowland plains; these are the predominant landform associated with the major catchments of Maria Creek and the Hull Rivers.

2. Coastal ranges, including sections of the Walter Hill Range, the Tam O'Shanter Range, and the Granadilla Range. Clump Mountain is the highest point at 395 metres.
3. Tidal flats, including extensive mangrove communities which surround the estuaries of Maria Creek, Hull River and their tributaries.
4. Floodplains, forming extensive low-lying areas of periodically inundated land which is dominated by *Melaleuca* (Goosem 1992a).

1.4.3 Vegetation

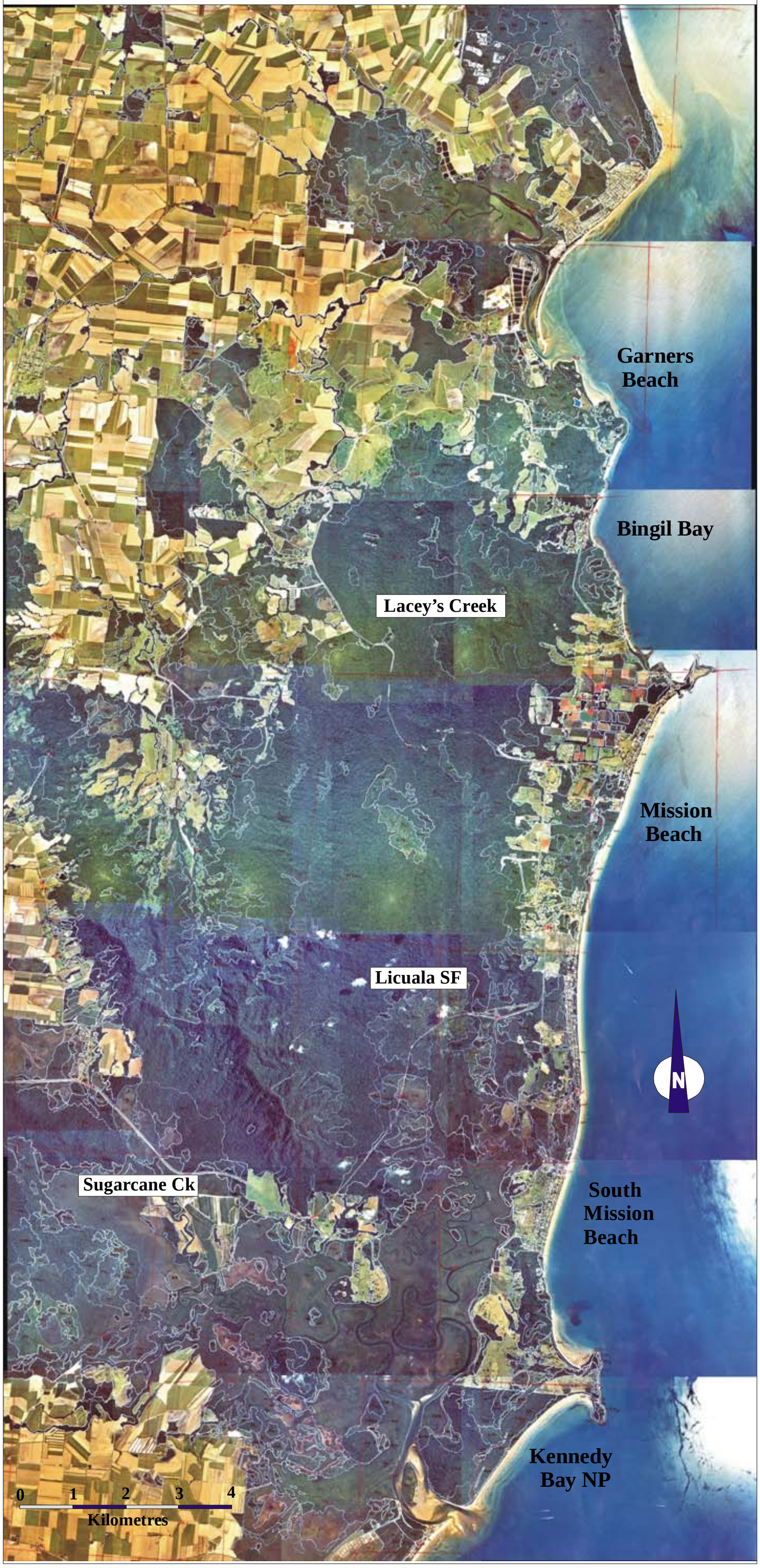
The vegetation of the Mission Beach area has been indicatively mapped by Tracey and Webb at 1: 100,000 (Tracey and Webb 1975) and is extremely diverse both in floristics and structure. The area comprises a large number of vegetation complexes and mosaics, which result from a combination of soil nutrition and soil water levels (Goosem 1992). Apart from *Acacia* dominated rainforest on the dry higher ridges (Type 12c Tracey 1982), the majority of the Tam O'Shanter State Forest has been logged and the rainforest in this area is still recovering from the past disturbance.

Goosem (1992a) described eight major vegetation communities for the area and these are listed below with their respective categories from Tracey 1982:

- rainforests and closed forests (Types 1a, 2a, 2b, 3a, 3b, 12a, 12c, 13a, 13d)
- open forests and woodlands(Types 15a, 16)
- coastal beach ridges and swales (Type 17)
- swampy coastal plains (Type 18)
- coastal floodplains and piedmont slopes (Type 19)
- texture contrast soils with impeded drainage on coastal plains (Type 20)
- saline littoral zone (Type 22)
- cleared areas (Type 24)

Figure 1.2

Land clearing in the Mission Beach area as of September 1997



It is estimated that 80% of the most important lowland cassowary habitat has been cleared and most of what remains is not only highly fragmented but is without any form of protective tenure (Goosem 2000). Clearing has been particularly severe in the Russell River and Murray River lowlands where up to 85% of cassowary habitat has been cleared (Goosem 2000). As a result, Mission Beach is almost totally isolated by agricultural and urban development, and Critical Cassowary Habitat is still being cleared on freehold properties (Figure 1.2). It has been predicted that most vegetation outside the protected estate will be cleared in the next five years (Goosem 2000).

The rainforest of the Mission Beach region is separated from the main rainforest block to the west by extensive agricultural clearing. While a tenuous link may exist at Smith's Gap north of Tully, the Bruce Highway forms a substantial obstacle to east-west cassowary movement. Similar impediments to north-south movement by cassowaries exist at Maria Creek to the north of Mission Beach and at Hull River to the south, although some birds may still swim across.

1.4.4 Climate

Mission Beach is located within the wettest region in Australia. The eastern coast between Tully and Babinda has an average annual rainfall in excess of 4000mm with Tully often averaging >4300mm per annum. The climate is characterised by very humid to wet summers and relatively mild winters. Rainfall is summer dominant although significant falls (100mm\day) may occur at any time of the year (Goosem 1992a). There is a steep rainfall gradient extending inland from the coast which correlates closely with the height and orientation of coastal scarps and ranges.

The rainfall in the Mission beach study area varies from approximately 2800 mm over the coastal lowlands, to about 3200-3600 along the Walter Hill Range. The area surrounding the coastal peak of Clump Mountain has the highest rainfall, receiving approximately 4000 mm per year. As there are no long-term rainfall data for the Mission Beach area the mean monthly and annual rainfall for Tully, approximately 15 kilometres to the west are presented in Table 1.1.

Table 1.1

Mean monthly and annual rainfall (mm) for Tully *

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	TOTAL (mm)
575	758	771	480	335	225	138	138	120	110	135	192	**3977**

* 34 years of rainfall records

CHAPTER 2

CASSOWARIES IN THE WET TROPICS

The Southern Cassowary *(Casuarius casuarius johnsonii*) in the Wet Tropics area is classified as Endangered under both the Queensland *Nature Conservation Act 1992* and under Schedule 1 of the (Commonwealth) Environment Protection and Biodiversity Conservation Act 1999. A recovery plan for the species has been prepared by the Queensland National Parks and Wildlife Service (QPWS 2002).

Based on a nine-month survey of cassowaries throughout the Wet Tropics, Crome & Moore (1988, 1990) estimated that there were between 2500-4000 adults remaining in the region. As a result of further studies (Crome & Bentrupperbaumer 1992; Crome & Moore 1993; Moore 1996a-d, Moore 1998, 1999a-c), it is now considered that the true number could be less than 1500 adults (Moore 2000).

The endangered Southern Cassowary populations are severely threatened in the Wet Tropics and there is general acceptance in the scientific community that the species is declining. The major cause of the species decline in the Wet Tropics is believed to habitat loss, degradation, and fragmentation. It is also apparent that additional complex population dynamic influences are also involved in this decline *eg* demographic stochasticity, environmental stochasticity, reduced genetic diversity, and the uncertain population fluctuations due to the complex dynamics within a given ecosystem.

2.1 Distribution of cassowaries in the wet tropics

In the first major cassowary survey in 1988, over 2500 kilometres were walked throughout the Wet Tropics during a nine-month study (Crome and Moore 1988, 1990). This work resulted in a detailed description of the distribution, status, threatening processes and conservation of the cassowary between Townsville and Cooktown, and is the basis of what is known of cassowary distribution and abundance in the Wet Tropics. Figure 2.1 presents the distribution and relative densities of cassowaries in the Wet Tropics, which resulted from the 1988 cassowary survey and subsequent studies.

In Crome and Moore's (1988) study, droppings, footprints, sightings, and public survey responses were all combined to develop an index of activity that reflected likely cassowary densities *eg* low, low-moderate, moderate-high and high, across the Wet Tropics. They found that cassowary populations were not uniformly distributed throughout the Wet Tropics, with highest densities occurring in the coastal or foothill areas *ie* the Daintree lowlands, Woopen Creek (north-west of Innisfail), the Moresby Range, and Mission Beach. An exception to this trend was the inland area surrounding Wallaman Falls, near Ingham, where cassowary densities equalled that of most coastal areas and the birds appeared to comprise larger-sized individuals (Moore *pers obs*).

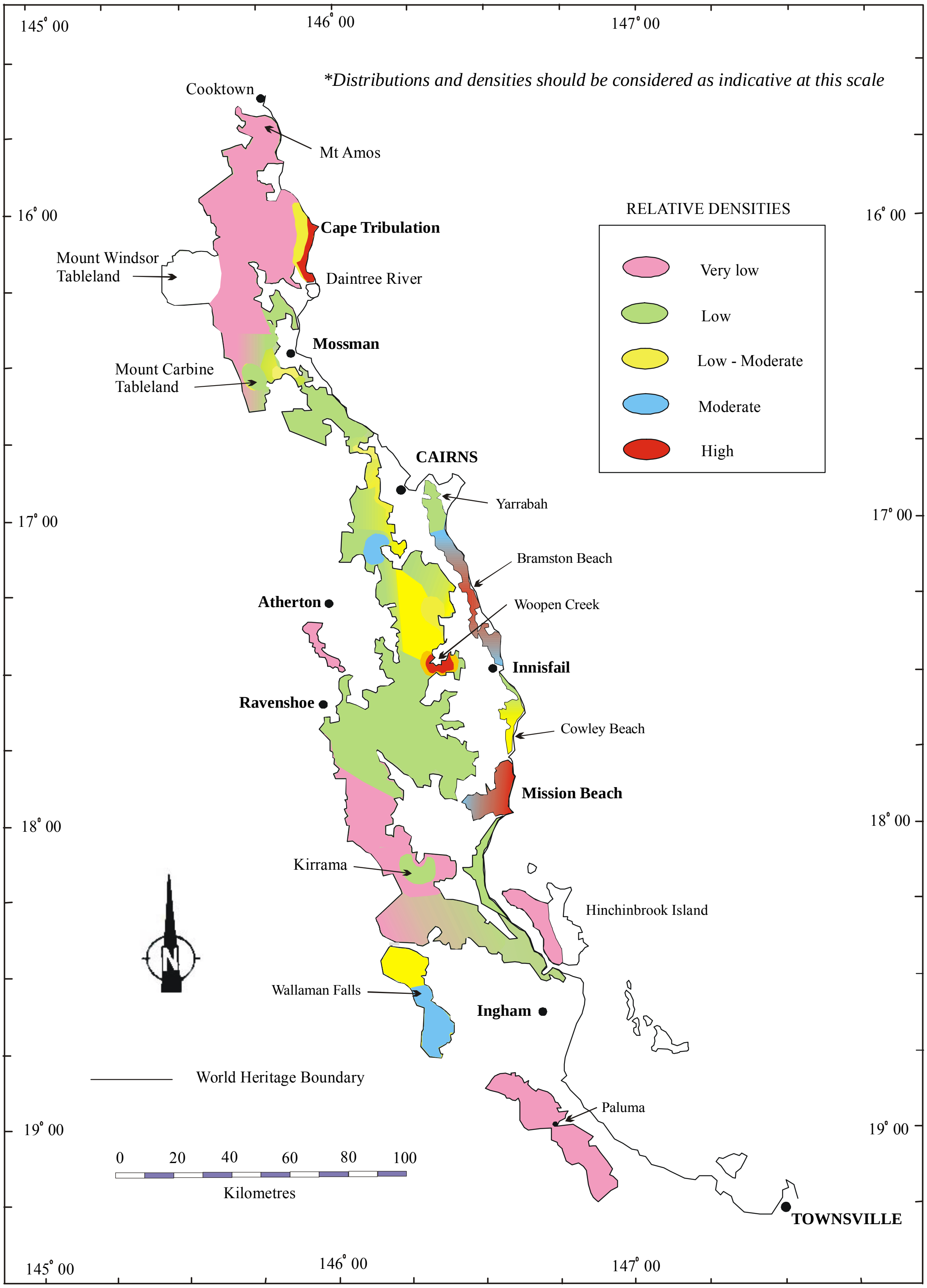
The extensive fieldwork undertaken in 1988 also showed that clearing and development have isolated many cassowary populations in the Wet Tropics *ie* Mission Beach, Coquette Point and Moresby Range, Flying Fish Point, and the Ella Bay area. Due mainly to agricultural or urban development, populations have been reduced or eliminated from most forest patches on the Atherton Tableland, the lower Goldsborough Valley and the Clohesy River region (Crome and Moore 1988, 1990). It appears certain that the isolated and southernmost population of cassowaries at Paluma Range near Townsville is on the verge of extinction due to a persistent reduction in their numbers over the last ten years. It has been estimated that there are less than seven birds in total remaining (Moore 1999h). Unfortunately, this southern population is not identified in the Cassowary Recovery Plan (QPWS 2001), even though such extinction would represent a major reduction in the distributional range of the species.

2.2 Known ecology

Cassowaries are obligate frugivores (Crome 1976; Stocker and Irvine 1983). Foraging is strictly diurnal and predominantly comprises fallen fruits, although vertebrate and invertebrate items are also eaten (Crome 1976; Stocker and Irvine 1983; Crome and Moore 1988; Bentrupperbaumer 1998).

Figure 2.1

Distribution and relative densities of cassowaries in the Wet Tropics



Source: Les Moore 2001

The species has a primitive digestive system with a weak flaccid crop and stomach and short intestines (Pycraft 1900; Crome and Moore 1988). Cassowaries do not use stones and grit in the gizzard and with their gentle digestive system they cannot access the nutritious seeds within the fruit (Stocker and Irvine 1983). They tend, therefore, to feed on fruit with flesh containing high nutritive values (Crome 1976). Seeds are voided whole, often with flesh still adhering. This gentle treatment makes the bird an efficient disperser of fleshy-fruited seeds and the only major disperser of approximately 100 rainforest plants within the north Queensland forests (Crome and Moore 1988, 1990).

In tropical forests elsewhere this role as a major seed dispersal agent is carried out by many guilds of birds and mammals and possibly reptiles (Crome and Moore 1988). The cassowary, therefore, can be considered a "keystone" species *ie* a species whose presence is necessary for the survival of a large range of other species, and whose loss from the ecosystem may be equivalent to losing several disperser species from other tropical forests (Crome and Moore 1988).

2.3 Social organisation

Cassowaries are solitary, highly mobile animals whose preferred habitat is the thick vegetative cover of disturbed rainforest. Adult cassowaries maintain home ranges that vary in size and shape seasonally, and from year to year depending upon environmental conditions and patterns of food abundance (Bentrupperbaumer 1998; Crome and Bentrupperbaumer 1992; Moore 1996a-b, 1998, 1999a-c). Crome and Bentrupperbaumer (1992) also found that the adult population at Kennedy Bay National Park (Mission Beach) remained very stable in size, with the major population variation accounted for by the disappearance of subadults. They also concluded that while the home ranges of adult cassowaries expanded from May-September, the “core zone” *ie* that area where individuals can be found time and again, appeared to remain stable.

Although their home ranges overlap considerably at Mission Beach, the core zones of male cassowaries appear more or less mutually exclusive (Crome and Bentrupperbaumer 1992; Moore 1996a-b, 1999a-c; Bentrupperbaumer 1998). Multiple use of “non-core” areas usually occurs while males are caring for young, but timing of their use appears staggered so birds do not meet. Female ranges however, overlap those of males comprehensively (Moore 1996a-b, 1999a-c, 2000a, 2001; Bentrupperbaumer 1998). In contrast, adult female home ranges only rarely overlap with each other except within the home range of an adjoining male with whom both mate (Moore 1996a-b, 1999a-c, 2000a, 2001; Bentrupperbaumer 1998).

Chance encounters of juveniles and subadults suggested they maintained a nomadic existence, generally in more marginal habitat areas amongst existing adult home ranges.

2.4 Mating system

There is a lack of detailed information on the mating system of cassowaries. The Handbook of Australian, New Zealand, and Antarctic Birds (HANZAB 1990) describe the cassowary mating system as <u>predominantly</u> successively polyandrous, with females mating with up to three males in succession. However, Crome (1976), and Handford and Mares (1985), have classified the mating system of cassowaries as predominantly monogamous with sequential polyandry (Bentrupperbaumer 1998).

Nonetheless, the most authoritative data from which to define a likely mating system comes from Bentrupperbaumer's Kennedy Bay study (1998). Her field observations indicate that males bond with two or more females simultaneously in a breeding season *ie* polygony (pair bond between a male and more than one female). Although not observed in her study, it was also suggested that females were likely to breed simultaneously or sequentially with several males *ie* polyandry (sexual relationship between a female and two or more males such that the incubating and caring for the young are left to the males).

Observations made by the author during numerous cassowary surveys conducted over the past twelve years support Bentrupperbaumer's conclusions (Crome and Moore 1988, 1990, 1993; Moore and Crome 1992; Moore 1995, 1996a-d, 1998a-d, 1999b-i, 2000a, 2001).

2.5 Breeding cycles (courtship/incubation/parental care)

Bentrupperbaumer (1998) constructed a breeding profile of five resident male cassowaries in her Kennedy Bay study site, which showed the periods during which the males were occupied with courtship, incubation, and parental care. A synopsis of her findings is presented in Table 2.1. The data showed that 80% of males in her study area breed only once every 2-3 years, with only one bird (*ie* 20%) completing two breeding sequences within the three-year period. These data indicate that the majority of male cassowaries breed only once in 24-36 months, although depending on local conditions, some birds may be capable of breeding every second year *ie* they may have an 18 months breeding cycle.

Table 2.1

Male cassowary breeding sequences

(Bentrupperbaumer 1998)

No. of occurrences	Breeding sequences completed over three years (Courtship\incubation\parental care)	Breeding Interval (months)*	% Occurrence
2	1	36	40%
2	1.5	24	40%
1	2	18	20%

*Mean breeding investment of males with dependent young = 15-22 months (Crome and Moore 1988, 1990; Bentrupperbaumer 1998).

2.6 Reproduction

The eggs are incubated by the male, and this may start anytime after the laying of the first egg (Fisher 1968). Bentrupperbaumer (1998) observed that the male does not appear to eat over the two months that he sits on the eggs and gradually gathers leaves and debris around the nest site, forming a diagnostic “ring” (Crome and Moore 1988; Bentrupperbaumer 1998; Moore *pers obs*). Males are very defensive of the eggs and chicks both in captivity and the wild (Crome 1976, Crome and Moore 1988). The chicks usually stay with the male for approximately nine months (Crome 1976) but may remain up to 11 months

(Bentrupperbaumer 1998). Observations have been made of young chicks being chased away from a male when younger than nine months by a courting female eager to breed with the parent bird (Moore *pers obs*).

Cassowary chicks begin life as downy striped young, the stripes fading into brown juvenile plumage at between three and six months of age. Naked skin begins to colour between six and nine months of age coinciding with the onset of black adult feathering which progressively develops from the mantle down to the rump and flanks (Moore *pers obs*). Black body feathers predominate at 18-24 months of age, at which stage the casque begins to develop (Crome 1976; Crome and Moore 1988; Bentrupperbaumer 1998).

2.7 Habitat requirements

The major plant families which provide much of the diet of cassowaries are Lauraceae, Myrtaceae (especially the two genera *Syzygium* and *Endiandra*), and Elaeocarpaceae (Crome 1976; Stocker and Irvine 1983; Crome and Moore 1988; Bentrupperbaumer 1998). The birds' precise habitat requirements are poorly understood but cassowaries are known to use other habitats *eg* mangroves, melaleuca woodlands and swamps (Moore 1996a-b, 1999a-c). It is unlikely, however, that populations or even individual birds can be permanently maintained in non-rainforest habitats, since the lower plant species diversity would be unlikely to supply the food resources that cassowaries need year-round. These alternative habitats, however, are capable of providing supplementary food resources that may be seasonally unavailable in the rainforest (Bentrupperbaumer 1998; Crome and Moore 1988, 1990; Moore 1996a-b, 1999a-c).

Cassowaries appear to favour habitat with an intermediate level of disturbance. However, severe damage which entails loss of understorey and much of the canopy, generally results in reduced bird numbers or local population extinctions (Crome and Moore 1988, 1990). As they need to drink every day, a reliable year-round water supply must be available within their home range (Bentrupperbaumer 1998; Crome and Bentrupperbaumer 1992; Crome and Moore 1988, 1990).

In some areas pads are created by birds using regular pathways to access favourite feed trees, water or breeding partners (Werren 1992; Moore 1996a-d, 1998, 1999a-c). Such movement corridors make use of topography, vegetation, and/or streams, to travel between habitat patches and along ecotones (Crome and Moore 1993; Moore 1995, 1996a-d, 1998, 1999a-c; Werren 1992). These pathways are generally traditional and can be best seen where they intersect with roads and tracks such as frequently occurs in the Mission Beach area (Moore 1998; Werren 1992). This overlap in usage can result in collisions with vehicles and is a major cause of mortality in cassowaries around Mission Beach.

It has been previously assumed that the highest densities of cassowaries occur in areas containing mosaics of different vegetation complexes (Crome and Bentrupperbaumer 1992a-b, Goosem 1992a-b). Surveys in the Daintree lowlands, however, suggest that this assumption may be based on a sampling artifact created by using incomplete Mission Beach data in isolation. It appears that the relationship between cassowary density and habitat complexity is not straightforward. For example, the majority of areas carrying high cassowary numbers in the Daintree lowlands occur in relatively homogeneous habitat *ie* variations of Complex Mesophyll Vine Forest (*sensu* Tracey 1982). Similarly, that area containing the largest block of continuous high quality cassowary habitat at Mission Beach is an area between Double Mountain (north of El Arish-Mission Beach Road), and Mount Douglas (north of the Tully-Mission Beach Road), encompassing the catchments of Lacys Creek, Jurs Creek and the North Hull River (Moore 1998, 2000a). This area primarily comprises variations of Complex Mesophyll Vine Forest similar to those found in the Daintree lowlands.

2.8 Existing known threats in the Wet Tropics

A number of potential and actual threatening processes have been identified as affecting cassowaries across the Wet Tropics region generally (Crome and Moore 1988, 1990, 1993; Moore 1996a-b, 1999a-c). These regional threats are summarised below (not in priority order), and those operating in the Mission Beach area are indicated.

Habitat clearing and development It is likely that most of the best cassowary habitat in the Wet Tropics has already been cleared (Crome and Moore 1988,1990). Clearance in the remaining strongholds in the coastal lowlands and foothills continues, however, and there are strong indications that cassowary populations in these areas are declining as a result.

Mission Beach is no exception to this trend. Using aerial photography taken of the area in 1992 and 1997, Small (1998) found that at least 42% of the original Critical Cassowary Habitat on freehold land (*sensu* Goosem 1992a-b) had been cleared. Of all vegetation on freehold land within the Mission Beach area, 18% had been cleared within the last five years (1992-1997), exceeding the total amount cleared over the previous 35 years (1957-1992). Furthermore, a significant proportion of the remaining Critical Cassowary Habitat on freehold land is currently zoned for residential subdivision (Bentrupperbaumer 1998; Moore 1998).

Habitat fragmentation Habitat fragmentation may decrease the ability of a cassowary population to survive catastrophes by reducing the opportunity for birds to recolonise after local extinctions; by reducing the access to traditional resources in times of shortage; and by threatening genetic variation within populations due to loss of breeding opportunity (Moore 1996a-b, 1999a-c). In the Mission Beach area the Important Linkage Zones identified by Goosem (1992) are rapidly diminishing due to development pressure and their loss of function will remove the connectivity between the coast and hinterland.

Hunting Illegal shooting still occurs for "sport" and meat, and birds are occasionally shot or poisoned if they raid orchards. The most common form of illegal shooting however, occurs when hunting pig dogs corner a cassowary which is then shot to prevent injury to the dogs (Crome and Moore 1988, 1990; Moore 1996a-b, 1999a-c). Instances of both have been recorded in the Mission Beach area.

Dog attacks Control of domestic and working dogs is a major challenge for the conservation of the cassowary but the threat comes not only from local animals. In the Daintree area a major threat to cassowaries derives from non-resident hunting parties and/or tourists/campers with dogs (Moore 1999a). A number of cassowaries are known to have been killed by dogs around Mission Beach; most of the dogs involved have been local animals.

Road Crossings The major cause of known cassowary mortality in the Wet Tropics region is collision with motor vehicles, with approximately 42 deaths recorded in the Mission Beach area in the past 12 years (Figure 2.2). With increases in vehicle numbers and/or speed, the risk of injury or death to cassowaries increases dramatically. Thus, widening, sealing or other road upgrade activities have the potential to significantly increase cassowary mortality.

Cassowaries cross roads for a number of reasons (Goosem 1992a-b; Moore 1999a-c) including*:*

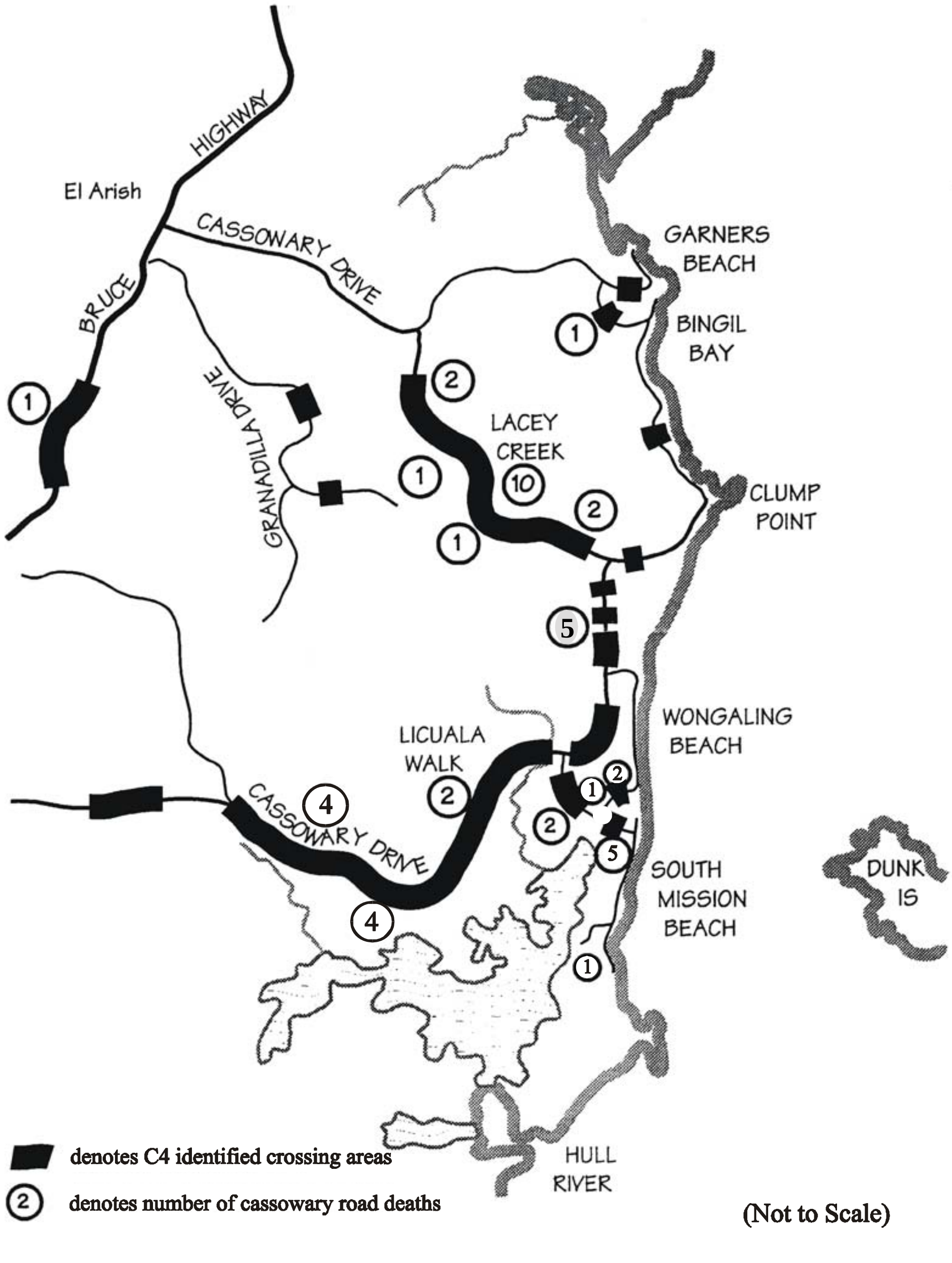
- roads may divide parts of a cassowary's traditional home range
- normal foraging activity requires access to the entire home range
- access to permanent water during the dry season may require road crossing
- social interaction *eg* in the breeding season requires cassowaries to move to find mates
- cassowaries may exploit roadside vegetation
- habituated birds may come to associate roads with people and food
- natural dispersal of juvenile and subadult birds

It is important to note that road death is also the largest single source of mortality for the highly endangered Florida Panther *Felis concolor coryi*, with at least 44 known deaths since 1972 (CBSG 1999).

Figure 2.2

Cassowary Road Deaths in Mission Beach District 1986 - 2000 *

** Source: Community for Coastal and Cassowary Conservation*



Feral pigs Competition and predation by this introduced pest may be a problem for cassowaries (Crome and Moore 1988, 1990). There is anecdotal evidence that pigs destroy nests and would certainly predate chicks if they could get close enough. There is, however, no information on the frequency or importance of this to cassowaries. Although damage to cassowary habitat and disturbance to fallen fruit are the most visible impacts of pigs, their role in spreading disease has not been assessed. They are known to be hosts for avian tuberculosis and many other diseases (Seddon 1965), and harbour numerous parasites (tapeworms *etc*).

An on-going and successful pig-trapping program has been in place at Mission Beach for a number of years but pig capture numbers continue to remain high, suggesting the pig numbers may not have been greatly reduced. Unfortunately, a disturbingly high number of cassowaries have been accidentally caught in pig traps, often suffering severe injuries and death, or succumbing to starvation and/or thirst.

Disease During the original 1988 cassowary survey, two freshly dead birds from Mission Beach were autopsied. The pathological material sent to a veterinarian laboratory subsequently showed that both birds had been carrying significant infections prior to their deaths (Crome and Moore 1988, 1990). The first cassowary, an adult female, was diagnosed with a tuberculosis-related disease that had spread through the body cavity (David Spratt, CSIRO, *pers. comm*.). While it is likely that *Mycobacterium avium* was the organism involved, this has not yet been verified by culture. The second bird had died from the toxic effects of an advanced case of *Aspergillosis,* a fungal disease infecting the respiratory tract (Oonoonba Veterinary Laboratory, 21 February 1992).

Since the initial identification of disease in cassowaries in 1988, post-mortems are now routinely carried out on cassowaries, most of whom are killed on the roads surrounding Mission Beach. More cases of infection by *Mycobacterium spp*. and A*spergillosis spp.* have been found, along with instances of *Salmonella spp*., *Pasteurella spp*., acute nephritis, severe liver damage (unknown organism), and severe infestations of tapeworms (Moore 1998, 2000). In captivity, other diseases identified in ratites (ostriches, emus and rheas) include *Toxoplasmosis gondii* (Orosz *et al* 1992), *Candida albicans*, *Salmonella spp*. (Vanhooser and Welsh 1995), and acute hemorrhagic enterocolitis (Brown *et al* 1993). An unpublicised outbreak of avian tuberculosis in 1993 wiped out many cassowaries in a number of European zoos (Moore *pers. obs*.). It is of considerable concern that among the non-avian species that contracted the disease, various species of tree-kangaroo proved highly susceptible and rapidly succumbed to the disease.

The continued increase in urban development adjacent to and within former rainforest areas raises the possibility of new and unique diseases being introduced by domestic animals such as cats, dogs, pigs, aviary birds, poultry *etc* (Vanhooser and Welsh 1995; Moore 1997). This threat of disease must be assessed in view of the role avian diseases have been shown to play in the decline of the Hawaiian bird fauna (van Riper *et al* 1986).

2.9 Previous population estimates for Mission Beach

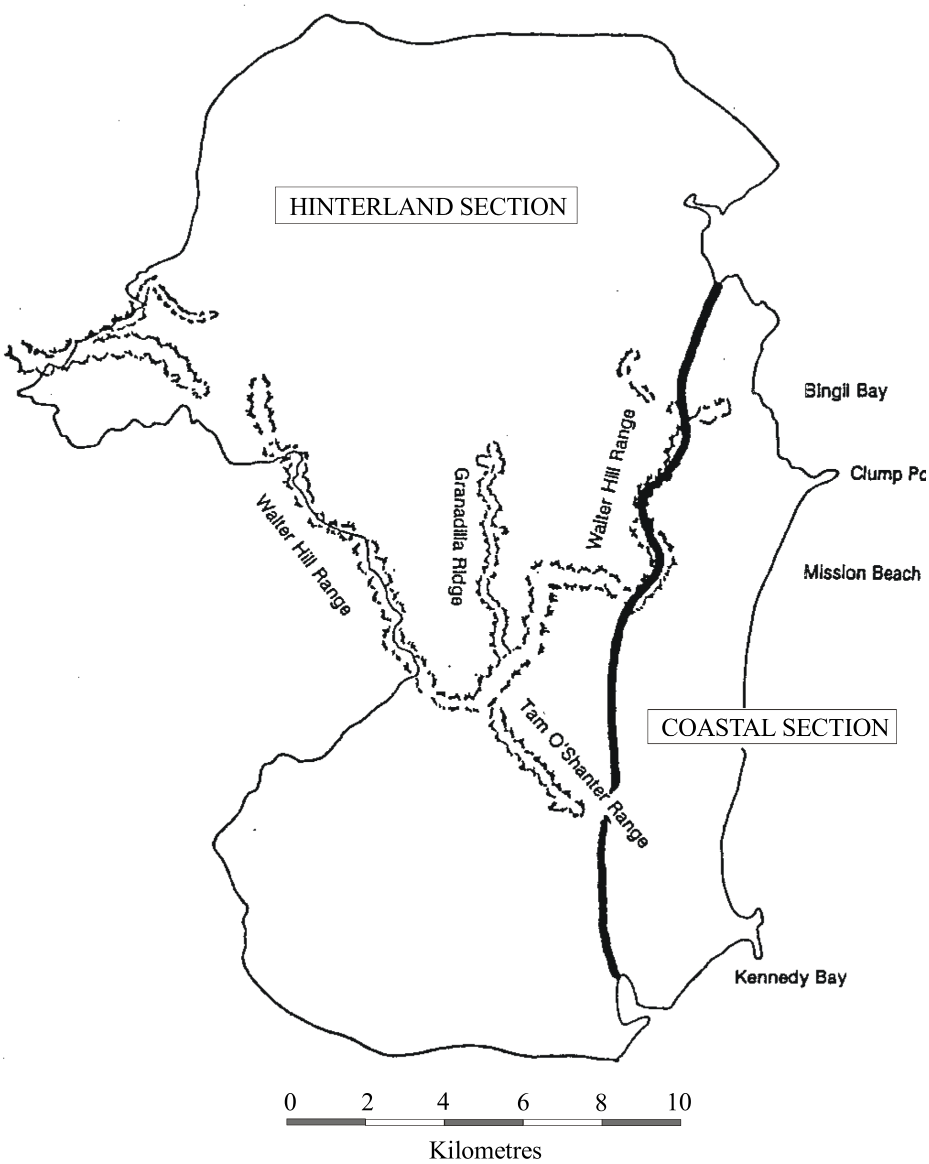
2.9.1 Population estimates 1988-1992

Cyclone Winifred, which struck the Mission Beach area on 1 February 1986, caused considerable defoliation to the rainforest of the region. The ensuing shortage of rainforest fruit resulted in cassowaries emerging from the forest to obtain supplementary food from rural and residential areas. The resultant increased visibility of cassowaries allowed an estimate of total population numbers to be made over a two-year period. Using community sightings and personal observations of individual cassowaries Bentrupperbaumer (1988) estimated the total Mission Beach adult cassowary population to be 63-72 adult birds.

To obtain this population estimate Bentrupperbaumer divided the Mission Beach area into two sections, "coastal" and "hinterland" (Figure 2.3). The coastal section comprised those areas east of the Hull River in addition to small sections of the Walter Hill Range (*ie* coastal lowlands <20 metres altitude). The hinterland referred to all forest west of this demarcation (*ie* that area beyond the coastal lowlands). The coastal section was monitored while the presence of individual birds in the hinterland areas were primarily assessed from opportunistic sightings by members of the community.

Figure 2.3

Delineation of Mission Beach cassowaries into "Coastal" and "Hinterland" populations by Crome and Bentrupperbaumer (1992a)



This population estimate was increased to 84-134 adult birds (Crome and Bentrupperbaumer 1991, 1992) and subsequently to 100-180 adult birds (Crome and Bentrupperbaumer *pers. comm.* in Goosem 1992). Both these estimates were unsupported by systematic surveys or field studies. Following a general coastal survey using public responses and opportunistic sightings in 1991, the population estimate was revised down to 89 adult cassowaries (Bentrupperbaumer 1992b). This latter figure comprised an estimated 54 adults in the Mission Beach coastal section and 35 adults in the hinterland.

2.9.2 Cassowary field surveys 1998-2001

Systematic field surveys of cassowaries crossing the El Arish-Mission Beach, the Tully-Mission Beach, and the South Mission Beach Roads were conducted from 1998 –2000 (Moore 1998, 1999i, 2000a). These studies concluded that the delineation of birds into coastal and hinterland populations was artificial. Moore showed that the majority of "coastal" birds (Bentrupperbaumer 1988, 1991, 1992a-b, 1998; Crome and Bentrupperbaumer 1991, 1992, 1993; Bentrupperbaumer 1998) live and breed in the hinterland, while making occasional or seasonal use of the coastal areas, thus inflating the earlier population numbers. Moore's studies (*ibid*) also showed that adult cassowary home ranges averaged 1-3km^2, not the 0.5km^2 previously estimated by Crome and Bentrupperbaumer (*loc. cit*). Based on this finding, it was predicted that the number of adult cassowaries making use of the coastal area was likely to be less than half that of the 1992 estimates. The total adult cassowary population at Mission Beach was therefore estimated to be less than 52 birds (Table 2.2).

Table 2.2

Estimates of the number of adult cassowaries in the Mission Beach area.

Location	Area (km^2)	Number of adult cassowaries	
		Bentrupperbaumer (1992b)	Moore (1998a)
Coastal section	17.5	54	<25
Hinterland section	67.0	35	22-27
Totals	**84.5**	**89**	**<52**

2.10 Cassowary habitat zones

Goosem (1992) prepared a Cassowary Management Plan for Mission Beach in which the existing vegetation was classified according to its perceived significance to cassowaries. In the plan Mission Beach was classified into six Primary Habitat Zones and four Secondary Areas. These zones are listed in Box 1 below. They comprise:

Primary habitat zones

- Critical Cassowary Habitat Zone
- Important Cassowary Habitat Zone
- Potentially Critical/Important Cassowary Habitat Zone
- Natural Corridor/Habitat Zone.
- Natural Corridor Zone
- Mangrove Zone

Box 1

Cassowary Habitat Zones of Mission Beach
(Source: Goosem 1992a-b)

*"**Critical Habitat*** - (blocks C1, C2, C3)
Possessing very high cassowary population densities, containing known preferred breeding areas, providing refuge areas after natural catastrophes (*ie.* cyclones) and furnishing adequate food resources during lean times.

***Important Habitat* -** (blocks I1, I2, I3)
Possessing high cassowary population densities, furnishing adequate food resources at most times of the year, with slightly less habitat complexity than the former category and not known to be the most important breeding areas.

***Potentially Critical/Important Habitat* -** (block P3)
Areas possessing similarly "recurring patterns of features which were found to consistently delineate critical or important cassowary habitat areas but have been inadequately researched to definitely place them into either of the above categories" (Goosem 1991). Following more research these areas are likely to be included into the Critical or Important zones.

Important Linkage Areas - (blocks C1, C2, C3) [1]
Areas which are largely cleared but retaining remnant patches of native vegetation located strategically between blocks of Critical or Important habitat.

[1] *Note: Important Linkage Areas comprise areas of rapidly disappearing vegetation and while once possibly viable as movement corridors are now questionable as valid Cassowary Habitat Zones. It is highly unlikely that these areas will continue to function as movement corridors in the Mission Beach lowlands unless there is a cessation in the loss of the vegetation within and surrounding them. Access to the coast by cassowaries will be impossible once these linkages are broken and the dynamics of the lowland vegetation complexes will be significantly compromised in the long-term.*

Natural Corridor/Habitat Areas - (blocks C1, C2, C3)
Defined as those areas of remaining native vegetation cover which are known to be used by cassowaries moving between blocks of Critical or Important habitat as well as the less favoured extensive areas of *Melaleuca*-dominated tracts on sites of impeded drainage providing connectivity of forest cover and some food resources.

Natural Corridor Areas - (blocks C1, C2, C3)
Defined as areas of native forest comprising predominantly extensive areas of Melaleuca communities with impeded drainage.

Mangrove Habitat - (blocks C1, C2, C3)
Saline tidal forests and associated samphire flats which may furnish some food resources, allow the sheltered passage of birds along the ecotone of adjoining communities and buffer resource-rich non-tidal habitat patches.

Secondary zones

- Coastal Buffer Areas
- Urban Areas
- Rural Areas
- Important Linkage Areas.

However, many changes have occurred since the original cassowary habitat zoning of the Mission Beach area. These changes include ongoing habitat clearing, road upgrades (Tully-Mission Beach Road completed, El Arish-MB Road upgrade pending), and increased resident and tourist populations, all of which have impacted areas used by cassowaries. Moreover, the original habitat zoning was developed and applied using the limited data available at the time and lacked the benefit of accurate information on cassowary distribution and behaviour, or an accurate estimate of the true number of birds existing in the Mission Beach area. Predictably, the resulting habitat zoning comprises too many categories with a number based on what are considered to be invalid criteria. The basis for this conclusion is detailed in Chapter 8 (Discussion).

2.11 Comparison of Mission Beach and Daintree lowlands cassowary populations

Until the Daintree area was surveyed, Mission Beach was thought to have the highest density of cassowaries in north Queensland. This status most probably derived from a variety of historical causes including easy accessibility with major service and tourist roads bisecting the main forest blocks, the existence of a strong tropical fruit industry (*ie* bananas and pawpaws) that has encouraged the birds to be more visible, an active community conservation group, and publicity focussed on the Mission Beach area by previous studies and events.

Between 1992 and 1998, however, intensive cassowary surveys were carried out in the Daintree lowlands from the Daintree River to Cape Tribulation, an area encompassing 160 km^2. Approximately 75% of this area (*ie* $120km^2$) was surveyed intensively (Crome and Moore 1993, Moore 1996a-j, 1999e). The remaining areas comprised predominantly medium and low woodland (Type 16–Tracey 1982), and other vegetation types considered unsuitable for maintaining cassowaries. These field surveys found there were about 54 adult birds in the Daintree lowlands, with the highest sample density reaching $0.5km^2$/adult at the mouth of Noah Creek (Crome and Moore 1993).

Further surveys using similar methodology (Moore 1996a-j) showed that approximately 90% of the identified birds maintained a home range of 1-3 km^2 with only two home ranges exceeding this area *ie* 4.17 km^2 and 5.76 km^2. These larger home ranges were in the northern sections of the Daintree study area where the rocky and steep terrain provides less suitable habitat for cassowaries.

The average home range size of birds in the Daintree, therefore, is very similar to those maintained by the majority of the Mission Beach birds (Moore 1998a, 1999i, 2000a). Because of this, Moore (1998a) predicted that Mission Beach would have a population of adult cassowaries comparable to that of the Daintree lowlands *ie* 50–60 adults.

CHAPTER 3

CASSOWARY FIELD SURVEY METHODOLOGY

The field survey was undertaken between 1 June and 15 December 2000. Although genetic techniques to identify individual cassowaries from sloughed intestinal cells collected from cassowary dung have been underway since 1997, the work has thus far been unsuccessful. In the absence of this technology, the cassowary field surveying techniques used in this study were those developed and tested by the author over numerous surveys carried out between 1988-1999 (Crome and Moore 1988, 1990, 1993, Moore and Crome 1992; Moore 1995, 1996a-j, 1997a-b, 1998a-d, 1999a-I, 2000a).

The primary field survey objective was to accurately locate, measure, and map all cassowary sign *ie* footprints, bird sightings, droppings, vocalisations, feet stamping. The survey techniques used in this study had been previously taught to Joan Bentrupperbaumer who used them to assist in mapping cassowary activity during her studies at Kennedy Bay (Hull River National Park), Mission Beach (Crome and Bentrupperbaumer 1991, 1992, 1993; Bentrupperbaumer 1998), and to Dr. Chris Clague, who conducted a survey of cassowary habitat in the Johnstone Shire (Clague 1993). The same methodology was also used to gather data for three comprehensive Regional Cassowary Management Plans (RCMP) for the Wet Tropics Management Authority (Moore 1999e-g). A brief summary of the field survey methods used is presented below.

1. The Search Areas were defined for the entire study area based on clearly recognisable features in the field such as ridgelines, creeks, catchments and roads.

2. The daily search routine began from one edge of the study area and moved successively through the adjoining Search Areas, maintaining a "front" that was re-established at the beginning of each day (Figure 3.1).

3. All cassowary sign was noted on the base map and a record taken of all other data such as vegetation condition, type, profile, and topographic observations.

4. Field observations were transcribed onto a master map at the end of each search day. A list of footprint sizes and their locations, particularly in relation to very fresh and fresh droppings, was also compiled.

5. A search was conducted for the cassowary itself only when the mapped sign defined an adequate picture of its current area of activity. From previous survey experience, it was considered important to minimise contact with the bird so that the first "deliberate" contact was not compromised by a previous attempt. Although cassowaries often followed or observed the researcher, this form of neutral interaction did not seem to adversely affect the bird when a deliberate meeting occurred.

6. When in company with the bird, the following observations were made: physical characteristics (identity profile), footprint measurements, behavioural and other notes to identify the bird and separate it from neighbouring birds. This process was repeated for each located cassowary, with a draft Indicative Home Range map completed for each based on the field observations.

7. Finally, the individual identifications and Indicative Home Range maps were field-tested by going into each home range and conducting a "directed" search for each individual bird (this was done for all neighbouring or overlapping individuals generally within the same day). In a directed search only the known high-use areas were surveyed.

3.1 Preparing the base map

The study area was first broken down into a series of Search Areas each ranging in size between 1-2km^2 in area. Prior to starting fieldwork, the relevant section of a 1:50 000 topographic map was copied for each Search Area. This was used as the base map. The approximate boundaries of the different vegetation units (as depicted by Tracey and Webb 1975) were then marked onto the base maps. These marked up maps were used to design survey routes, and the locations of all data recorded in the field were plotted onto field copies during the field survey.

The vegetation descriptions used in this thesis are a combination of the 1: 100,000 indicative mapping by Webb and Tracey (1975), mapping recently completed by Stanton which had been overlayed onto a 1997 aerial mosaic of the Mission Beach area (Stanton 2001), and field observations taken during the field survey.

3.2 Traversing the search area

To ensure all visible cassowary sign was detected, a thorough searching strategy was used. Each search area was surveyed on foot, using transects spaced at 100 metres apart. The area for 50 metres either side of each traverse was systematically searched and all signs of cassowaries were recorded onto the base maps. To check for new sign which may have indicated birds moving across the boundaries of the Search Areas, each day's search effort began within the Search Area of the previous day (Figure 3.1), with the birds or their sign located the previous day re-located before moving into new ground. The survey route was accurately plotted on the field map and a GPS used when possible to pinpoint trig-points. Private land was accessed only if the landowner's permission had been obtained. Access was obtained for all but a few marginal blocks of partly cleared land in the Garners Beach\Bingil Bay area.

On average, an area of approximately 1.5km^2 was intensively searched each day. During spring\summer the light within the forest was sufficient to allow for searching between about 0800 -1700 (9hours) and in winter from 0900 – 1530 (6.5 hours). The time outside this sampling period was spent re-locating birds from the previous day and\or walking into or out of Search Areas.

Figure 3.1

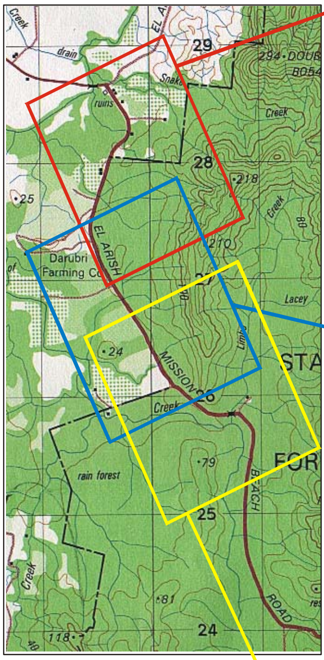
Field Survey Data from Consecutive Search Days

Lacey's Creek area - El Arish Road

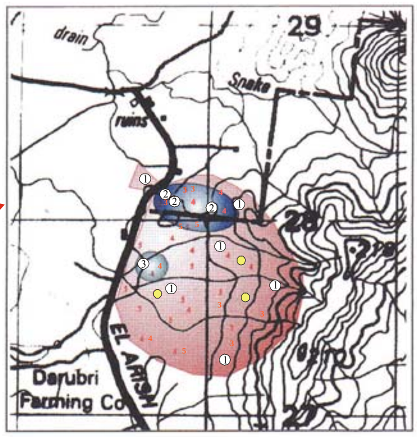
July 1998

* Each individual cassowary is given a separate colour to distinguish its indicative home range from its neighbours

Note overlapping search areas ("moving front")

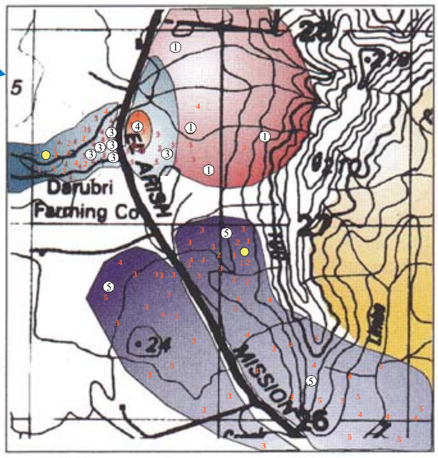


1 : 50 000 topographic map



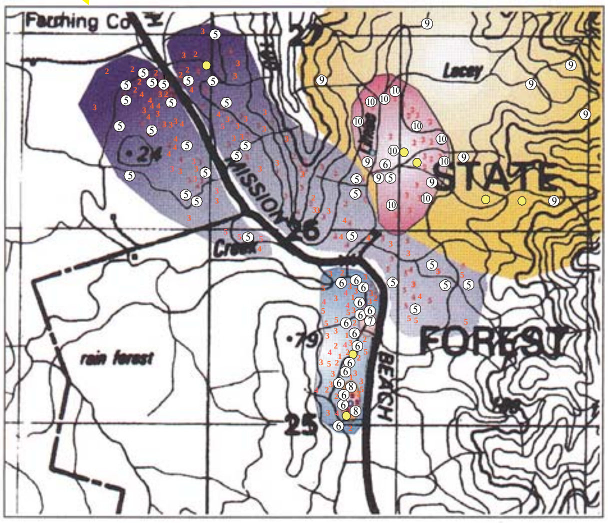
Day 1

Footprint 1 = 210 mm [Cassowary RED)
Footprint 2 = 140 mm [Cassowary BLUE]
Footprint 3 = 185 mm [Cassowary GREEN]
**FP1 sighted as adult (? Sex)*



Day 2

Footprint 1 = 200 mm [Cassowary RED]
Footprint 3 = 180 (*ca*)* [Cassowary GREEN]
* *[tentatively identified as Fp3 from Day 1*
- sighted as adult male]
Footprint 4 = 169 mm [Cassowary ORANGE]
Footprint 5 = 195 mm [Cassowary PURPLE]



Days 3 & 4

Footprint 5 = 195 mm [Cassowary PURPLE]
Footprint 6 = 160 mm [Cassowary BLUE]
Footprint 7 = 149 mm [Cassowary LIGHT PINK]
Footprint 8 = 123 mm [Cassowary ORANGE]
Footprint 9 = 214 mm [Cassowary YELLOW]
Footprint 10 = 165 mm [Cassowary DARK PINK]

KEY

1 = Very fresh dropping
2 = Fresh dropping
3 = Recent dropping
4 = Old dropping
5 = Very old dropping
①= Footprint ID
● = Cassowary Sighting

Source: Les Moore 2000

3.3 Recording cassowaries and their sign

All records of cassowaries were noted and plotted onto the field map. Records consisted of sightings, footprints, droppings, and vocalisations. Although sightings of individual birds were the most certain evidence of occurrence, footprints and droppings were the most common signs of a cassowary's presence. Particular effort was made to locate and measure footprints and locate the birds responsible for making them. When adjoining cassowaries had similar footprint measurements and/or physical characteristics, a search was made to locate the second individual and confirm the existence of two birds.

3.3.1 Footprints

As adult cassowaries can weigh between 35-80kg, footprints are often left in soft soil, stream banks, pig wallows and occasionally in deep rainforest litter. In most circumstances the distance between the heel and tip of the large central toe can be accurately measured. Over many years of measuring footprints it has become apparent that the variation in foot size is sufficient in many cases to separate individual birds from their neighbours.

Figure 3.2 shows a typical cassowary footprint and details the diagnostic features and method of measurement. Examples of very fresh and fresh *in-situ* footprints from South Mission Beach are illustrated in Plates 1-2. It should be noted, however, that the likelihood of footprints being formed depends on soil types and local weather conditions.

Footprint measurements are taken in the field as follows:

- All footprints are measured using a section of cane laid along the print: this allows the cane to be precisely cut with secateurs at the heel and end of the middle toe of the print. This template is then measured as the individual's footprint size;
- The footprint template is labelled with the measurement in millimetres, date and location, and is able to be rapidly checked against all other located prints;
- This usually results in having daily templates of 5-10 "prints" with which to check sizes of footprints: all located footprints are checked with these "templates" and re-measured with a tape where appropriate;

- Generally new footprint templates are cut and measured each day to avoid shrinkage and other possible sources of error;
- In practice cassowary footprints are extremely constant: making a template helps avoid measurement error and the possibility of distortion to the print associated with using a hand tape or calipers for each measurement;
- It is always necessary, however, to interpret the influence of soils and other conditions when measuring footprints.

Although sighting the individual responsible for each footprint is essential and the only valid proof of age or identity, the following range of footprint measurements were used as a guide to the likely ages of those birds making them (Table 3.1). These data were determined by measuring footprints from 67 known individual birds in the Daintree lowlands (Moore 1998c).

Table 3.1

Indicative footprint sizes of Mission Beach cassowaries

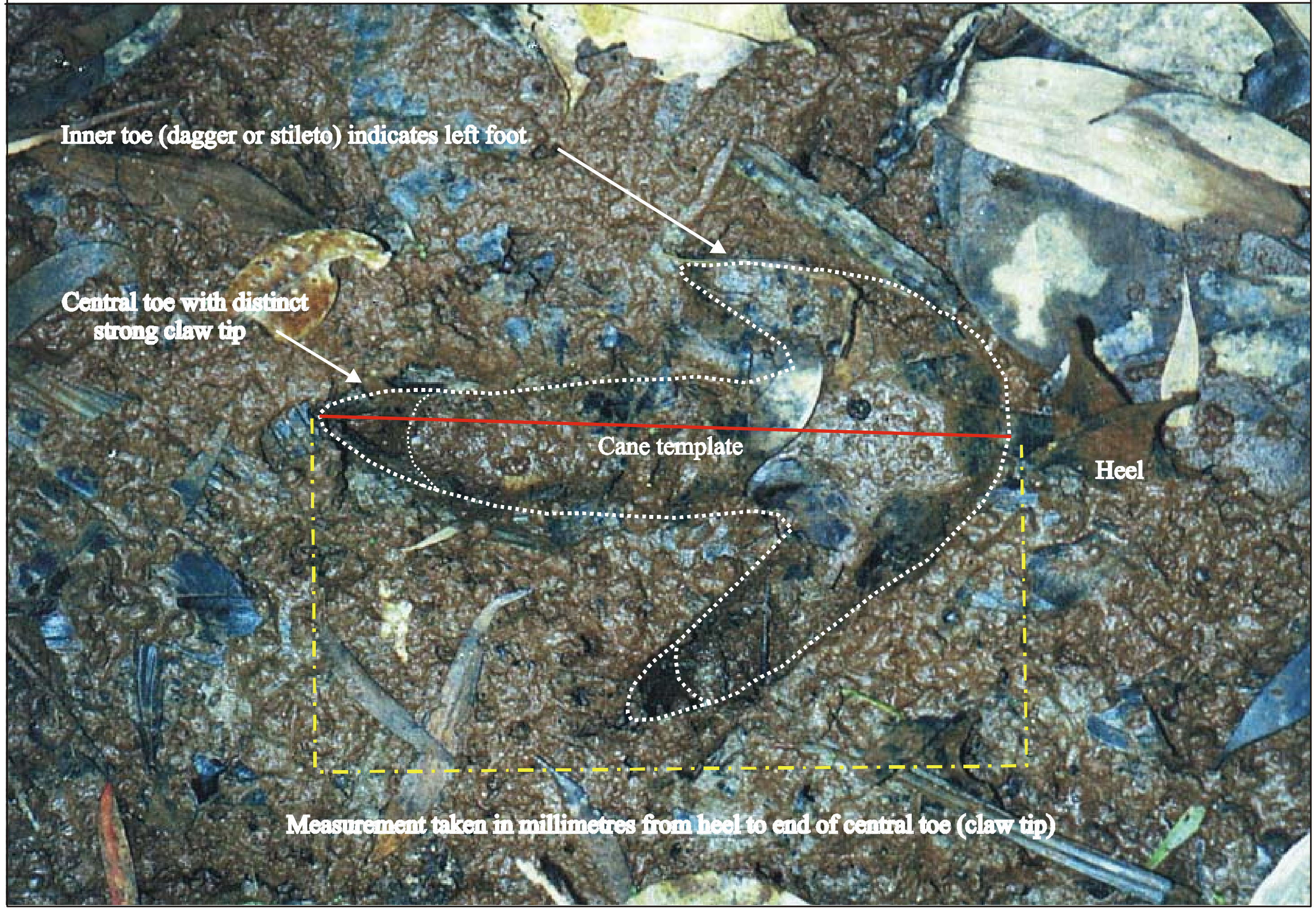
Footprint length (mm)	Age and sex
< 160	juveniles\young subadults (less than 12 months old);
160 – 200	older subadults (12-36 months);
180 - 225	adult males;
200 - 245	adult females.

Although there is overlap between these size\age groupings, all footprint measurements contribute an important element to the total identification profile of each cassowary. In any one area, differences in footprint measurements may indicate use of the area by different birds. Additionally, with practice, it was possible to age footprints in the same way as for droppings *ie* very fresh - very old, thus gaining some indication of the temporal use of an area by different individuals.

It should be noted that although temporary or seasonal food shortage may result in a lack of droppings with which to determine the presence or absence of cassowaries in an area, moving birds will <u>always</u> leave footprints, and thus their presence can be readily established.

Figure 3.2

Cassowary Footprint Showing Diagnostic Features and Measuring Point



Source: Les Moore 2000

Plate 1.
Very fresh cassowary footprint found in swampy soil at the edge of a *Melaleuca* swamp. Note the strong indentation of the middle toe with the distinct claw tip.

Plate 2.
Fainter fresh footprint found on an overgrown track along the rainforest edge (note the *Acacia* leaves in picture). The typical reticulation of the under skin of the foot can be clearly seen in this photograph.

3.3.2 Droppings

Although less informative than footprints, droppings are an extremely useful tool in surveying cassowaries. It is most important to note, however, that although droppings can indicate how a bird uses an area, they cannot be used to either identify a bird or calculate the number of birds present in an area. Additionally, the physical condition of the dropping can be affected by prevailing weather conditions *eg* rain or high temperatures, and these possible changes should be taken into account when aging droppings using the classification system outlined below.

Through a season and from year to year a bird will concentrate its activity in those areas of its range that yield adequate food, and fresher droppings are concentrated in such areas. The distribution of old and very old droppings is often spread wider and indicates the past use of the home range. It was possible, therefore, to make reasonable interpretations of the habitat usage of the bird based on its droppings.

Age categories for droppings were developed by the author over previous field surveys carried out between 1988-1999 (Crome and Moore 1988, 1990, 1993, Moore and Crome 1992; Moore 1995, 1996a-j, 1997a-b, 1998a-d, 1999a-i, 2000a). A dropping is classified as follows and illustrated by the indicated plates:

Very Fresh Dropping wet and sometimes "steaming". Deposited within the last 12 hours (Plates 3-4).

Fresh Dropping has a thin dry outer layer but is still very wet underneath. Deposited within the last 36 hours (Plates 5-6).

Recent Dropping dry but wet at centre and base. Deposited within the last four days (Plates 7-8).

Old Dropping still maintains its shape but completely dry throughout. Deposited more than four days previously (Plates 9-10).

Very Old Dropping consists of exposed seeds with detritus partially or completely broken down. Depending upon rainfall patterns, such droppings could be 1-3 months old (Plates 11-14).

A field experiment to document the aging of freshly produced dung left for varying periods of time was abandoned due to the effects of constant heavy rain, and the difficulty of finding and monitoring an adequate sample of suitable droppings.

3.3.3 Vocalisations and foot stamping

Vocalisations and foot stamping are only audible in close proximity of the bird and often accompany a sighting. Foot stamping generally occurs when a bird is out of sight and first becomes aware of the observer. It is usually followed by the bird either moving quietly away or escalating its display into vocalising. Depending upon the stage of the search routine, the bird may be followed and its physical characteristics recorded, or left alone for future re-location and description.

Calls vary depending on the level of interaction the bird intends to pursue. The most commonly heard calls are:

- Booming- repeated booms given by both male and females.
- Grunting - similar to the booming call but more guttural. It has been used immediately prior to aggressive attacks on other birds and on the author (Moore *pers obs*.).
- Rumbling - low rumbling that appears to be used as a low-level threat (Crome 1976; Moore *pers obs*).
- Coughing - usually given when bird is out of sight and newly located and may be an alarm call (Crome 1976; Moore *pers obs*).
- Mewing - thought by Crome (1976) to occur in a male-male interaction context but unheard by author.
- Contact calls - repeated soft coughing call given by males to keep their chicks nearby. This call was also given by an adult female when foraging in company with a courting male (June 2000 - Moore *pers. obs*.).
- Chick and young subadult whistling - frequent whistling calls given by small chicks and also by independent young subadults. These birds can often be “called up” by imitating the call.

VERY FRESH DROPPING

Dropping wet and sometimes "steaming". Deposited anytime within the last 12 hours.

Plate 3 Example 1

Plate 4 Example 2 - after overnight rain.

FRESH DROPPING

Dropping has a thin dry outer layer but is still very wet underneath. Deposited within the last 36 hours.

Plate 5 Example 1

Plate 6 Example 2

RECENT DROPPING

Dropping dry but wet at centre and base. Deposited within the last four days.

Plate 7 Example 1

Plate 8 Example 2

OLD DROPPING

Dropping still maintains its shape but completely dry throughout. Deposited more than four days previously.

Plate 9 Example 1

Plate 10 Example 2

VERY OLD DROPPING (i)

Dropping consists of exposed seeds with detritus partially or completely broken down. Depending upon rainfall patterns, such droppings could be 1-3 months old.

Plate 11 Example 1 - dropping > 1 month old. Seeds separated but still with detritus of connective material

Plate 12 Example 2 - dropping likely >4 weeks old. Mostly separated seeds with little visible connective detritus.

VERY OLD DROPPING (ii)

Dropping consists of exposed seeds with detritus partially or completely broken down. Depending upon rainfall patterns, such droppings could be 1-3 months old.

Plate 13 Example 3 - Dropping approximately 2-3 months old. Bare seeds only remaining.

Plate 14 Example 4 - Dropping > 3 months old. Seeds germinating, exact age of dropping depends on tree species.

3.3.4 Sightings

Sightings may be either of an individual bird or of a family group. The following attributes are used to identify individual cassowaries:

Physical characteristics

Adults and older subadults are individually identifiable based on visible physical characteristics. These characteristics may include: size and shape of the casque, presence or absence of markings on exposed surfaces *eg* blotches on the casque; visible scars on legs\neck\head\beak; the length and shape of the wattles, the size and sex of the bird; the presence or absence of chicks; and the number and relative ages and size of any chicks accompanying the male parent.

Chicks

Broods of young chicks, otherwise unidentifiable, are identified by association with their fathers. Family parties of cassowaries may comprise from 1-5 chicks. The chicks have a range of plumage depending on age. Young chicks to six weeks are small and striped. With increasing age they lose their stripes, turning to brown then assuming varying shades of brown-black.

Size

Unaccompanied males (no chicks) are usually identifiable by their relatively small size (in comparison to adult females), and the presence of a distinctive "drooped tail" to their ventral profile. Adult females are generally clearly larger and present a horizontal line to their ventral profile, lacking the commonly occurring "tail" of the male bird.

Footprint measurements

Footprint measurements of each bird (and chicks) were verified while still in the company of the bird(s). Thus the measurements are able to be directly related to footprints measured elsewhere in the search area, identifying the source bird and chronicling its movements over the survey period and longer.

Due to the large area surveyed (130km^2), differences were generally noted at the individual separation stage *ie* the age and sex of the individual and whether its physical characteristics separated it from known adjoining birds.

Video filming

An attempt was made to film located cassowaries using a video camera to detect physical characteristics of individual birds. Unfortunately, although they sometimes visit farms and houses, cassowaries are extremely cautious of humans when in the forest, and as a result filming was not useful in identifying individuals. Much opportunity to observe birds was lost due to the time taken to access and set up the camera (located in a waterproof bag in a backpack). Movements have to be measured and few when in proximity to cassowaries, and a constant eye maintained lest the bird slip away. Often by the time filming began the bird had moved behind vegetation or out of sight completely. Locating it again after "spooking" with the camera was always difficult.

However, good footage was obtained of some family parties and adult females, indicating that this technique has potential for use in future cassowary behavioural studies or small area surveys where more time can be spent with individual birds.

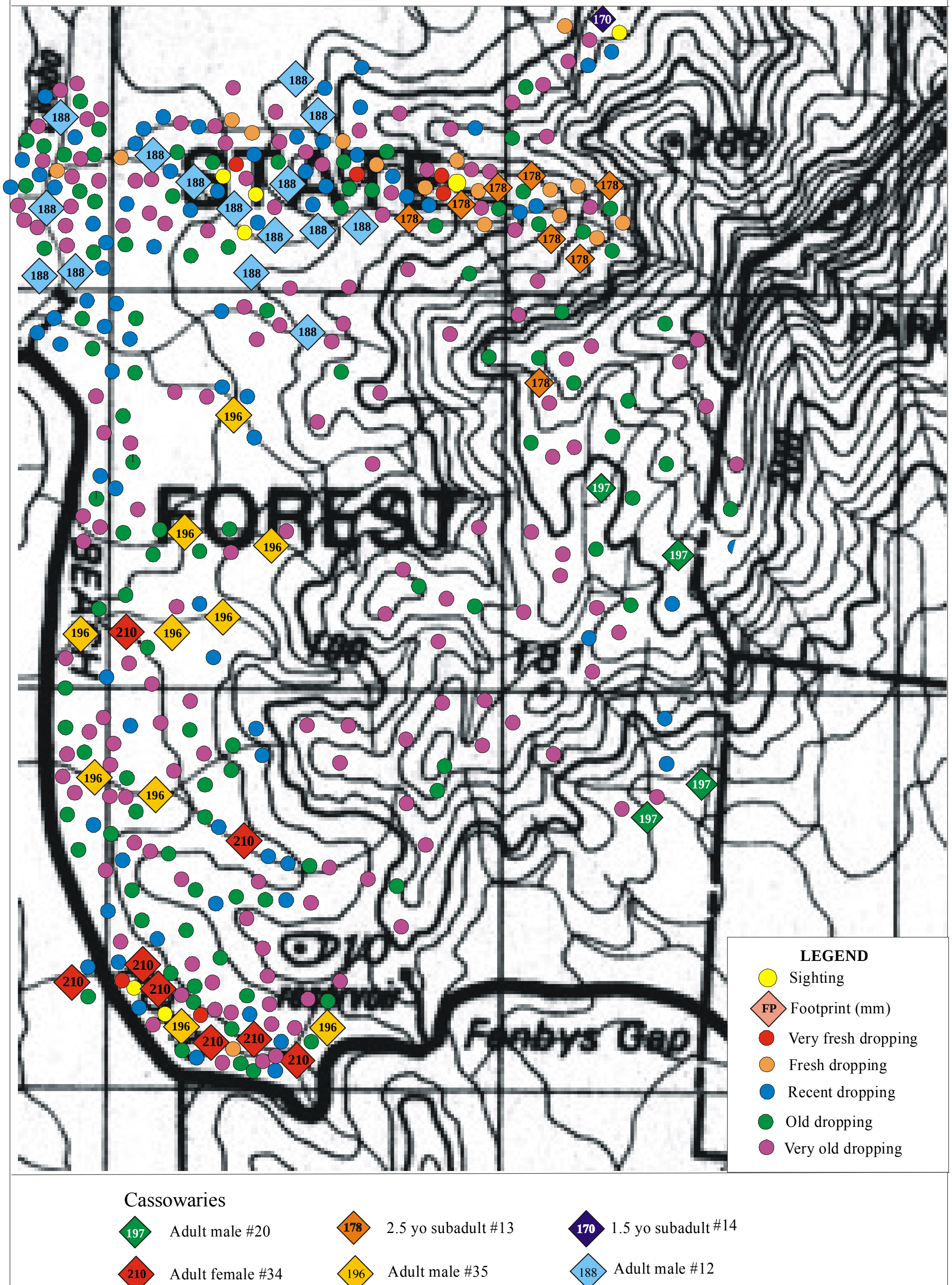
3.4 Mapping indicative home ranges

Cassowary home ranges vary over time depending on environmental conditions and patterns of food abundance. Thus the total extent of any bird's home range (*ie* that area used over a number of years) can only be determined by long-term field studies and are subject to continual change and adjustment.

The home ranges of cassowaries in this study were estimated using a minimum convex polygon calculation. This home range estimate was based primarily on sightings and measured footprint locations for an identified bird and was produced by joining the outermost points of the scatter of mapped observations. Additionally, a detailed map was constructed using the distribution and age of located cassowary droppings, the location of footprint measurements from each bird, and the location of sightings of individually identified birds made throughout the search areas during the survey period (Figure 3.3). The resultant map of observations represents each bird's current home

Figure 3.3

Example of mapped cassowary field survey data (3 days)
Lacey's Creek - Clump Mountain Range



Source: Les Moore 2001

range, and an approximation of its foraging activities over a number of preceding weeks or months (*ie Indicative Home Range*). A transparent grid marked in dots and blocks was then placed over the map and the number of blocks and dots counted within the home range area measured and the area determined from the scale of the map *ie* 1:50,000.

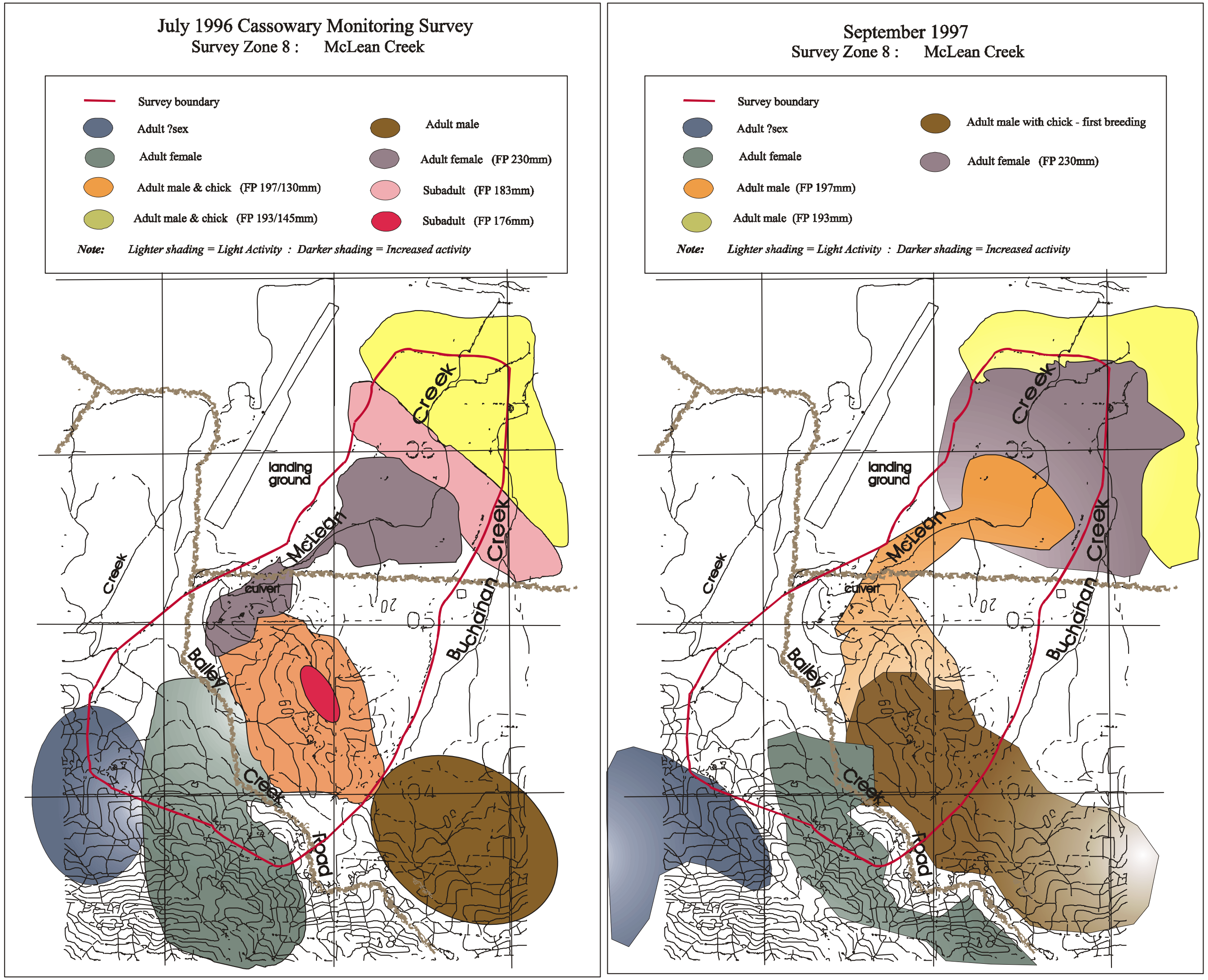
The indicative home ranges shown in this study should be considered spatially and temporally dynamic. The maturing of a subadult or the death of a resident adult can alter surrounding home ranges considerably as birds adjust to social and spatial change. This fluidity is illustrated in Figure 3.4, which shows the variation in home ranges of neighbouring birds in the Daintree lowlands over two successive years. Much of this variation was due to the successful breeding of a young adult male, who expanded his range at the expense of the considerably older resident breeding pair.

Home Range Estimation software

It was decided in this study not to use home range estimation software to calculate cassowary home ranges. The mapping technique outlined above takes full account of intrinsic irregularities in the shapes of home ranges, which often reflect the constraints of topography, watercourses, vegetation type and structure, and the shape of habitat patches, whereas automated computations implemented in computer packages tend to simplify these elements. Additionally, the mapping method described minimises assumptions about the distribution of individual cassowary locations, and gives a clear visual display of the actual observations made.

Figure 3.4

Variation in cassowary home ranges over time



Source: Les Moore 2001

CHAPTER 4

RESULTS

A total of 101.66 km^2 of rainforest was surveyed on foot over the six months of the Mission Beach cassowary study. The total search effort used in the analyses amounted to 582.54 field hours, resulting in 345.78 kilometres of search transects which located 4729 cassowary signs comprising sightings, footprints, droppings, and vocalisations. A breakdown of the signs located is presented in Table 4.1.

Table 4.1

Breakdown of located cassowary sign

Sightings *	Footprints	Droppings	Vocalisations	Foot stamping	Total Sign
177	1198	3347	7	0	**4729**

*(includes multiple sightings of individual birds)

4.1 Cassowary population size

A total of 110 cassowaries comprising 49 adults, 28 subadults, 31 chicks and 2 independent birds of unknown status, were identified during the Mission Beach cassowary survey. All but the two unknown cassowaries were sighted and matched to their footprints. A demographic breakdown of the population is presented in Table 4.2 and Figure 4.2.

Of the 49 adult cassowaries identified within the Mission Beach study area, 25 were identified as males, 19 as females, and two adult birds were of unknown status. Three other birds, although inadequately sighted, are believed to be adult males. The population densities used in this thesis (particularly Chapter 5) have thus been based on the estimates of 28 adult males and 19 adult females.

Detailed search area results are presented in Table 4.3. The boundaries of Search Zones listed in Table 4.3 are shown on Figure 4.3, with the locations of all footprint measurements and cassowary sightings presented on Figure 4.4.

Data on grid locations of individual cassowaries are presented in Table 4.4 with the Grid Square Key presented in Figure 4.5. The cassowary home range locations in this table represent a General Location only, as Indicative Home Ranges usually exceeded individual Search Zone boundaries. For example, the location of *Jurs Gap* is just west of the Bean Tree Track, and overlaps two Search Zones 5 and 6 (*eg.* Cassowary #39 [FP=215mm).

Table 4.2

Mission Beach cassowary demography December 2000

Adult males	Chicks	Adult Females	Adults ?sex	Subadults	?age \sex	Total birds
25	31	19	2	28	5*	**110**

*Three probable males; 2 unknown age and sex.

Footprint measurements of located cassowaries have been grouped into frequencies and are shown in Figure 4.1. No footprint measurements were taken of chicks that were still in the company of males.

Figure 4.1

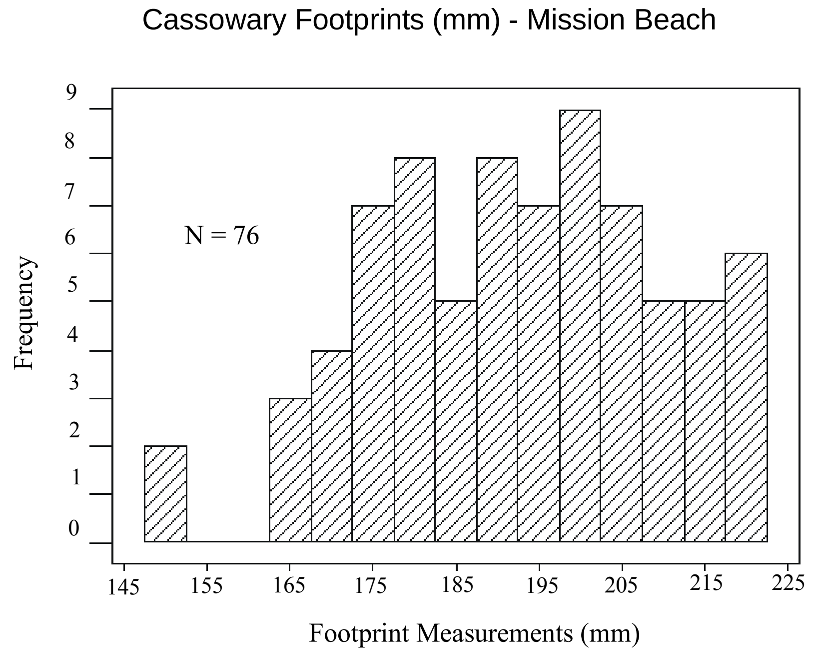
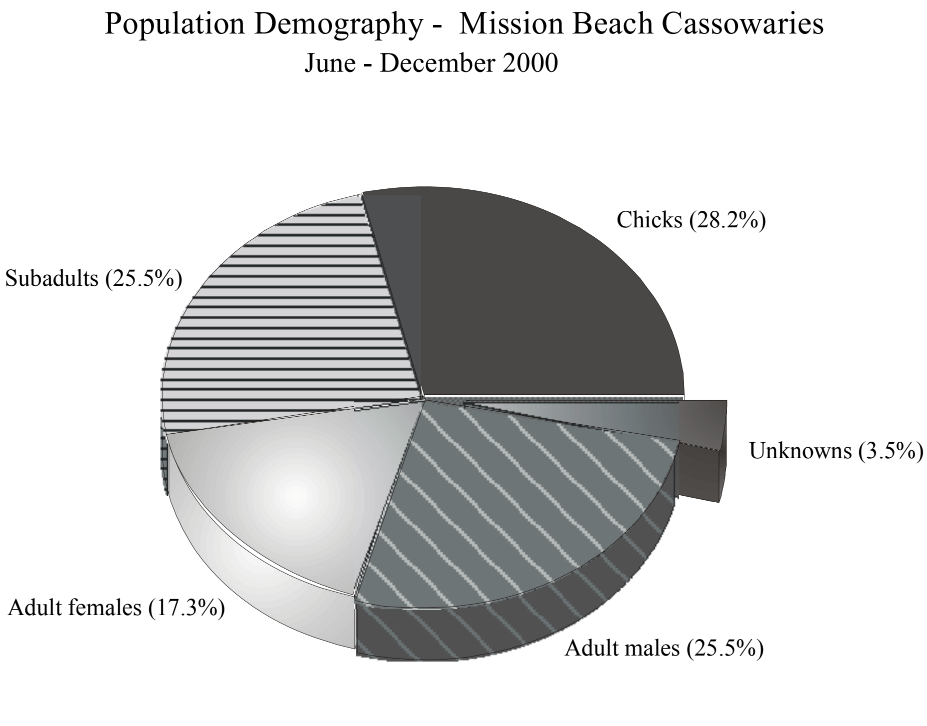


Figure 4.2

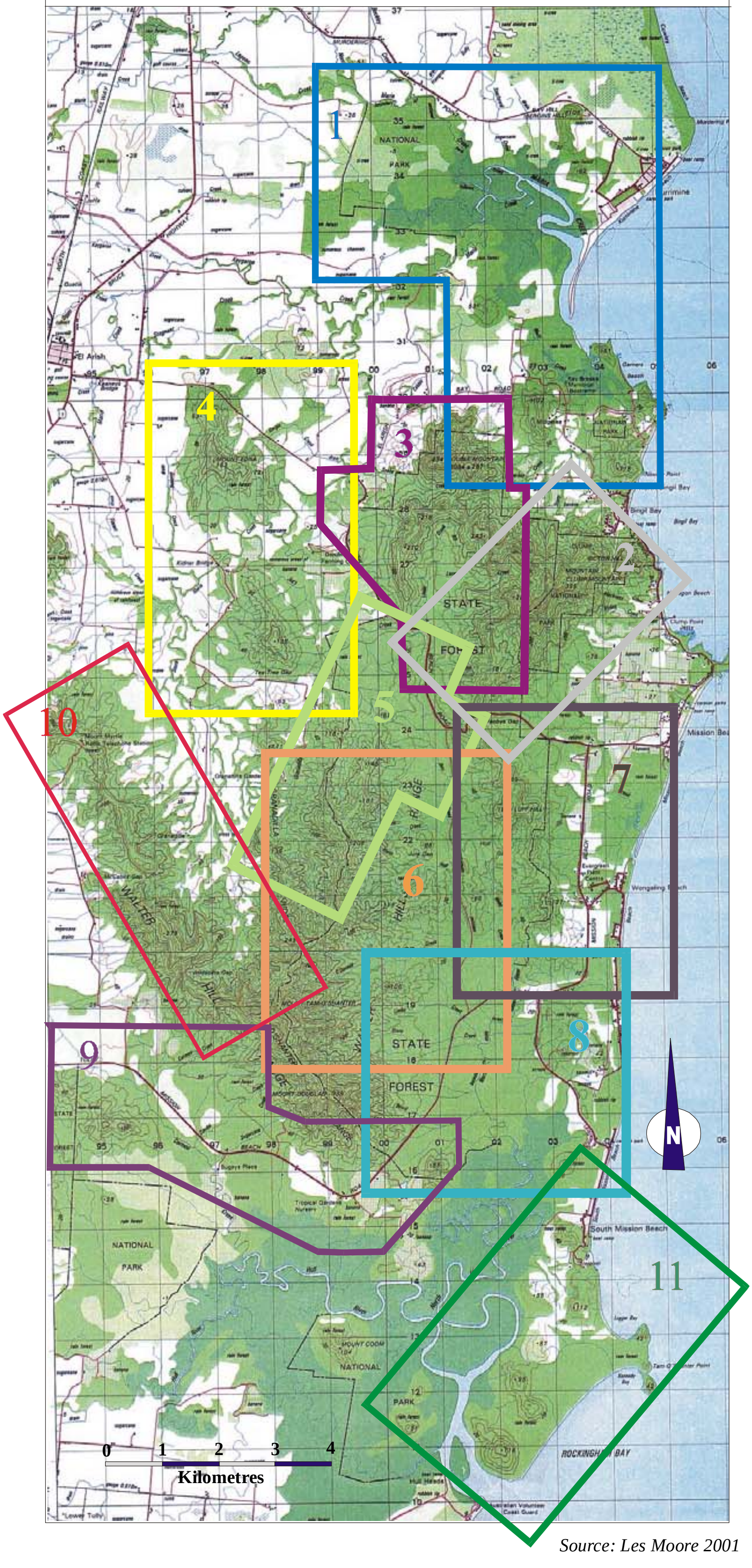


4.1.1 Unknown or insufficiently sighted cassowaries

A total of seven birds were categorised as Unknown. These comprised two un-sexed adults (#36 and #48) and five birds not adequately sighted to determine age or sex with confidence. Of these, three are almost certainly adult males (Cassowaries # 42, #44, #64). Of the remainder, one is likely to be a subadult, (Cassowary #50), while the presence of droppings suggest the possibility of at least one bird in the southern section of Maria Creek National Park (tentatively designated Cassowary #83). In addition, although no adequate footprints or sightings were obtained, it is believed another independent bird may have been present during the survey of the Kennedy Bay section of the Hull River National Park. The presence of this individual would need to be confirmed by further surveying and it has not been included in the population totals.

Figure 4.3

Mission Beach Search Area Locations
(from Table 4.3)



Source: Les Moore 2001

Table 4.3

Search Area Results

For search area locations refer to Figure 4.3.

***Droppings only - rated as one (1) bird for Maria Creek National Park*

Search Zone	Search Location	Search Time (hrs)	Distance (metres)	Cassowary Sign	Sign per 1000m	Number of birds (Total\Ad) [footprints mm]	Search Area (km^2)	Sample Density[1] (km^2 \birds)
1	Maria Creek NP 1 (North)	6.50	5800	0	0	0	1.25	0
1	Maria Creek NP 2 (South)*	7.50	4200	3	0.71	1 X	1.75	1.75
1	Garners Beach NP	10.00	4300	19	4.42	1 180	1.50	1.50
1	Cedar Creek east	4.66	900	108	120	2 (1) 211,180	0.50	0.25
1	Cedar Creek west	4.50	2250	15	6.67	1 186	0.40	0.40
1	Dragonheart	4.20	1700	12	7.06	1 170	0.75	0.75
2	Bicton Hill	8.50	6300	9	1.43	(1) X	2.50	2.50
2	North Clump Mt Range	10.20	8500	6	0.71	1 ?205	2.25	2.25
2	East Clump Mountain 1	7.75	4700	188	40.00	3 (2) 185,214,197	2.25	0.75
2	East Clump Mountain 2	7.00	3200	72	22.50	3 (2) 172,214,205	1.00	0.33
2	Clump Mountain Camp 1	6.50	3200	67	20.94	1 197	1.00	1.00
2	Clump Mountain Camp 2	8.50	4700	51	10.85	2 (1) 197,185	1.20	0.60
2	South Clump Mt Range 1 (Fenby's)	9.66	8000	95	11.88	3 (1) 196,170,178	3.00	1.50

Search Zone	Search Location	Search Time (hrs)	Distance (metres)	Cassowary Sign	Sign per 1000m	Number of birds (Total\Ad) [footprints mm]	Search Area (km^2)	Sample Density[1] (km^2 \birds)
2	South Clump Mt Range 2	2.80	6500	26	4.00	1 ?215	1.20	1.20
3	Jurs Creek tributaries 1-4	9.66	6200	162	26.13	3 (2) 180,196,215	1.30	0.43
3	Lacy's Creek east arm	9.20	4400	102	23.18	1 188	1.00	1.00
3	Lacys Creek 1 (main stream S)	8.50	3700	118	31.89	3 (2) 210,177,188	1.25	0.42
3	Lacys Creek 2 (main stream N)	8.25	4200	79	18.81	4 (3) 210,165,200,190	1.25	0.31
3	Lacys Creek 3 (W ridgeline)	8.75	5200	107	20.58	4 (2) 210,188,165,177	1.50	0.38
3	Lacys Creek 4 (NE trib1)	5.50	2700	52	19.26	1 177	0.75	0.75
3	Lacys Creek 5 (NE trib 2 + E ridge)	9.00	5100	89	17.45	4 205,170,188,177	1.33	0.33
3	West of Lacy's Creek (x2)	15.50	11000	235	21.36	5 (3) 193,203,170, 178,188	2.25	0.45
3	Double Mountain	7.75	4300	60	13.95	2 (1) 200, 165	1.75	0.88
4	Mt Edna 1	9.00	4800	22	4.58	1 195	1.75	1.75
4	Mt Edna 2	8.50	3900	9	2.31	2 195, 207	1.75	0.88
4	Mt Edna 3	5.00	2600	5	1.92	1 195	1.50	1.50
5	Upper Jurs Creek	8.00	3700	94	25.41	5 (4) 190,180,215, 200,188	1.25	0.25
5	North Walter Hill Range 1	8.25	4700	56	11.91	2 190,210	1.33	0.67
5	North Walter Hill Range 2	9.25	5200	83	15.96	4 (3) 210,215,180,202	1.60	0.40
5	North Walter Hill Range 3	6.00	4300	60	13.96	2 (1) 202,175	0.75	0.38
5	North Bean Tree Track 1	8.50	4500	87	19.33	5 (4) 200,180,197, 215,193	1.10	0.22

Search Zone	Search Location	Search Time (hrs)	Distance (metres)	Cassowary Sign	Sign per 1000m	Number of birds (Total\Ad) [footprints mm]	Search Area (km^2)	Sample Density[1] (km^2 \birds)
5	North Bean Tree Track 2	7.50	4200	71	16.91	3 (3) 215,197,190	1.00	0.33
6	Bean Tree Track 1	9.50	4800	69	14.38	2 (1) 201,176	1.25	0.63
6	Bean Tree Track 2	8.00	4300	79	18.37	3 (3) 197,193,215	1.25	0.42
6	Bean Tree Track 3	9.25	4900	73	14.90	4 (3) 193,215, 196,187	1.25	0.31
6	Bean Tree Track 4	10.00	5800	97	16.72	4 (2) 176,187,218,193	2.00	0.50
6	Bean Tree Track 5	10.50	7100	68	9.58	3 (1) 185,188,218	2.75	0.92
6	Bean Tree Track 6	10.00	7300	100	13.70	4 (4) 210,191,212, 215	2.25	0.56
6	Bean Tree Track 7	8.00	4400	77	17.50	4 (3) 188,193,210,174	2.00	0.50
6	Bean Tree Track 8	8.25	4300	62	14.42	3 (3) 210,190,193	1.50	0.50
6	Bean Tree Track 9	9.25	4900	71	14.49	4 (2) 210,190,185,174	1.60	0.40
6	Bean Tree Track 10	8.75	5100	73	14.31	3 (1) 198,175,185	1.50	0.50
6	Bean Tree Track 11	9.50	5300	76	14.34	3 (2) 210,198,165	1.50	0.50
6	Granadilla Creek 1	8.50	4800	46	9.58	3 (1) 187,202,176	1.50	0.50
6	Granadilla Creek 2	9.00	5100	39	7.65	3 (2) 218,202,187	1.00	0.50
7	North Luff Range	9.00	5400	100	18.52	1 190	2.00	2.00
7	South-east Luff Range (Xing 12 area)	8.25	4900	123	25.10	2 (1) 203,168	1.00	0.50
7	South-west Luff Range (Hull Gap)	8.75	4600	94	19.18	3 (2) 211,205,185	1.00	0.33
7	North Hull River –Webb Creek	7.50	4200	53	14.01	1 185	0.50	0.50

Search Zone	Search Location	Search Time (hrs)	Distance (metres)	Cassowary Sign	Sign per 1000m	Number of birds (Total\Ad) [footprints mm]	Search Area (km^2)	Sample Density[1] (km^2 \birds)
7	R214 – Wongaling Road	6.00	3300	40	12.12	3 203,190,183	1.00	0.33
7	Xings 13 & 14	7.75	3900	90	23.08	2 (1) 190,178,185	1.00	0.33
8	North Hull River South 1	7.00	4500	88	19.55	2 (1) 193,185	0.60	0.30
8	North Hull River South 2	10.00	7300	144	19.73	3 (2) 175,193,212	1.25	0.42
8	Limbo Creek (Licuala)	8.50	4800	30	6.25	2 (1) 181,200	1.75	0.88
8	Hull River Landing 1	6.50	3600	6	1.66	2 (1) 190,150	1.50	0.75
8	Hull River Landing 2	8.00	4330	27	6.24	2 (1) 190,150	0.75	0.38
9	Bovril –Sugarcane Creek 1	8.50	6500	43	6.62	3 (2) 200,181,X	1.50	0.50
9	South Mt Douglas 1	8.50	4500	70	15.56	1 200	1.25	1.25
9	South Mt Douglas 2	5.50	2500	16	6.40	1 X	1.00	1.00
9	South Mt Douglas 3	5.66	2750	40	14.55	1 207	1.00	1.00
9	Carmoo Creek 1	8.50	5200	73	14.04	4 (3) 218,214,201,168	1.75	0.44
9	Carmoo Creek 2	9.50	5400	59	10.93	4 (3) 218,214,201,168	2.00	0.50
9	Carmoo Creek 3	8.00	4700	67	14.26	3 (3) 214,218,188	1.50	0.50
10	Granadilla Range 1 (Windsors Gap)	9.50	5500	49	9.07	3 (2) 177,210,201	2.00	0.67
10	Granadilla Range 2 (McCabes Gap)	8.50	4750	27	5.68	2 177,210	1.75	0.87
10	Granadilla Range 3 (NW Granadilla)	8.25	4800	24	5.00	2 X	1.75	0.87

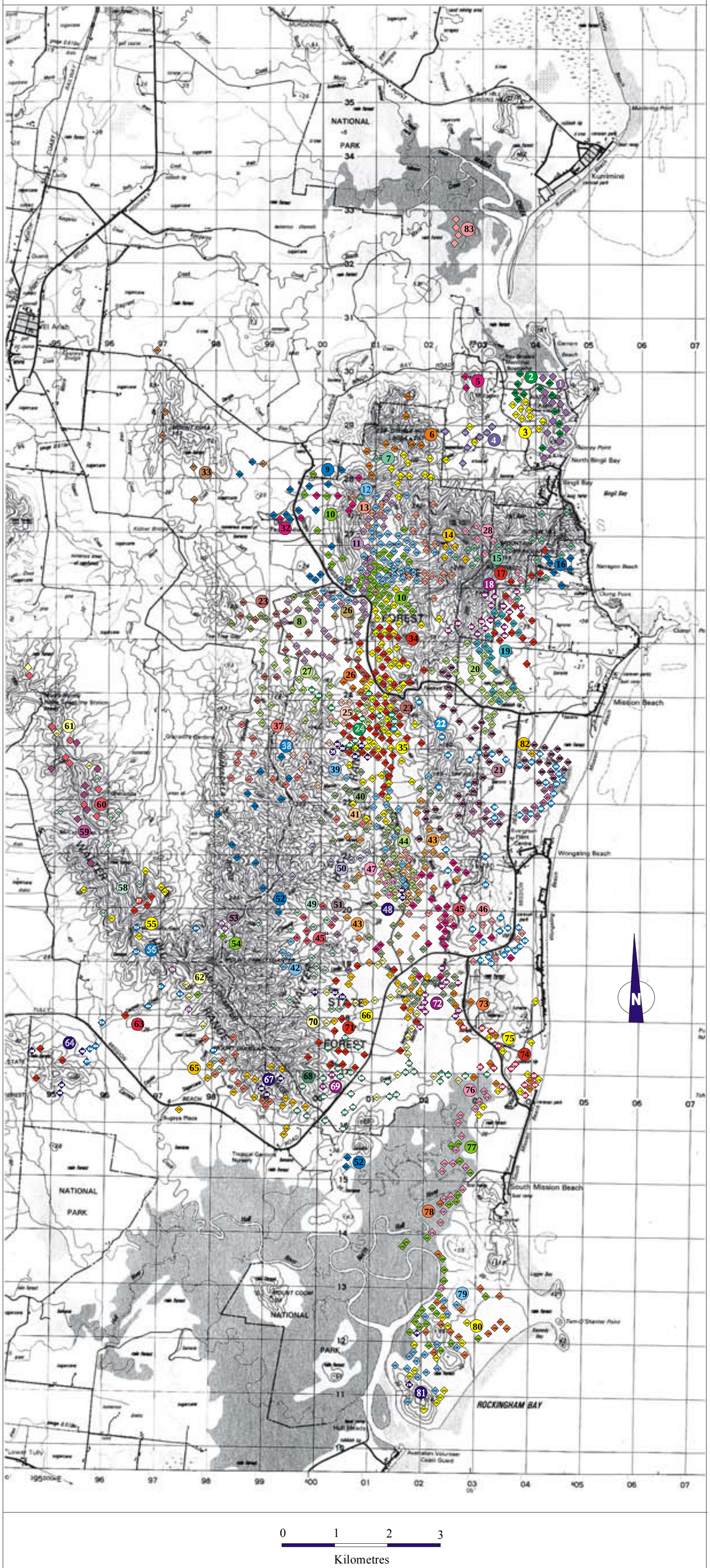
Search Zone	Search Location	Search Time (hrs)	Distance (metres)	Cassowary Sign	Sign per 1000m	Number of birds (Total\Ad) [footprints mm]	Search Area (km^2)	Sample Density[1] (km^2 \birds)
10	Granadilla Range 4 (Mount Myrtle)	10.00	6800	18	2.65	2 X	2.00	1.00
11	Kennedy Bay NP 1	8.50	5300	67	12.64	2 207,190	1.50	0.75
11	Kennedy Bay NP 2	8.75	6200	88	14.19	4 200,207,1998,190	1.00	0.25
11	Kennedy Bay NP 3	9.00	6500	108	15.85	4 220,200,198,190	1.50	0.38
11	Kennedy Bay NP 4	9.75	6500	94	14.46	3 198,190,200	1.50	0.50
	TOTAL	**582.54**	**345 780**	**4729**			**101.66**	**Mean = 0.70[2]**

[1] ***Sample density*** *is defined by search area (km^2). It can be seen that this calculation does not cater for birds that occur over several search areas and as such true cassowary densities (**population density**) will be considerably lower than the sample densities reflected in this table. This sampling error, common to previous studies at Mission Beach, is discussed* in Chapter 5.1.

[2] *Median = 0.50; SD = 0.49; Range 0 – 2.5.*

Figure 4.4

Location of cassowary footprints and sightings
June - December 2000



Source: Les Moore 2001

Table 4.4

Individual cassowary location data

Cassowary Identity Number	General location	Adult	Subadult	Male	Female	Unknown	Grid Square Locations	Footprint (mm)	Home[1] range (km^2)
1	Garners\west Cedar Ck	1	0	1	0	0	62, 71, 72, 73	192	1.23
2	Garners	0	1	0	0	0	50, 61, 62, 73	180	1.25
3	Garners\east Cedar Ck	1	0	0	1	0	61, 62, 70, 71, 73, 81	210	1.83
5	Midgeree	0	1	0	0	0	60	176	0.35
6*	Double Mountain	1	0	1	0	0	59, 69, 70	200	1.05
7	Double Mountain	0	1	0	0	0	69, 70, 80	165	0.41
8*	West Jurs Ck	1	0	1	0	0	102	190	1.60
9	west Lacy's Creek	1	0	0	1	0	67, 69, 79, 80, 90, 91	203	1.09
10*	Lacy's Creek	1	0	1	0	0	68, 79, 80, 81, 91, 92, 102, 103	193	2.29
11	Lacy's Creek	1	0	0	1	0	69, 80, 81, 91, 101, 102, 113, 114	215	2.44
12	Lacy's Creek	1	0	1	0	0	80, 81, 91, 92, 93, 101, 102	188	1.90
13	east Lacy's Creek	0	1	0	0	0	80, 81, 82, 92, 93, 104	178	1.47
14	Clump Mt Ridge	0	1	0	0	0	93	170	0.40
15*	Bicton Hill\Clump Mt	1	0	1	0	0	84, 93, 94, 95, 105	205	1.49
16	Mackness Creek	1	0	1	0	0	95	198	0.60
17	east Clump Mt ridge	1	0	0	1	0	94, 95, 105, 117	214	1.27
18	east Clump Mt ridge	1	0	0	1	0	104, 105	220	0.83
19	Wongaling Creek	0	1	0	0	0	105, 116, 117, 129	185	1.10
20	Wongaling Creek	1	0	1	0	0	116, 117, 129	197	1.51
21	Luff Hill ridge	1	0	0	1	0	116, 128, 129, 140, 141, 142, 150, 151, 152, 153	203	3.93
22*	Luff Hill ridge	1	0	1	0	0	127, 128, 140, 142, 152, 153, 162, 163, 173, 174	190	4.87

Cassowary Identity Number	General location	Adult	Subadult	Male	Female	Unknown	Grid Square Locations	Footprint (mm)	Home[1] range (km^2)
23	Tea Tree Gap	1	0	1	0	0	100, 101, 112, 113, 114, 115, 124, 127	200	2.28
24	west Jurs Creek	1	0	0	1	0	113, 114, 126, 127	220	1.89
25	Nth Walter Hill Range	0	1	0	0	0	125, 126, 137	175	1.09
26	west Jurs Creek	0	1	0	0	0	101, 102, 114	180	0.46
27*	west Bean Tree Track	1	0	1	0	0	112, 113, 114, 124, 125, 126, 127	202	2.24
28	Bicton Hill\Clump Mt	0	1	0	0	0	82, 83, 93, 94, 105	172	1.13
31	Sth Bean Tree Track	0	1	0	0	0	161	180	0.82
32	west Lacy's Creek	0	1	0	0	0	79, 80	170	0.71
33*	Mt Edna	1	0	1	0	0	43, 55, 66, 77	195	1.86
34	Nth Bean Tree Track	1	0	0	1	0	103, 114, 115, 126, 127, 138, 139	210	2.76
35*	Nth Bean Tree Track	1	0	1	0	0	103, 104, 114, 115, 126, 127, 138, 139, 149, 150	196	3.77
36[2]	Nth Bean Tree Track	1	0	0	0	1	126, 138	205	0.25
37	Nth Walter Hill Range	0	1	0	0	0	124, 125, 136, 137, 149	187	1.56
38	Walter Hill Range	1	0	0	1	0	136, 137, 147, 158, 159, 170	218	2.34
39	Jurs Gap	1	0	0	1	0	138, 139, 140, 149, 150, 161	215	1.36
40*	Licuala\Jurs Gap	1	0	1	0	0	138, 139, 140, 149, 150, 160, 161, 171, 172, 183, 184	193	5.08
41	Jurs Gap	0	1	0	0	0	149	150	0.25
42	Mt Tam O'Shanter	0	0	0	0	1	170, 181	191	0.50
43	Licuala\Jurs Gap	1	0	0	1	0	149, 150, 151, 160, 161, 162, 171, 172	212	3.85
44	Licuala	0	0	0	0	1	150, 161	190	1.27
45	Licuala	0	1	0	0	0	161, 162, 172, 173, 174	186	3.01
46	Licuala	0	1	0	0	0	150, 161, 172, 173, 174	174	1.83
47	Licuala	1	0	0	1	0	161	220	0.34[1]
48	Licuala	1	0	0	0	1	161	205	0.35[1]
49*	west Licuala	1	0	1	0	0	161, 169, 170, 171, 181, 182	198	1.91
50	Jurs Gap	0	0	0	0	1	148, 149, 159, 160	189	0.81

Cassowary Identity Number	General location	Adult	Subadult	Male	Female	Unknown	Grid Square Locations	Footprint (mm)	Home[1] range (km^2)
51	north Limbo Creek	0	1	0	0	0	171, 182	165	0.68
52[3]	Lindsay Road	0	1*	0	0	0	214	182	-
53	Mt Tam O'Shanter	0	1	0	0	0	169, 179	174	0.65
54	Mt Tam O'Shanter	0	1	0	0	0	169, 179	182	0.51
55*	Nth Wildsoets Gap	1	0	1	0	0	155, 156, 157, 167	201	1.80
56	Carmoo Creek	1	0	0	1	0	167, 168, 178, 179, 188, 191	214	2.04
57	Wildsoets Gap	0	1	0	0	0	156, 167	177	0.34
58	McCabes Gap	1	0	0	1	0	133, 144, 145, 156, 166	210	1.98
59*	Nth McCabes Gap	1	0	1	0	0	121, 132, 133, 144, 155	-	1.30
60	Nth McCabes Gap	1	0	1	0	0	120, 121, 132, 133, 144	-	1.22
61	Sth Mt Myrtle	0	1	0	0	0	121, 133	183	0.41
62	Sugarcane Creek	1	0	0	1	0	179, 190, 191, 202, 203	207	1.64
63	Sth Carmoo Creek	1	0	0	1	0	187, 188, 189, 198	218	1.24
64	Sth Carmoo Creek	0	0	0	0	1	187, 188, 198	188	1.01
65*	Sugarcane Creek	1	0	1	0	0	190, 192, 201, 202, 203, 213	194	1.82
66	Stony Creek	0	1	0	0	0	182, 183, 184, 193	175	1.75
67	Sugarcane Creek	0	1	0	0	0	202, 203	166	0.32
68*	Bovril Creek	1	0	1	0	0	193, 194, 203, 204, 205, 206, 207, 214	200	3.13
69	Bovril Creek	0	1	0	0	0	204	178	0.20
70	Limbo Ck-Nth Hull Rv	0	1	0	0	0	172, 182, 183, 193, 194, 205, 206	181	2.08
71	Stony Ck-Nth Hull Rv	1	0	0	1	0	182, 183, 192, 193, 194	220	3.64
72	North Hull River	1	0	1	0	0	183, 184, 194	205	1.15
73	South Mission Beach	1	0	0	1	0	184, 195, 196, 197, 206, 207	215	1.73
74*	South Mission Beach	1	0	1	0	0	195, 196, 197, 206, 207	195	1.31
75	South Mission Beach	0	1	0	0	0	186, 196, 197, 207	170	1.30
76	Hull River Landing	0	1	0	0	0	206, 207, 216, 226, 236	150	1.22
77	Kennedy Bay	1	0	1	0	0	216, 226, 236, 245, 246, 247, 258	190	2.28
78	Kennedy Bay	1	0	0	1	0	226, 236, 246, 247, 257	209	2.53
79*	Kennedy Bay	1	0	1	0	0	246, 256, 2578, 263	198	2.13

Cassowary Identity Number	General location	Adult	Subadult	Male	Female	Unknown	Grid Square Locations	Footprint (mm)	Home[1] range (km^2)
80	Kennedy Bay	1	0	1	0	0	246, 256, 256, 264	200	1.65
81	Kennedy Bay	0	1	0	0	0	245, 246, 256, 257	176	0.44
82[2]	Porters Creek R214	0	1	0	0	0	141	183	0.25
83[2]	North Maria	0	0	0	0	1	29	-	0.45
	Total	**46**	**28**	**25**	**19**	**7**			**120.204**

* Breeding males.

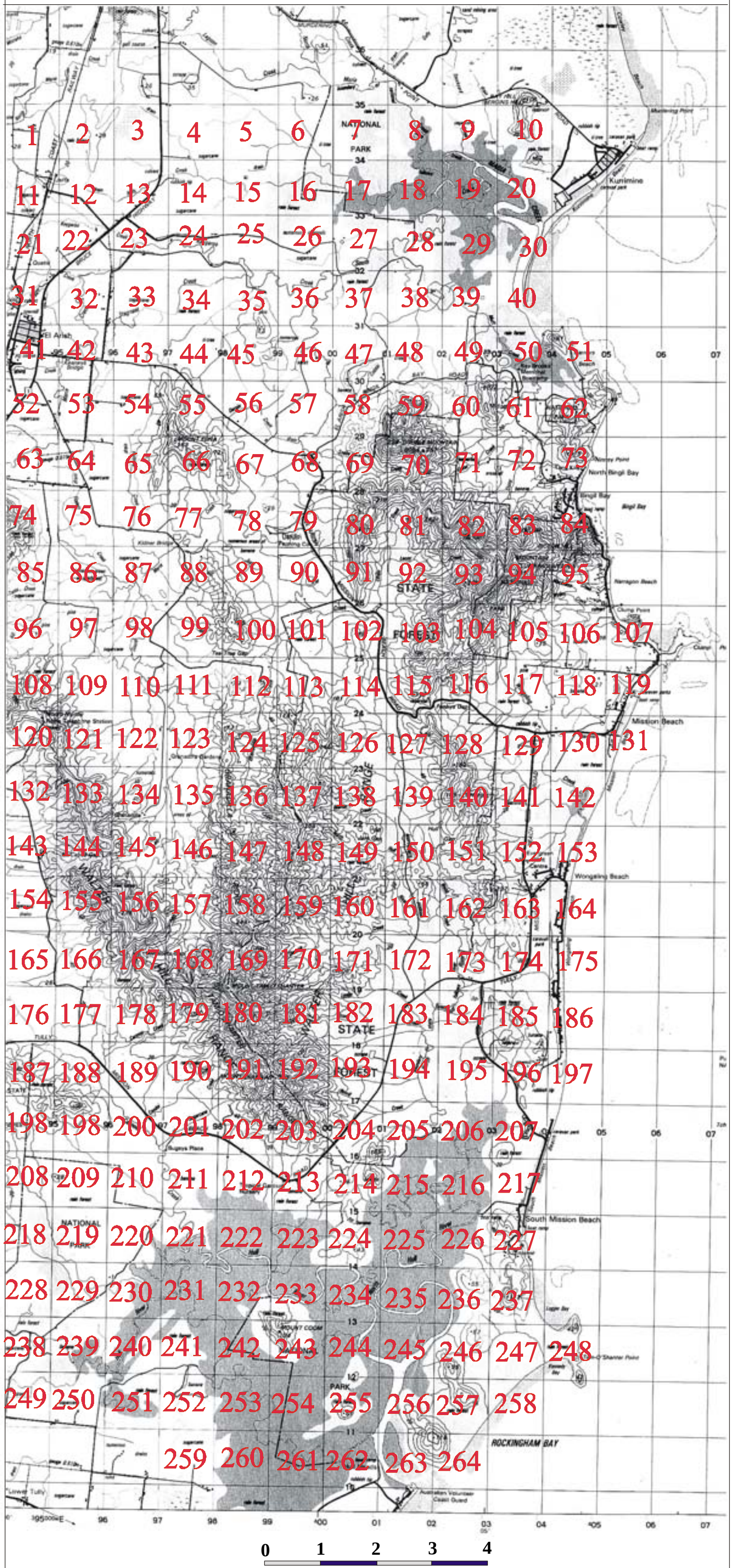
[1] Home ranges estimated using a minimum convex polygon calculation based primarily on sightings and measured footprint locations for an identified bird and produced by joining the outermost points of the scatter of mapped observations (*ie Indicative Home Range*).

[2] Not used in home range analysis due to inadequate location data.

[3] 18 month old subadult considered likely to be Cassowary #70.

Figure 4.5

Mission Beach Grid Square Key
1: 50 000



Source: Les Moore 2001

4.1.2 Population density

The population density of adult cassowaries for the Mission Beach area was 0.48 adults/1km^2 *ie* 1 adult per 2.09km^2 (49 adults/101.66km^2), almost half the density of adult birds calculated for the Lacy's Creek catchment (Crome and Bentrupperbaumer 1992), and one-sixth the density estimated by Bentrupperbaumer (1998) for Kennedy Bay area and coastal areas of Mission Beach. Overall population density of independent birds *ie* adults and subadults and excluding chicks, was 1 bird per 1.29 km^2 (79 birds/101.66km^2). The density of subadults in the Mission Beach area was 1 subadult per 3.63km^2 (28 subadults/101.66km^2). A density estimate of *C. casuarius* subadults either in the Wet Tropics or New Guinea has not been possible previous to this study. A breakdown of cassowary densities according to age and status is given in Table 4.5.

Table 4.5

Mission Beach cassowary densities

Age and status	Population densities (km^2/ bird)	Area densities (bird/km^2)
Adults and subadults	1.29	0.78
Adults	2.09	0.48
Adult males	3.63	0.28
Adult females	5.35	0.19
Subadults	3.63	0.28

4.1.3 Sex Ratios

The known adult male to adult female sex ratio was 1.32 (25 males/19 females). With the inclusion of an extra three likely adult male cassowaries, the adult male cassowaries outnumbered adult females by 28 to 19, a male to female ratio of 1.47.

4.2 Distribution of cassowaries at Mission Beach

The distribution of the cassowaries at Mission Beach was tested against a poisson distibution to determine whether the population is more clumped (aggregated) than random. A frequency table was constructed of the number of cassowaries occurring within each $1km^2$ grid square with the null hypothesis that cassowary occurrence is random throughout the Mission Beach survey area. The resulting poisson variance/mean ratio was 3.34550/2.81538 = 1.18829, indicating that the cassowary population is clumped rather than randomly dispersed throughout the study area. The X^2 significance level of P= 0.012 shows that the poisson distribution indicating a clumped cassowary population within the MB study area is significant.

4.3 Cassowary sign vs number of birds using an area

Using data presented in Table 4.3 (Search Area Results) a regression found no relationship between the amount of cassowary sign per 1000m surveyed and the number of birds using an area (P = 0.111, t = 1.61, R-Sq(adj) = 2.2%, 95.0% CI = 2.187 - 5.307). This finding confirms that the number of cassowaries in an area cannot be inferred by a simple count of cassowary sign *ie* cassowary density is not related to sign count. This correlation was never implied in past work as has been erroneously stated by other researchers (Westcott 1999).

There are a number of possible explanations as to why no correlation exists between the amount of cassowary sign and the number of birds in an area. These include:

- A single bird or family party often produces a large amount of sign when using a small area constantly;
- Birds may be using an area intermittently as part of their use of larger areas;
- Seasonal resource availability can result in high mobility (*ie* less time in any one area) and lower dropping numbers due to lack of fruit.

However, in the absence of an alternative survey methodology *eg* genetic identification from droppings, the location and measurement of footprints and subsequent sightings of target birds is considered to be an efficient method of identifying individual birds, and thus estimating cassowary numbers within a search area (Figure 3.3). Moreover, contrary to the conclusions of a previous study, (Westcott 1999), it was found that significantly more cassowary droppings and footprints were located within the forest than on tracks and trails. Given the difficult nature of surveying rainforest and the ease of locating droppings on bare tracks, it is considered that the probability of sign detection within forest is a direct reflection of the field expertise of the observer rather than more droppings being deposited along tracks (Moore *in prep*.).

4.4 Indicative home ranges (IHR)

Indicative Home Ranges (IHRs) of cassowaries are primarily based on sightings and measured footprint locations for each identified bird, and are produced by joining the peripheral locations of these observations to each other by connecting the outermost points of the scatter of mapped locations (minimum convex polygon). The area of the resulting polygon was then calculated using a forestry area scale calibrated to the Mission Beach 1:50,0000 topographic map. The resultant map of observations represents each bird's current home range and is an approximation of its foraging activities over a number of preceding weeks or months. Home range size estimated in this way is likely to be an underestimate of the total area used by each bird due to seasonal variation in habitat usage and the fact that many areas, which contain numerous droppings, do not yield footprints with which to identify the individual depositing them.

Figure 4.6 presents a comparison of the frequency distributions of IHR size for adults and subadults, with estimates of indicative home range size summarised in Table 4.6. The individual IHRs determined for adult female, adult male and subadult cassowaries are shown in Figures 4.7a-c.

Those cassowaries with only a few field observations (<5) were excluded from the calculation of home range sizes to avoid biasing the analysis. The mean indicative home range for adult cassowaries (males + females, n=43) was 2.09 (± 1.02), the mean indicative home range (IHR) of adult females (n=18) was 2.13 km^2 (SD=0.93); and mean IHRs of known adult males (n=25) was slightly smaller at 2.06 km^2 (SD=1.099). Although subadults ranged over many grid squares, their mean home range (n=25) of 0.95 km^2 (SD=0.71) was substantially smaller than that of combined adult cassowaries (P=0.0001, t = 4.94, df = 66).

There was no significant difference between combined male home ranges (non breeding + breeding) and female home range size (two-tailed test: P = 0.82, t = 0.23, df = 41), nor of breeding males versus adult females (two-tailed test: P = 0.56, t = 0.59, df = 32). Although not quite statistically significant, there appears to be a relationship between adult male breeding status and increased home range size (two-tailed test: P = 0.073, t = 1.88, df = 23). It can be seen, however, that the mean Indicative Home Range for breeding males was 2.3531/1.5356 = 1.53, or 53% larger than non-breeding adult males. The possibility of an increased area requirement for breeding males has important implications for conservation management and will need to be looked at further.

Table 4.6

Indicative Home Ranges for Mission Beach cassowaries

Status	Mean (Standard Deviation)	Min (km^2)	Max (km^2)
Total cassowaries (n=68) (adults and subadults)	1.6704 (± 1.0666)	0.20	5.08
Total adults (n=43)	2.0898 (± 1.0202)	0.60	5.08
Adult male (n=25) (combined non-breeding & breeding)	2.0588 (± 1.0994)	0.60	5.08
Adult female (n=18)	2.1328 (± 0.9283)	0.83	3.93
Adult male breeding (n=16)	2.3531 (± 1.2298)	1.05	5.08
Adult male (n=9) (non-breeding)	1.5356 (± 0.5559)	0.60	2.28
Subadult (n=25)	0.9492 (± 0.7056)	0.20	3.01

Figure 4.6

Mission Beach Cassowaries
Indicative home range comparisons

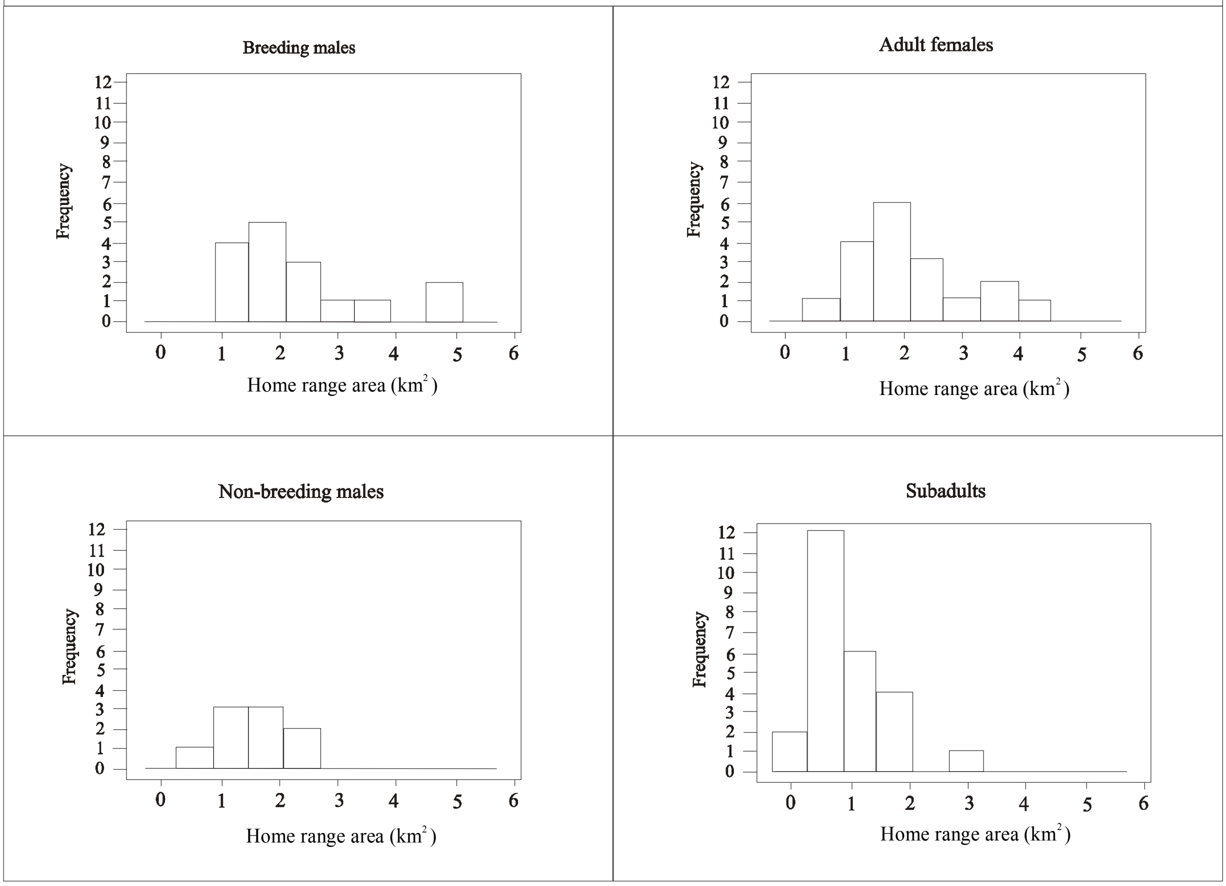
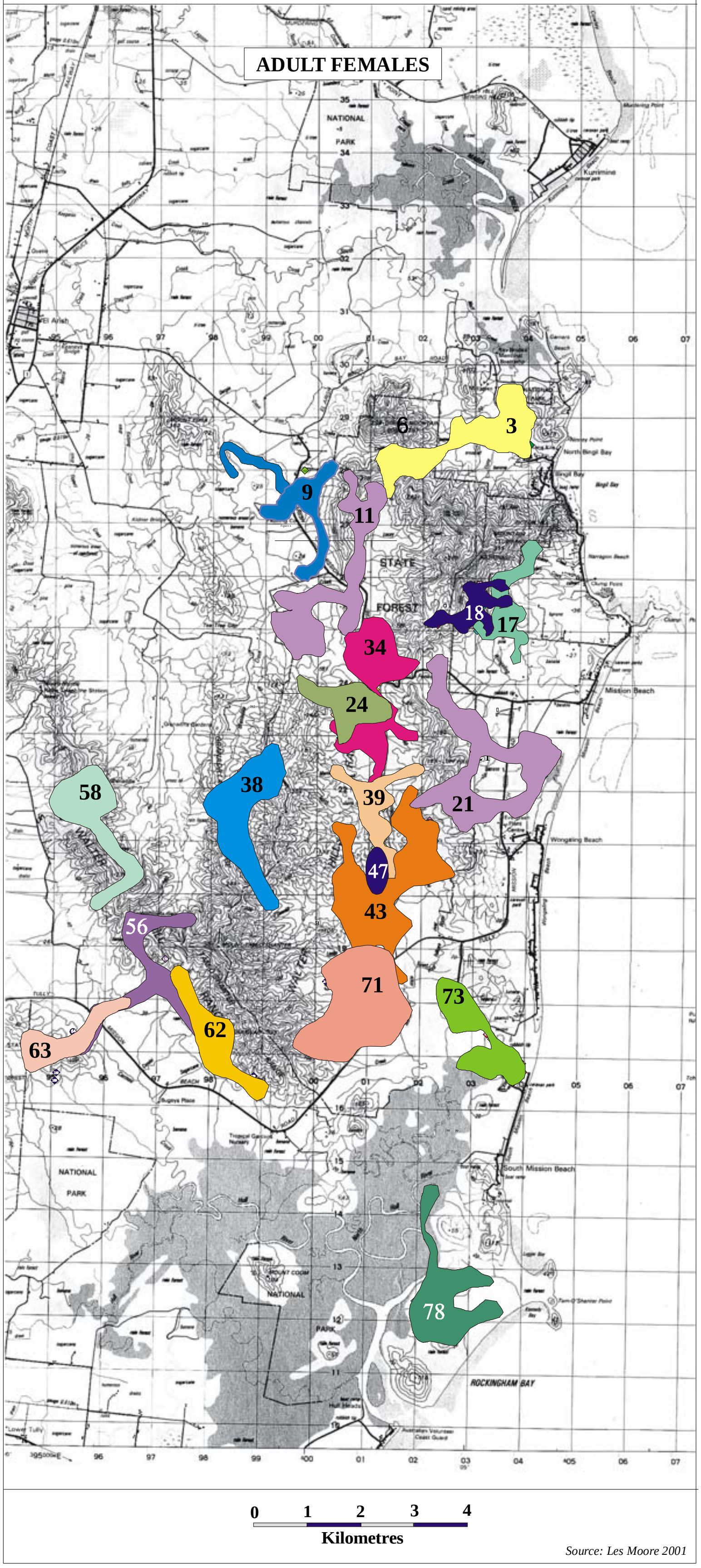


Figure 4.7a

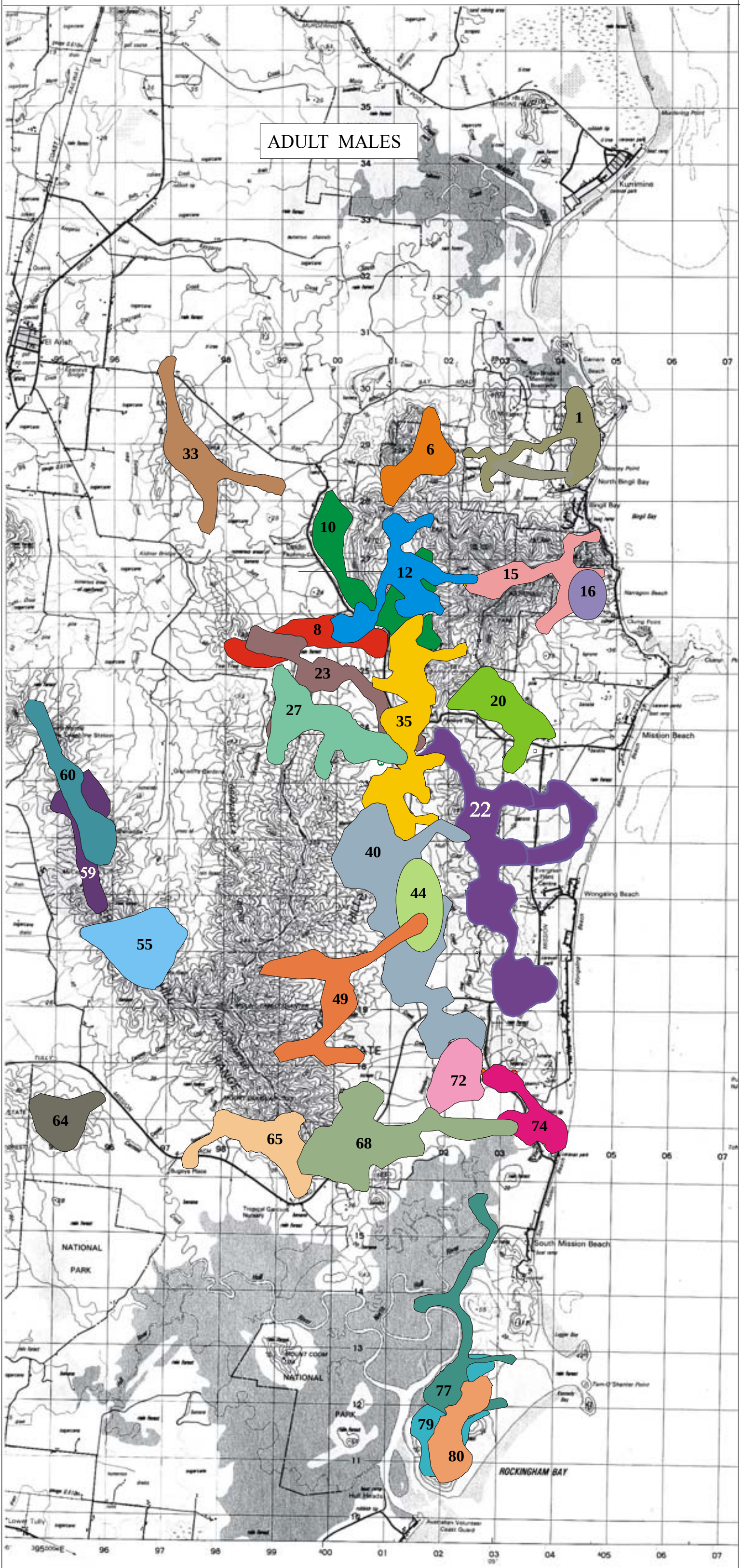
Mission Beach Cassowaries - Indicative Home Ranges
June - December 2000



Source: Les Moore 2001

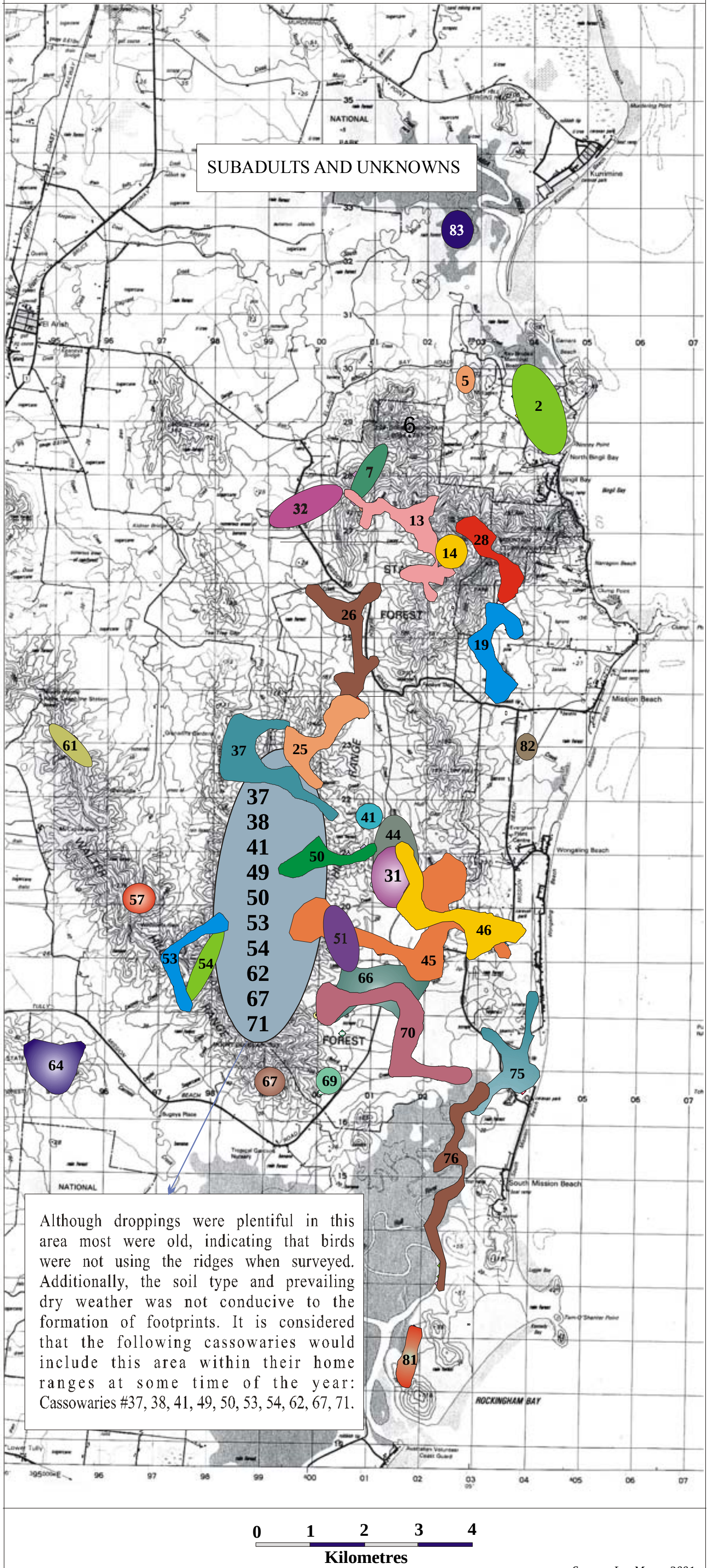
Figure 4.7b

Note: Cassowaries #44 and #64 are included as likely adult males



Source: Les Moore 2001

Figure 4.7c



Source: Les Moore 2001

4.5 Breeding observations

A total of 16 males *ie* 61 % of known males (n=25), were recorded escorting 31 chicks. Locations and Indicative Home Ranges for breeding males are presented separately in Figure 4.8. Chick ages ranged from a few weeks to >8 months old, with the majority of new chicks appearing in September 2000. Although anecdotal observations indicate that broods of 4 -5 chicks have been sighted in the Mission Beach area in the past, all family parties observed in this study contained between 1 and 3 chicks (Table 4.7), with two chicks being the most common (mean = 1.94). Detailed breeding observations are presented in Table 4.8. Of total chicks observed, 33.5% were brown (11/31) and 66.5% striped (20/31).

Regular sightings of males foraging prior to being seen with newly hatched young indicate that not all incubating males sit without eating throughout the incubation period (Bentrupperbaumer 1998). One male, Cassowary #35 from north Bean Tree Track, was sighted alone most days from 22 July – 12 October 2000. On 13 October his footprints were overlaid with what appeared to be faint smaller prints and a search located him on the 14 October with three very small striped chicks.

Male Cassowary #40 from the Licuala area of the Bean Tree Track had a similar history, with frequent sightings along the track and adjacent forest from 24 July – 28 September, and a subsequent sighting of the male escorting two new striped chicks on 3 October 2000.

Table 4.7

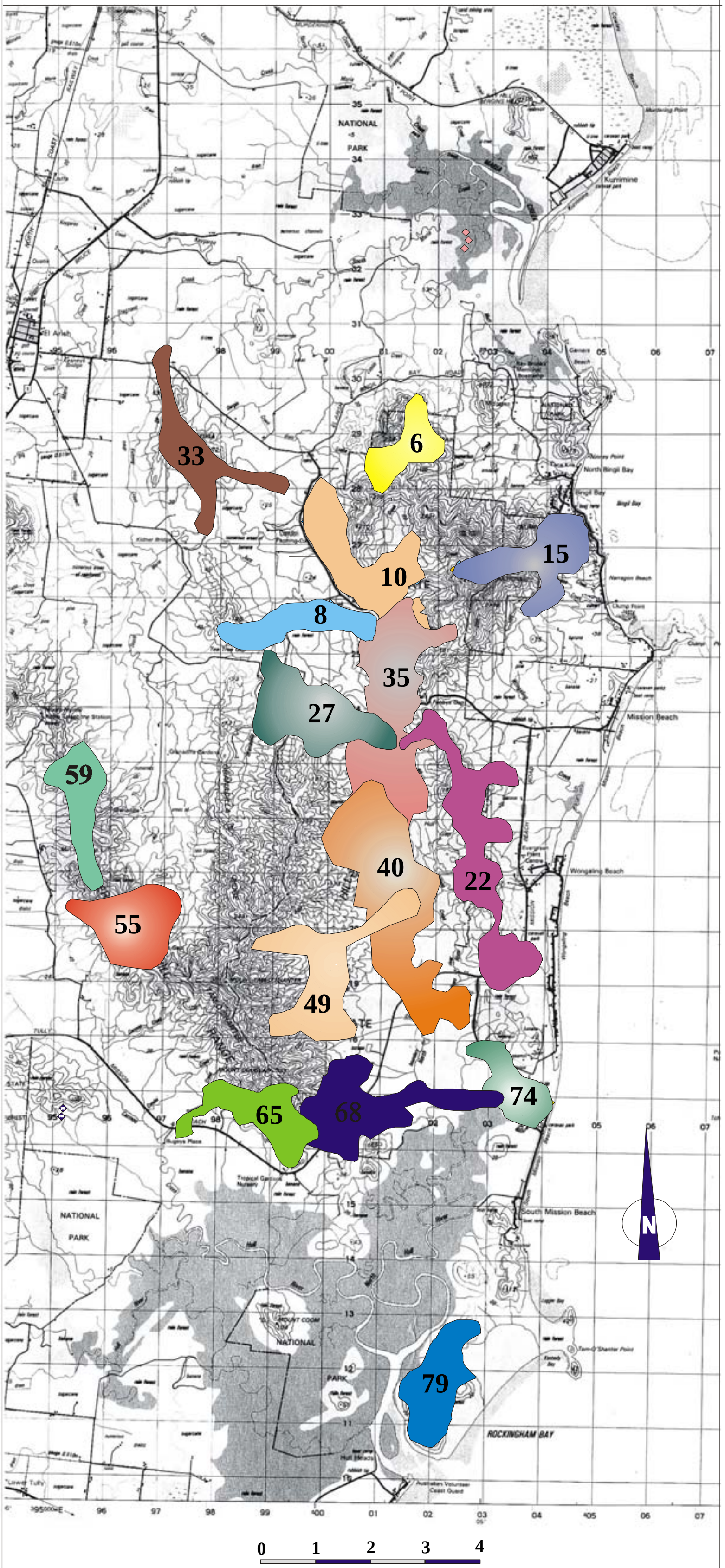
Season 2000 - chicks\ adult male ratios

1 Chick	2 Chicks	3 Chicks	4 or more Chicks	Total chicks	Mean chicks/breeding males (n=16)	Mean chicks/total males (n=25)
5	7	4	0	**31**	**1.94**	**1.19**

Figure 4.8

Indicative Home Ranges of breeding males
June - December 2000

**Numbers within polygons represent cassowary identity number (refer to Table 5)*



Source: Les Moore 2001

Table 4.8

Breeding data June – December 2000

Adult male Identity No.	Number of chicks	Description of chicks
10	3	Striped
35	3	Striped
40	3	Striped
79	3	Striped
6	2	Striped
8	2	Brown
15	2	Striped
22	2	Striped
27	2	Brown
55	2	Striped
59	2	Brown
33	1	Brown
49	1	Brown
65	1	Striped
68	1	Brown
74	1	Brown
Total (n = 16)	**31**	

4.6 Subadult population

There was evidence of a widespread distribution of subadults throughout existing adult cassowary home ranges. Twenty-eight subadults were located during the survey and a breakdown of identified age cohorts is presented in Table 4.9. Ages of non-adult birds were determined using observations made in previous studies and by reference to physical descriptions given by Bentrupperbaumer (1998). The observed cross-section of subadult cohorts (age bands) in the Mission Beach area appears inclusive, with located birds ranging from 0.9 - 3.5 years old.

Table 4.9

Mission Beach subadult age classes June- December 2000

6-9 mo	12-18 mo	24-30 mo	36+ mo	Uncertain age	Total
2 (recently independent)	12	7	4	3	**28**

4.7 Cassowaries visiting people (visitation)

The study identified nine Mission Beach residences regularly visited by cassowaries. It is certain, however, that the total number of properties frequented by cassowaries is much higher. Although it initially appeared that up to 16 adult cassowaries were visiting the nine residences, field observations and photographs indicated that only twelve birds were involved (six adults, three subadults, and three chicks) (Table 4.10).

Table 4.10

Visiting cassowaries June – December 2000

Study Identity No.	Status	Chicks
1	Adult male	0
2	Subadult	-
3	Adult female	-
21	Adult female	-
22	Adult male	2
73	Subadult	-
74	Adult male	1
75	Adult female	-
82	Subadult	-
Total	**9**	**3**

Adult cassowaries visiting Garners Beach, Bingil Bay, Wongaling Creek Conservation Reserve R214 and South Mission Beach (*ie* coastal area *sensu* Crome and Bentrupperbaumer *loc. cit*.), were found to have the majority of their home ranges further west (hinterland area *sensu* Crome and Bentrupperbaumer *loc. cit*). For example, the adult male and female using Cedar Creek and Garners Beach National Park (Cassowaries #1 and #3) were found to move between the National Park and the north end of Lacy's Creek catchment. Similarly, the adult male and female visiting houses in Mission Circle and Mission Estate spent the majority of their time along the Luff Hill Range.

It was not possible to define the movement corridors used by cassowaries to access Garners Beach National Park and Bingil Bay as the majority of the land was privately owned and permission to traverse was hard to obtain. The area is substantially cleared for urban and agricultural development and much of the land is being cultivated for bananas. There is, however, a known crossing point just south of Plantation Road and it is likely that cassowaries may also cross at or near Cedar Creek Bridge, possibly using the stream to do so. These crossing points into the Garners Beach and Bingil Bay areas are considered tenuous, with a low probability that they will continue to function as movement corridors.

4.8 Areas under immediate threat

The following four areas are considered to be under immediate threat due to fragmentation, habitat clearing, dog attack, and risk of collision with cars.

Garners Beach\Bingil Bay

The area of Garners Beach and Bingil Bay is classified as Critical Habitat Zone (Goosem 1992) with connecting Important Linkage Zones, but only two adults and one subadult cassowary were recorded making use of the area during the survey (Cassowaries #1, #2, #3). Another adult male (possibly Cassowary #15) is known to infrequently visit the area but was not present during the survey.

The area surrounding the Garners Beach National Park is substantially cleared and much is under bananas. The remaining habitat is extremely fragmented, with the National Park and adjacent rainforest completely bounded to the south, west and north by residential development and agricultural clearing, while the east is bounded by ocean. What remains of the past cassowary movement corridors into the National Park are extremely tenuous and have a limited future as functional cassowary movement corridors. Unfortunately, the area of the National Park is not large enough (<2 km^2) to support its own resident population (mean adult home range = $2.09 km^2$) without the capacity for dispersal back into the main forest block. Additionally, the quality of cassowary habitat in this area is poor, the vegetation predominantly comprising highly disturbed rainforest and regrowth. If connectivity is permanently lost, therefore, the area will unquestionably lose its cassowary population.

Wongaling Road

A similar prognosis applies to those vegetation corridors assisting birds to cross east over the Tully-Mission Beach Road north of Wongaling, into Conservation Reserve R214. The vegetation corridors in this area have degraded markedly due to the impacts of edge effects and attrition. Road traffic and vehicle speed have increased noticeably over recent years and a road death of the adult male or female is imminent. With the loss of either of these birds the likelihood of R214 retaining its cassowary population are negligible, as replacement birds will first have to surmount the disincentives posed by diminishing movement corridors and increased road traffic.

The adult birds crossing into Conservation Reserve 214 have the bulk of their home ranges along Luff Hill Range, and as such their use of the reserve is likely to be seasonal. Given the highly disturbed nature of the vegetation along the Luff Hill Range, however, the more diverse foraging areas along Wongaling and Porters Creek may be of critical importance to these cassowaries. Further work, therefore, is required to evaluate the significance of R214 to the long-term viability of the resident cassowaries.

South Mission Beach Road

The movement of birds across Tully-Mission Beach Road and into the South Mission Beach Road forest (Crossing Points #13 & #14 – Moore 1998) has been severely compromised by recent clearing for residential development in the area (Plate 15).

Given the extent of the clearing and its future development for housing and roads, it is uncertain how long cassowaries will continue to make use of the remaining forest surrounding the development. There is an extreme risk of collision with cars for cassowaries crossing the road east of the junction of South Mission Beach and Tully-Mission Beach Roads (Crossing Point #14) and a near miss involving an adult male and chick was observed during this survey.

Hull River National Park (Kennedy Bay Section)

Five cassowaries were identified in the Hull River National Park (Kennedy Bay Section) during this survey (Cassowaries #77 - #81). These comprised an adult female, three adult males (one with three chicks), and a subadult cassowary. It is possible that another bird, may have also been present but there were inadequate data to prove its existence. A sixth bird, a young subadult (Cassowary #76) located foraging around Hull River landing, is also likely to use the area.

Freehold land encroaches at the northern end of Kennedy Bay near Tam O'Shanter Point and this land has been comprehensively cleared. The National Park is all but isolated, with only a narrow riparian strip of mangroves leading to the Hull River boat ramp and a narrow fringe of trees along the coast at Tam O'Shanter Point. Both these vegetation corridors are likely to be lost to attrition through exposure or further deliberate clearing.

CHAPTER 5

CASSOWARY DENSITIES AND HOME RANGE ESTIMATES

5.1 The effect of survey area size on density estimates

Most of the present-day techniques of population estimation have precision such that only large differences within or between populations, or a large influence or factor, can be detected. For example, if an estimate has a precision of only 30% then we cannot detect differences between times or between areas unless the difference is >30% (Davis and Winstead 1980). Unfortunately, there are few reliable ways to determine the level of precision when sampling to establish the number of animals per unit area. The results of this study provide an opportunity to check density estimates against a known population to determine the effect of sampling area on cassowary population estimates. The following section presents a preliminary analysis to assess the effectiveness of using search areas in multiples of $1km^2$ to estimate cassowary density.

5.2 Mission Beach cassowary density estimates

The inaccuracy inherent in using a small area to estimate cassowary density is highlighted in Table 5.1 and Figure 5.1. To calculate cassowary density to area ratios, the Mission Beach search area map (1: 50,000) was overlaid with a $1km^2$ study grid; field data from the survey was subsequently mapped and all records given an AMG and study grid location. The totals of individual birds known to occur within each grid square were then tallied and the birds per grid square tabled. The analysis shows that none of the surveyed 130 grid squares reflected the true cassowary density of 1 bird/$1.29km^2$. The most common frequency found (only 26% of the area) was one bird/$1km^2$ (single grid square n=34), which is the only frequency to approximate but still under-estimate the known overall cassowary density. This analysis indicates that at a survey scale of $1km^2$ there is little chance of reflecting true cassowary densities and a 74% probability of over-estimating the population density.

Descending down the frequency table only increases the estimated bird per km^2 density to an unrealistic figure of 1 bird per $0.09km^2$ (9 hectares), where 11 birds were known to make use of one grid square. Additionally, the mean of all $1km^2$ grid square totals contributes little to the accuracy of the estimate, with a mean of 1 bird per $0.28km^2$ (28 hectares) *ie* 450% greater than the known density.

Table 5.1

Cassowaries per 1 km^2 grid square

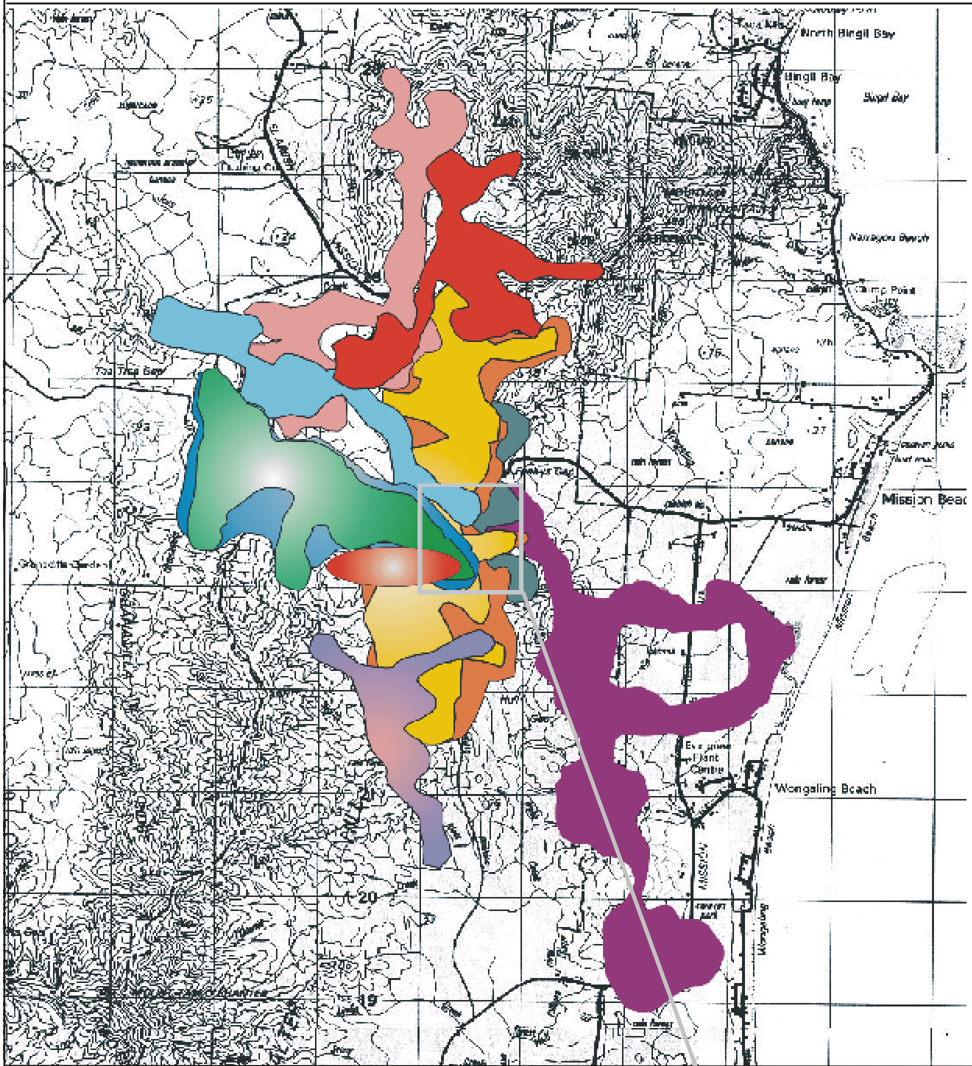
No. birds using $1km^2$ grid square	Frequencies *ie* no. of squares (% of grid)	Density estimate (ha/birds)
1	34 (26.1%)	100
3	31(23.8%)	33
2	25 (19.2%)	50
4	17 (13.2%)	25
5	11 (8.5%)	20
7	5 (3.8%)	14
0	3 (2.3%)	0
6	2 (1.5%)	17
8	1 (0.8%)	13
11	1 (0.8%)	9
	N = 130	**Mean = 28 ha**

Cassowaries with a home range in excess of $2km^2$ and a high mobility will, therefore, require a considerable survey plot size. Given the above survey frequencies, it is considered that small sample plots *eg* ±$1km^2$, will significantly over-estimate cassowary densities. Depending on the resolution required and the environmental parameters of the target area, it is estimated that a sample plot between 5-$15km^2$ may be necessary to reflect true cassowary density.

Figure 5.1

Effect of survey area on cassowary density estimates

*Coloured polygons represent individual cassowary Indicative Home Ranges.



The inherent inaccuracy in using a small area to estimate cassowary density is highlighted in Inset A. In this example eight cassowaries were located in the 1km^2 sample plot and the density was, therefore, 1 bird/0.125km^2. When the unit area is increased to approximately 15km^2, however, it can be seen that eleven birds are contained within the sample plot and the density estimate is now 1 bird/1.36km^2, more accurately reflecting the known population density of 1 bird/1.29km^2.

Inset A

Source: Les Moore 2001

5.3 Sample densities, population density, home ranges, and minimum habitat size

The distinction between the measurements of *density estimate* and *population density* is often blurred and the terms transposed when discussing cassowary populations. This is a significant error that has considerable implications in estimating the true size of cassowary populations.

5.3.1 Cassowary density estimates *vs* population density

Density estimate or ***sample density*** is the number of animals per sampled unit area (density per unit area); ***population density*** is that density per sampled unit area that reflects the true density of the sampled population. A sample density estimate is an important ecological parameter because it directly relates the population to habitat conditions at a given time (Davis and Winstead 1980). As such it is a simple but powerful measure of how animals use habitat over a stated period of time. It does not, however, indicate population density or carrying capacity, nor that the population size is proportional to the number of birds per sampled unit area.

Considerable problems exist when attempting to obtain accurate density estimates from which to calculate true cassowary population size. The species maintains large home ranges, >2km^2 at Mission Beach and the Daintree lowlands; individuals are difficult to detect as they deliberately avoid contact with humans; and cassowaries are solitary, highly mobile animals whose preferred habitat is the thick cover of disturbed rainforest. The majority of past cassowary studies at Mission Beach have calculated estimates of cassowary density (expressed as birds per square kilometre) on the number of birds found within relatively small search areas, generally < 2.0 km^2. This practice of surveying small areas has led to constant over-estimates of cassowary population density.

Kennedy Bay cassowary population

The population density estimate of the Kennedy Bay cassowary population calculated by Bentrupperbaumer (1998) is not strictly a density estimate, being instead a "usage index" based on total individuals using the area over a number of years. Using data from Crome and Bentrupperbaumer (1992), a presence and absence table for those adult cassowaries identified at Kennedy Bay over the two years 1990-1991 was analysed in an attempt to determine new cassowary population densities for the Kennedy Bay area.

For this exercise it was assumed that the population density within any month at Kennedy Bay (Crome and Bentrupperbaumer 1992) remained static *ie* there was no significant change in the population due to immigration or emigration. Allowing this, the number of individual cassowaries known to use the study site in each month of the two years was calculated to develop a monthly mean density of adult cassowaries (Table 5.2). As a result, the calculated mean number of adult cassowaries using the Kennedy Bay study area per month during 1990 was 5.4 adult birds; in 1991 it had dropped to 4.1 adult birds.

The cassowary density over the two years at Kennedy Bay, therefore, was 1 adult/0.74km^2 and 1 adult/0.98km^2 respectively (*ie* 1990 - 400ha/5.4 birds; 1991 - 400ha/4.09 birds). The mean monthly density over the two years was 1 adult/0.84km^2 (400 ha/4.76 adult birds). It is important to note that some of these birds obviously had part or the majority of their home ranges outside the boundaries of Bentrupperbaumer's study area.

The mean monthly and annual adult population in the Kennedy Bay area over the two years accords with the results of this Mission Beach cassowary survey *ie* approximately 4-5 adult birds with the bulk of their home range within the Kennedy Bay National Park. It is considered, therefore, that this is the true number of adults resident in this area (*ie* 4-5 adults) and not the 11 adults previously stated by Bentrupperbaumer (1998).

The remaining adults had unknown location rates of 52.2% – 95.8%. It must be assumed, therefore, that these birds only visited the Kennedy Bay area and had the majority of their home ranges outside the National Park.

Table 5.2

Number of monthly sightings at Kennedy Bay study site
(from Crome and Bentrupperbaumer 1992)

IDENTITY (Crome and Bentrupperbaumer)	Year	J	F	M	A	M	J	J	A	S	O	N	D	% months known to be present (occupancy)
Eugenia	1990	1	1	6	1	3	0	7	4	5	2	1	1	**100**
	1991	5	1	3	5	1	1	0	2	0	-	0	2	**72.7**
Dillenia	1990	1	9	11	3	21	9	6	10	6	2	4	4	**100**
	1991	11	6	0	0	7	0	6	2	3	-	0	0	**54.6**
Ficus	1990	0	2	3	3	0	0	9	5	5	3	3	0	**66.7**
	1991	3	2	0	1	1	1	0	0	0	-	0	0	**45.5**
Jasminum	1990	0	0	0	0	11	9	4	1	0	2	2	3	**58.3**
	1991	1	1	1	0	1	0	4	2	2	-	5	3	**81.8**
Bowenia	1990	1	5	0	2	0	1	0	1	0	0	0	1	**50**
	1991	1	0	0	0	2	1	2	0	0	-	1	0	**45.5**
Acmena	1990	2	5	0	1	0	0	1	2	0	0	0	1	**50**
	1991	0	0	0	1	0	0	0	0	0	-	1	0	**18.2**
Gondoi	1990	0	2	2	0	0	0	0	1	2	0	0	0	**33.3**
	1991	1	0	0	1	0	0	0	0	1	-	0	0	**27.3**
Myristica	1990	0	0	0	0	0	1	0	0	0	0	0	0	**8.3**
	1991	0	0	0	0	0	0	0	0	0	-	0	0	**0**
Helicia	1990	0	0	0	0	2	0	1	0	0	1	0	0	**25**
	1991	0	8	0	0	0	1	0	1	0	-	0	0	**27.3**
Leea	1990	0	0	0	0	0	1	1	0	3	0	0	0	**25**
	1991	2	0	0	0	0	0	0	0	1	-	0	0	**18.2**
Kamala	1990	0	0	0	0	3	2	0	0	0	1	1	0	**25**
	1991	0	0	0	0	0	0	0	0	5	-	0	0	**9.1**
Intsia	1990	0	0	0	0	1	0	1	0	0	0	0	0	**16.7**
	1991	0	0	0	0	0	0	0	0	1	-	0	0	**9.1**
Total adult birds	**1990**	**4**	**6**	**4**	**5**	**5**	**6**	**7**	**7**	**5**	**6**	**5**	**5**	**0 = 5.42**
Total adult birds	**1991**	**7**	**5**	**2**	**4**	**5**	**4**	**4**	**4**	**5**	**-**	**3**	**2**	**0 = 4.09**
Mean birds/month	**90/91**	**5.5**	**5.5**	**3**	**4.5**	**5**	**5**	**5.5**	**5.5**	**5**	**-**	**4**	**3.5**	**0 = 4.76**

5.3.2 Indicative home ranges of Kennedy Bay cassowaries

This current survey located four adult cassowaries in the Kennedy Bay area and their calculated Indicative Home Ranges are presented below in Table 5.3. The IHRs of the four adults ranged from 1.65 – 2.53 km^2, with a mean of 2.15 km^2. These home ranges are considered to reflect a more accurate measure of home range size for this area and match those found elsewhere at Mission Beach.

Table 5.3

Indicative Home Ranges for Kennedy Bay Adult Cassowaries (Moore 2001)

Cassowary Identity No. (Moore 2001)	Sex	Indicative Home Range (km^2)
77	Male	2.28
78	Female	2.53
79	Male	2.13
80	Male	1.65
		mean = 2.15 (SD=0.37)

5.4 Minimum habitat size

Using the findings of her study at Kennedy Bay, Bentrupperbaumer (1998) proposed the concept of minimum habitat size when considering that area required to maintain a viable population of cassowaries. Minimum habitat size *(sensu* Bentrupperbaumer 1998) represents:

- that area of habitat required to support a least 11 breeding adult cassowaries (the estimated Kennedy Bay population size);
- an area capable of producing three surviving subadults per year; and which
- results in a stable breeding population capable of long-term persistence.

In effect, the term Minimum Habitat Size is equivalent to the more accepted **minimum dynamic area** (MDA); that area of suitable habitat necessary for maintaining the minimum viable population (MVP) of a species (Pickett and Thompson 1978; Primack

1998). Shaffer (1981) first coined the term minimum viable population to define that number of individuals necessary to ensure the long-term survival of a species *ie* an estimate of how large a population must be to assure long-term survival. This population parameter is of critical importance to the assessment of survival probabilities for the small cassowary population of Mission Beach.

Unfortunately, in the case of the cassowary we simply do not know as yet just how many is enough. Therefore, the minimum dynamic area (*ie* "minimum habitat size" *sensu* Bentrupperbaumer) can be estimated only after a minimum viable population for the species has been established.

5.4.1 Evaluation of bird numbers and the Minimum Habitat Size concept

Bentrupperbaumer's conclusion that an area of 4 km^2 can hold a source population of eleven breeding adult cassowaries (1998) is not supported either by detailed surveys in the Mission Beach area (Moore 1998a, 1999i, 2000a, 2001) or by her data reproduced in Table 5.2. As is evident from the table, her hypothesis was based on a faulty density estimate of 0.35km^2 per adult bird, and the flawed supposition that eleven adult birds actually lived in the Kennedy Bay study area full-time (Bentrupperbaumer 1998). The amended analyses indicate that approximately 4 - 5 adults were present in the study at any one time and at the most only four of these could be considered as full-time residents. The remainder of identified birds obviously had the greater part of their home ranges outside the 400 hectare study area. Given these findings, therefore, Bentrupperbaumer's hypothesis of a minimum habitat size of 400 hectares supporting a source population of eleven adults is unsustainable.

This current study found that overall adult cassowary density for the Mission Beach area was 1 adult/2.09 km^2 (49 adult birds/101.66km^2), with males and females having mean home ranges of 2.06 km^2 and 2.13 km^2 respectively. Additionally, at 0.95 km^2, subadult cassowary home ranges were twice that estimated by Crome and Bentrupperbaumer (1992). Given these new density data, therefore, it would require an area greater than 23 km^2 to hold a population of eleven adults, almost six times that stated by Bentrupperbaumer (1998). Given that the IHRs calculated in this study are best considered the minimum home range size for cassowaries, it would likely take a far larger area of habitat to support them over a number of years and a range of environmental variations.

5.4.2 Cassowaries and the concept of Minimum Viable Population (MVP)

It is essential however, that we first determine whether the eleven adult birds suggested by Bentrupperbaumer are likely to form a minimum viable cassowary population. There are a complex set of factors that the MVP concept raises for small populations which need careful research and evaluation *eg* inbreeding and genetic drift, demographic and environmental stochasticity, population vulnerability, and plain bad luck (Miller and Lacy 1999). Given the significant genetic considerations and the pressures of stochastic processes, it is considered that the small population of eleven adults postulated by Bentrupperbaumer (1998) would not be genetically viable nor capable of withstanding stochastic uncertainty, and the population would need to be considerably larger. Population viability analyses presented in Chapters 6-7 of this thesis clearly show that without management intervention even the current population of cassowaries at Mission Beach (110 birds total) is inadequate to maintain itself in the short to medium term.

To function as a "source" moreover, such a diminutive population (11 adult birds) would need to be connected to other cassowary populations to facilitate emigration and immigration. This raises the separate management issue of whether such a population can actually function as a Minimum Viable Population if it is part of a highly fragmented metapopulation. Additionally, there is the need to address the interplay of sources and sinks, with the accompanying complexity of patch population dynamics, metapopulation dynamics, population demography, habitat quality, patch size and situation, linkages, recruitment, population "drainage", and landscape.

One quickly becomes aware that due to the rapidly decreasing options created by habitat removal and the compromising of those forest remnants that still exist, we have to be cautious of willingly entering the world of animal husbandry rather than that of threatened species conservation. Nothing is as simple as we would like it to be, and this area of cassowary conservation is no exception. Unfortunately, as the habitat of the cassowary succumbs to clearing, fragmentation, pests and disease, it is an area that we will have to come to terms with if the species is to survive over the greater part of its previous distribution.

CHAPTER 6

PVA OF THE MISSION BEACH CASSOWARIES

6.1 Synopsis of population viability analysis (PVA)

Population viability analysis (PVA) is the quantitative evaluation of all known factors and their interactions that act on populations and contribute to their risks of short and long-term decline or extinction (Boyce 1992). Extinction vulnerabilities of small populations (generally <500 individuals) are estimated using computer simulation modelling (Clark *et al* 1991; Lindenmayer *et al* 1993). Numerous studies have demonstrated that PVA can contribute significantly to conservation policy and management of rare species (*eg* Clark *et al* 1991; Lacy 1993; Lindenmayer *et al* 1993; Possingham 1994; Ruggiero *et al* 1994). Conversely, other studies have concluded that predictions of future population sizes and quasi-extinction events can only be accurate if the data used adequately captures the distribution of population growth rates (Coulson *et al 2001*)

There are accepted limitations and pitfalls in the use of PVA with endangered species, particularly if the quantitative models are built on poor demographic data (Lindenmayer *et al* 1993; Beissinger and Westphal 1998). Although a PVA can be tailored to suit the data available, often the parameters and structures of such models result in large uncertainties (Akcakaya 1999). Analytically comprehensive analyses of persistence probabilities require extensive ecological data (Beissinger and Westphal 1998), and any PVA will only be as good as the data on which it is based. Other limitations of PVAs include the difficulty of validating stochastic models, the frequent neglect of environmental trends and periodic fluctuations, the omission of risks that are hard to estimate, and the fact that alternative model structures often result in different predicted effects of management regimes (Caughley and Gunn 1996; Taylor 1995; Beissinger and Westphal 1998; Ludwig 1999).

Notwithstanding these deficiencies, the results of PVA are often used to guide research programs, develop conservation strategies, and inform decision and policy making for both endangered and non-endangered species (Clark *et al* 1991; Lindenmayer *et al* 1993; Boyce 1997; Rolls and Taylor 1997; Shaffer 1997). PVA can be particularly valuable when viewed in the context of adaptive management, as it is a process that significantly assists in gathering all the available data with which to build a simulation model to represent our current understanding of the population (Lindenmayer *et al* 1993). It usually follows therefore, that in the process of making a PVA model information about a species must be synthesised, which often (usually) highlights inadequacies in current knowledge and thus suggest where field data is needed *eg* on immigration/emigration rates.

The amount of information required for an effective PVA is considerable and in practice data are often not available for many variables, particularly demographic variables such as population size, age structure, sex ratio, life history traits, habitat quality and availability (Reed *et al* 1998). In this PVA of the Mission Beach cassowaries, the population and demographic data resulting from the comprehensive six-month field survey of the Mission Beach area augmented by information from previous studies was used to drive the modelling process.

Underlying principles of PVA

PVA uses simulation to assess the viability of a population (Possingham 1999). It began as an attempt to answer the question of how large must a population be for it to have a reasonable chance of survival (usually defined as 95%) for a reasonably long period of time (usually taken as 100 years) (Soule 1993). However, it is unlikely that any modelling effort by itself can determine why a population is declining or why it has declined in the past (Caughley and Gunn1994). The predictions made from PVA models should be considered, therefore, to be projections about what would be most likely to happen to the population ***if*** various hypotheses about the status of the population and threats were true (Miller and Lacy 1999). For population modelling to be successful in evaluating options for the management of threatened species however, it must be part of a larger process that incorporates other approaches, including the study of natural history, field observations and experiments, analysis of historical and current data, and long-term monitoring (Akcakaya *et al* 1999).

It is important to accept that the concepts of population extinction and loss of genetic diversity are based on probabilities rather than certainties. Thus the PVA results can only provide us with information on the probability of extinction given certain assumptions about the biology and status of the population. As a result, we are really not able to predict or guarantee exactly what will happen to these populations with any certainty (Shaffer 1987). It is unlikely therefore, that we will be able to create conservation strategies that will ensure the survival of any threatened population. A properly conducted PVA, however, should provide the information required to devise and implement management strategies that will decrease the likelihood of extinction of a population over a given period of time (Soule 1986).

Selection of species for PVA

Soule (1987) listed some of the criterion used to select those species appropriate for viability analysis, they include:

- Species whose activities create critical habitat for several others (*eg* keystone species)*;
- Mutualistic species whose behaviours enhance the fitness (*eg* reproduction and dispersal) of other species;
- Predatory or parasitic species that regulate the populations of other species, and whose absence would ultimately lead to a decrease in species diversity;
- Species that have spiritual, aesthetic, recreational, or economic value to humans*;
- Rare or endangered species*;
- Indicator species sensitive to changes in the environment and that are easily monitored.

**These criteria particularly apply to cassowaries.*

Table 6.1 presents a selection of some of the threatened species whose population viability has been assessed using PVA:

Table 6.1

Selected examples of PVA studies

Species	Major conservation issues	PVA Program	Selected References
Lord Howe Island Woodhen (*Tricholimnas sylvestris*)	• Small population size (10 breeding pairs) • Declining numbers • Habitat loss • Exotic predators	VORTEX 7.0	Brook *et al* 1997
Orange-bellied Parrot (*Neophema chrysogaster*)	• Small population size (< 200 birds) • Loss of winter habitat • Exotic predators • Competition from introduced birds • Loss of genetic variation	VORTEX	Brown and Wilson 1982-1985; Stephenson 1992.
Helmeted Honeyeater (*Meliphaga cassidix*)	• Small population size • Declining numbers • Habitat loss • Inter-specific competition • Loss of genetic identity	ALEX VORTEX	Clark and Seebrook 1990
Leadbeater's Possum (*Gymnobelideus leadbeateri*)	• Limited distribution • Habitat loss • Man-made disturbance *ie* logging resulting in loss of nesting and roosting hollows • Fragmentation of population into patches	ALEX VORTEX	Lindenmayer, D.B, and possingham, H.P. (1994).
Javan Hawk-eagle (*Spizaetus bartetsi*)	• Small population size • Habitat loss • Fragmentation • Hunting and disturbance	VORTEX	Manansang *et al* 1996
Eastern Barred Bandicoot (*Parameles gunnii*)	• Habitat loss • Exotic predators • Disease	VORTEX	Clark and Lacy 1990
Mountain Gorilla (*Gorilla gorilla beringei*)	• Two distinct populations • Habitat loss • Declining population size • Hunting and poaching • War and civil unrest • Tourism • Disease	VORTEX	Werikhe *et al* 1997
Ugandan Chimpanzee (*Pan troglodytes schweinfurthii*)	• Habitat loss • Poaching • Diseases • Political instability • Tourism activities • Human-Chimpanzee interaction	VORTEX	Edroma *et al* (1997)
Arabian Leopard (*Panthera pardus nim*) and Tahr (*Hemitragus jayakari*)	• Small population size • Habitat loss • Poaching • Droughts • Population fragmentation • Loss of genetic variation	VORTEX	CBSG (SSC/ICUN) 2000

Species	Major conservation issues	PVA Program	Selected References
	• Disease		
Florida Panther *Puma concolor coryi*	• Geographic isolation • Small population size • Habitat loss • Loss of genetic variation • Hunting • Human-Panther interactions	VORTEX	CBSG (SSC/ICUN) 1999
Killer Whale *Orcinus orca*	• Decline in habitat quality and food supply • Boating • Industrial activity • Environmental impacts *eg* oil spills, epizootics	VORTEX	Taylor and Plater (2001)
Tree-kangaroos (*Dendolagus* spp)	• Habitat loss • Hunting • Declining population • Insufficient information	VORTEX	Bonnaccorso *et al* 1999

6.2 VORTEX population viability analysis package (PVA)

Computer simulation modelling provides a tool for exploring the viability of populations subjected to many complex, interacting deterministic and random processes. One such simulation model, VORTEX (*A Stochastic Simulation of the Extinction Process* - Lacy 1993) has been used extensively by the Captive Breeding Specialist Group (Species Survival Commission ICUN), and by numerous wildlife agencies (Table 6.1). Version 8.42 of the VORTEX simulation software package was used to model the probability of extinction for the Mission Beach cassowary population.

The VORTEX PVA program models population processes as discrete, sequential events *eg* births, deaths, sex ratios among offspring, catastrophes etc, that occur according to defined probabilities (Lacy 1993, 1995, 2001). In Australia, VORTEX has been used to model a number of endangered fauna species including the Orange-bellied Parrot, Eastern Barred bandicoot, Brush-tailed Rock-wallaby, and Leadbeater's Possum. It has been shown to realistically model the recent history of the Lord Howe Island Woodhen population (Brook *et al* 1996).

VORTEX is an *individual-based* model *ie* it creates a representation of each animal in its memory and follows the fate of the animal through each year of its lifetime (Lacy 1993) using the typical life cycles of sexually reproducing, diploid organisms. It keeps track of the sex, age, and parentage of each animal, modelling demographic events (birth, sex determination, mating, dispersal and death) by determining whether any of the events occur for each animal in each year of the simulation. Events occur according to a Monte Carlo simulation of the effects of deterministic forces, as well as demographic, environmental, and genetic stochastic events on wild populations (Miller and Lacy 1999).

Demographic stochasticity is, therefore, a consequence of the uncertainty regarding whether each demographic event occurs for any given animal. Interpretation of the output depends on knowledge of the species, the conditions affecting the population, and the possible changes in those conditions.

Lacy (1993, 1995), and Miller and Lacy (1999), present detailed account of the VORTEX Population Viability Analysis package and the functions used to estimate genetic evolution, population trends, and extinction probabilities.

6.3 Input parameters for simulations

6.3.1 Iterations and years of population projection

Cassowaries are long-lived birds and thus to reveal the complete extinction dynamics simulations were run for 500 years using the mortality estimates presented in Table 6.2, with data output results given at intervals of 50 years.

To enable more detailed management interpretation, the remaining scenarios were simulated 500 times with population projections extending for 100 years. Output results were summarised at 10-year intervals for use in the tables and figures that follow. All simulations were conducted using VORTEX version 8.42 (Miller and Lacy 2001).

6.3.2 Mating system

The mating system in cassowaries is poorly understood but appears to be a complex arrangement of simultaneous polygony (pair bond between a male and more than one female) and sequential polyandry (sexual relationship between a female and two or more males such that the incubating and caring for the young are left to the males). This is yet to be confirmed by long-term field studies and/or DNA investigation

6.3.3 Age of first reproduction

The exact age of first breeding is unknown but adult plumage is attained at approximately 4 years of age. Although it is not certain that the birds can successfully breed at that age, it is probable they are capable of breeding within their fifth year. Given the long courtship and egg-laying phase, a breeding age of five years has been used in this PVA.

6.3.4 Age of reproductive senescence

This is unknown. Cassowaries are known to live up to 50 years in captivity (Crome and Moore 1988), and observations at Mission Beach (Jorrisen 1978) have recorded males breeding for at least 14 years *ie* >19 years old. There are reports (with accompanying photographs) of an individual male cassowary breeding on Mt Whitfield Cairns over a 25-year period (Moore and Crome 1992) prior to being killed by dogs in 1995.

Due to the uncertainty regarding age of reproductive senescence (RS), a sensitivity analysis was conducted using 35, 30, and 25 years RS, moderate mortality (Table 6.2), and % breeding of 50% (1 in 2 years). The results showed little difference in the probability of extinction (PE) between the 35 and 30 years parameters (46% and 50% respectively). However, an RS of 25 years (*ie* 20 years potential breeding) increased the probability of extinction to 68% over the 100-year simulation (an increase of 48%).

The age of reproductive senescence, therefore, appears to be an important parameter and may be a determinant of population viability in cassowaries.

Owing to the known longevity of cassowaries and the uncertainty surrounding the age of reproductive senescence, a conservative model using 35 years as the age of last breeding was selected. By this age an individual would have only nested 10 times at 33% breeding (1 in 3 years) or 15 times at 50% breeding (2 in 3 years). Given Bentrupperbaumer's data from Kennedy Bay (Bentrupperbaumer 1998), this could result in an individual male successfully producing from 7-10 young in his reproductive lifetime (33% and 50% @ 0.67 young/year).

6.3.5 Maximum number of young per breeding cycle

The maximum number of possible offspring per year was set at five. This variable remained constant in all simulations and comprised an estimate based on known breeding records and sightings of family parties at Mission Beach and elsewhere. Crome and Moore (1988) gathered data from the literature on twelve cassowary clutches from the wild, resulting in a mean clutch size of 3.9 (SD=0.99). They also documented four clutches laid in captivity comprising three sets of 3 eggs, and one each of 4 and 5. Three of the four nests found by Bentrupperbaumer (1998) had three eggs, the fourth having just two. Box 2 presents the offspring estimate based on these data and used in all simulations.

Box 2

Offspring as percentage occurrence:

1 = 5%
2 = 20%
3 = 40%
4 = 30%
5 = 5%

6.3.6 Female breeding numbers (= male parameter in VORTEX)

The sex roles are reversed in cassowaries. Following advice (Lacy *pers. comm.*) this parameter was used to reflect the male cassowary breeding numbers. Studies indicate that approximately 80% of cassowary males breed only once every 2-3 years, with only approximately 20% completing two breeding sequences within the three-year period (Bentrupperbaumer 1998). Therefore male breeding numbers were calculated as follows:

- 33% = breeding once in 3 years
- 50% = breeding once in two years[2]

Both parameters were modelled in all PVA scenarios.

6.3.7 Male breeding pool (= female parameter in VORTEX)

As above, this parameter was reversed to reflect the reversed sex roles in cassowaries (Lacy *pers. comm.*). Although no data are available for this parameter, it has been assumed that all adult females are available for breeding in a given year, as they have no commitment to parental responsibilities. Bentrupperbaumer (1998) recorded one female in her study area laying eggs in at least two out of three years.

6.3.8 Mortality

The models are based on age-specific mortalities which assume the same mortality rates for both sexes. In order to test the sensitivity of cassowaries to uncertainty in estimates of mortality rates, three alternative models were developed in which mortality rates increased from LOW to HIGH (Table 6.2). An additional mortality estimate by the author was also simulated (MB study estimates). This latter estimate is based on data from previous studies (Moore *loc. cit*, Bentrupperbaumer *loc cit*), augmented by known Mission Beach cassowary deaths over a 12-year period (C4 database) and is considered to most closely reflect the current field situation.

[2] Considered to be atypical

Due to a lack of data on age-specific mortality rates in wild populations of cassowaries, the annual mortality figures used in the simulations should be considered broad estimates meant to reflect a wide range of potential mortality rates. The columns comprise an estimated percentage mortality rate followed by an estimated standard deviation (SD) due to environmental variation *eg* 55 (25).

Table 6.2
Mortality Rates (percentage mortality)

Age Class	MB study estimates (Moore)	High	Moderate	Low
0 - 1	75 (25)	75 (25)	55 (25)	40 (15)
1 – 2	50 (20)	50 (20)	40 (15)	30 (10)
2 - 3	40 (15)	50 (20)	40 (15)	30 (10)
3 – 4	33 (15)	30 (10)	25 (10)	20 (7.5)
4 - 5	25 (10)	30 (10)	25 (10)	20 (7.5)
Adults	4* (1.5)	7* (3)	5* (2)	3* (1)
Offspring Survival (Recruitment)	**3.75%**	**3.1%**	**9.11%**	**18.8%**

*7 % of 50 adults = 3.5 adult deaths per year

*5 % of 50 adults = 2.5 adult deaths per year

* 4 % of 50 adults = 2.0 adult deaths per year

*3 % of 50 adults = 1.5 adult deaths per year

It is considered from past studies in the Mission Beach area (Moore *loc. cit*, Crome and Bentrupperbaumer *loc cit*), that the Low Mortality rates used in these analyses are not ecologically realistic, and the results from this parameter are better viewed as a theoretical benchmark or management target. To assist in evaluating the likelihood of each set of mortality rates, the predicted offspring survival to adulthood (recruitment) resulting from each mortality model is given at the bottom of the table (Offspring Survival).

A separate set of scenarios tested the sensitivity of adult mortality estimates by using a range of mortality scenarios simulated at 0% - 5% per year. This model effectively examines the impact of human-added mortality on the viability of the cassowary population *ie* road deaths, dog kills, pig traps.

6.3.9 Initial population size

The cassowary population size of the Mission Beach area was established in this study (Moore 2002). A total of 110 cassowaries comprising 49 adults, 28 subadults, 2 independent birds of unknown age or sex, and 31 chicks were identified in the Mission Beach cassowary survey. Of the 49 adult cassowaries identified within the Mission Beach study area, 28 were males, 19 were females, and two adult birds were of unknown sex and not included in the detailed demographic analyses. The population size and demography of the simulations have thus been based on 28 adult males, 19 adult females, 28 subadults and two unknowns *ie* 79 birds. Models were also run with an initial population size of 130 individuals in order to test the viability of a population of greater size.

6.3.10 Carrying capacity (K)

The amount of remaining habitat suitable for cassowaries at Mission Beach is approximately 110-130km^2. Thus the carrying capacity (K) was set at 100 independent birds *ie* 130km^2/1.29km^2 (available habitat/population density of independent birds). VORTEX has the capability of imposing density-dependent effects on reproduction that change as a function of K, but since no data are available for Southern Cassowary populations, density-dependence was not included in the models.

6.3.11 Catastrophes

Catastrophes are singular environmental events that are outside the bounds of normal environmental variation affecting reproduction and/or survival (CBSG 1996). These events are modelled in VORTEX by assigning a probability of occurrence and a severity factor ranging from 0.0 (maximum or absolute effect) to 1.0 (no effect).

Located in tropical eastern Australia, Mission Beach is subject to occasional severe climatic events such as cyclones with heavy rains and strong winds (*eg* Cyclone Winifred 1986), and infrequent "droughts" that reduce the amount of rainforest fruit and restrict the availability of water. As such three major parameters were modelled in this section of the PVA:

1. Catastrophe 1: 3% - Reproduction 0.25, Survival 0.75 (severe cyclones simulated as a 1:33 year event). This scenario results in a loss of 75% reproductive capacity and a 25% increase in mortality across all age classes;

2. Catastrophe 2: 1% - Reproduction 0.50, Survival 0.75 (severe drought or poor fruiting event simulated as a 1:100 years event). This scenario results in a loss of 50% of reproductive capacity and a 25% increase in mortality across all age classes;

3. No catastrophes.

6.3.12 Genetic drift and in-breeding depression

It is likely that inbreeding depression may produce deleterious effects in this small cassowary population. As such, the VORTEX default values of 3.14 lethal equivalents have been modelled (the median of 40 populations surveyed by Ralls *et al* 1988), with 50% of that due to lethal alleles. Scenarios without inbreeding were also simulated to assess the contribution of genetic processes to population viability.

6.3.13 Immigration\Supplementation

The Mission Beach area is all but isolated. As such an immigration component was not included in the baseline simulations *ie* no recruitment. This parameter was included to examine the probability of persistence for a self-sustaining population at Mission Beach in the absence of re-colonisation. There are, however, three tenuous "corridors" that may still allow varying movement in and out of the main forest complex if protected and enhanced. They comprise:

- Walter Hill Range at Kennedy Highway to the east;
- Maria Creek to the north;
- Hull River to the south.

As such, a separate set of simulations were run with immigration scenarios ("supplements"), spaced at differing time intervals and migrant numbers, to determine the level of immigration required to maintain the Mission Beach population. The age of "successful" immigrants was set at 3 years, as it was considered that this age group had passed the higher mortality offspring period but had yet to develop the territorial fidelity of older subadults.

6.3.14 Definition of extinction

The standard extinction risk of the complete absence of one or the other sex has been used in this analysis. There are benefits in using quasi-extinction *ie* the probability of the population dropping below a user-defined threshold size but it was considered that this result could be obtained from examining the modelling output data, which are summarised at 10-year intervals.

6.4 Sensitivity analyses

Sensitivity testing in PVA is necessary to establish the extent to which uncertainty in input parameters results in uncertainty regarding the future fate of the population. If alternative reasonable parameter values result in inconsistent predictions for the population, then it is important to try to resolve the uncertainty (Miller and Lacy 1999). This usually requires better data. However, sensitivity to certain parameters also indicate that those parameters could identify factors that may be key determinants of population viability, and thus candidates for management actions designed to extend the persistence of the population (Miller and Lacy 1999).

In the sensitivity analyses for this cassowary PVA, complete sets of scenarios were systematically run with a range of parameter values. Scenario results are combined in graphs plotted at 10-year intervals for the 100 years projections to illustrate changes in predicted population size, population persistence, probability of extinction, time to extinction, and genetic diversity in response to altered parameters. Due to a lack of long-term field studies, some of the parameters used in the simulations were based on assumptions derived from previous studies and augmented with data from this field survey. Seven major variables were modelled within all scenarios:

- population size;
- carrying capacity;
- breeding intervals *ie* 33% (1 in 3 years) and 50% (1 in 2 years);
- genetic influences;
- catastrophes;
- mortality; and
- immigration rates.

6.5 Sample VORTEX files

6.5.1 VORTEX INPUT File

An example of the INPUT File for a VORTEX simulation modelled over 500 years and with 500 iterations is shown below:

500_MOD.OUT ***Output Filename***

Y ***Graphing Files?***

N ***Details each Iteration?***

500 ***Simulations***

500 ***Years***

50 ***Reporting Interval***

0 ***Definition of Extinction***

1 ***Populations***

Y ***Inbreeding Depression?***

3.140000 ***Lethal equivalents***

50.000000 ***Percent of genetic load as lethals***

Y ***EV concordance between repro and surv?***

2 ***Types Of Catastrophes***

Q ***Monogamous, Polygynous, or Hermaphroditic***

5 ***Female Breeding Age***

5 ***Male Breeding Age***

35 ***Maximum Breeding Age***

50.000000 ***Sex Ratio (percent males)***

5 ***Maximum Litter Size (0 = normal distribution) *****

N ***Density Dependent Breeding?***

500_mod

50.00 **breeding

12.50 **EV-breeding

5.000000 ***500_mod: Percent Litter Size 1***

20.000000 ***500_mod: Percent Litter Size 2***

40.000000 ***500_mod: Percent Litter Size 3***

30.000000 ***500_mod: Percent Litter Size 4***

55.000000 *FMort age 0

25.000000 ***EV

40.000000 *FMort age 1

15.000000 ***EV

40.000000 *FMort age 2

15.000000 ***EV

25.000000 *FMort age 3

10.000000 ***EV

25.000000 *FMort age 4

10.000000 ***EV

5.000000 *Adult FMort

2.000000 ***EV

55.000000 *MMort age 0

25.000000 ***EV

40.000000 *MMort age 1

15.000000 ***EV

40.000000 *MMort age 2

15.000000 ***EV

25.000000 *MMort age 3

10.000000 ***EV

25.000000 *MMort age 4

10.000000 ***EV

5.000000 *Adult MMort

2.000000 ***EV

3.000000 ***Probability Of Catastrophe 1***

0.250000 ***Severity--Reproduction***

0.750000 ***Severity--Survival***

1.000000 ***Probability Of Catastrophe 2***

0.500000 ***Severity--Reproduction***

0.750000 ***Severity--Survival***

Y ***All Males Breeders?***

N ***Start At Stable Age Distribution?***

1 ***Initial Females Age 1***

6 ***Initial Females Age 2***

4 ***Initial Females Age 3***

4 ***Initial Females Age 4***

1 ***Initial Females Age 5***

1 ***Initial Females Age 6***

1 ***Initial Females Age 7***

1 ***Initial Females Age 8***

1 ***Initial Females Age 9***

2 ***Initial Females Age 10***

1 ***Initial Females Age 11***

1 ***Initial Females Age 12***

1 ***Initial Females Age 13***

1 ***Initial Females Age 14***

1 ***Initial Females Age 15***

1 ***Initial Females Age 16***

1 ***Initial Females Age 17***

1 ***Initial Females Age 18***

1 ***Initial Females Age 19***

1 ***Initial Females Age 20***

1 ***Initial Females Age 21***

1 ***Initial Females Age 22***

1 ***Initial Females Age 23***

1 ***Initial Females Age 24***

1 ***Initial Females Age 25***

1 ***Initial Females Age 26***

1 ***Initial Females Age 27***

1 ***Initial Females Age 28***

0 ***Initial Females Age 29***

1 ***Initial Females Age 30***

1 ***Initial Females Age 31***

0 ***Initial Females Age 32***

1 ***Initial Females Age 33***

1 ***Initial Females Age 34***

1 ***Initial Females Age 35***

1 ***Initial Males Age 1***

6 ***Initial Males Age 2***

3 ***Initial Males Age 3***

3 ***Initial Males Age 4***

1 ***Initial Males Age 5***

1 ***Initial Males Age 6***

1 ***Initial Males Age 7***

0 ***Initial Males Age 8***

1 ***Initial Males Age 9***

2 ***Initial Males Age 10***

1 ***Initial Males Age 11***

0 ***Initial Males Age 12***

1 ***Initial Males Age 13***

0 ***Initial Males Age 14***

1 ***Initial Males Age 15***

1 ***Initial Males Age 16***

1 ***Initial Males Age 17***

0 ***Initial Males Age 18***

1 ***Initial Males Age 19***

1 ***Initial Males Age 20***

1 ***Initial Males Age 21***

1 ***Initial Males Age 22***

1 ***Initial Males Age 23***

1 ***Initial Males Age 24***

1 ***Initial Males Age 25***

1 ***Initial Males Age 26***

0 ***Initial Males Age 27***

1 ***Initial Males Age 28***

0 ***Initial Males Age 29***

0 ***Initial Males Age 30***

0 ***Initial Males Age 31***

0 ***Initial Males Age 32***

1 ***Initial Males Age 33***

0 ***Initial Males Age 34***

0 ***Initial Males Age 35***

100 ***K***

10.000000 ***EV--K***

N ***Trend In K?***

N ***Harvest?***

N ***Supplement?***

N ***AnotherSimulation?***

6.5.2 VORTEX OUTPUT File

VORTEX records the output results of individual iterations in detailed form in a standard ASCII file, the name of which is chosen by the researcher. All summary results for each scenario, however, are appended to a separate ASCII file named **VORTEX.sum**. The VORTEX.sum file that contains the results of these simulations is attached as Appendix Two. The OUTPUT File for a VORTEX simulation modelled over 500 years and with 500 iterations is shown below. Figure 6.1 depicts a sample graphical display showing the results of a simulation with 100 iterations.

500_MOD.OUT

1 population(s) simulated for 500 years, 500 iterations

Extinction is defined as no animals of one or both sexes.

Inbreeding depression modeled with 3.14000 lethal equivalents per individual,
comprised of 1.57000 recessive lethal alleles,
and 1.57000 lethal equivalents not subject to removal by selection.

First age of reproduction for females: 5 for males: 5
Maximum breeding age (senescence): 35
Sex ratio at birth (percent males): 50.000000

Population: 500_mod

Long-term Polygynous mating; all adult males in the breeding pool.

50.00 percent of adult females produce litters.
EV in % adult females breeding = 12.50 SD

Of those females producing litters, ...
5.00 percent of females produce litters of size 1
20.00 percent of females produce litters of size 2
40.00 percent of females produce litters of size 3
30.00 percent of females produce litters of size 4
5.00 percent of females produce litters of size 5

55.00 percent mortality of females between ages 0 and 1
EV in % mortality = 25.000000 SD
40.00 percent mortality of females between ages 1 and 2
EV in % mortality = 15.000000 SD

40.00 percent mortality of females between ages 2 and 3
EV in % mortality = 15.000000 SD
25.00 percent mortality of females between ages 3 and 4
EV in % mortality = 10.000000 SD
25.00 percent mortality of females between ages 4 and 5
EV in % mortality = 10.000000 SD
5.00 percent mortality of adult females (5<=age<=35)
EV in % mortality = 2.000000 SD
55.00 percent mortality of males between ages 0 and 1
EV in % mortality = 25.000000 SD
40.00 percent mortality of males between ages 1 and 2
EV in % mortality = 15.000000 SD
40.00 percent mortality of males between ages 2 and 3
EV in % mortality = 15.000000 SD
25.00 percent mortality of males between ages 3 and 4
EV in % mortality = 10.000000 SD
25.00 percent mortality of males between ages 4 and 5
EV in % mortality = 10.000000 SD
5.00 percent mortality of adult males (5<=age<=35)
EV in % mortality = 2.000000 SD

EVs may be adjusted to closest values possible for binomial distribution.
EV in reproduction and mortality will be concordant.

Frequency of type 1 catastrophes: 3.000 percent
multiplicative effect on reproduction = 0.250000
multiplicative effect on survival = 0.750000

Frequency of type 2 catastrophes: 1.000 percent
multiplicative effect on reproduction = 0.500000
multiplicative effect on survival = 0.750000

Initial size of 500_mod: 79
Age 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 Total

1 6 3 3 1 1 1 0 1 2 1 0 1 0 1 1 1 0 1 1
1 1 1 1 1 1 0 1 0 0 0 0 1 0 0 34 Males
1 6 4 4 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 0 1 1 0 1 1 1 45 Females

Carrying capacity = 100

EV in Carrying capacity = 10.00 SD

Deterministic population growth rate

(based on females, with assumptions of no limitation of mates, no density dependence, no functional dependencies, and no inbreeding depression)

r = -0.004 lambda = 0.996 R0 = 0.934

Generation time for: females = 15.52 males = 15.52

Stable age distribution:

Age class	females	males
0	0.151	0.151
1	0.067	0.067
2	0.040	0.040
3	0.024	0.024
4	0.018	0.018
5	0.013	0.013
6	0.013	0.013
7	0.012	0.012
8	0.011	0.011
9	0.011	0.011
10	0.010	0.010
11	0.009	0.009
12	0.009	0.009
13	0.008	0.008
14	0.008	0.008
15	0.008	0.008
16	0.007	0.007
17	0.007	0.007
18	0.006	0.006
19	0.006	0.006

20	0.006	0.006
21	0.005	0.005
22	0.005	0.005
23	0.005	0.005
24	0.005	0.005
25	0.004	0.004
26	0.004	0.004
27	0.004	0.004
28	0.004	0.004
29	0.003	0.003
30	0.003	0.003
31	0.003	0.003
32	0.003	0.003
33	0.003	0.003
34	0.003	0.003
35	0.002	0.002

Ratio of adult (>= 5) males to adult (>= 5) females: 1.000

Population 1: 500_mod

Year 50
N[Extinct] = 19, P[E] = 0.038
N[Surviving] = 481, P[S] = 0.962
Mean size (all populations) = 37.87 (1.06 SE, 23.63 SD)
Means across extant populations only:
Population size = 39.31 (1.04 SE, 22.92 SD)
Expected heterozygosity = 0.881 (0.003 SE, 0.064 SD)
Observed heterozygosity = 0.950 (0.003 SE, 0.058 SD)
Number of extant alleles = 15.35 (0.25 SE, 5.46 SD)
Lethal alleles / diploid = 1.46 (0.02 SE, 0.52 SD)

Year 100
N[Extinct] = 154, P[E] = 0.308

N[Surviving] = 346, P[S] = 0.692
Mean size (all populations) = 19.33 (1.01 SE, 22.52 SD)
Means across extant populations only:
Population size = 27.71 (1.21 SE, 22.46 SD)
Expected heterozygosity = 0.759 (0.007 SE, 0.122 SD)
Observed heterozygosity = 0.849 (0.008 SE, 0.140 SD)
Number of extant alleles = 7.38 (0.17 SE, 3.13 SD)
Lethal alleles / diploid = 1.23 (0.04 SE, 0.66 SD)

Year 150
N[Extinct] = 332, P[E] = 0.664
N[Surviving] = 168, P[S] = 0.336
Mean size (all populations) = 8.22 (0.75 SE, 16.67 SD)
Means across extant populations only:
Population size = 23.98 (1.64 SE, 21.28 SD)
Expected heterozygosity = 0.642 (0.012 SE, 0.157 SD)
Observed heterozygosity = 0.725 (0.014 SE, 0.188 SD)
Number of extant alleles = 5.00 (0.17 SE, 2.14 SD)
Lethal alleles / diploid = 0.87 (0.05 SE, 0.60 SD)

Year 200
N[Extinct] = 428, P[E] = 0.856
N[Surviving] = 72, P[S] = 0.144
Mean size (all populations) = 3.38 (0.50 SE, 11.10 SD)
Means across extant populations only:
Population size = 23.03 (2.38 SE, 20.20 SD)
Expected heterozygosity = 0.566 (0.022 SE, 0.186 SD)
Observed heterozygosity = 0.647 (0.027 SE, 0.231 SD)
Number of extant alleles = 3.74 (0.17 SE, 1.48 SD)
Lethal alleles / diploid = 0.72 (0.07 SE, 0.57 SD)

Year 250
N[Extinct] = 468, P[E] = 0.936
N[Surviving] = 32, P[S] = 0.064

Mean size (all populations) = 1.15 (0.25 SE, 5.60 SD)

Means across extant populations only:

Population size = 17.28 (2.60 SE, 14.73 SD)

Expected heterozygosity = 0.476 (0.041 SE, 0.233 SD)

Observed heterozygosity = 0.534 (0.048 SE, 0.272 SD)

Number of extant alleles = 3.19 (0.22 SE, 1.23 SD)

Lethal alleles / diploid = 0.57 (0.08 SE, 0.46 SD)

Year 300

N[Extinct] = 492, P[E] = 0.984

N[Surviving] = 8, P[S] = 0.016

Mean size (all populations) = 0.23 (0.12 SE, 2.63 SD)

Means across extant populations only:

Population size = 14.00 (5.82 SE, 16.48 SD)

Expected heterozygosity = 0.204 (0.103 SE, 0.291 SD)

Observed heterozygosity = 0.228 (0.113 SE, 0.319 SD)

Number of extant alleles = 1.88 (0.48 SE, 1.36 SD)

Lethal alleles / diploid = 0.25 (0.13 SE, 0.36 SD)

Year 350

N[Extinct] = 498, P[E] = 0.996

N[Surviving] = 2, P[S] = 0.004

Mean size (all populations) = 0.04 (0.03 SE, 0.77 SD)

Means across extant populations only:

Population size = 9.50 (7.50 SE, 10.61 SD)

Expected heterozygosity = 0.277 (0.277 SE, 0.391 SD)

Observed heterozygosity = 0.235 (0.235 SE, 0.333 SD)

Number of extant alleles = 2.00 (1.00 SE, 1.41 SD)

Lethal alleles / diploid = 0.00 (0.00 SE, 0.00 SD)

Year 400

N[Extinct] = 500, P[E] = 1.000

N[Surviving] = 0, P[S] = 0.000

Mean size (all populations) = 0.00 (0.00 SE, 0.00 SD)

Year 450

N[Extinct] = 500, P[E] = 1.000

N[Surviving] = 0, P[S] = 0.000

Mean size (all populations) = 0.00 (0.00 SE, 0.00 SD)

Year 500

N[Extinct] = 500, P[E] = 1.000

N[Surviving] = 0, P[S] = 0.000

Mean size (all populations) = 0.00 (0.00 SE, 0.00 SD)

In 500 simulations of 500_mod for 500 years:
500 went extinct and 0 survived.

This gives a probability of extinction of 1.0000 (0.0000 SE),
or a probability of success of 0.0000 (0.0000 SE).

500 simulations went extinct at least once.
Median time to first extinction was 125 years.
Of those going extinct,
mean time to first extinction was 135.84 years (2.79 SE, 62.28 SD).

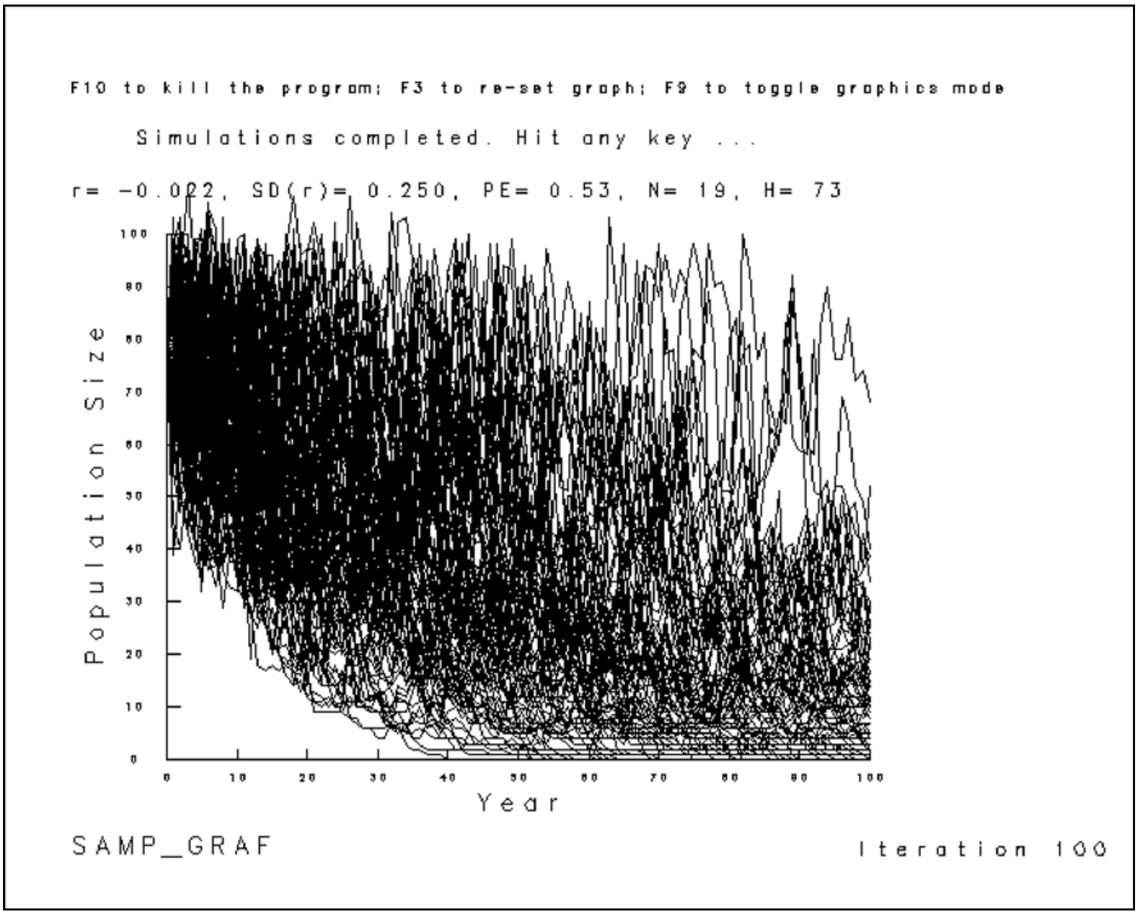
Means across all populations (extant and extinct)
Mean final population was 0.00 (0.00 SE, 0.00 SD)

Age 1	2	3	4	Adults	Total	
0.00	0.00	0.00	0.00	0.00	0.00	Males
0.00	0.00	0.00	0.00	0.00	0.00	Females

Across all years, prior to carrying capacity truncation,
mean growth rate (r) was -0.0158 (0.0010 SE, 0.2673 SD)

Figure 6.1

Sample VORTEX graphical Output



The summary information at the top of the graph includes the mean and standard deviation of the stochastic growth rate, the probability of population extinction, the final mean size of those populations that did not become extinct, and the heterozygosity retained in the population at the end of the simulation.

6.6 Population simulations

Three main modelling exercises were conducted:

1. Baseline modelling using demographic parameters described in Chapter 6.1 and including the range of estimated mortality figures (Low, Moderate, High, LM Study Estimates) for <u>all</u> age classes (Table 6.2);

2. Adult mortality percentages ranging from 0% - 5% per year (all other subadult mortality figures remain at their baseline values);

3. The effect of immigration rates on persistence probabilities (also simulated in conjunction with adult mortality).

In all these simulations, differing breeding percentages (33% and 50%), catastrophes (0 or 2), and inbreeding - no inbreeding, were incorporated into the models. A summary of their effects on the analyses is presented in Chapter 7 (PVA Results). The summary population output data are presented in Table 7.1 and include deterministic growth rate (det.r), stochastic growth rates (stoc.r), SD of stochastic growth rate (SD(r), probability of extinction (PE), mean surviving population size (N-extant), Heterozygosity (Het), and mean time to extinction (Mean-TE).

6.6.1 Baseline models (with and without inbreeding depression)

The demographic and environmental parameters described in Chapter 6.1 were assembled in the VORTEX model to assess the status of the Mission Beach cassowary population to a range of mortality and breeding scenarios. These simulations represent the Baseline Population Models and all subsequent model results were compared to these baseline scenarios. To review, the baseline scenarios modelled the following parameters:

- cassowary population of 79 independent cassowaries with a reproductive lifespan of 30 years (beginning at age 5 and ceasing at age 35);
- adult males breeding in a given year estimated as 33% (breeding once in 3 years) and 50% (breeding once in two years). Both parameters were modelled in all PVA scenarios.
- all adult females available in the breeding pool in a given year (Bentrupperbaumer 1998);
- estimated mortality categories as presented in Table 6.2;
- non-stable age distribution using demographic data obtained during the 2000 field survey;
- carrying capacity (K) of 100 independent birds;

- three catastrophe scenarios: Catastrophe 1: 3% - Reproduction 0.25, Survival 0.75 (severe cyclones simulated as a 1:33 year event); Catastrophe 2: 1% - Reproduction 0.50, Survival 0.75 (severe drought or poor fruiting event simulated as a 1:100 years event); No catastrophes.
- No supplementation *ie* immigration (modelled separately).

6.6.2 Adult mortality assessment

In addition to natural background population mortality, each year many adult cassowaries are victims of road death, dog attack, shooting, and disease, all human-derived pressures. To measure the effect of altering mortality levels of adult breeding cassowaries on the likely population persistence of the Mission Beach cassowaries, the following range of annual mortality figures were simulated:

- 0 % - no adult deaths\year;
- 1 % - 0.5 adult deaths\year;
- 2 % - 1.0 adult deaths\year;
- 3 % - 1.5 adult deaths\year;
- 4 % - 2.0 adult deaths\year;
- 5 % - 2.5 adult deaths\year.

6.6.3 Effect of immigration on persistence probabilities

The effect of immigration on maintaining population size was examined in conjunction with the adult mortality scenarios. In this simulation, immigration was modelled using the "Supplement" option in VORTEX and involved the addition of birds of the age class 3-4 years. This cassowary age class was chosen as being: independent, past the high-risk juvenile mortality period, close to adulthood, and having not yet achieved sexual, territory or site fidelity. Simulations were run using a range of bird numbers and time intervals, with the remaining following parameters derived from the Baseline modelling:

- ***Immigration (=supplements) 4 birds\year – 2 M & 2 F (3-4yo);***
- Catastrophe 1: 3% - Reproduction 0.25, Survival 0.75;
- Catastrophe 1: 1% - Reproduction 0.50, Survival 0.75;

- 50% breeding males (breeding once in 2 years – this is admittedly a generous figure).
- 100% females in breeding pool;
- K = 100;
- Population size = 79;
- Not age-stable population;
- Inbreeding pressures activated.

CHAPTER 7

PVA RESULTS

These scenarios hypothesise the probable persistence of an isolated cassowary population at Mission Beach in the absence of immigration. Descriptions of the column headings for the summary population data output are presented in Table 7.1.

Results of the Baseline simulation models appear in Table 7.2 and Table 7.5, with summary data presented in Tables 7.3 - 7.6 and Figures 7.1 - 7.11.

Results of the simulations into the effect of adult mortality are presented in Table 7.8, with summary data given in Table 7.9 and Figures 7.12 - 7.15.

The influence of immigration on the population viability of the population is evaluated and the results presented in Table 7.10, with summary data given in Table 7.11 and Figures 7.16 - 7.17.

Table 7.1

Summary of Population Output data

File:	Unique run or scenario identifier.
% Breeding	Two parameters used: 33% = breeding once in 3 years; 50% = breeding once in two years.
Mortality	As per Table 6.2, plus separate adult mortality scenarios.
det.r (r_d)	**Deterministic growth rate.** If "r" is negative then the population is in deterministic decline (deaths outpace births) and will become extinct even in the absence of stochastic fluctuations (Miller and Lacy 1999)[3].

3 Positive values indicate population growth, while negative values indicate population decline. A population with $r_d<0$ is in deterministic decline (deaths >births) and will go extinct. The difference between the deterministic population growth rate (r_d) and the stochastic population growth rate (s_d) resulting from simulations can give an indication of the impact of stochastic factors on population persistence.

stoc.r (r_s)	**Stochastic growth rate.** The difference between the deterministic population growth and the stochastic growth rate can give an indication of the importance of stochastic factors as threats to population viability.
SD(r)	**Mean (standard deviation) stochastic growth rate**. Calculated directly from observed annual population sizes across the 500 simulations.
PE	**The probability of population extinction.** Determined by the proportion of 500 simulated populations within a given model that became extinct during the model's 100 years time frame.
N-Extant	Mean final size of those populations remaining extant after 100 years.
HET	Expected heterozygosity (gene diversity) in the simulated populations after 100 years.
Mean TE	The mean predicted time to extinction for those populations becoming extinct during the simulations.

7.1 Baseline modelling with inbreeding depression

Results of the simulation models appear in Table 7.2. Each row presents the response of the Mission Beach cassowary population to a specified set of conditions, for example differing breeding cycles, mortality rates, or the presence or absence of inbreeding depression. Within all tables, the results are organised in a nested structure *ie* each population was run with or without catastrophes under specified breeding regimes.

Table 7.2

Cassowary population viability: Initial population size (N_0) = 79: K=100;

Inbreeding depression (Heterosis model: 3.14 lethal equivalents)

Note: These statistics are based on 500 simulations over 100 years.
For 10-year summaries of data refer to individual RUNS in Appendix Two.
Mortality rates are from Table 6.2.
No recruitment.

Run File	% Breeding*	Mortality Rates	det.r	stoc.r	SD(r)	PE	N-extant	Het	MeanTE
Catastrophes									
RUN51	33	LM+	-0.067	-0.055	0.271	0.98	5.7	0.6629	55.4
RUN58	33	High	-0.101	-0.085	0.296	0.998	3	0.6111	37.2
RUN66	33	Mod	-0.029	-0.03	0.264	0.676	14.39	0.7128	69.5
RUN74	33	Low	0.024	0.02	0.196	0.016	61.93	0.8536	81.9
RUN50	50	LM+	-0.047	-0.043	0.297	0.908	7.96	0.6079	62
RUN59_1	50	High	-0.08	-0.07	0.327	0.998	2	0.625	42.9
RUN67	50	Mod	-0.003	-0.009	0.274	0.304	28.49	0.7527	74.5
RUN75	50	Low	0.055	0.048	0.202	0	76.62	0.8554	0
No Catastrophes									
RUN54	33	LM+	-0.056	-0.045	0.256	0.924	8.63	0.6769	63.9
RUN62	33	High	-0.089	-0.073	0.289	1	0	0	42.5
RUN70	33	Mod	-0.017	-0.017	0.244	0.348	22.21	0.7567	76.7
RUN78	33	Low	0.036	0.034	0.177	0	75.78	0.8771	0
RUN55	50	LM+	-0.036	-0.032	0.286	0.73	11.93	0.7042	70.7
RUN63	50	High	-0.069	-0.062	0.318	0.994	9	0.6962	47.6
RUN71	50	Mod	0.008	0.005	0.254	0.086	43.43	0.819	81.3
RUN79	50	Low	0.067	0.063	0.18	0	83.34	0.8665	0

*33% = breeding 1in 3 years; 50% = breeding 1 in two years
+ = LM Study estimates

7.1.1 33% male breeding (1 in 3 year cycle)

The data summaries for this simulation are presented in Table 7.3 and Table 7.4. Graphical displays of results are given with accompanying comment in Figures 7.1-7.5.

High-moderate mortality and catastrophes

Deterministic growth rates are strongly negative (r_d = -0.029 to -0.101) with a 1 in 3 year male breeding cycle in the presence of catastrophes and under conditions of high, moderate, and study-estimated mortality, deterministic. This negative growth culminates in a probability of extinction (PE) of 67.6% to 99.8% and a mean time to extinction (TE) from 37 to 69 years. The mean deterministic growth rate of the three simulations is –6.6% over the 100 years simulation. As can be expected, the degree of heterozygosity in the population after 100 years is extremely low, with only 61% to 71% of the original heterozygosity remaining and a mean predicted population size of 3 to 15 birds.

Stochastic growth, although of a higher rate than deterministic growth, remains strongly negative indicating that the influences of stochastic factors are outweighed as a threat to population persistence by the severity of the deterministic decline.

Low mortality and catastrophes

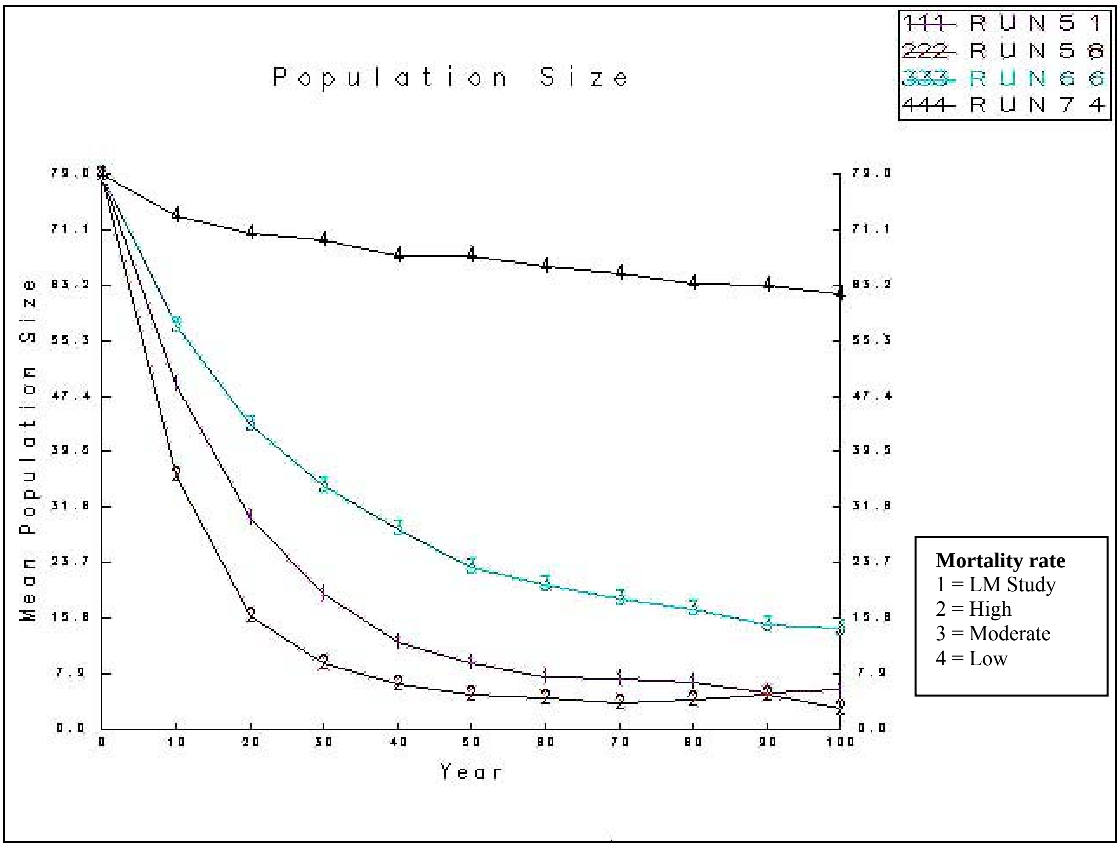
By contrast, the deterministic growth rate is positive when mortality rates are low (r_d = +0.024). The final population size at this low mortality level, nonetheless, declines by 17 birds (-21.5%) over the 100 years simulation *ie* -0.215% per year (r_s = 0.02; SD_r = 0.196). This population decrease is matched by a significant decrease in original heterozygosity to 85.4% of its original base.

No catastrophes

If catastrophes are eliminated from the simulations deterministic growth rates increase from about 11.9% (High mortality) to 41% (Moderate mortality). However, deterministic growth rates continue to remain strongly negative (r_d = -0.017 to –0.089) for all but Low mortality (r_d = +0.036). Although only a small decrease, under Low mortality values the population is again predicted to decline by approximately 3 birds (-3.8%) over the 100 years simulation.

Figure 7.1

Population Size (33% male breeding - 1 In 3 Years)



Effects of annual juvenile and adult mortality parameters (Table 6.2) on mean population size at 10-year intervals over 100 years. Male breeding parameter was set at 33 % (1 in 3 years) with two catastrophes and activated inbreeding pressures (Table 7.2).

Figure 7.1 shows the Mission Beach cassowary population is unable to reach the estimated carrying capacity (K) of 100 adult birds regardless of the estimated mortality rates. The population of 79 independent birds (excluding chicks) decreased significantly under Low (4) mortality rates (–21.5%), with the more realistic Moderate (3), High (2), LM Study (1) mortality rates giving striking negative growth rates, with a loss of >81% – >96% of the population over the 100 years period.

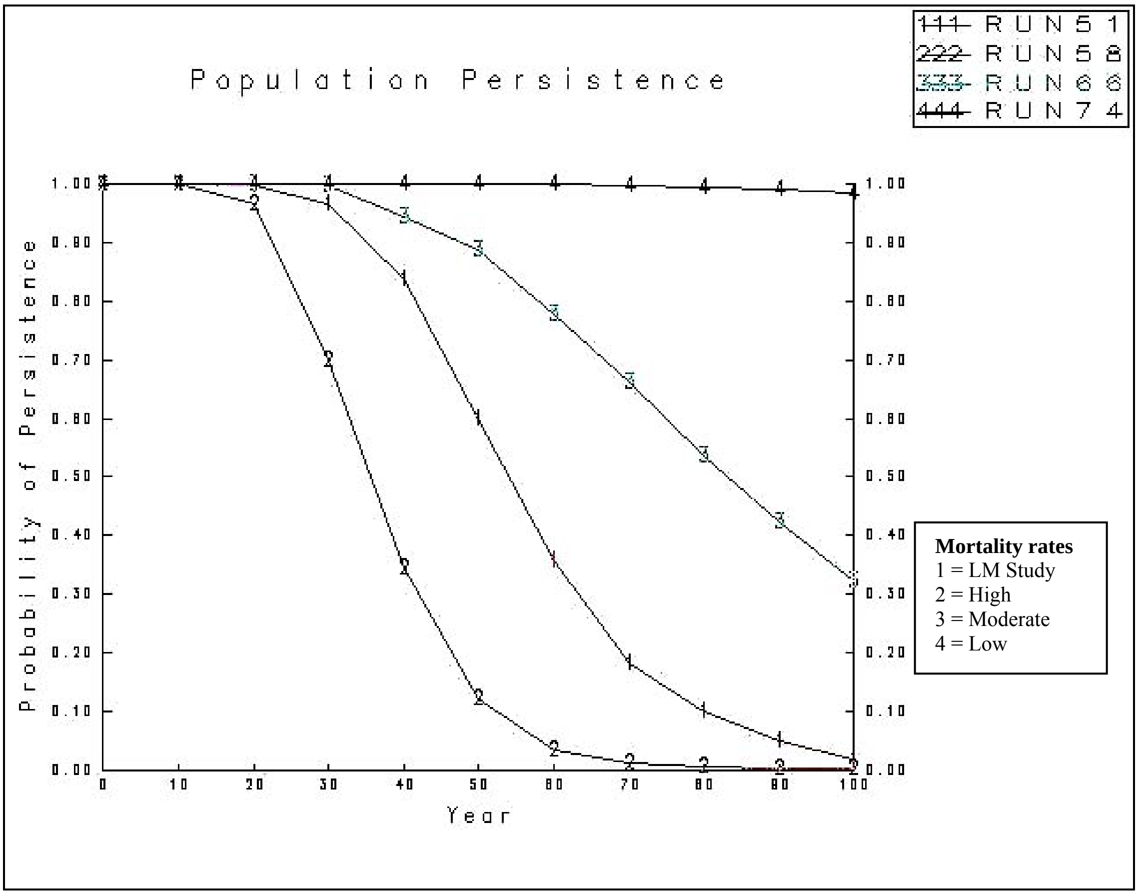
Table 7.3

Summary of results – Inbreeding (33% breeding)

Simulation identifier	Population size after 100 years	Population growth
1 = Run 51 (**Study** mortality estimates).	Approx. 5.5 birds extant	**- 93%**.
2 = Run58 (**High** mortality estimates)	Approx. 3 birds extant	**- 96.2%**.
3 = Run 66 (**Moderate** mortality estimates).	Approx. 14.5 birds extant	**- 81.6%**.
4 = Run 74 (**Low** mortality estimates).	Approx. 62 birds extant	**- 21.5%**

Figure 7.2

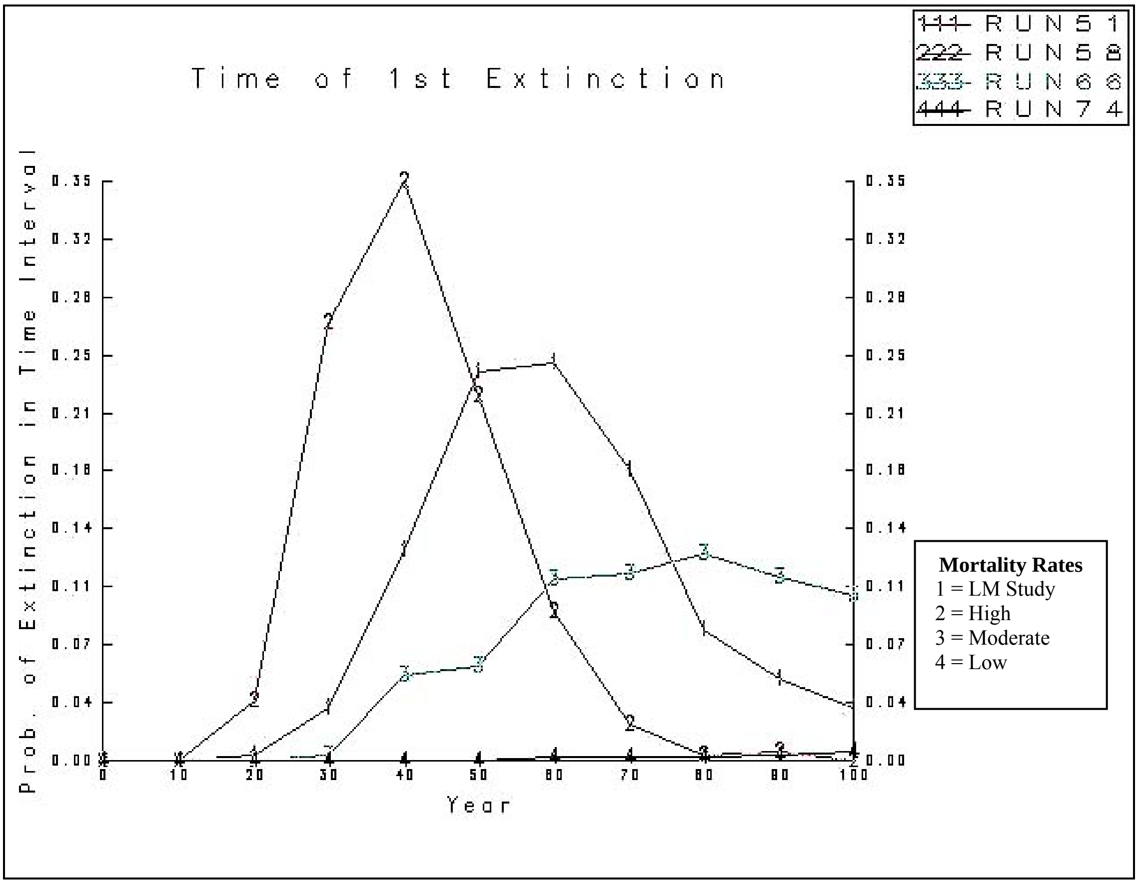
Population Persistence (33% male breeding)



Effects of juvenile and adult mortality parameters (Table 6.2) on population persistence. Male breeding = 33 % with two catastrophes and active inbreeding pressures (Table 7.2). The Low (4) mortality scenario was the only simulation certain to persist over the 100 years period but at 80% of its original population size.

Figure 7.3

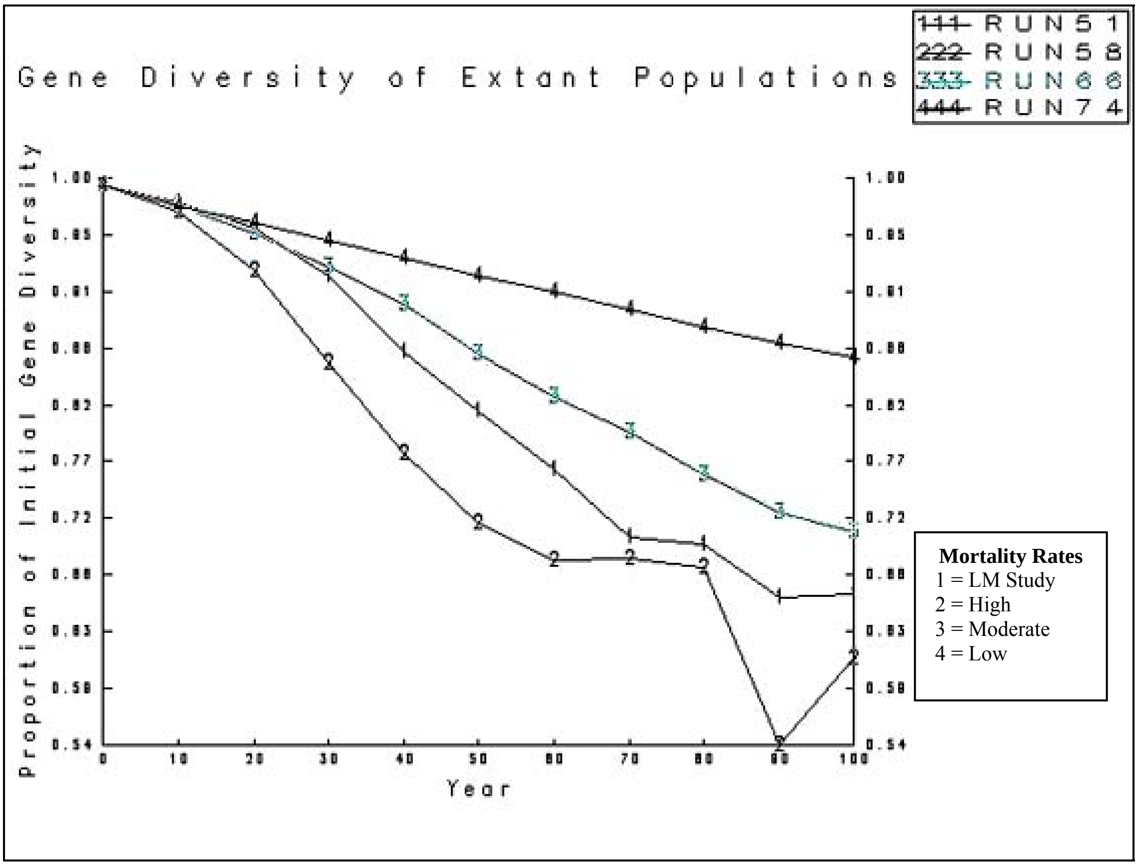
Time to 1st Extinction (33% male breeding)



Mean time to extinction for those simulated populations that became extinct. The probability of extinction (PE) at Low mortality (4) was 16%, while PE ranged from 68% (3 – Moderate mortality) to 99.8% (2 - High mortality) over the100 years period. The time to extinction for these latter mortality levels varied from 37-70 years.

Figure 7.4

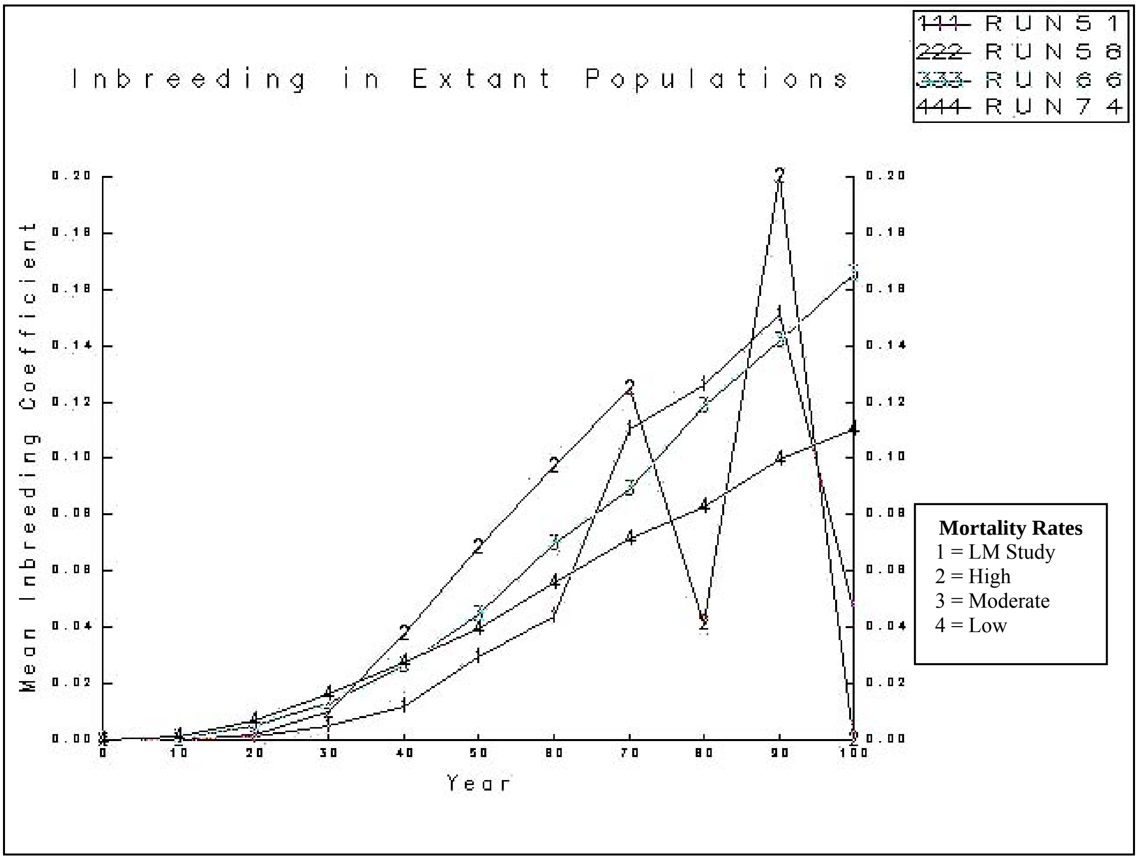
Gene Diversity (33% male breeding)



The degree of heterozygosity in the population decreased significantly after 100 years, with only 61 –71% of the original heterozygosity remaining in the Moderate (3), High (2), and Study (1) mortality simulations. Interestingly, even the Low (4) mortality simulation expressed a significant decrease in heterozygosity, to only 85.4% of its original base.

Figure 7.5

Inbreeding (33% male breeding)



Inbreeding becomes a significant factor within the Mission Beach population after approximately 30 years when the population has dropped to below half its current size.

7.1.2 50% male breeding (1 in 2 year cycle))

The data summaries for this simulation are presented in Table 7.2 and Table 7.5. Graphical displays of results are given with accompanying comment in Figures 7.6-7.9.

High–Moderate mortality–LM Study estimates–Catastrophes

Simulating 50% breeding (1 in 2 year cycle) increased deterministic growth rate by 20% (LM Study estimates) to 72% (Moderate mortality). Nonetheless, in the presence of catastrophes and with 50% of the male population breeding in a given year, deterministic growth rates still remained negative (r_d = -0.003 to -0.08). This negative growth culminated in a probability of extinction (PE) from 30.0% to 99.8% within the 100 years simulation, and a mean time to extinction (TE) of 43 to 75 years. Due to the greater number of breeding cycles, the degree of heterozygosity in the population after 100 years is lower than that of the 1 in 3 year cycle *ie* between 61.0% to 75.0% of its original base, with a mean predicted population size of only 2 to 28 birds.

Stochastic growth generally remained strongly negative although at a higher rate (13%) than deterministic growth rate. This difference indicates that the increased breeding rate does little to reduce the threat to population persistence posed by the severe deterministic decline.

Low mortality and catastrophes

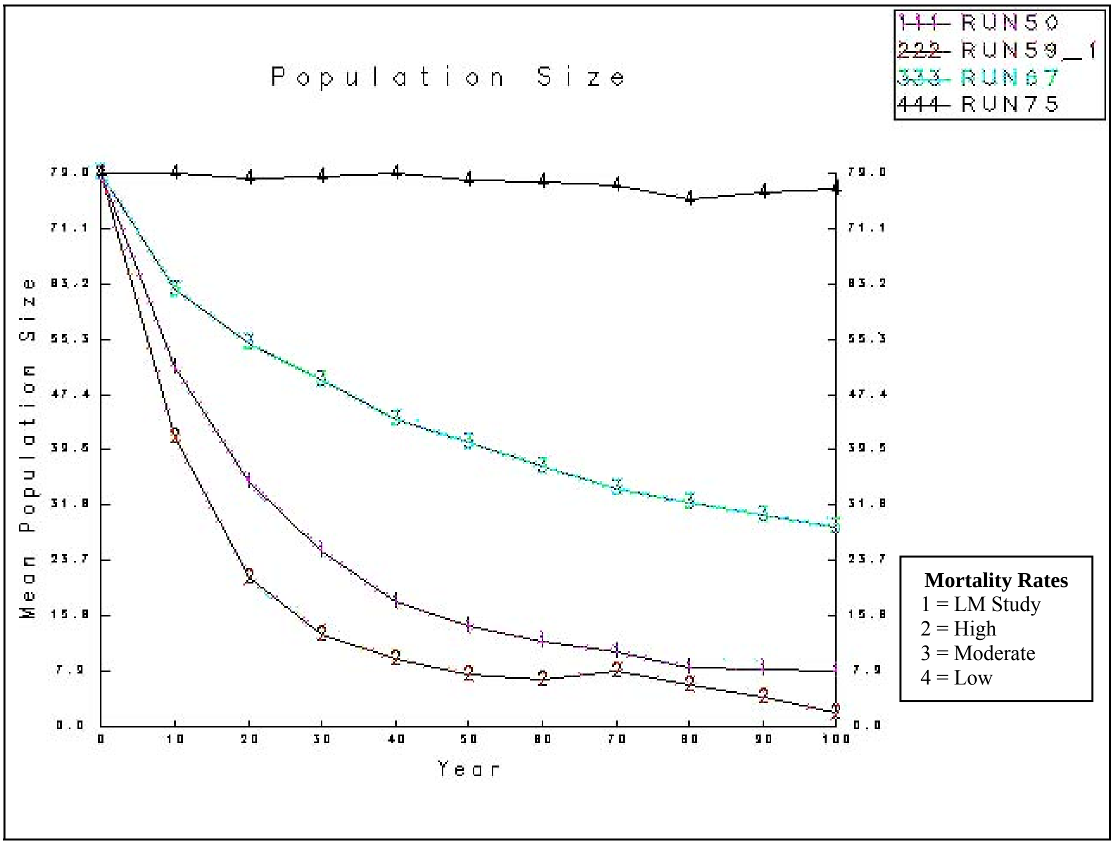
Under Low mortality the deterministic growth rate of males who breed once in two years (50%) is double that of birds that breed at a 1 in 3 year cycle (33%) *ie* an r_d of +0.55 compared to +0.024. The mean population size at this low mortality level, nonetheless, is still predicted to decline by 2 birds (-2.5%) over the 100 years simulation. The predicted heterozygosity over this period is similar to that of 33% breeders *ie* 85% of its original base.

No Catastrophes

In the absence of catastrophes in this simulation, deterministic growth rates for High and LM Study mortality estimates increase by 14% to 24%, but continue to remain strongly negative (r_d = -0.036 to –0.069). Interestingly, deterministic growth for Moderate mortality without catastrophes shifts from negative to positive growth (–0.003 to +0.008). Simulated Low mortality values without catastrophes increase deterministic growth rates (r_d = +0.067) so that population size increases +5.06% (+four individuals). Notwithstanding, the small population size is reflected in the decrease in heterozygosity to below 87%.

Figure 7.6

Population Size (50% male breeding)



Male breeding parameter set at 50% (1 in 2 years) with two catastrophes and active inbreeding pressures (Table 7.2). Effects of annual juvenile and adult mortality parameters on mean population size are shown at 10-year intervals over 100 years. This simulation indicates that the Mission Beach cassowary population is unable to reach the estimated carrying capacity (K) of 100 adult birds even at Low (4) mortality rates.

Table 7.4

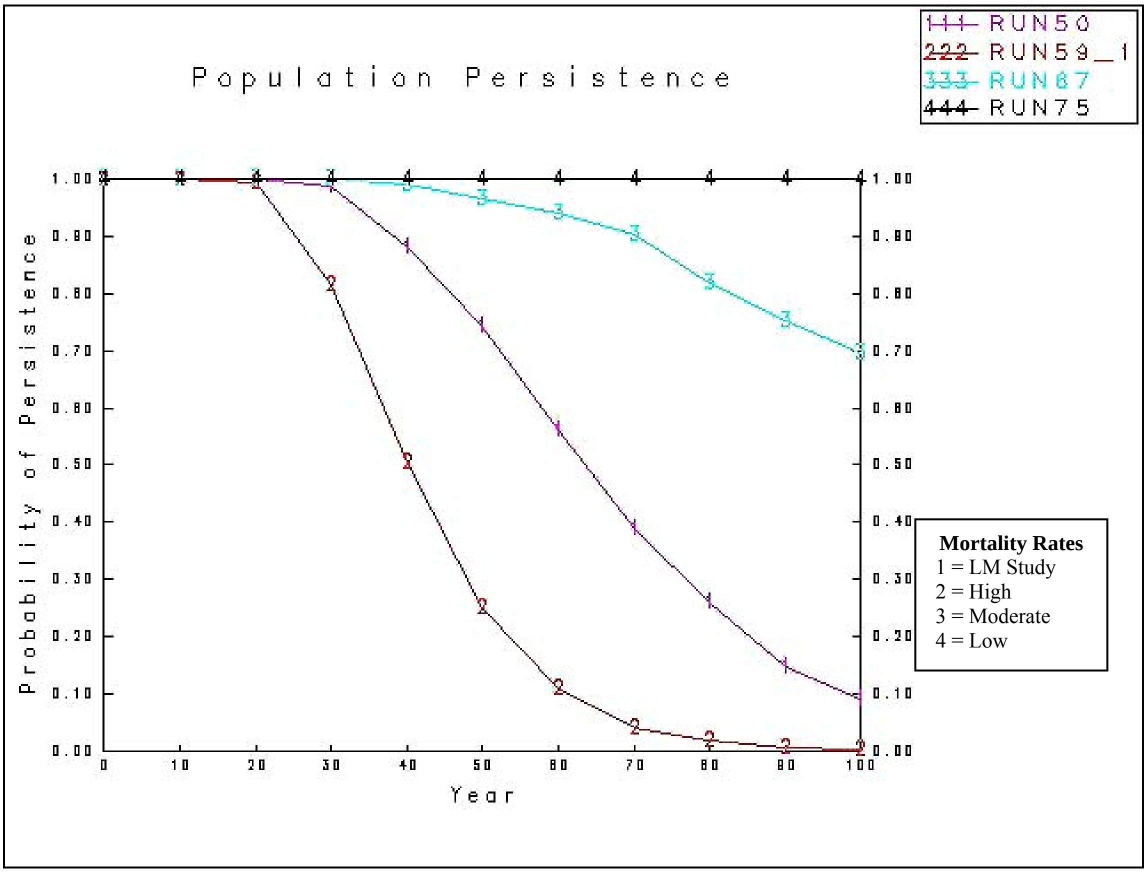
Summary of results – Inbreeding (50% male breeding)

Simulation identifier	Population size after 100 years	Population growth
1 = Run 50 (**Study** mortality estimates).	Approx. 8 birds extant	**- 90%**.
2 = Run59_1 (**High** mortality estimates)	Approx. 2 birds extant	**- 97.5%**.
3 = Run 67 (**Moderate** mortality estimates).	Approx. 28 birds extant	**- 64%**.
4 = Run 75 (**Low** mortality estimates).	Approx. 76 birds extant	**- 3%**

The Mission Beach cassowary population did not increase above its current size even under Low (4) mortality rates, where it declined by 3%. The more realistic Moderate (3) –High (2) –Study (1) mortality rates show striking negative growths beginning almost immediately and accelerating from 20 years onwards.

Figure 7.7

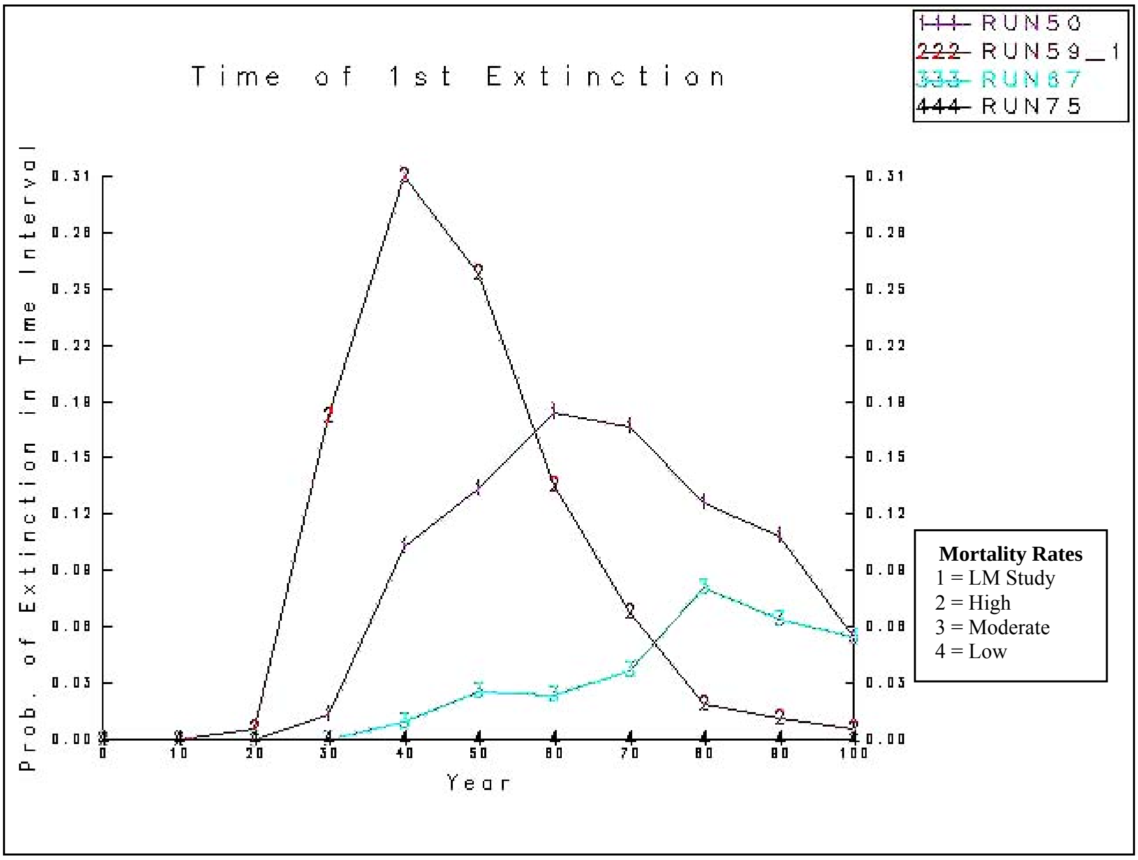
Population Persistence (50% male breeding)



Study (1) and High (2) mortality estimates show a 91-100% probability of extinction over the 100 years period, while Moderate (3) mortality levels provide the population with a 70% probability of surviving, albeit with only 29 individuals remaining from the original population of 79 *ie* a **population decline of 63%**. Low (4) mortality maintained a relatively stable population with a predicted loss of only 2-3 birds.

Figure 7.8

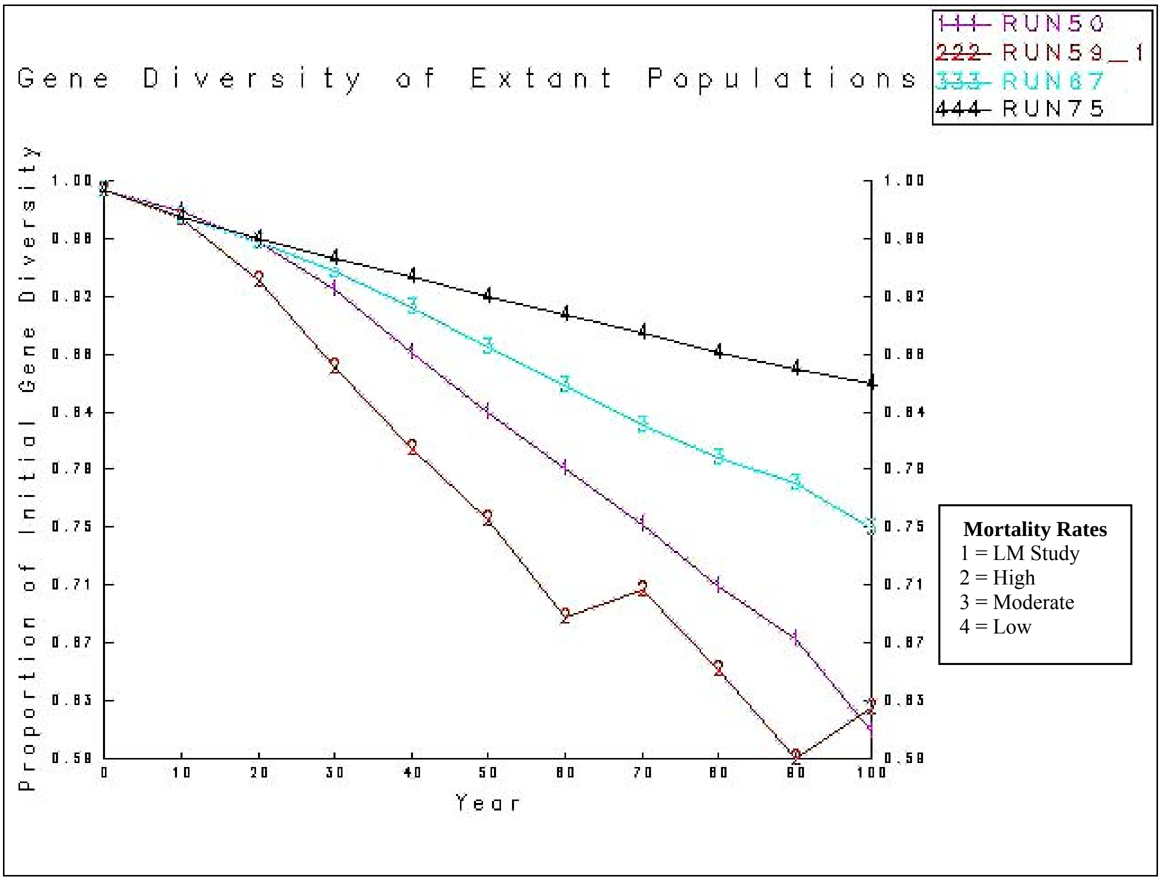
Time to 1st Extinction (50% male breeding)



With the probability of extinction (PE) ranging from 31% (Moderate mortality) to 99.8% (High mortality) over the 100 years simulation, the mean time to extinction was predicted to be between 43-75 years. The probability of extinction (PE) under Low mortality rates is 0%.

Figure 7.9

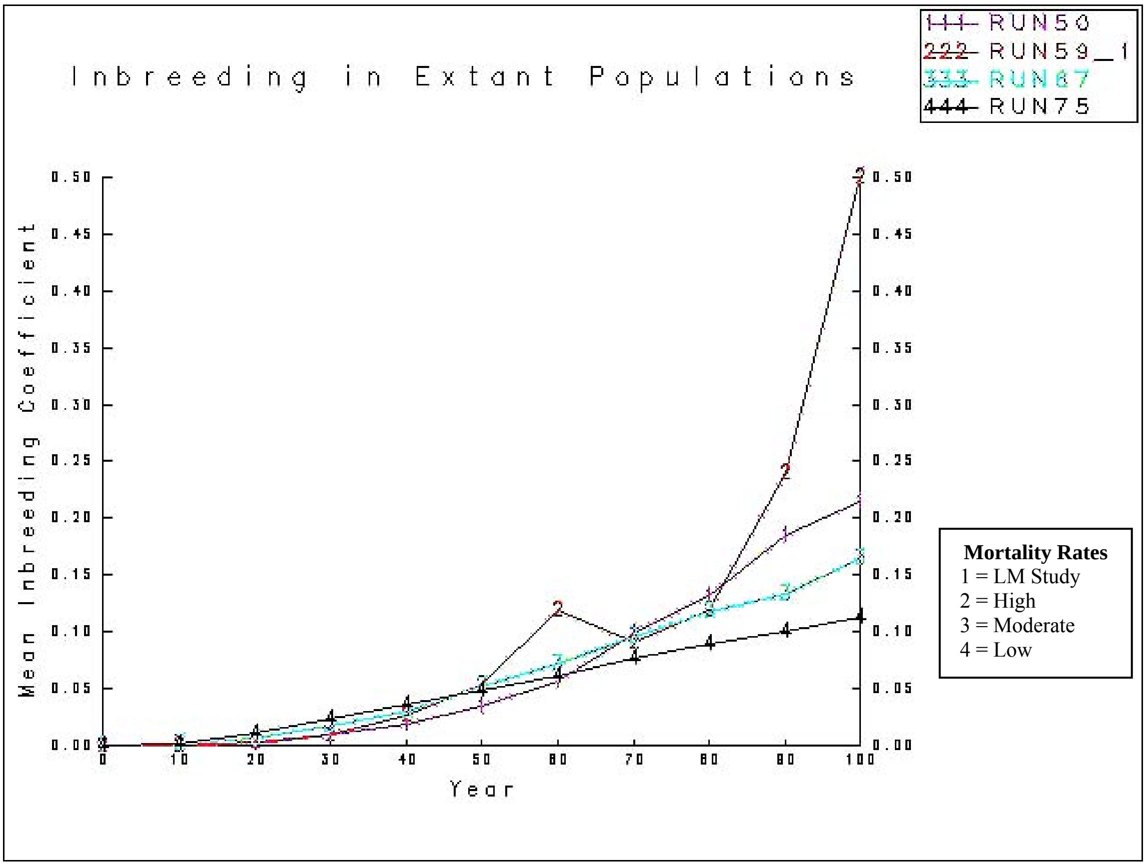
Gene Diversity (50% male breeding)



Heterozygosity in the Mission Beach population decreased significantly after 100 years, declining to 61% –75% in the Moderate, High, and Study mortality simulations. Surprisingly, even the Low mortality simulation expressed a significant decrease in heterozygosity, dropping to only 85.4% of its original base. This genetic effect is similar to that reflected in Figure 7.4 (*ie* 33% male breeding).

Figure 7.10

Inbreeding (50% male breeding)



Inbreeding with 50% male breeding *ie* breeding once in 2 years appears to become a factor within the Mission Beach population after approximately 60 years, twice that time period for birds who breed once in 3 years.

7.1.3 Summary of Baseline modelling – inbreeding depression

The Mission Beach cassowary population is in deterministic decline (deaths outpace births and immigration) and the influences of stochastic factors are heavily outweighed as a threat to population persistence by this decline. As a result, the extinction of the Mission Beach cassowary population is virtually certain under High, Moderate, and LM Study mortality values. The probabilities of extinction (PE) generated by VORTEX range from 30% – 99.8%, with a predicted mean time to extinction between 37 to 70 years. Of considerable importance is the overall decrease in heterozygosity, with the original genetic variation declining to between 61.0% to 75.0% of its original base in both 33% and 50% breeding scenarios.

Simulating 50% breeding (1 in 2 year cycle) increased deterministic growth rate by a factor of 20% (LM Study estimates) to 72% (Moderate mortality). Nonetheless, in the presence of catastrophes and with 50% of the male population breeding in a given year, deterministic growth rates still remain negative (r_d = -0.003 to -0.08). However, Low mortality rates combined with 50% breeding more than doubled the deterministic growth rate from +0.024 to +0.055. This indicates that there is >50% reduction in deterministic growth rate if male cassowaries are able to breed only once in 3 years.

In the presence of the baseline parameters presented in Section 8.2.1, the persistence of Mission Beach cassowary population over the 100-year simulation requires Low Mortality rates across all age classes and male cassowaries to breed once in every two years. Notwithstanding, this persistence was only achieved with a population decline of 21.5% (a loss of 17 independent birds), and a significant genetic reduction of approximately 14%. If catastrophes are eliminated, deterministic growth increases by about 12%. Regardless, all mortality scenarios still resulted in a strong population decline of –0.4% to greater than -1.0% per year. It should be emphasised, moreover, that the Low Mortality rates used in these analyses are not considered realistic, and the results from this parameter are better viewed as a theoretical benchmark or management target.

The results of these Baseline models indicate that such a small population of cassowaries is not capable of supporting itself if isolated. An effective level of immigration, therefore, is likely to be important for the long-term persistence of the species at Mission Beach.

7.2 Baseline modelling - no inbreeding depression

It is considered that in such a small population of cassowaries inbreeding depression will significantly hasten the extinction VORTEX. Thus, inbreeding effects were excluded from the following simulations to evaluate the influences of this parameter on the Mission Beach population. The remaining Baseline parameters were unchanged. The data summaries for this model are presented in Table 7.5 and an assessment of observed inbreeding effects on population size using the results of the 33% (1 in 3 year) breeding cycle is presented in Table 7.6. A graphical display of the resultant population size over the 100-year simulation is shown in Figure 7.11.

Table 7.5

Cassowary population viability: Initial population size (N_0) = 79: K=100; No inbreeding depression

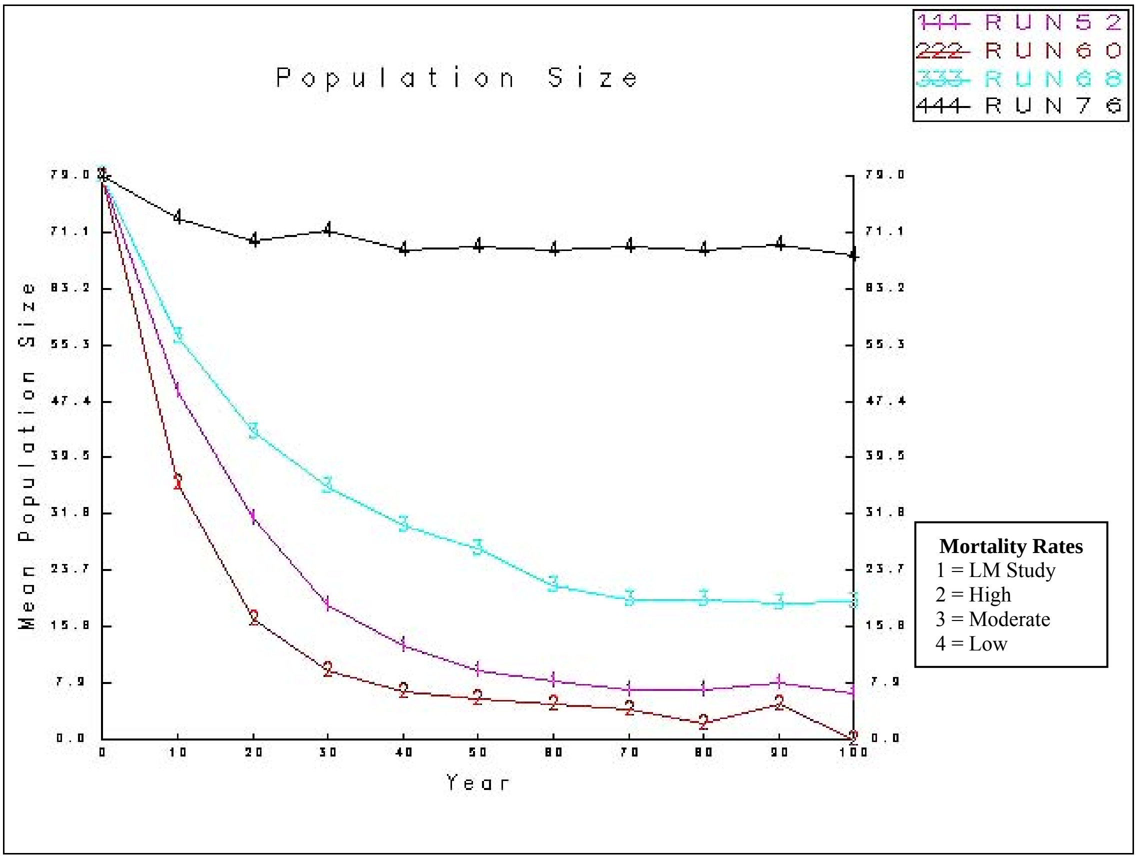
Note: These statistics are based on 500 simulations over 100 years.
For 10-year summaries of data refer to individual RUNS in Appendix Two.
[1] Mortality rates are from Table 6.2.
No recruitment.

File	% Breeding*	Mortality[1] rates	det.r	stoc.r	SD(r)	PE	N-extant	Het	Mean TE
Catastrophes									
RUN52	33	LM	-0.067	-0.052	0.274	0.968	6.44	0.6291	56.1
RUN60	33	H	-0.101	-0.081	0.298	1	0	0	38.7
RUN68	33	M	-0.029	-0.025	0.274	0.578	19.38	0.6932	69
RUN76	33	L	0.024	0.025	0.202	0.006	67.76	0.8473	68
RUN53	50	LM	-0.047	-0.039	0.309	0.854	9.45	0.6469	63.6
RUN61	50	H	-0.08	-0.068	0.335	0.998	4	0.5938	43.9
RUN69	50	M	-0.003	-0.004	0.284	0.224	36.55	0.7568	73.3
RUN77	50	L	0.055	0.055	0.207	0.002	80.45	0.8455	56
No Catastrophes									
RUN56	33	LM	-0.056	-0.042	0.267	0.868	7.58	0.6775	64.5
RUN64	33	H	-0.089	-0.07	0.293	1	0	0	43.1
RUN72	33	M	-0.017	-0.012	0.252	0.23	29.79	0.7685	75.8
RUN80	33	L	0.036	0.039	0.181	0	77.48	0.8705	0
RUN57	50	LM	-0.036	-0.029	0.294	0.664	16.98	0.7139	69
RUN65	50	H	-0.069	-0.058	0.33	0.984	4.13	0.5419	49.4
RUN73	50	M	0.008	0.011	0.262	0.038	50.93	0.8072	73.7
RUN81	50	L	0.067	0.069	0.187	0	83.83	0.8537	0

*33% = breeding once in 3 years; 50% = breeding once in two years

Figure 7.11

Population Size – No inbreeding (33% breeding)



100 years population projection for simulated Mission Beach cassowary population in the presence of NO inbreeding, male breeding parameter set at **33 %** (1 in 3 years), with two catastrophes (Table 7.5). Effects of annual juvenile and adult mortality parameters on mean population size are shown at 10-year intervals over 100 years.

Table 7.6

% Inbreeding effects (33% male breeding)

Simulation identifier	POPULATION SIZE			
	Inbreeding[4]	No Inbreeding[5]	Inbreeding effect/100 years	No. birds/100 years
1 (**Study** mortality)	-92.8%	- 91%.	1.8%	-0.7
2 = (**High** mortality)	-96.2%	- 100%.	3.8%	-3
3 = (**Moderate** mortality)	-81.8%	- 76%.	5.6%	-4.5
4 = (**Low** mortality).	-21.6%	- 14%	7.5%	-6

7.2.1 Effect of inbreeding depression on the decline of Mission Beach cassowaries

The data show lower impacts of inbreeding depression (approximately 2-4%) at higher mortality rates, presumably due to the more rapid loss of individuals and a reduced persistence. However, inbreeding effects double at lower mortality rates to influence population persistence by approximately 5-8%.

7.3 Adult mortality

It is probable that the decline of adult cassowaries at Mission Beach (and elsewhere) is strongly related to human activities *ie* habitat clearing, road death, dog attack, and shooting, all human-derived pressures. Thus a range of adult mortality figures were simulated (Table 7.7) to measure the effect of differing rates of adult mortality on the population persistence of the Mission Beach cassowaries.

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[4] Refer Table 7.2
[5] Refer Table 7.5

Table 7.7

Simulated adult cassowary mortality rates

Mortality rate %	Adult deaths\year
0	0
1	0.5
2	1.0
3	1.5
4	2.0
5	2.5

The remaining key parameters were derived from the Baseline modelling and are listed below:

- No catastrophes;
- Two catastrophes: Catastrophe 1: 3% - Reproduction 0.25, Survival 0.75
  Catastrophe 1: 1% - Reproduction 0.50, Survival 0.75;
- 33% breeding males (1 in 3 years);
- 50% breeding males (1 in 2 years);
- 100% females in breeding pool;
- K = 100;
- Total Population = 79;
- Not age-stable population;
- Inbreeding depression;
- Adult mortality as per Table 7.7;
- Juvenile and subadult mortality = Moderate (Table 6.2);
- All other parameters as per previous simulations.

The data summaries for this simulation are presented in Table 7.8 and an assessment of observed inbreeding effects on population size using the results of the 33% (1 in 3 years) and 50% (1 in 2 years) breeding cycle is presented in Table 7.9. A graphical display of the resultant population size over the 100-year simulation is shown in Figures 7.12 -7.15.

Table 7.8

Effects of adult mortality: Initial population size (N_0) = 79: K=100; Inbreeding depression

Note: These statistics are based on 500 simulations over 100 years.

For 10 year summaries of data refer to individual RUNS in Appendix Two.

[1] Mortality rates (M) are from Table 6.2.

No recruitment.

File	% Adult mortality	Mortality[1]	det.r	stoc.r	SD(r)	PE	N-extant	Het	MeanTE
Catastrophes - 33% Breeding									
RUN201	0	M	0.008	0.009	0.227	0.044	50.35	0.8682	81.7
RUN201_1	1	M	0	0.002	0.232	0.060	41.1	0.8435	77.4
RUN201_2	2	M	-0.007	-0.006	0.235	0.148	32.62	0.8112	77.5
RUN201_3	3	M	-0.015	-0.014	0.243	0.272	23.57	0.7837	75.9
RUN201_4	4	M	-0.022	-0.022	0.249	0.47	19.54	0.7349	73.4
RUN201_5	5	M	-0.029	-0.031	0.256	0.698	12.85	0.6822	70.1
No Catastrophes – 33% breeding									
RUN201A	0	M	0.019	0.024	0.212	0.002	68.07	0.898	88
RUN201B	1	M	0.012	0.015	0.215	0.002	59.73	0.8856	99
RUN201C	2	M	0.004	0.009	0.216	0.02	53.39	0.8712	79.5
RUN201D	3	M	-0.003	0	0.22	0.056	39.78	0.8383	84.2
RUN201E	4	M	-0.01	-0.009	0.226	0.152	27.5	0.7947	78.7
RUN201F	5	M	-0.018	-0.018	0.234	0.328	20.69	0.7648	76.2
Catastrophes - 50% Breeding									
RUN200A	0	M	0.031	0.03	0.25	0.004	66.32	0.8771	83.5
RUN200B	1	M	0.024	0.022	0.253	0.01	59.26	0.8643	67.8
RUN200C	2	M	0.017	0.014	0.254	0.028	52.87	0.8488	79.2
RUN200D	3	M	0.01	0.006	0.258	0.086	44.25	0.8261	74.2
RUN200E	4	M	0.003	-0.002	0.263	0.152	37.4	0.7971	77.9
RUN200F	5	M	-0.004	-0.009	0.267	0.266	30.21	0.7682	74
No Catastrophes – 50% breeding									
RUN200_0	0	M	0.043	0.045	0.239	0	75.78	0.8908	0
RUN200_1	1	M	0.036	0.036	0.238	0	72.52	0.8869	0
RUN200_2	2	M	0.029	0.028	0.238	0	67.3	0.8761	0
RUN200_3	3	M	0.022	0.021	0.239	0.004	61.12	0.8663	76
RUN200_4	4	M	0.015	0.013	0.242	0.024	52.68	0.8479	74.8
RUN200_5	5	M	0.007	0.005	0.244	0.05	43.93	0.8238	79.6

*33% = breeding once in 3 years; 50% = breeding once in two years.

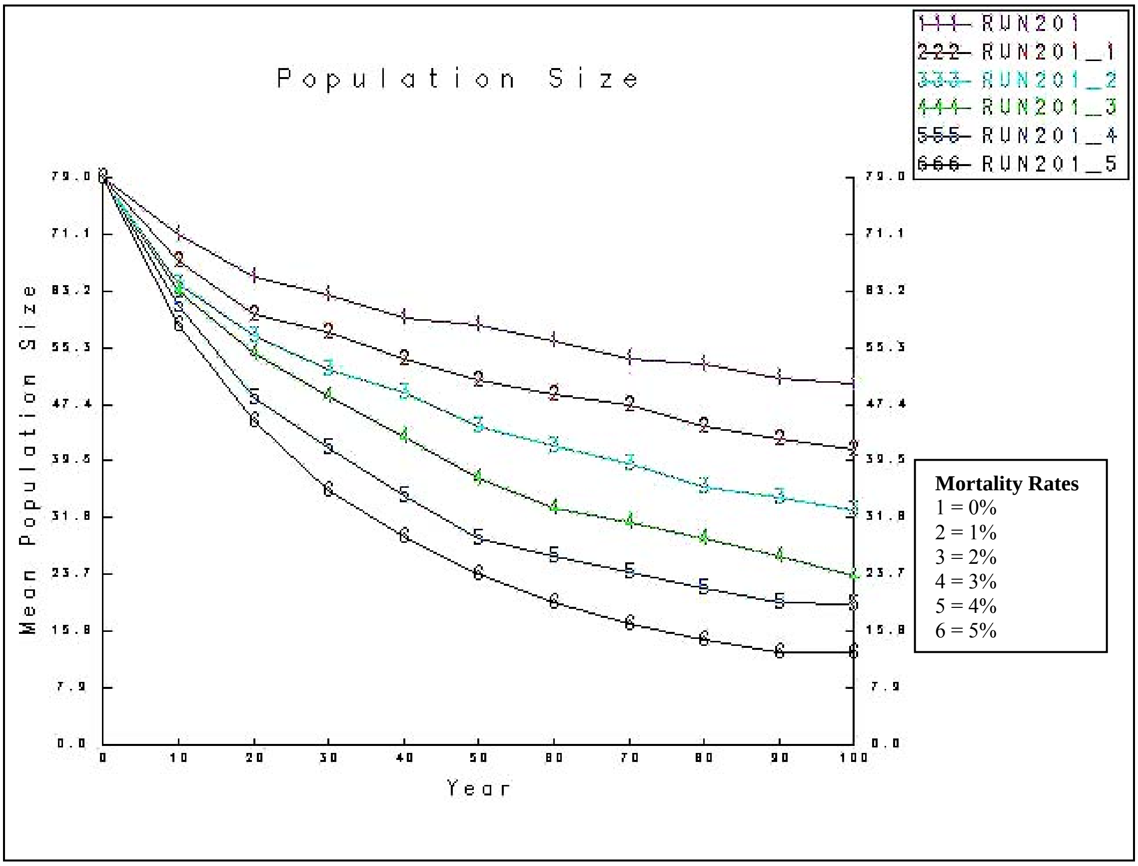
Table 7.9

Summary of adult mortality simulations - Inbreeding depression; (33% male breeding)

Simulation identifier (Adult mortality rates)	Population size after 100 years (independent birds)	Population growth
33% breeding		
1 = Run 201 (0%)	50	**- 32.7%**.
2 = Run 201_1 (1%)	41	**- 48.1%**.
3 = Run 201_2 (2%)	33	**- 57.2%**.
4 = Run 201_3 (3%)	24	**- 69.6%**
5 = Run 201_4 (4%)	20	**-74.7%**
6 = Run 201_5 (5%)	13	**-83.5%**
50% breeding		
1 = Run 200A (0%)	66	**- 16.4%**.
2 = Run 200B (1%)	59	**- 25.1%**.
3 = Run 200C (2%)	53	**- 32.9%**.
4 = Run 200D (3%)	44	**- 44.3%**
5 = Run 200E (4%)	37	**-53.2%**
6 = Run 200F (5%)	30	**-62%**

Figure 7.12

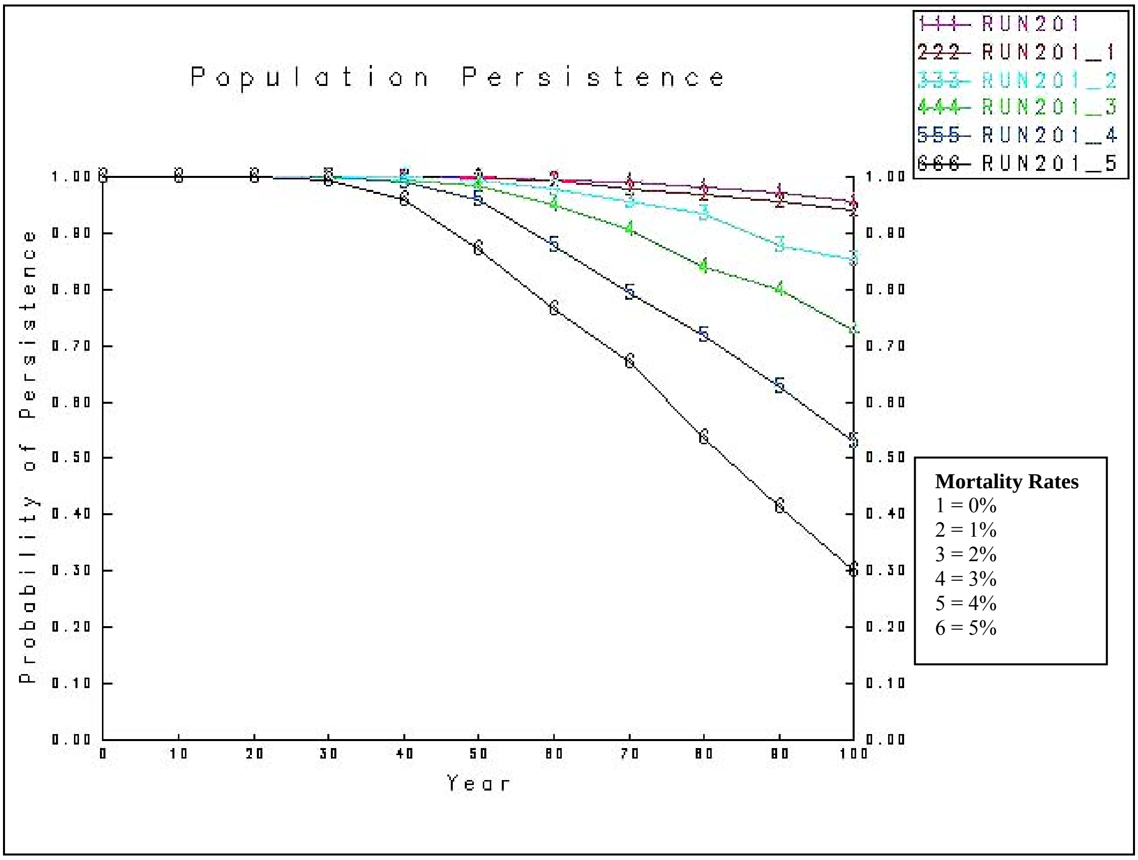
Population Size - Adult mortality (inbreeding depression)



Male breeding set at **33 %** (1 in 3 years) and with two catastrophes. Effects of annual juvenile and adult mortality parameters on mean population size are shown at 10-year intervals over 100 years.

Figure 7.13

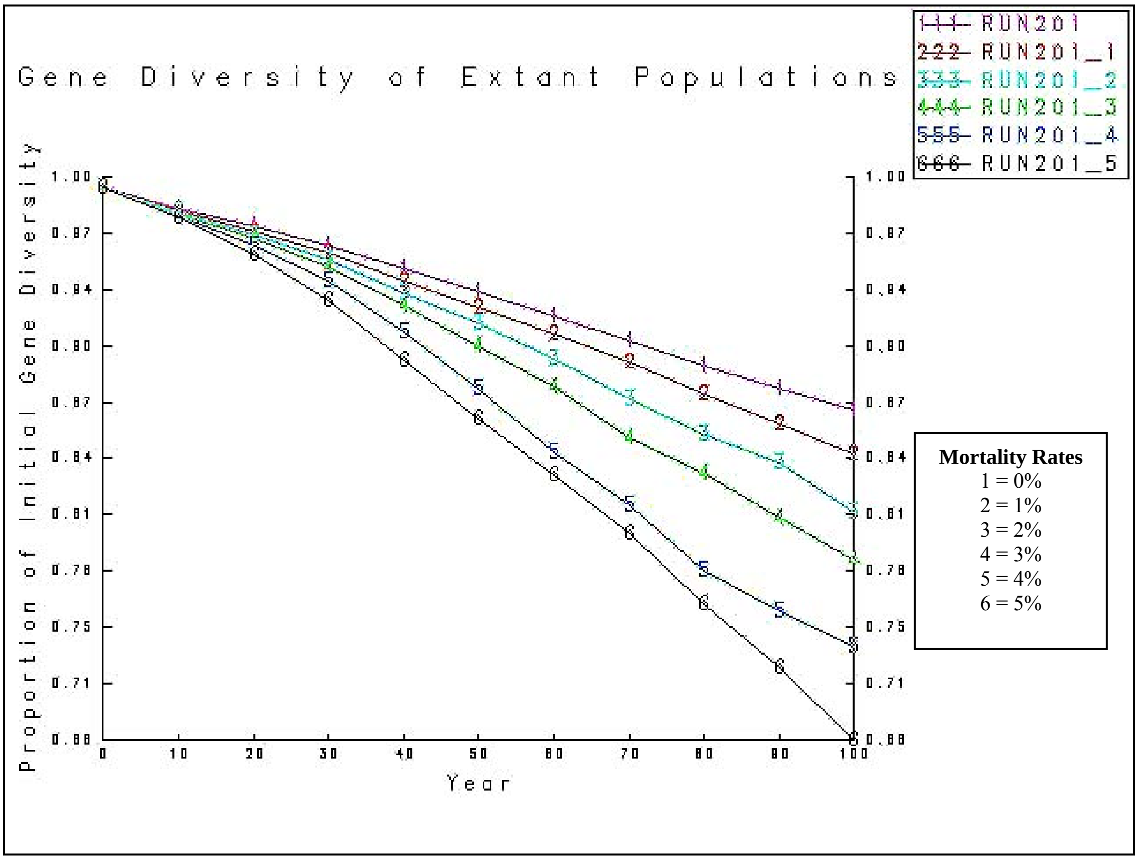
Population Persistence - Adult mortality (inbreeding depression - 33% male breeding)



Effects of varying adult mortality rates on cassowary population persistence are shown at 10-year intervals over 100 years. Male breeding set at **33 %** (1 in 3 years) and with two catastrophes. Persistence probability decreases even with 0% adult mortality and drops sharply when >2%.

Figure 7.14

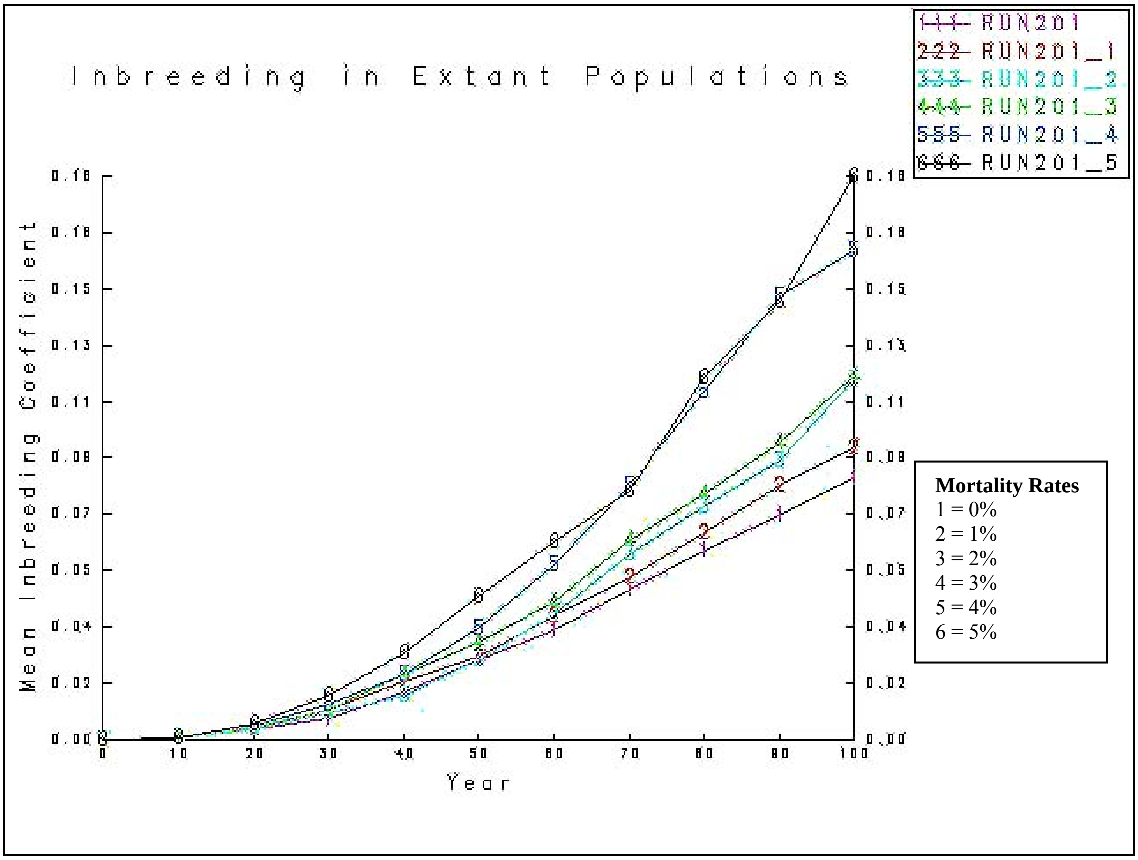
Gene diversity - Adult mortality (33% male breeding)



100 years population projections for Mission Beach cassowaries in relation to varying adult mortality rates. Male breeding set at 33 % (1 in 3 years) with two catastrophes and inbreeding pressures. Apart from a slightly lesser decline at 50% breeding, there was little difference between the two male breeding intervals (*ie* 33% & 50%).

Figure 7.15

Inbreeding - Adult mortality (33% male breeding)



100 years population projections for Mission Beach cassowaries in relation to varying adult mortality rates. Male breeding was set at 33 % (1 in 3 years) with two catastrophes and inbreeding depression. The inbreeding effect is similar from 0% to 3% but then curves sharply from 4% - 5%.

7.3.1 Effect of adult mortality rates on Mission Beach cassowary population

These simulations suggest that adult mortality rate is a significant element affecting the viability of the cassowary population at Mission Beach.

33% male breeding

At 2 % adult mortality (1.6 birds/year) and breeding once in 3 years, the independent population declines by >57% (- 44 birds). At 5% adult mortality the population loses approximately 66 birds (>83 %). The population decline, although not proportionate, is generally 7-10% per 1% percentage adult mortality increase (mean = 7.6% per 1% adult mortality).

50% male breeding

In the presence of a 50% breeding cycle (1 in 2 years – considered atypical), the population declines over the 100 years population projection by 33% (loss of 26 birds) at 2 % adult mortality. At 5% mortality rates this decline more than doubles to –62% (loss of 49 birds). The population decline per 1% percentage adult mortality increase is similar to that occurring at the lower breeding rate *ie* 6-10% (mean = 7.2% per 1% adult mortality).

Accordingly, the negative deterministic and stochastic growth rates reflected in this simulation support the conclusion of little change in the final population prognosis. To illustrate the point, the cassowary population size at Mission Beach is predicted to decrease 16.5% to 32.7% even in the presence of 0% adult mortality (50% and 33% breeding cycles respectively). This finding suggests that in the absence of effective immigration, the effects of inbreeding depression *ie* deleterious alleles and/or other genetic disadvantages, will play a significant role in the decline of the Mission Beach cassowary population.

7.4 Immigration

All prior simulations indicate that the significant decline of the cassowary population at Mission Beach may be exacerbated or caused by genetic complications resulting from a lack of adequate immigration into the area. To assess the level of immigration required to maintain population size and thus genetic diversity, immigration scenarios were simulated using the Baseline input parameters outlined in Chapter 6.1 and the "Supplement" parameter in VORTEX. The age of preferred immigrants was set at 3-4 years, the age group that has survived the higher mortality offspring period while yet to develop territorial fidelity typical of older birds.

Summary results of the simulation models are given in Tables 7.10 – 7.11. A graphical summary of the effect of immigration on population size over a 100 years population projection is presented in Figure 7.16. A comparison of the effects on population size of the successful immigration of four birds per year (2 females/2 males) into Mission Beach with a scenario of no immigration is presented in Figure 7.17. The simulation was run over a 500 year population projection period.

Table 7.10

Effect of immigration into the MB population
Inbreeding depression (Heterosis model: 3.14 lethal equivalents)
Initial population size (N_0) = 79: K=100

Catastrophe 1: 3% - Reproduction 0.25, Survival 0.75
Catastrophe 1: 1% - Reproduction 0.50, Survival 0.75
100% females in breeding pool
K = 100
TP = 79
Not age-stable population
Inbreeding activated
[1] Mortality rates are from Table 6.2.

Run File	% Breeding*	Mortality[1]	det.r	stoc.r	SD(r)	PE	N-extant	Het	MeanTE
No immigration (from Table 7.2)									
RUN51	33	LM	-0.067	-0.055	0.271	0.98	5.7	0.6629	55.4
RUN58	33	H	-0.101	-0.085	0.296	0.998	3	0.6111	37.2
RUN66	33	M	-0.029	-0.03	0.264	0.676	14.39	0.7128	69.5
RUN74	33	L	0.024	0.02	0.196	0.016	61.93	0.8536	81.9
RUN50	50	LM	-0.047	-0.043	0.297	0.908	7.96	0.6079	62
RUN59_1	50	H	-0.08	-0.07	0.327	0.998	2	0.625	42.9
RUN67	50	M	-0.003	-0.009	0.274	0.304	28.49	0.7527	74.5
RUN75	50	L	0.055	0.048	0.202	0	76.62	0.8554	0
Immigration @ 4 Birds\Year (2M & 2F - <4yo)									
51_supp	33	LM	-0.067	0.008	0.218	0.000	59.84	0.9839	0.0
58_supp	33	H	-0.101	-0.003	0.227	0.000	44.49	0.9807	0.0
66_supp	33	M	-0.029	0.026	0.221	0.000	70.29	0.9807	0.0
74_supp	33	L	0.030	0.070	0.179	0.000	**84.60**	0.9787	0.0
50_supp	50	LM	-0.047	0.016	0.251	0.000	63.37	0.9825	0.0
59_1_supp	50	H	-0.081	0.001	0.263	0.000	48.49	0.9795	0.0
67_supp	50	M	-0.004	0.043	0.246	0.000	74.74	0.9779	0.0
75_supp	50	L	0.060	0.096	0.190	0.000	**87.08**	0.9740	0.0

Run File	% Breeding*	Mortality[1]	det.r	stoc.r	SD(r)	PE	N-extant	Het	MeanTE
Immigration @ 6 Birds\Year (3M & 3F - <4yo)									
66_SUPP_2	33	M	-0.029	0.041	0.205	0.000	78.38	0.9855	0.0
67_SUPP_2	50	M	-0.004	0.060	0.230	0.000	**79.61**	0.9834	0.0
Immigration @ 10 Birds\Year (5M & 5F - <4yo)									
66_SUPP_3	33	M	-0.029	0.072	0.194	0.000	**84.16**	0.9890	0.0
67_SUPP_3	50	M	-0.004	0.091	0.216	0.000	**84.98**	0.9876	0.0

*33% = breeding 1in 3 years; 50% = breeding 1 in two years

A summary of the effect of immigration on the Baseline input parameters is given below in Table 7.11**.** Driven by the immigration of four birds per year, increases in population persistence at higher mortality rates range from 38% to 71%. This increased survival, however, is not sufficient to bring about a positive growth rate, and the population size is still predicted to decrease by 6% (Moderate mortality) to 45% (High mortality). At Low mortality rates the growth rate rises by only 13% - 29%, but this is enough to achieve positive population size increases of approximately six birds at 33% breeding *ie* 7.1%, and nine birds at 50% breeding *ie* 10.3%.

Table 7.11

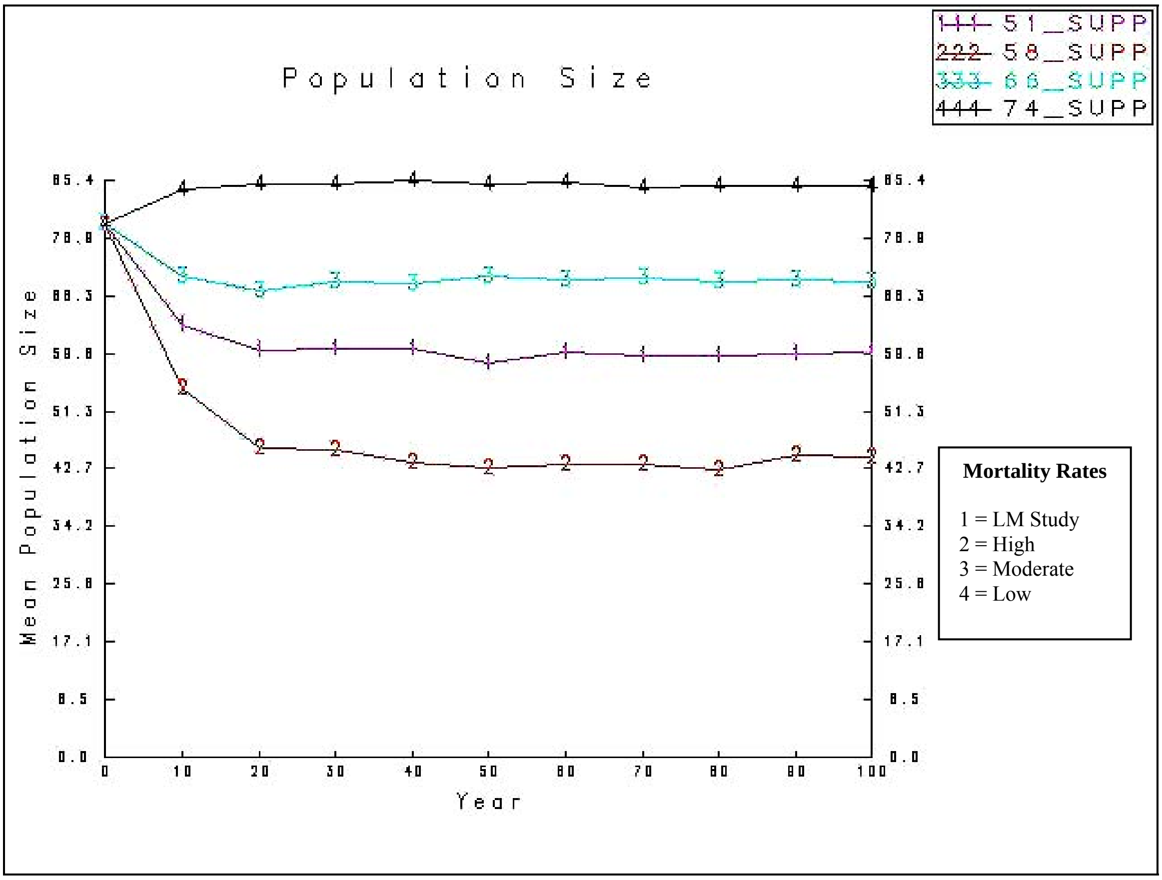
Effects of immigration @ 4 Birds/Year (2M & 2F - <4yo)

Mortality Rates (Table 6.2)	33% breeding			50% breeding		
	No immigration (% change)	4 birds/year (% change)	Effect (%)	No immigration (% change)	4 birds/year (% change)	Effect (%)
1 = **(LM Study**)	-92.8%	- 24.0%.	+68.8	-89.9%	-19.8%	+70.1
2 = (**High**)	-96.2%	- 43.7%.	+52.5	-76.5%	-38.6%	+37.9
3 = (**Moderate**)	-81.8%	- 11.0%.	+70.8	-63.9%	-5.4%	+58.5
4 = (**Low**).	-21.6%	+ 7.1%	+28.7	-3.0%	+10.2%	+13.2

At the conservative Moderate mortality rates (Table 6.2) it required six birds per year (3 males and 3 females <4 years old) to maintain the current population size of approximately 79 independent birds. Increasing immigration rates to 10 birds a year resulted in a predicted population increase of 7.5% over the 100-year simulation *ie* plus 6-7 birds.

Figure 7.16

Effect of immigration on Mission Beach population – 100 years projection (4 Birds\Year (2M & 2F - <4 years old)



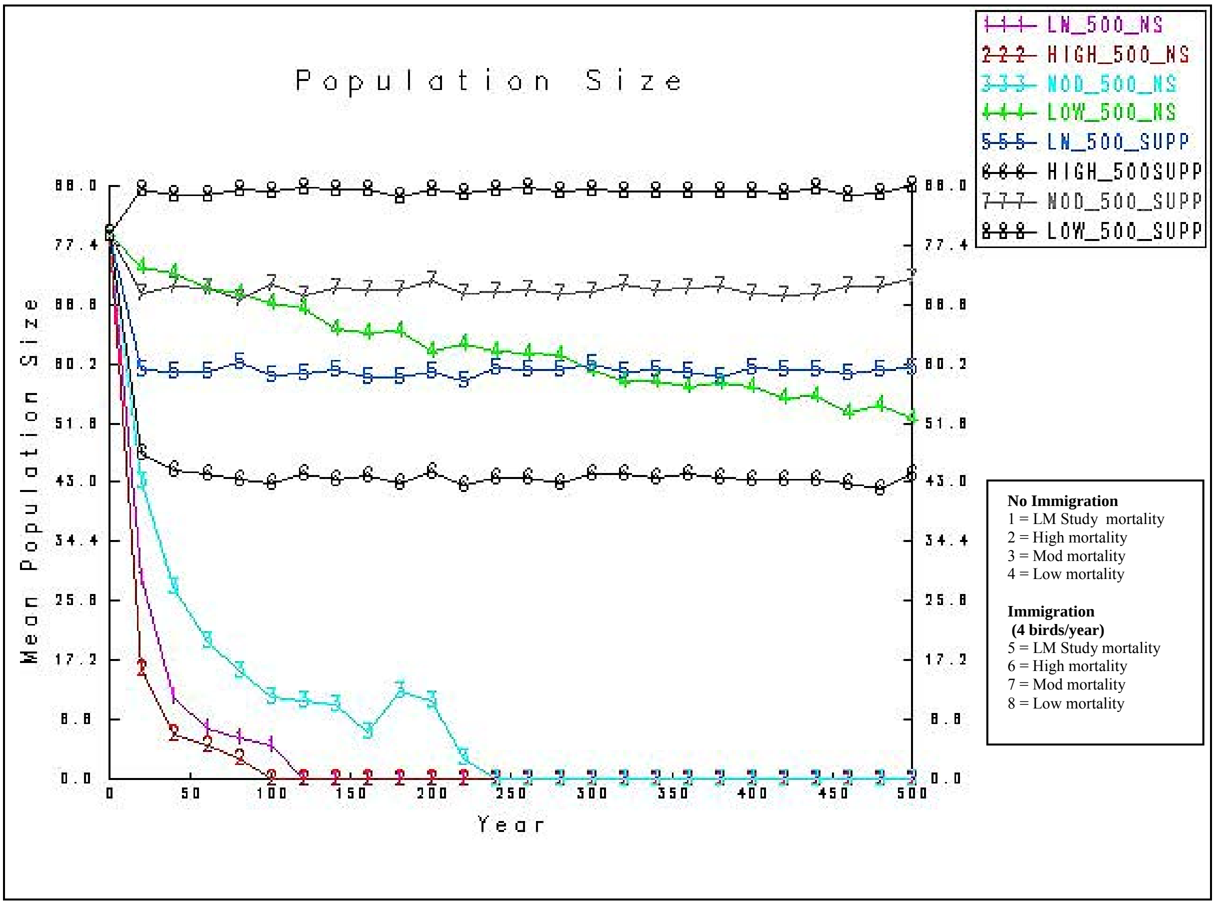
Male breeding set at 33% (1 in 3 years) with two catastrophes and inbreeding pressures. The Baseline input parameters (Chapter 6) were supplemented with 2 males and 2 females <4 years of age every year. The population size of all but the Low mortality rates drops appreciably over a 20 year period before stabilising at a considerably lower level for the remainder of the 100 years simulation. Supplementing the population at Low mortality rates results in an immediate population size increase of approximately 8% in the first 10 years before stabilising at that size which then remains constant for the remainder of the simulation.

7.4.1 Comparison of non-immigration *vs* immigration over 500 years

Due to the long life-spans of cassowaries and the relatively few generations encapsulated within the standard 100 years of iterations used in this PVA, a set of simulations were run over a 500 year projection using the Baseline input parameters described in Chapter 6.1. These scenarios were simulated with and without immigration of 4 Birds\Year (*ie* 2 males and 2 females <4 years old). The graphical results are presented below in Figure 7.17.

Figure 7.17

Comparison of immigration and no immigration on population size (500 year projection)



Male breeding set at 33% (1 in 3 years) using Baseline input parameters (Chapter 7). Graph lines 1-4 represent simulations with NO immigration. Graph lines 5-8 represent simulations supplemented with 4 birds/year.

No immigration (33% breeding)

It can be seen that the population represented by the green line (4 – Low mortality) is still extant after the 500 year projection in the absence of immigration, albeit with 35% decrease in population size. However, extinction is predicted for the remaining non-immigration models at approximately 100 years (High mortality), 120 years (LM Study mortality), and 240 years (Moderate mortality). These populations, however, could be considered to have reached non-viable levels at approximately 30-50 years, and persisting further only due to the long-lived nature of the species (>40years).

Immigration (33% breeding)

Supplementing the Mission Beach population by four birds/year (2 males and 2 females < 4yo) ensures the persistence of the cassowary population over the 500 year projection. Excluding the Low mortality model, however, the population size of all other simulations reduces significantly, by 11% to 44% *ie* a loss of 8 – 34 birds. The population size of the Low mortality model increases by seven birds at 33% breeding *ie* +8.8% [6].

[6] It should be noted that the Low Mortality rates used in these analyses are not considered ecologically realistic, and the results from this parameter are better viewed as a theoretical benchmark or management target.

CHAPTER 8

DISCUSSION

The primary causes of a species decline are usually easy to understand; for example, habitat clearing, road deaths, dog attacks, and disease have all been implicated in cassowary mortality at Mission Beach. Although often easy to study and model, however, primary causes are generally difficult to reverse. Even if the original causes of decline are removed, a small isolated population is vulnerable to additional forces, intrinsic to the dynamics of small populations, which may drive it to extinction (Miller and Lacy 1999). Often the final extinction of small populations occur not so much because of a continuation of the pressures that led to the initial decline, but because of bad luck (Miller and Lacy 1999).

Of particular impact are stochastic, or chance processes, which normally have little influence on long-term population dynamics so long as the population is abundant, widespread, and distributed through a variety of habitats (Lacy 1993; Primack. 1998). When a population becomes small, genetically compromised, isolated, and localised, however, chance events can become so important as to dominate the long-term dynamics and determine the fate of a population (Shaffer 1981; Soule 1986). This then, would appear to be the uncertain future faced by the small population of cassowaries at Mission Beach.

8.1 Cassowary survey results

8.1.1 "Coastal" and "hinterland" populations

This survey confirmed that apart from four adult birds in the Kennedy Bay section of the Hull River National Park, there is no permanent coastal cassowary population *sensu* Crome and Bentrupperbaumer (Bentrupperbaumer 1992a, 1998; Crome and Bentrupperbaumer 1991, 1992, 1993) at Mission Beach (Moore *loc.cit.*). However, an old nest site located in coastal vegetation (Type 17 – Tracey, 1982) at South Mission Beach (Bentrupperbaumer 1991) indicates cassowaries were once able to breed in this area and on rare occasions may still do so.

These findings have significant implications for cassowary management strategies at Mission Beach, effectively shifting the emphasis of cassowary conservation away from the coastal fringe and back onto the Mission Beach population as a whole.

8.1.2 Adult cassowary population

This field survey located 110 cassowaries in the study area, approximately 49 of which were adults. This is about 27-37% of the maximum number of adults estimated for the Mission Beach area by Crome and Bentrupperbaumer (84-134 adults - 1992), and DEH (100-180 adults, Goosem 1992). The much lower adult number is not considered to be wholly due to bird and habitat loss over the intervening period, but rather an over-estimation in previous studies caused by a lack of adequate data from which to extrapolate a reliable population estimate (refer to Chapter 5).

It is certain, however, that birds have been lost from the Mission Beach cassowary population due to habitat clearing, dog attack, disease, and road death. Just how many cassowaries have been permanently lost is unknown. It is probable that Bentrupperbaumer's original 1988 post-cyclone estimate of 63 adult birds represents a good population count. Given 63 adults as a likely baseline population, therefore, we may have lost around 22% of the adult population (approximately 14 birds) since 1988 *ie* a loss of almost 2% of the adult population per year

Although all age classes are well represented in this survey, adult numbers are low by any standard, and are a matter of concern. Given the limited amount of available habitat remaining it is difficult to identify areas where other birds, if available, could be supported at Mission Beach. All suitable habitat appears fully occupied, supporting at least 79 independent cassowaries (49 adults, 28 subadults, 2 unknowns), and comprising a demographic mix one would consider necessary for the maintenance of a stable population (fundamental mix of adults\subadults\chicks). It is certain, moreover, that ongoing clearing of cassowary habitat will increase pressure on the remaining habitat at Mission Beach, and is likely to result in a reduced carrying capacity.

8.1.3 Sex ratio

Bentrupperbaumer concluded that the sex composition of her Kennedy Bay population was “skewed toward females” *ie* 1 male to 1.25 females. This ratio, however, is believed to be an artifact created by a combination of small sampling area *ie* < 400ha, and idiosyncratic population density estimates for the Kennedy Bay cassowary population (Bentrupperbaumer 1998). In most polyandrous species males generally outnumber females (Thompson 1964). This trait is strongly reflected in cassowaries, with males considerably outnumbering females (28 males/19 females). The sex ratio of the Mission Beach cassowary population of 1.47 males to 1 female is greater than that found in the strictly polyandrous emu, *ie* 1.26 males to 1 female (Coddington and Cockburn 1995).

There are no published data regarding the sex ratio of cassowaries at birth. However, it is possible that a contributing factor of this imbalance may well be the species' behavioural traits, and thus not related to sex ratio at birth. To explain, although male cassowaries fight with each other readily (Bentrupperbaumer 1998, Moore *pers obs*,), their interactions usually comprise a quick confrontation followed by a noisy chase. Females, however, have been seen to fight from 5minutes to 1hour 5 minutes (Benntrupperbaumer 1998, Moore *pers obs*.). Additionally, there are numerous anectdotal records of similar fights between female cassowaries at hand-feeding sites.

As evidence of the risks of such confrontations, the author has found three cassowary skeletons with deep puncture marks in the sternum and in one instance the skull, which fit the shape and size of a cassowaries' middle claw. These severe injuries were believed to have been the cause of death for these birds. It is possible therefore, that intrasexual interactions between females may be the mechanism behind the skewed sex ratio at Mission Beach.

Notwithstanding, although characteristic of a polyandrous species, the strongly biased adult male to female ratio may be of concern given the small population size and relatively high mortality of the Mission Beach cassowaries. The implications of such a considerable sex imbalance include an increased risk of genetic drift and inbreeding depression, and the consequent loss of genetic variation. The solitary and territorial behaviour of the cassowary contribute to the possibility that the effective genetic population size will be less than its census size at Mission Beach, thus increasing the risk of genetic irregularity (Caughley and Sinclair 1994).

Additionally, while the skewed sex ratio may be a normal reflection of the social and mating system of cassowaries *per se*, the small number of birds at Mission Beach places this particular population at risk from threatening demographic events that can occur in small populations (Meffe and Carol 1997). For example, the Dusky Seaside Sparrow (*Ammodramus maritimus nigrescens*) from Florida (USA) was doomed to extinction when the last six known individuals happened to be males (Kale 1983). Despite attempts to mate the males with females of closely related sub-species, the species became extinct in 1987.

8.1.4 Females as a limiting factor in cassowary population dynamics

As adult females are in low numbers at Mission Beach, Bentrupperbaumer's finding (1992b, 1998) that the availability of males was the limiting factor in cassowary population dynamics needs to be re-examined. The low proportion of females means that the males as caregivers should <u>not</u> be the limiting sex (Robert Lacy *pers comm.*). On examination, this conclusion is supported by Bentrupperbaumer's (1998) observations of available adult males at Kennedy Bay not producing chicks although unencumbered by caregiving duties. It is considered that such examples of non-breeding in available males can be best explained by the unavailability of reproductively mature females *ie* the availability of adult females is likely to be a limiting factor in cassowary population dynamics.

8.1.5 Breeding and breeding cycles

Although almost two-thirds of known adult males were recorded with chicks, brood numbers were relatively low (mean = 1.94, SD = 0.772). Additionally, although the field survey was undertaken during what is the recognised peak nesting period (May-December), only nine males *ie* 36% (9/25) were recorded with striped chicks. The remaining males were escorting chicks up to about 8 months old, the majority of which would have hatched either at the end of the previous year (November-December) or early in 2000 (January to March). Low fruit availability existing throughout the majority of the survey period may have contributed to the non-breeding of the remaining nine adult males (38.46% of the known adult male population). However, they equally may have just been between breeding cycles[7].

Regular sightings of males foraging prior to being seen with newly hatched young indicate that not all incubating males sit without eating throughout the incubation period. While this is believed to be customary behaviour (Moore 2000a, 2001), it may also be an indication of scant resources.

8.1.6 Adult home ranges

The mean Indicative Home Range[8] of adult females was 2.13 km^2 (SD = 0.928), while males maintained a slightly smaller IHR of 2.06 km^2 (SD = 1.099). There was no significant difference between male indicative home ranges (non-breeding + breeding) and female indicative home range size, nor between breeding males and adult females. There is an indication that breeding males have an increased area requirement than non-breeding males. Although this relationship was not quite statistically significant ($P=0.073$), possibly due to the small size of the sample, it has important management implications and needs to be investigated further.

The study showed that male and female home ranges at Mission Beach are of a similar size, and all are larger (combined male and female mean = 2.09 km^2) than previously estimated by Crome and Bentrupperbaumer (1992) for the Mission Beach area. The distribution and size of individual home ranges confirmed the inappropriateness of defining separate cassowary densities for coastal and hinterland areas of Mission Beach as the majority of "coastal" birds (*sensu* Bentrupperbaumer 1988, 1991, 1992a-b, 1998;

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[7] Bentrupperbaumer's data (1998) indicate that the majority of male cassowaries breed only once in 24-36 months, although depending on local conditions some birds may be capable of breeding every second year *ie* 18 months breeding cycle.

[8] Each bird's home range at the time of the study and an approximation of its foraging activities over a number of preceding weeks or months.

Crome and Bentrupperbaumer 1991, 1992, 1993) lived in the hinterland while making occasional or seasonal use of the coastal areas.

8.1.7 Subadult numbers

Twenty-eight subadults (*ie* >25% of the total Mission Beach cassowary population) were located in this survey (refer Figure 4.2 – Table 4.2). The observed cross-section of subadult cohorts (age bands) appears comprehensive, with located birds ranging from 0.9 - 3.5 years old and widespread throughout existing adult cassowary home ranges. If dependent chicks are excluded, subadults represent greater than one-third (35.5%) of all independent cassowaries. This proportion indicates a healthy subadult population (previously a matter of concern) and, although there is a tendency for an increased number of subadult birds along the Jurs Creek and North Hull River basin (Bean Tree Track area), they were found to occur throughout most forested areas.

8.1.8 Subadult home ranges

The data indicate that subadults maintain a home range, albeit smaller than adults (mean = 0.95 km^2), with most individuals recorded using the same area continually for the entire field program *ie* 6 months. This behavioural feature has not been noted previously due to the lack of comprehensive field surveys using methodology appropriate for gathering demographic data. Maintaining a home range that overlaps multiple adult home ranges has important ecological implications for subadults *eg* the acquisition of local knowledge of the surrounding habitat and potential food resources; an increased opportunity for discovery of vacant home ranges; use of multiple areas containing high quality food resources; a foraging strategy which reduces the probability of agonistic interactions with adults; and an awareness of the surrounding social system which would be essential as an adult bird.

8.1.9 Cassowary densities

The population density of adult cassowaries for the Mission Beach area was 1 adult per 2.09km^2 (*ie* 49 adults/101.66km^2), almost half the density of adult birds calculated for the Lacy's Creek catchment (Crome and Bentrupperbaumer 1992), and one-sixth the density estimated by Bentrupperbaumer (1992, 1998) for the Kennedy Bay and Mission Beach coastal areas.

Overall population density of independent birds *ie* adults and subadults and excluding chicks, was 1 bird per 1.29 km^2 (79 birds/101.66km^2). The density of subadults in the Mission Beach area was 1 subadult per 3.63km^2 (28 subadults/101.66km^2). A density estimate of *Casuarius casuarius* subadults either in the Wet Tropics or New Guinea has not been possible previous to this study.

8.1.10 Survey area size and density estimates

The practice of surveying small areas at Mission Beach has led to constant over-estimates of cassowary population density. In addition, these estimates have generally been applied with the assumption that they are proportional to the area of habitat available *ie* the total population size is proportional to the number of birds per unit area. This custom has resulted in population over-estimates at Mission Beach of greater than 300%.

This study showed that using a single sample area of 1km^2 (or less) yielded a cassowary density unrepresentative of the true population density *ie* none of the surveyed 130 grid squares reflected the factual cassowary density of 1 bird/1.29km^2. The results indicate that at a scale of 1km^2 there is little or no chance of reflecting true cassowary densities. Depending on the resolution required and the environmental parameters of the target area, it is considered that a sample plot between 5-15km^2 may be necessary to reflect the true cassowary population density (refer Figure 5.1).

8.1.11 Kennedy Bay cassowary population

The original density calculated for the Kennedy Bay area by Bentrupperbaumer *ie* 1 adult/0.35km^2, is not strictly a density estimate, being instead a "usage" index based on total individuals using the area over a number of years. Analysis of Bentrupperbaumer's data found that only four adult cassowaries spent > 50% of their time in the Kennedy Bay study site over the two years 1990-1991. The remaining eight adults were elsewhere for 52.2% – 95.8% of the survey period, with six birds spending 70% – 95% outside the study area. It must be assumed that these birds only visited the Kennedy Bay area and had the majority of their home ranges outside the National Park.

It is considered, therefore, that the true carrying capacity of the Kennedy Bay area is 4-5 adult cassowaries and not the 11 adults previously estimated by Bentrupperbaumer. This amended density estimate is supported by the identification of four adult birds using the Kennedy Bay area when surveyed during this study.

8.1.12 Movement corridors and Important Linkage Zones (IlZ)

Unfortunately for Mission Beach cassowaries, most of their movement corridors require the birds to cross roads, and the majority of adult birds (>30) use road crossings on a daily basis. These cassowary road crossings have been detailed in previous reports (Moore 1998, 1999i, 2000a), and a brief synopsis is given later in this chapter.

Parts of Garners Beach\Bingil Bay and Wongaling Road, which have been previously classified as Important Linkage Zones[9] by Goosem (1992), are rapidly degrading and will cease functioning as movement corridors within a short time. The breakdown of these traditional movement corridors has important implications to the areas involved, particularly Garners Beach National Park, which was primarily gazetted due to its historic cassowary population. Accordingly, these areas are briefly discussed below.

8.1.13 Cassowary Visitation

The study identified nine Mission Beach residences regularly visited by cassowaries. It is certain, however, that the total number of properties frequented by cassowaries is much higher. Although it initially appeared that up to 16 adult cassowaries were visiting the nine residences, field observations and photographs indicated that only twelve birds were involved (six adults, three subadults, and three chicks). Adult cassowaries visiting residences at Garners Beach, Bingil Bay, Porters Creek Reserve

[9] Cleared areas which retain patches or remnants of native vegetation which are strategically located and can form the framework for tree planting programs to re-establish corridors linking cassowary habitat areas.

R214, and South Mission Beach were found to have the majority of their home ranges further west in the hinterland

Hand feeding or providing food for cassowaries has become a tradition in much of the Mission Beach area. Unfortunately, this practice has produced a population of adult and subadult birds that have become habituated to humans from an early age after being regularly taken as chicks by males to sites where feeding is practised. Following separation from their parent, surviving chicks have generally stayed close to hand-feeding locations, resulting in frequent deaths or injury caused by collisions with cars or by attacks from dogs. In addition to feeding by residents in urban areas, it is known that a high number of cassowaries visit the many banana and tropical fruit farms which adjoin the main rainforest blocks.

Hand feeding cassowaries is a complex and sensitive problem, which requires an innovative and sympathetic approach. Most people feeding cassowaries are potential supporters of efforts to conserve the species. It is essential, therefore, that strategies be developed for dealing with the issue of hand-feeding cassowaries without alienating a potential community support base. There is potential, moreover, to make use of this visitation in future management strategies (refer Chapter 8.3).

8.1.14 Daily movement pattern

During this study it was found that adult birds at Mission Beach move widely with most birds covering a straight-line distance of at least 3-4 kilometres a day. For example, the adult female and male using Cedar Creek and adjacent Garners Beach National Park (Cassowaries #1, #2) move between the National Park and the northern end of Lacy's Creek catchment, more than 2 kilometres to the west. Similarly, adult male Cassowary #68 and his chick were followed from north of the Tully-Mission Beach Road along Bovril Creek, across to Frog Hollow at South Mission Beach in the one day (>3.5 kilometres). Frequent sightings of adult male Cassowary #35 often found him foraging at opposite ends of his home range within a few hours, covering a distance of approximately 4 kilometres. In the case of this bird, his movement would have been

This movement pattern was observed throughout the Mission Beach cassowary population with many home ranges reaching 3-4 kilometres in length. While it is possible that this mobility may have partially been in response to low fruiting levels at the time of the survey, it is considered more likely to be customary behaviour.

8.1.15 Humanisation

Due to the relatively small area of forest involved and the almost total enclosure of the area by agricultural and urban development, most Mission Beach cassowaries can be considered “humanised” *ie* many cassowaries have some form of regular contact with humans with the result that people recognise and form attachments to individual birds. Similarly, some cassowaries associate people with food, particularly in times of fruit shortage and when males are caring for chicks. It is recommended that this phenomenon be considered a fact of life at Mission Beach and policies and strategies developed to cope with the implications. This includes the acceptance of the inevitability of “incidents” which may arise from humanised cassowaries entering backyards and caravan parks or confronting tourists for food such as occurs at Licuala State Forest car park and Lacy’s Creek rainforest walk. There are, moreover, opportunities to take advantage of the visitation of cassowaries as outlined in the conservation management strategies in Chapter 8.3.

This program would require the development of "best practice guidelines" to protect both cassowaries and people from injury. Such safety procedures may include:

- exclusion of the current practice of hand-feeding in preference to separated feeding stations;
- dog restraint or complete removal from known feeding sites;
- strategic cassowary signage and reduced speed limits;
- monitoring to ensure non-contaminated food (*Aspergillosis* spp., *Salmonella* spp.).

8.1.16 Habitat clearing

The extent of cleared land and the distribution of remaining vegetation in the study area are shown on Figure 1.2. Plate 15 shows a typical example of extensive clearing of Critical Cassowary Habitat (Goosem 1992), which occurred along South Mission Beach Road just prior to the commencement of this study.

Aerial flights over the coastal area south of Mission Beach in October 2000 located substantial clearing of cassowary habitat north of the Tully River and between the Tully and Murray Rivers (Plates 16-17). This recent clearing threatens the already tenuous connectivity provided by the Mt. Mackay to Tully Heads Linkage (almost broken) and Mt. Caruchan to Meunga Creek Linkage of the Wet Tropics Coastal Wildlife Corridors. If connectivity is broken in either of these areas, it will remove the opportunity for cassowary movement in and out of the Mission Beach area, and will permanently isolate the population. Plates 18 and 19 show the fragmented agricultural landscape of the upper Tully and Murray Rivers east of the Bruce Highway.

Plate 15 Critical cassowary habitat cleared approximately April 2000 at the junction of South Mission Beach and Tully-Mission Beach Roads.

Clearing of cassowary habitat north of the Tully River and between the Tully and Murray Rivers

Plates 16 and 17

Fragmented agricultural landscape of the upper Tully and Murray Rivers west of the Bruce Highway.

Plates 18 and 19

8.1.17 Mission Beach cassowary road crossings

El Arish-Mission Beach Road

Twelve Crossing Points were identified on the El Arish-Mission Beach Road between Bingil Bay Road and the junction with Tully - Mission Beach Road, a distance of 8.4 kilometres (Figure 8.1). They were found to service sixteen adult birds, most of who made use of more than one crossing point, and representing approximately 33% of the total adult cassowary population of Mission Beach (Moore 1998a, 2000a, 2001).

Tully-Mission Beach Road

Ten Cassowary Crossing Points were identified between the junction of the El Arish and Tully - Mission Beach Roads and Sugarcane Creek, a distance of approximately 15.2 kilometres (Figure 8.1). Field surveys identified that seventeen adult cassowaries made use of these crossing points *ie* approximately 35% of the adult cassowary population of Mission Beach (Moore *loc cit*).

8.1.18 Mission Beach areas under immediate threat

Garners Beach National Park

Immediate management strategies are needed for Garners Beach and Bingil Bay area to avoid the local extinction of one of the best-known cassowary populations in the Wet Tropics. Such strategies should be aimed at protecting and enhancing linkages for cassowaries between Garners Beach and other blocks of rainforest.

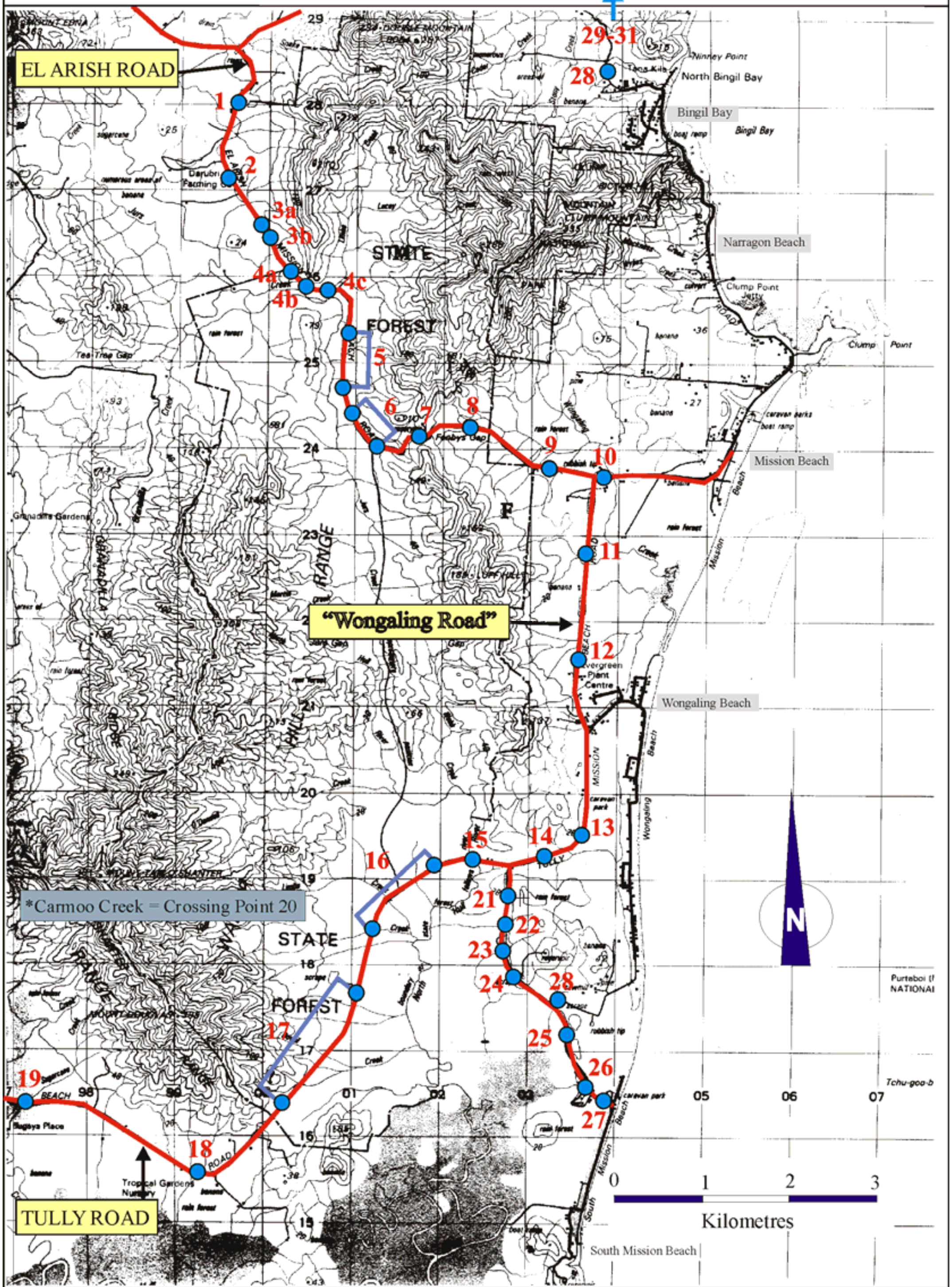
Hull River National Park (Kennedy Bay section)

The narrow vegetation corridors connecting the Kennedy Bay section of the Hull River National Park to adjacent intact forest are under extreme pressure from clearing on adjoining freehold land. The loss or further compromise of this tenuous connectivity will create an isolated population of cassowaries that will certainly decline and die out. To protect the viability of the Kennedy Bay section of the Hull River National Park as long-term cassowary habitat requires immediate management action aimed at the protection and enhancement of the remaining vegetation, and preferably the acquisition of suitable adjoining land as a buffer strip.

Figure 8.1

Mission Beach Roads

Location of Cassowary Road Crossing Points
(Moore 1998, 1999, 2000)



● Cassowary Crossing Point with individual identification number.

Source: Les Moore 2002

8.1.19 Critical cassowary habitat (*sensu* Goosem 1992)

Previous population estimates concluded the coastal section of Mission Beach supported the greater part of the cassowary population (Bentrupperbaumer, 1988, 1991,1992a; Crome and Bentrupperbaumer 1992, 1993). Subsequent studies, however, (Moore 1998, 1999i, 2000a, 2001) showed that the majority of the cassowaries at Mission Beach live and breed in the "hinterland", while making occasional or seasonal use of the "coastal" areas (*sensu* Bentrupperbaumer and Crome). The heartland or core region of the cassowary population is an area between Double Mountain (north of El Arish Road) and Mount Douglas (Tully-Mission Beach Road), incorporating the valley floors and surrounding ridges of Lacys Creek, Jurs Creek, and the North Hull River catchment. The area described is delineated on Figure 8.2.

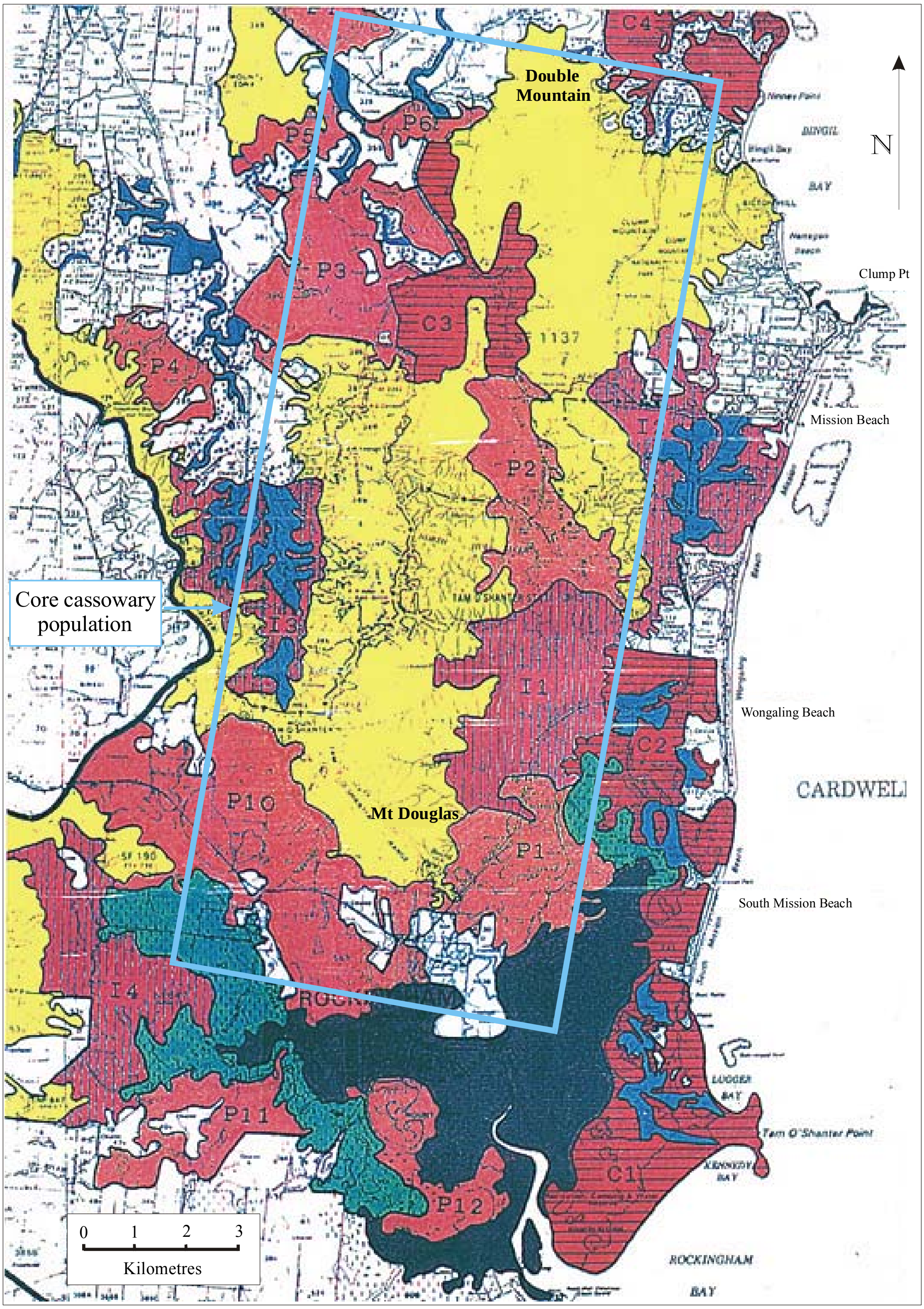
Unfortunately, under the present zoning system only a small portion of this area, the Lacys Creek catchment previously surveyed by Bentrupperbaumer (1992), is regarded as Critical Habitat. The remaining 96% of the core cassowary population area shown in Figure 8.2 comprises the following Habitat Zones:

- Natural Corridor/Habitat Areas
- Important Cassowary Habitat Areas
- Potentially Critical/Important Areas

Goosem's (1992) criteria for Critical Habitat include areas with high densities of cassowaries, a high representation of all age classes, and known to be major cassowary nesting and breeding areas. These areas largely dictate the long-term sustainable cassowary population carrying capacity of the district, providing refuge after natural catastrophes such as severe cyclones and adequate food supplies in times of shortage (Goosem 1992). These criteria are exemplified in the above core cassowary area (Double Mountain to Mount Douglas). The habitat zoning of this region, therefore, needs to be upgraded to reflect its true importance to cassowary conservation at Mission Beach.

Figure 8.2

Mission Beach Cassowary Habitat Zones



(From Goosem 1992b)

Legend for Figure 8.2

Goosem 1992

C1 - C3	Critical Cassowary Habitat Areas
I1 - I4	Important Cassowary Habitat Areas
P1 - P12	Potentially Critical/Important Areas
N1- N4	Natural Corridor/Habitat Areas
NC	Natural Corridor Areas
IL	Important Linkage Areas
M	Mangrove Areas

Core cassowary population (Moore 2001)

8.1.20 Cassowary habitat zones

The current Mission Beach cassowary habitat zones are flawed in their location and\or relevance to the true distribution of Mission Beach cassowary population. Some brief comments and recommendations are given below to assist in a review of the cassowary habitat zones following the results of this survey:

Critical Cassowary Habitat Zone

The areas currently classified under this zoning do not meet the necessary criteria and are instead a result of impressions formed from easily accessible areas where birds were frequently sighted. There is no evidence that cassowaries currently breed (*ie* nest) in any Critical Habitat Zone except the C1 block at Kennedy Bay (Hull River National Park), which is the only area that complies with its previous Critical Habitat Zone classification. Earlier assessments of high cassowary densities in what was classified as Critical Habitat Zone are considered to be a function of high cassowary visibility (*eg* visitation), without contextual knowledge of where birds originated or how they used the habitat.

Important Cassowary Habitat Zone & Potentially Critical/Important Habitat Zone

It is considered that the two categories of ***Important Cassowary Habitat Zone*** and ***Potentially Critical/Important Habitat Zone*** are not separable and reflect the uncertainty principle being applied in an environment of inadequate data. There are small areas that may warrant this debatable classification, mainly on the periphery of Critical Habitat, but the validity of both classifications require investigation.

Natural Corridor/Habitat Zone

This zone extends west of the Bruce Highway and that area was not surveyed in this study. However, it appears to be a non-existent habitat category in the Mission Beach region. The two major areas placed in this classification within the study area comprise: the area extending from Double Mountain south to Luff Hill; and the Granadilla\Walter Hill Range from El Arish Road to Mount Douglas. Both areas have high cassowary densities and support the majority of breeding birds and stable home ranges at Mission Beach, and their re-classification to Critical Cassowary Habitat is warranted and urgent. There is no justification for the assumed larger home range requirements originally estimated for this zone, particularly home ranges up to “14 times larger than normal”

(Goosem 1992). This would suggest home ranges in some areas of between 9-14km^2, similar to that found in upland populations (Moore 1999e-h). This survey revealed no such significant differences in the home range size of adult birds in different areas of Mission Beach.

Natural Corridor Zone

This study confirmed that these areas may operate as movement corridors at Mission Beach but nonetheless are significant cassowary habitat. It is considered, therefore, that these areas are classified as *Potentially Critical/Important Habitat Zone* pending a comprehensive review of the overall zoning system.

Important Linkage Zone

Most areas classified as Important Linkage Zones (ILZ) no longer effectively link areas of functional cassowary habitat due to increases in urban and agricultural development, tourist activity, road traffic and road upgrades. In retrospect, it is fair to say that most of these ILZs only ever provided linkage from viable cassowary habitat to non-viable fragments, rather than linking cassowary habitat areas. It is important to realistically assess areas previously designated as ILZ to determine whether they have a future so far as potential tree-planting programs or corridor enhancement. In some ILZ it is highly unlikely that tree planting programs to re-establish cassowary movement corridors would achieve anything more than leading birds through areas of high risk and into isolated patches of fragmented habitat.

Mangrove Zone

Goosem (1992) considered that mangroves were marginal areas in relation to cassowary conservation and recommended that mangrove conservation be separated from cassowary conservation issues. Mangroves in the Daintree lowlands and at Mission Beach, however, are regularly used by adult and subadult cassowaries as movement corridors and alternative foraging areas, and thus are very important to cassowaries adjoining this habitat (Moore 1996a-b, 1999e).

8.1.21 Recommended habitat zoning amendments

Critical Habitat Zoning

The results of the 1998 Conservation Roads study and this survey indicate that the Critical Habitat Zone classification should be altered to reflect the true distribution and breeding habitat of cassowaries in the Mission Beach area. It should retain the Kennedy Bay block C1 as Critical Habitat but should include most of those areas previously classified as Important Habitat Zone; Natural Corridor/Habitat Zone; and Potentially Critical Zone. The survey clearly showed that these areas have high densities of cassowaries, a high representation of age classes, contain crucial nesting and breeding areas and contain all the home ranges of almost all known adult cassowaries in the Mission Beach area (Figures 4.4 and 8.2). Those areas which require re-zoning to Critical Habitat Zone include most of the forest contained in a polygon extending from Double Mountain in the north, south to the North Hull and Hull Rivers (south of Tully-Mission Beach Road) and west to include the western arm of the Walter Hill Range and the Carmoo Creek National Park.

Mangrove Zone

As mangroves function as movement corridors and alternative foraging areas, future cassowary conservation in the lowlands will need to incorporate mangroves into any management strategies.

Habitat Zones to be removed at Mission Beach

It is recommended that the three categories of ***Important Cassowary Habitat Zone, Potentially Critical/Important Habitat Zone,*** and ***Natural Corridor/Habitat Zone*** be merged into Critical Habitat Zone and deleted as cassowary habitat zones.

8.1.22 Threatened cassowary habitat – a new category?

Some smaller areas previously zoned as Critical or Important Cassowary Habitat could be considered significant due more to the fact that cassowaries may not exist in them much longer rather than the areas themselves being fundamental to the future viability of the Mission Beach cassowary population. Examples include Garners Beach, Bingil Bay, and the Kennedy Bay section of Hull River National Park. This trend towards increasingly threatened habitat is likely to continue at Mission Beach and as such it may be necessary to include a new habitat zoning *ie* Threatened Cassowary Habitat.

8.1.23 Comparison of Mission Beach and Daintree cassowary populations

There is remarkable similarity between the Mission Beach and Daintree lowlands adult cassowary population. Due in part to a smaller study area, the total adult population of the Mission Beach study area is only slightly less than that found in the Daintree lowlands *ie* approximately 49 adults (Mission Beach) compared to approximately 54 adults (Daintree). Moreover, mean home ranges of birds at Mission Beach *ie* 1-3km^2 are similar in size to those maintained by the majority of the birds in the Daintree lowlands. In addition, cassowary densities occurring in the two lowland areas are almost identical *ie* 1 adult/2.08km^2 at Mission Beach compared to 1 adult/2.22km^2 in the Daintree lowlands.

8.2 Population viability analysis

8.2.1 Baseline models (with and without inbreeding depression)

Baseline simulation modelling, which used a range of mortality rates, breeding cycles, presence and absence of catastrophes and inbreeding effects, indicates that the Mission Beach cassowary population is in severe deterministic decline. Under all scenarios but that of Low mortality (considered to be improbable mortality rates), the extinction of the Mission Beach cassowary population is virtually certain, with a predicted mean time to extinction between 37 to 70 years. The stochastic growth rate, although of a slightly higher rate than deterministic growth, remains strongly negative, signifying that stochastic influences are outweighed as a threat to population persistence by the severity of the deterministic decline. Of considerable consequence is the overall decrease in heterozygosity, which is predicted to decline to between 61.0% and 75.0% of its original diversity.

The PVA simulations reveal that this small population of cassowaries is not capable of supporting itself if isolated. Therefore, effective immigration, or in its absence, supplementation of the population, is a critical factor in the long-term persistence of the species at Mission Beach.

8.2.2 Effect of adult mortality on population persistence

This analysis showed that although the population is predicted to persist for a greater period of time if adult mortality can be kept to 1-2% (≥1 adult/year), the predicted cassowary population size still decreased by –32.7% (at 33% breeding). This finding strongly suggests that the effects of inbreeding depression *ie* deleterious alleles and/or other genetic impacts, will play a significant role in the decline of the Mission Beach cassowary population in the absence of immigration.

8.2.3 Effect of immigration on population persistence

It appears that the critical factor for the survival of the cassowaries at Mission Beach is either the preservation of effective immigration from other cassowary populations, or the supplementation of the population with at least four "foreign" birds a year.

By ensuring the immigration or supplementation of four birds per year, the Mission Beach population retention at higher mortality rates increases substantially, ensuring the persistence of the cassowary population over both the 100 years and 500 year projections. This recruitment, however, still results in a population size <u>decrease</u> in the 100 years simulation of 6% (Moderate mortality) to 45% (High mortality). At Low mortality rates[10] deterministic growth rate rises by only 13% - 29%, but this is enough to achieve <u>positive</u> population size increases of approximately six birds at 33% breeding *ie* 7.5% (approximately 85 birds total), and eight birds at 50% breeding *ie* 10.3% (approximately 87 birds total).

[10] It should be noted that the Low Mortality rates used in these analyses are not considered ecologically realistic, and the results from this parameter are better viewed as a theoretical benchmark.

However, to maintain the current population size of approximately 79 independent birds at Moderate mortality rates (Table 6.2) requires augmenting the population by at least six birds per year (3 males and 3 females <4 years old).

8.2.4 Sensitivity analysis

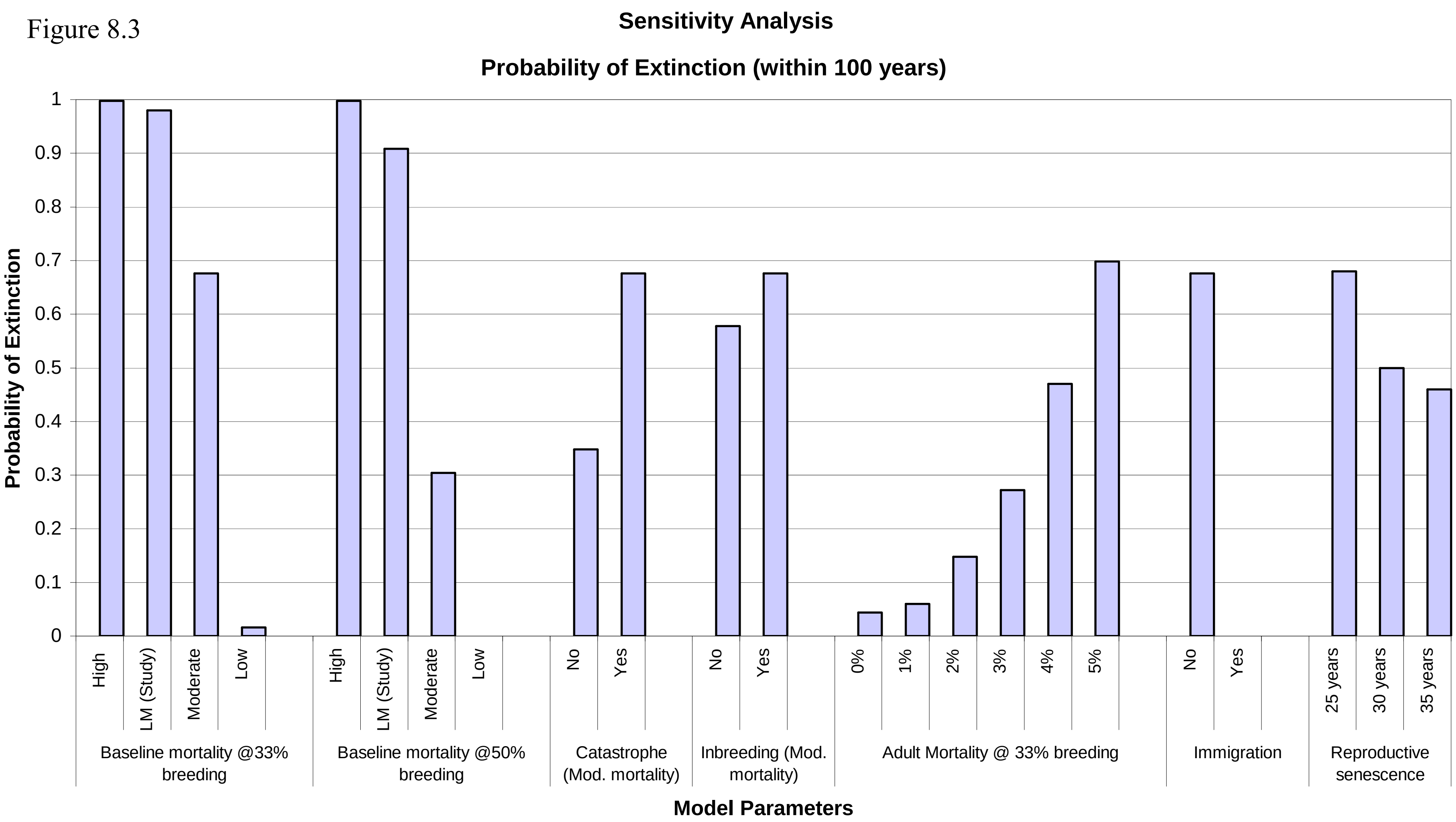
The sensitivity analysis presented in Figure 8.3 illustrates the high probability of extinction (PE) trend of the Mission Beach cassowary population revealed by most simulations. The analyses indicate there is a strong chance that the simulated population may become extinct within the 100 years projection period under most PVA models.

Stochastic growth rates generally remained strongly negative although at a slightly higher rate than deterministic growth rate. The relatively small differences between the two rates demonstrate that stochastic influences are outweighed as a threat to population persistence by the severity of the deterministic decline.

It appears that catastrophes may have a profound impact on the viability of the cassowary population, doubling the PE under Moderate mortality rates from 35% to 68%. In addition, the population shows a sensitivity to changes in adult mortality, particularly mortality >2% per year. Of greatest importance, however, is the significant role of effective immigration, the presence of which results in a nil risk of extinction for all simulated mortality rates (Table 6.2).

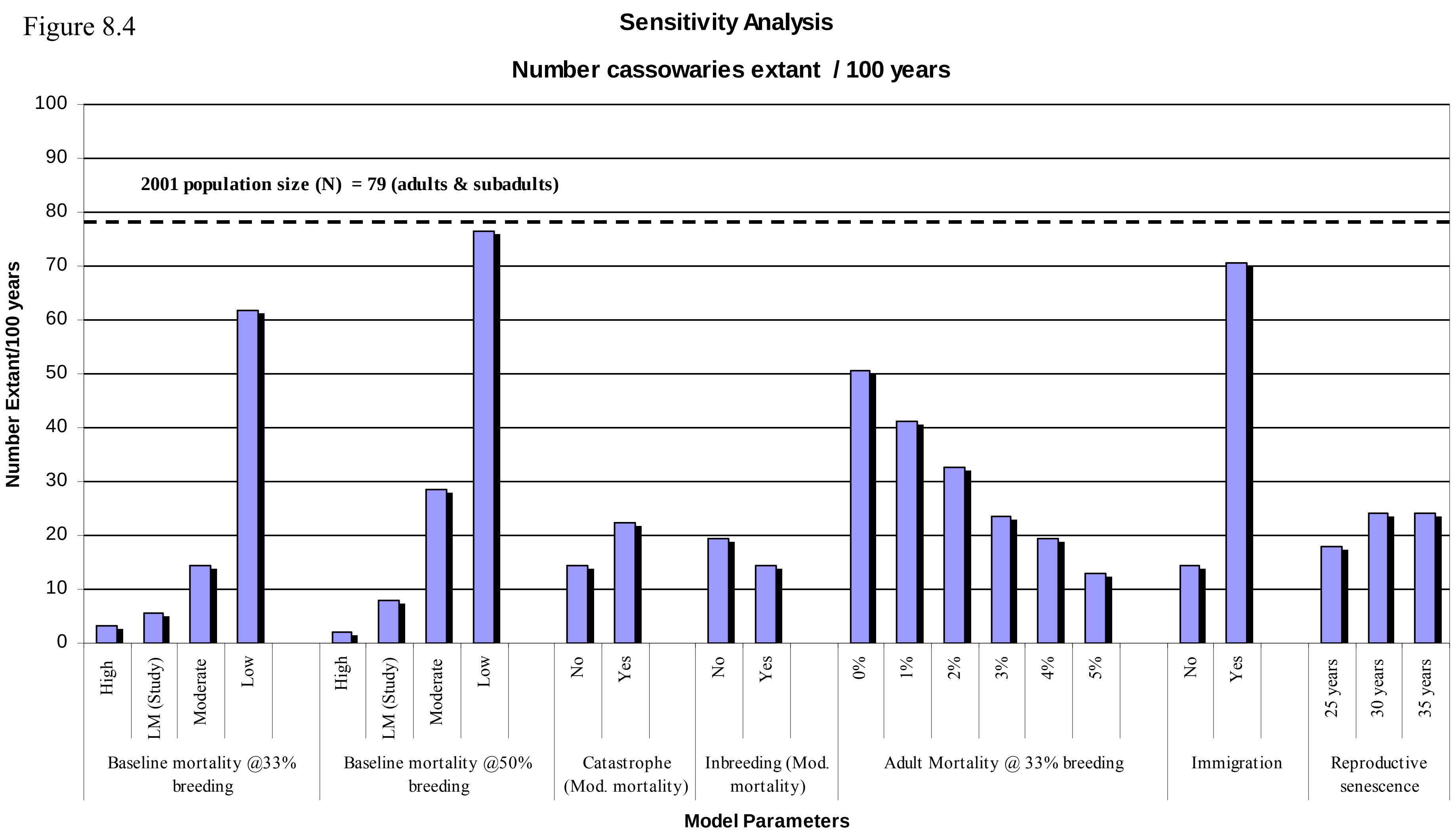
Figure 8.4 demonstrates that although the Mission Beach cassowary population may still be in existence at the end of many of the 100 years simulations, it is likely to be as a non-viable population whose persistence is due mainly to the longevity of the species *ie* >50 years. Excluding the unrealistic Low mortality simulations (Table 6.2), a viable cassowary population is retained only in the presence of successful immigration of greater than four birds a year.

Figure 8.3



Sensitivity Analysis
Probability of Extinction (within 100 years)
Probability of Extinction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
High
LM (Study)
Moderate
Low
High
LM (Study)
Moderate
Low
No
Yes
No
Yes
0%
1%
2%
3%
4%
5%
No
Yes
25 years
30 years
35 years
Baseline mortality @33% breeding
Baseline mortality @50% breeding
Catastrophe (Mod. mortality)
Inbreeding (Mod. mortality)
Adult Mortality @ 33% breeding
Immigration
Reproductive senescence
Model Parameters

Figure 8.4


Sensitivity Analysis
Number cassowaries extant / 100 years
Number Extant/100 years
100
90
80
70
60
50
40
30
20
10
0
2001 population size (N) = 79 (adults & subadults)
High
LM (Study)
Moderate
Low
High
LM (Study)
Moderate
Low
No
Yes
No
Yes
0%
1%
2%
3%
4%
5%
No
Yes
25 years
30 years
35 years
Baseline mortality @33% breeding
Baseline mortality @50% breeding
Catastrophe (Mod. mortality)
Inbreeding (Mod. mortality)
Adult Mortality @ 33% breeding
Immigration
Reproductive senescence
Model Parameters

8.2.5 General observations on PVA results

The PVA simulations revealed:

1. In the absence of effective immigration, the extinction of the Mission Beach cassowary population is virtually certain (LM Study estimates, High mortality, Moderate mortality) within the 100 years time frame, with probabilities of extinction (PE) ranging from 68% – 99.8%. At 50% breeding[11], PE varies from 31% (Moderate mortality) to 99.8% (High mortality).

2. Baseline input simulations indicate that only with a combination of Low mortality rates across all age classes and male cassowaries breeding every two years can the Mission Beach cassowary population remain extant over the 100 years period of the simulations. However, this persistence is achieved with significant genetic decline and reduced population size.

3. Genetic diversity of the Mission Beach population dropped significantly even when input parameters kept the population relatively stable. Heterozygosity reduced to between 61% and 85%, and inbreeding depression increased markedly from about 30 years onwards, varying little with decreased adult mortality.

4. The critical factor for the persistence of cassowaries at Mission Beach is the preservation of effective immigration from other cassowary populations, or the supplementation of the population with at least four "foreign" birds a year.

5. At 33% breeding, catastrophes comprise approximately 18% of any population size reduction, twice that rate found in 1:2 years breeding systems (*ie* 8.9%).

6. A combination of Low mortality rates and 50% breeding more than doubled the deterministic growth rate from 0.024 to 0.055 *ie* the deterministic growth rate is reduced by >56% if male cassowaries are only able to breed once every 3 years.

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[11] Considered to be atypical.

7. At 33% breeding the frequency and severity of catastrophes due to cyclones or droughts had considerable effects on population growth rates *eg* 12% (High mortality) to 41% (Moderate mortality) but did not significantly increase extinction probability. In the absence of catastrophes deterministic growth rates continued to remain strongly negative (r_d = -0.017 to –0.089) for all but Low mortality (r_d = +0.036). Although only a small decrease, under Low mortality values the population was again predicted to decline by approximately by -3.8% (3 birds) over the 100 years simulation.

8.3 Supplementation of the Mission Beach cassowary population

The results of the survey and PVA of the Mission Beach cassowary population emphasise the importance of ensuring continued genetic exchange with neighbouring populations. The preferred conservation option is the maintenance of existing movement corridors to permit the immigration of at least four "foreign" birds into Mission Beach per year. The simulations show clearly, however, that if effective connectivity is lost between Mission Beach and neighbouring populations such that emigration and immigration are significantly compromised, artificially augmenting the cassowary population will be necessary to avoid extinction. One such way this supplementation may be achieved is briefly outlined below. It is stressed that any such population maintenance program will need careful evaluation as to its aims and likely contribution to the reduction of extinction risk, as well as the certainty of adequate funding over the long-term. It will also require screening of all participating birds for diseases and genetic health.

Briefly, the major components of the maintenance program comprise:

1. The establishment of a captive population of subadult birds close to or within Mission Beach study area, using high-risk 1-3 year old cassowaries from neighbouring areas *eg* Tully or Jarrah Creek (birds from Mission Beach may help retain numbers in the short-term but will not supply the required genetic diversity).

2. This program may involve some captive breeding ex-situ from Mission Beach, with subadults being brought to Mission Beach for familiarisation prior to release.

3. The age at which subadults could be introduced into the Mission Beach population is tentatively set at 3 years. Although accepting the negative issues of non-familiarity with local resources and the existing social structure, it is considered that this age group has passed the higher mortality offspring period but is yet to develop the territorial fidelity of older subadults.

4. Using high-risk birds (*ie* greatest mortality between 1-4 years and/or hand-fed juveniles) should pose minimal risk to the source population. To further reduce this risk, however, it is recommended that "paired translocations" be undertaken. This would involve the simultaneous exchange of birds between two selected sites *eg* subadults from Mission Beach relocated into Jarra Creek in exchange for those removed to supplement the Mission Beach population. This will include the establishing of similar captive housing facilities at the source location.

8.4 Mission Beach cassowaries as a metapopulation

The results of all simulations highlight the conclusion that the Mission Beach cassowary population is functioning as part of a metapopulation *ie* a network of populations that have some degree of intermittent or regular gene flow among geographically separate units (Meffe and Carrol 1997). Because these populations are linked together by the emigration and immigration of individuals between patches, a subpopulation (*eg* Mission Beach) can go temporarily extinct in a patch, which then may be recolonised at a later date (Levins 1969). The rate or success of colonisation, however, depends on the dispersal ability of the species (high in the case of the cassowary) and the persistence of effective movement corridors (currently threatened in the case of Mission Beach).

When a subpopulation is small, occasional immigrants or supplements from adjacent subpopulations may prevent extinction. Brown and Kodrick-Brown (1977) term this the **rescue effect**, and consider it to be a major factor in maintaining small populations. It is clear, therefore, that links allowing effective emigration and immigration between habitat patches are critical to the maintenance of the overall metapopulation.

8.4.1 Metapopulation modelling of the Wet Tropics cassowaries

As metapopulation species live in a number of patches, much depends on exactly where those patches are *ie* their spatial arrangement and distance between patches. In addition, it is necessary to determine how similar (or correlated) the environmental conditions are in neighbouring patches. Thus, the estimation of the risk of extinction for a species in a metapopulation is not possible from a single-population model such as Mission Beach, or even from a collection of such models. To simulate the dynamics of a metapopulation, a number of subpopulations in the metapopulation must be modelled together, and their geography (or local characteristics) must be part of the model. Metapopulation models examine many factors including the patterns of abundance and distribution of local populations, subpopulation dynamics, metapopulation dynamics, metapopulation genetics, effective genetic populations, population variation, connectivity requirements, and immigration and emigration rates.

It is considered extremely important that metapopulation modelling be undertaken for the cassowary population within the Wet Tropics. This modelling can be driven using demographic data from previous surveys of Wet Tropics cassowary subpopulations (Moore 1995, 1996a-j, 1997a-b, 1998a-d, 1999a-i, 2000a), and the extensive population genetic theory of the consequences of metapopulation structure in small populations.

CHAPTER 9

CONCLUSION

There are far fewer cassowaries at Mission Beach than previously believed *ie* approximately one-third of previous estimates. Unfortunately, the conflict between the ecological requirements of cassowary home ranges and diminishing habitat present little opportunity for increasing carrying capacity beyond that already existing. Remaining freehold land in the Mission Beach area is vulnerable to clearing and continuing development threatens increased fragmentation and loss of habitat. In addition, movement corridors linking Mission Beach with other major blocks of cassowary habitat are tenuous and/or ephemeral, and it is likely that effective emigration and immigration will shortly cease. In cassowary terms, therefore, Mission Beach is crowded, with all suitable habitat utilised by adults and subadults alike, and facing the high probability of shortly becoming an isolated population.

The PVA simulations, which used a range of mortality rates, breeding cycles, presence and absence of catastrophes and inbreeding effects, indicate that the Mission Beach cassowary population is in deterministic decline. The VORTEX PVA modelling also showed population persistence appears to be profoundly affected by the level of immigration. In the absence of immigration, the simulations indicate the extinction of the Mission Beach cassowary population is virtually certain, with probabilities of extinction (PE) ranging from 68% – 99.8%. The simulations also predicted a mean time to extinction (based on the presence of only one sex) of between 37 and 82 years.

Mission Beach has only a small population of cassowaries, and a small population can die out entirely by chance even when its members are healthy and the environment favourable. When a population becomes small, isolated, and localised, chance events can become so important as to dominate the long-term dynamics and fate of a population (Miller and Lacy 1999). The small isolated population of cassowaries at Mission Beach, therefore, would appear to face an uncertain future.

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Appendix One

Summary results of PVA simulations

Run number	det.r	stoc.r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	Het	SD(Het)	AllelN	SD(A)	Med.TE	MeanTE
RUN1	-0.068	-0.06	0.228	0.977	6	4.51	0.16	1.12	0.7071	0.152	5.14	3.29	49	51
RUN2	-0.067	-0.059	0.225	0.983	3.6	1.52	0.13	0.6	0.6229	0.1195	3.2	1.1	51	52.1
RUN3	-0.065	-0.06	0.227	0.97	3.11	1.27	0.13	0.61	0.5188	0.1764	2.78	0.83	50	50.9
RUN4	-0.031	-0.036	0.244	0.753	12.26	11.05	3.23	7.55	0.7015	0.1353	5.93	3.08	72	64.3
RUN4	-0.031	-0.038	0.242	0.803	10.73	7.43	2.32	5.33	0.6819	0.1906	5.66	2.98	73	66.9
RUN5	-0.031	-0.038	0.245	0.783	11.54	10.64	2.69	6.81	0.6877	0.1755	5.74	3.03	74	65.3
RUN6	-0.031	-0.032	0.251	0.677	18.19	16.4	6.09	12.52	0.7081	0.1468	6.13	2.92	80	66.8
RUN7	-0.031	-0.034	0.25	0.687	13.89	12.34	4.53	9.37	0.6888	0.1477	5.62	2.87	79	63.6
RUN10	-0.126	-0.121	0.324	1	0	0	0	0	0	0	0	0	25	26.2
RUN11	-0.126	-0.118	0.325	1	0	0	0	0	0	0	0	0	26	26.9
RUN12	0	-0.013	0.26	0.372	28.46	22.54	18.1	22.38	0.7375	0.1364	6.88	2.84	0	71.5
RUN13	0	-0.008	0.265	0.298	37.77	25.15	26.61	27.17	0.7342	0.1443	7.08	3	0	63.2
RUN14	0.082	0.069	0.196	0.002	80.85	17.62	80.69	17.97	0.8442	0.0449	11.35	2.02	0	48
RUN14	0.082	0.068	0.196	0	79.7	18.08	79.7	18.08	0.844	0.0448	11.17	2.02	0	0
RUN15	0.082	0.078	0.2	0	84.9	16.1	84.9	16.1	0.8282	0.0489	10.52	1.93	0	0
RUN16	-0.111	-0.108	0.314	1	0	0	0	0	0	0	0	0	28	29.1
RUN17	-0.111	-0.105	0.32	1	0	0	0	0	0	0	0	0	28	29.9
RUN18	0.016	0.005	0.236	0.122	47.24	25.52	41.56	28.37	0.8014	0.0997	9.37	3.24	0	73
RUN19	0.016	0.012	0.238	0.054	56.11	25.18	53.1	27.56	0.7996	0.0979	9.27	2.84	0	65.7
RUN20	0.099	0.087	0.17	0	86.45	13.31	86.45	13.31	0.8555	0.0401	11.97	2	0	0
RUN21	0.099	0.094	0.176	0	88.74	12.69	88.74	12.69	0.8423	0.0422	11.23	1.97	0	0
RUN22	-0.056	-0.053	0.299	0.968	7.25	4.28	0.29	1.49	0.6659	0.1015	4.5	1.51	54	54.7
RUN12_1.OUT	-0.013	-0.026	0.277	0.57	22.06	20.78	9.69	17.36	0.7254	0.1392	6.32	3.07	91	69.2
RUN12A_1.OUT	-0.013	-0.024	0.284	0.51	20.69	18.26	10.38	16.29	0.7071	0.1469	6	2.87	98	71.1
RUN12A.OUT	-0.013	-0.023	0.284	0.52	23.38	20.9	11.46	18.47	0.7151	0.1464	6.45	3.37	99	68.9
RUN12.OUT	-0.013	-0.022	0.279	0.494	23.77	20.78	12.21	18.86	0.736	0.1198	6.73	3.12	0	69
RUN13.OUT	-0.013	-0.018	0.292	0.416	28.57	24.13	16.89	23.06	0.7055	0.1564	6.44	3.07	0	68.9
RUN12-50YRS.OUT	-0.013	-0.021	0.281	0.5	24.56	20.27	12.56	18.67	0.7201	0.1673	6.88	3.47	99	83.1
RUN12-50X.OUT	-0.013	-0.026	0.284	0.62	21.68	12.94	8.42	13.11	0.7621	0.0987	7.32	3.18	80	64.5

Run number	det.r	stoc.r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	Het	SD(Het)	AllelN	SD(A)	Med.TE	MeanTE
RUN12-50X.OUT	-0.013	-0.026	0.282	0.54	16.04	15.6	7.54	13.13	0.7144	0.1483	5.74	2.91	91	73.4
RUN23.OUT	-0.09	-0.084	0.316	1	0	0	0	0	0	0	0	0	35	37.3
RUN24.OUT	-0.09	-0.083	0.323	1	0	0	0	0.09	0	0	0	0	36	37.6
RUN25.OUT	-0.013	-0.023	0.282	0.526	24.59	21.22	11.83	18.98	0.7402	0.1119	6.68	2.92	97	69
RUN26.OUT	-0.013	-0.018	0.292	0.436	32.45	25.67	18.51	24.97	0.722	0.1428	6.72	2.89	0	68
RUN27.OUT	0.051	0.042	0.208	0.002	83.16	18.67	83	19.01	0.8633	0.0398	12.99	2.38	0	91
RUN28.OUT	0.051	0.048	0.214	0.002	83.52	19.1	83.35	19.44	0.8567	0.047	12.59	2.44	0	56
RUN22_1	-0.053	-0.053	0.293	0.968	6.81	5.28	0.31	1.61	0.6409	0.1434	4	1.59	53	54.5
RUN29	0.015	-0.004	0.281	0.242	38.33	26.41	29.22	28.09	0.767	0.111	7.74	2.87	0	73.3
RUN30	-0.004	-0.017	0.282	0.466	25.44	20.86	13.81	19.69	0.7374	0.1356	6.9	2.99	0	70.5
RUN31	-0.028	-0.028	0.276	0.718	13.25	11.25	3.99	8.35	0.6832	0.1554	5.3	2.46	80	66.5
RUN32	-0.064	-0.043	0.257	0.97	8.67	8.61	0.36	2.11	0.6929	0.0903	4.4	1.4	49	51.6
RUN33	-0.028	-0.005	0.269	0	30.86	18.89	30.86	18.89	0.9194	0.0253	22.71	6.52	0	67.2
RUN33	-0.028	-0.004	0.269	0	32.53	19.67	32.53	19.67	0.9204	0.0254	23.18	6.91	0	67.3
RUN34	-0.028	-0.008	0.3	0	26.97	18.25	26.97	18.25	0.9203	0.0253	22.02	6.78	0	71
RUN29_1	0.015	-0.003	0.281	0.228	40.94	26.84	31.74	29.04	0.768	0.1025	7.77	2.93	0	71.8
RUN30_1	-0.004	-0.017	0.289	0.432	23.49	19.38	13.57	18.53	0.7187	0.1482	6.41	2.81	0	71.9
RUN31_1	-0.028	-0.034	0.304	0.782	16.08	14.21	3.74	9.31	0.7008	0.1571	5.77	2.75	76	66
RUN32_1	-0.064	-0.059	0.343	0.988	5.83	3.87	0.12	0.78	0.6449	0.0928	3.5	1.05	48	50.3
RUN35	0.015	0.019	0.267	0	57.15	22.06	57.15	22.06	0.9294	0.0201	29.27	6	0	55
RUN36	0.015	0.031	0.26	0	68.76	18.86	68.76	18.86	0.9569	0.0107	47.04	6.69	0	0
RUN37	0.015	0.05	0.252	0	76.33	16.88	76.33	16.88	0.9728	0.0057	67.32	8.23	0	0
RUNA	-0.01	0.006	0.263	0	47.44	21.47	47.44	21.47	0.9385	0.0167	30.98	6.85	0	67.6
RUNB	-0.01	0.017	0.256	0	62.13	20.16	62.13	20.16	0.9643	0.0086	51.09	8.37	0	0
RUNC	-0.01	0.038	0.247	0	72	16.28	72	16.28	0.9779	0.0045	75.73	9.31	0	0
RUND	-0.01	0.054	0.24	0	76.93	14.92	76.93	14.92	0.9832	0.0033	92.22	10.95	0	0
RUNE	-0.01	0.069	0.231	0	80.64	13.83	80.64	13.83	0.9858	0.0027	104.04	12.1	0	0
RUN39	0.007	0.001	0.248	0.092	41.22	24.12	37.5	25.79	0.808	0.0997	9.6	3.27	0	80.6
RUN39_1	0.007	0.008	0.257	0.048	50.85	23.4	48.44	25.25	0.8143	0.0787	9.81	2.98	0	75.1
RUN40	0.027	0.014	0.247	0.066	53.43	25.4	49.95	27.83	0.816	0.0849	9.75	2.73	0	74.5
RUN41	0.076	0.063	0.195	0	81.78	15.32	81.78	15.32	0.8475	0.0461	11.65	2.02	0	0
RUN42	-0.001	-0.003	0.215	0.14	39.91	24.44	34.46	26.39	0.8303	0.0814	10.69	3.8	0	75.9
RUN43	0.008	0.001	0.252	0.114	45.75	26.14	40.6	28.49	0.8247	0.0872	10.56	3.71	0	77.2
RUN44	-0.059	-0.056	0.293	0.978	4.18	2.75	0.15	0.78	0.5702	0.2391	3.73	1.85	52	53.8

Run number	det.r	stoc.r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	Het	SD(Het)	AllelN	SD(A)	Med.TE	MeanTE
RUN45	0.008	0.001	0.252	0.078	43.9	25.47	40.54	27.06	0.8224	0.0876	10.47	3.8	0	79.9
RUN46	0.064	0.056	0.19	0	85.27	13.65	85.27	13.65	0.8755	0.032	14.34	2.24	0	0
RUN47	0.064	0.057	0.191	0	84.85	14.2	84.85	14.2	0.8773	0.029	14.24	2.2	0	0
RUN50	-0.047	-0.043	0.297	0.908	7.96	7.92	0.86	3.31	0.6079	0.213	4.28	2.2	64	62
RUN51	-0.067	-0.055	0.271	0.98	5.7	3.89	0.18	1	0.6629	0.0629	3.8	0.79	54	55.4
RUN52	-0.067	-0.052	0.274	0.968	6.44	4	0.27	1.35	0.6291	0.1371	3.81	1.22	55	56.1
RUN53	-0.047	-0.039	0.309	0.854	9.45	9.16	1.56	4.8	0.6469	0.171	4.59	2.42	68	63.6
RUN54	-0.067	-0.055	0.269	0.974	6.46	6.21	0.21	1.43	0.6179	0.1184	3.54	1.27	53	54.5
RUN54	-0.056	-0.045	0.256	0.924	8.63	10.38	0.78	3.64	0.6769	0.1755	5.21	2.9	65	63.9
RUN55	-0.036	-0.032	0.286	0.73	11.93	10.62	3.46	7.57	0.7042	0.1551	5.72	2.91	79	70.7
RUN56	-0.056	-0.042	0.267	0.868	7.58	6.94	1.16	3.57	0.6775	0.1224	4.55	1.78	67	64.5
RUN57	-0.036	-0.029	0.294	0.664	16.98	15.36	5.93	11.89	0.7139	0.133	6.03	2.99	84	69
RUN58	-0.101	-0.085	0.296	0.998	3	0	0.01	0.13	0.6111	0	3	0	35	37.2
RUN59	-0.08	-0.072	0.331	1	0	0	0	0.04	0	0	0	0	39	41.2
RUN59_1	-0.08	-0.07	0.327	0.998	2	0	0.02	0.18	0.625	0	3	0	41	42.9
RUN60	-0.101	-0.081	0.298	1	0	0	0	0	0	0	0	0	36	38.7
RUN60_1	-0.101	-0.082	0.298	1	0	0	0	0	0	0	0	0	35	38
RUN61	-0.08	-0.068	0.335	0.998	4	0	0.01	0.2	0.5938	0	3	0	41	43.9
RUN60_1	-0.101	-0.08	0.301	1	0	0	0	0	0	0	0	0	36	38.8
RUN62	-0.089	-0.073	0.289	1	0	0	0	0	0	0	0	0	41	42.5
RUN63	-0.069	-0.062	0.318	0.994	9	6.56	0.07	0.82	0.6962	0.0972	5	2.65	46	47.6
RUN64	-0.089	-0.07	0.293	1	0	0	0	0.04	0	0	0	0	40	43.1
RUN65	-0.069	-0.058	0.33	0.984	4.13	1.13	0.1	0.58	0.5419	0.2421	3.13	1.13	48	49.4
RUN66	-0.029	-0.03	0.264	0.676	14.39	12.86	4.86	9.87	0.7128	0.1273	5.87	2.6	84	69.5
RUN67	-0.003	-0.009	0.274	0.304	28.49	21.65	20	22.18	0.7527	0.1354	7.45	3.23	0	74.5
RUN68	-0.029	-0.025	0.274	0.578	19.38	18.52	8.39	15.27	0.6932	0.1522	5.73	2.82	90	69
RUN69	-0.003	-0.004	0.284	0.224	36.55	24.45	28.48	26.26	0.7568	0.1307	7.59	2.88	0	73.3
RUN70	-0.017	-0.017	0.244	0.348	22.21	17.95	14.69	17.8	0.7567	0.1278	7.35	3.17	0	76.7
RUN71	0.008	0.005	0.254	0.086	43.43	23.73	39.78	25.62	0.819	0.0785	9.84	3.04	0	81.3
RUN72	-0.017	-0.012	0.252	0.23	29.79	22.45	23.08	23.23	0.7685	0.1174	7.83	3.18	0	75.8
RUN73	0.008	0.011	0.262	0.038	50.93	24.01	49.02	25.44	0.8072	0.0904	9.66	2.81	0	73.7
RUN74	0.024	0.02	0.196	0.016	61.93	22.67	60.96	23.74	0.8536	0.0572	12.25	2.9	0	81.9
RUN75	0.055	0.048	0.202	0	76.62	17.09	76.62	17.09	0.8554	0.0419	12.06	2.22	0	0
RUN76	0.024	0.025	0.202	0.006	67.76	20.84	67.35	21.43	0.8473	0.0603	11.96	2.71	0	68

Run number	det.r	stoc.r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	Het	SD(Het)	AllelN	SD(A)	Med.TE	MeanTE
RUN77	0.055	0.055	0.207	0.002	80.45	15.21	80.29	15.61	0.8455	0.0456	11.54	2.12	0	56
RUN78	0.036	0.034	0.177	0	75.78	15.02	75.78	15.02	0.8771	0.0293	14.38	2.2	0	0
RUN79	0.067	0.063	0.18	0	83.34	11.49	83.34	11.49	0.8665	0.0313	12.89	1.96	0	0
RUN80	0.036	0.039	0.181	0	77.48	13.85	77.48	13.85	0.8705	0.0356	13.87	2.44	0	0
RUN81	0.067	0.069	0.187	0	83.83	11.65	83.83	11.65	0.8537	0.0438	12.24	2.03	0	0
RUN100	-0.003	-0.01	0.268	0.174	38.83	28.25	32.18	29.48	0.8094	0.1022	10.02	4.25	0	79
RUN100_1	0.008	0.006	0.249	0.03	64.18	32.48	62.29	33.75	0.8646	0.0665	13.65	4	0	77
RUN100_2	0.008	0.009	0.255	0.018	70.35	33.31	69.12	34.26	0.8615	0.0707	13.69	3.87	0	80.9
RUN100_3	-0.003	0.017	0.256	0	84.96	27	84.96	27	0.9662	0.0073	57.74	8.74	0	0
RUN100_4	-0.003	0.03	0.247	0	111.18	26.91	111.2	26.91	0.9807	0.0035	95.32	11.01	0	0
RUN100_5	-0.003	0.03	0.248	0	109.66	26.98	109.7	26.98	0.9807	0.0037	95.18	10.99	0	0
RUN100_6	-0.003	0.04	0.246	0	76.92	17.28	76.92	17.28	0.9783	0.0046	78.3	9.65	0	0
RUN100_7	-0.029	0.013	0.223	0	99.52	28.57	99.52	28.57	0.9832	0.0031	100.75	14.22	0	0
RUN100_8	-0.003	0.004	0.255	0	136.6	77.13	136.6	77.13	0.9554	0.0127	50.09	12.66	0	0
RUN100_9	-0.003	-0.006	0.259	0.55	72.53	77.71	32.82	63.15	0.7176	0.1914	7.58	3.93	291	226.7
RUN100_10	0.032	0.032	0.243	0	219.19	52.28	219.2	52.28	0.898	0.0318	19.13	3.48	0	0
RUN100_11	0.025	0.024	0.246	0.01	213.63	60.33	211.5	63.68	0.8864	0.0442	17.11	3.5	0	283
RUN100_12	0.018	0.024	0.249	0	226.28	62.33	226.3	62.33	0.9665	0.0071	68.47	8.67	0	0
RUN100_13	0.018	0.019	0.246	0.01	196.69	67.39	194.7	69.88	0.9481	0.0161	35.78	8.04	0	81
RUN100_14	0.011	0.011	0.254	0	159.55	82.84	159.6	82.84	0.9274	0.042	28.92	9.71	0	0
RUN100_15	0.032	0.031	0.248	0	226.46	53.07	226.5	53.07	0.9574	0.0071	42.93	5.58	0	0
RUN100_16	0.025	0.024	0.247	0	204.33	67.17	204.3	67.17	0.9522	0.0136	38.85	7.71	0	0
RUN100_17	0.018	0.016	0.252	0	184.44	64.93	184.4	64.93	0.9437	0.0198	34.68	8.41	0	0
RUN100_18	0.011	0.01	0.254	0	163.12	78.17	163.1	78.17	0.9316	0.0393	30.31	9.44	0	0
RUN100_19	0.004	0.001	0.254	0.03	139.41	92.89	135.3	94.47	0.9013	0.0653	23.39	10.37	0	80.7
RUN100_20	-0.003	-0.007	0.259	0.06	95.06	75.79	89.37	76.87	0.8804	0.0726	18.24	9.46	0	72.7
RUN200	0.031	0.03	0.249	0.006	65.93	20.69	65.53	21.23	0.8745	0.0435	14.34	2.96	0	94
RUN200_A	0.031	0.029	0.251	0.002	65.39	21.14	65.27	21.32	0.8735	0.0432	14.14	2.98	0	87
RUN200_A	0.031	0.045	0.249	0	73.02	17.27	73.02	17.27	0.9493	0.0133	41.09	6.49	0	0
RUN200_1	0.031	0.03	0.249	0.004	65.57	20.08	65.31	20.45	0.8746	0.0381	14.36	2.91	0	71.5
RUN200_1	0.024	0.022	0.251	0.014	61.69	22	60.85	22.96	0.8644	0.0478	13.08	3.14	0	86.1
RUN200_2	0.017	0.015	0.255	0.03	54.04	22.64	52.43	24.09	0.8401	0.062	11.62	3.14	0	79.5
RUN200_3	0.01	0.006	0.258	0.084	44.71	25	41.03	26.84	0.8247	0.0758	10.33	3.31	0	80.1
RUN200_4	0.003	-0.003	0.263	0.182	35.58	23.15	29.23	24.9	0.7886	0.0989	8.55	3.19	0	75.9

Run number	det.r	stoc.r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	Het	SD(Het)	AllelN	SD(A)	Med.TE	MeanTE
RUN200_5	-0.004	-0.011	0.268	0.308	28.38	21.09	19.79	21.77	0.7575	0.1208	7.47	3.08	0	72.6
RUN201	0.008	0.009	0.227	0.044	50.35	22.54	48.19	24.23	0.8682	0.0566	13.9	3.9	0	81.7
RUN201_1	0	0.002	0.232	0.06	41.1	23.39	38.7	24.61	0.8435	0.0749	11.69	4.11	0	77.4
RUN201_2	-0.007	-0.006	0.235	0.148	32.62	23.2	27.93	24.19	0.8112	0.1013	9.87	3.86	0	77.5
RUN201_3	-0.015	-0.014	0.243	0.272	23.57	19.03	17.31	19.21	0.7837	0.0978	8.19	3.57	0	75.9
RUN201_4	-0.022	-0.022	0.249	0.47	19.54	17.89	10.58	16.14	0.7349	0.1252	6.65	3.02	0	73.4
RUN201_5	-0.029	-0.031	0.256	0.698	12.85	11.19	4.14	8.43	0.6822	0.1456	5.37	2.61	83	70.1
RUN200A	0.031	0.03	0.25	0.004	66.32	20.68	66.05	21.06	0.8771	0.0367	14.4	2.93	0	83.5
RUN200B	0.024	0.022	0.253	0.01	59.26	22.04	58.68	22.69	0.8643	0.0577	13.09	3.1	0	67.8
RUN200C	0.017	0.014	0.254	0.028	52.87	23.15	51.43	24.37	0.8488	0.0629	11.94	3.14	0	79.2
RUN200D	0.01	0.006	0.258	0.086	44.25	24.38	40.5	26.33	0.8261	0.0889	10.38	3.35	0	74.2
RUN200E	0.003	-0.002	0.263	0.152	37.4	24.33	31.86	25.96	0.7971	0.0982	8.99	3.2	0	77.9
RUN200F	-0.004	-0.009	0.267	0.266	30.21	21.66	22.31	22.74	0.7682	0.1246	7.98	3.26	0	74
RUN200N	-0.004	-0.009	0.266	0.288	29.98	21.48	21.56	22.45	0.7636	0.1149	7.75	3.17	0	78.8
RUN25YRS.OUT	-0.009	-0.018	0.270	0.462	23.16	19.81	12.60	18.47	0.7283	0.1383	6.57	2.86	0	72.8
RUN35YRS.OUT	-0.004	-0.012	0.267	0.312	24.34	20.19	16.93	20.06	0.7404	0.1301	7.00	3.09	0	72.2
RUN30YRS.OUT	-0.009	-0.018	0.272	0.496	24.29	19.27	12.41	18.19	0.7434	0.1175	6.85	2.82	0	70.9
RUN25_1YRS.OUT	-0.017	-0.028	0.278	0.684	17.54	16.31	5.71	12.20	0.6627	0.1644	5.27	2.54	82	68.0
RUN25_1YRS.OUT	-0.017	-0.026	0.280	0.660	17.75	17.58	6.23	13.17	0.6670	0.1559	5.18	2.35	86	69.9
RUN500YRS.OUT	-0.004	-0.016	0.270	1.000	0.00	0.00	0.00	0.00	0.0000	0.0000	0.00	0.00	125	135.3
500_MOD.OUT	-0.004	-0.016	0.267	1.000	0.00	0.00	0.00	0.00	0.0000	0.0000	0.00	0.00	125	135.8
500_LOW.OUT	0.060	0.041	0.178	0.008	74.03	17.55	73.44	18.66	0.5061	0.1713	3.26	0.98	0	452.0
500_HIGH.OUT	-0.081	-0.075	0.322	1.000	0.00	0.00	0.00	0.00	0.0000	0.0000	0.00	0.00	39	41.0
500_LM.OUT	-0.047	-0.044	0.293	1.000	0.00	0.00	0.00	0.00	0.0000	0.0000	0.00	0.00	64	65.6
500_LM.OUT	-0.047	-0.043	0.293	1.000	0.00	0.00	0.00	0.00	0.0000	0.0000	0.00	0.00	66	67.8
51_SUPP	-0.067	0.008	0.218	0.000	59.84	16.44	59.84	16.44	0.9839	0.0029	83.85	12.95	0	0.0
58_SUPP	-0.101	-0.003	0.227	0.000	44.49	15.49	44.49	15.49	0.9807	0.0037	66.54	12.66	0	0.0
66_SUPP	-0.029	0.026	0.221	0.000	70.29	17.50	70.29	17.50	0.9807	0.0038	81.08	11.11	0	0.0
74_SUPP	0.030	0.070	0.179	0.000	84.60	11.81	84.60	11.81	0.9787	0.0041	83.05	9.92	0	0.0
50_SUPP	-0.047	0.016	0.251	0.000	63.37	17.51	63.37	17.51	0.9825	0.0031	81.12	11.36	0	0.0
59_1_SUPP	-0.081	0.001	0.263	0.000	48.49	17.86	48.49	17.86	0.9795	0.0050	66.62	13.33	0	0.0
67_SUPP	-0.004	0.043	0.246	0.000	74.74	16.53	74.74	16.53	0.9779	0.0048	76.48	10.10	0	0.0
75_SUPP	0.060	0.096	0.190	0.000	87.08	11.93	87.08	11.93	0.9740	0.0054	73.73	8.29	0	0.0
66_SUPP	-0.029	0.026	0.220	0.000	69.64	16.43	69.64	16.43	0.9814	0.0034	82.59	10.57	0	0.0

Run number	det.r	stoc.r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	Het	SD(Het)	AllelN	SD(A)	Med.TE	MeanTE
66_SUPP_2	-0.029	0.041	0.205	0.000	78.38	13.21	78.38	13.21	0.9855	0.0027	101.84	11.20	0	0.0
66_SUPP_3	-0.029	0.072	0.194	0.000	84.16	11.80	84.16	11.80	0.9890	0.0019	123.68	13.34	0	0.0
67_SUPP_2	-0.004	0.060	0.230	0.000	79.61	14.08	79.61	14.08	0.9834	0.0032	93.81	10.28	0	0.0
67_SUPP_3	-0.004	0.091	0.216	0.000	84.98	11.66	84.98	11.66	0.9876	0.0022	116.06	12.54	0	0.0
67_SUPP_3	-0.004	0.132	0.197	0.000	90.26	10.44	90.26	10.44	0.9903	0.0018	137.40	15.66	0	0.0
LM_500_NS	-0.067	-0.056	0.264	1.000	0.00	0.00	0.00	0.00	0.0000	0.0000	0.00	0.00	53	55.2
HIGH_500_NS	-0.101	-0.085	0.289	1.000	0.00	0.00	0.00	0.00	0.0000	0.0000	0.00	0.00	36	37.4
MOD_500_NS	-0.029	-0.032	0.261	1.000	0.00	0.00	0.00	0.00	0.0000	0.0000	0.00	0.00	82	87.0
LOW_500_NS	0.030	0.014	0.176	0.266	52.24	25.23	38.36	31.61	0.4670	0.2092	3.03	1.10	0	344.0
LOW_500_SUPP	0.030	0.085	0.165	0.000	87.92	11.03	87.92	11.03	0.9838	0.0028	100.46	11.73	0	0.0
LOW_500_SUPP4	0.030	0.068	0.171	0.000	84.99	12.26	84.99	12.26	0.9786	0.0043	83.25	10.27	0	0.0
LM_500_SUPP	-0.067	0.008	0.212	0.000	59.50	15.65	59.50	15.65	0.9842	0.0030	84.98	13.37	0	0.0
HIGH_500_SUPP	-0.101	0.000	0.220	0.000	42.84	14.38	42.84	14.38	0.9804	0.0040	65.23	12.69	0	0.0
HIGH_500_SUPP	-0.101	0.000	0.219	0.000	43.22	15.25	43.22	15.25	0.9801	0.0041	64.85	13.04	0	0.0
HIGH_500SUPP	-0.101	0.000	0.219	0.000	44.28	16.14	44.28	16.14	0.9804	0.0041	65.92	13.65	0	0.0
MOD_500_SUPP	-0.029	0.025	0.212	0.000	72.46	15.70	72.46	15.70	0.9813	0.0033	83.63	10.44	0	0.0
LOW_500_SUPP	0.030	0.068	0.171	0.000	85.97	11.21	85.97	11.21	0.9785	0.0042	83.59	9.76	0	0.0