M INOR AMENDMENTS

Page 3, last para, line 2 should read: "maybe as early as 2000 ybp (Holdaway 1996)...."

Pages 14-16. Chapter Headings should read: Chapter 2: Sexing: Chapter 3: Diet; Chapter 4: Range, Spacing and Habitat use; Chapter 5: Communal Roosting

Page 90, para 2, line 9 should read: "....therefore this behaviour appears...."

Spacing and Ecology of the Australasian Harrier (*Circus approximans*) in the Rangitikei – Manawatu Sand Country

A thesis presented in partial fulfilment of the requirements
for the degree of Masters of Science in Zoology
at Massey University,
Palmerston North,
New Zealand

Matthew Donald Wong

April 2002

Acknowledgements

Although I endeavour to thank everyone if I have missed some people I sincerely apologise and appreciate all those who helped with this thesis.

Firstly I must thank my chief supervisor, Associate Professor Robin Fordham, for his infinite words of support, advice and guidance throughout this thesis. Thank you for encouraging my passion for ornithology and for being a supportive supervisor and friend. A very special thanks to Dr Isabel Castro for her friendship, generosity, enthusiasm and spirit, which at times I desperately needed. Thank you for the constructive comments, time and effort you gave to this thesis and for being an awesome supervisor and mentor. I am very appreciative of the time and effort Dr Ed Minot provided in the initial stages of the research and more importantly editing chapters towards the end. Your ideas and comments have been invaluable, providing a wealth of expertise and knowledge to this thesis.

I owe a great credit to the Department of Conservation, in particular the Palmerston North Area Office, for allowing me access to Pukepuke Lagoon and free accommodation. I would particular like to thank these staff: Don Ravine for providing helpful information on Pukepuke Lagoon and for showing a keen interest in my research, Rod Cossee for providing harrier banding records, Ralph Powlesland for his technical advice and supply of references and Tim Holmes for helping with permits.

This research was made possible with the support of the landowners and farmers of the Tangimoana area who allowed me to travel freely over their land. Thank you also to Jim Cook who kept me in constant supplied of bait for trapping. Thanks to Greg Brooks for flying round after birds and the Feilding Gliding Club for valuable harrier observations.

Thank you to all the people who helped with technical support, especially Dr Leon Huynen, for his contribution to the molecular sexing component, Dr Roger Lentle and Dr Murray Potter for assistance with home range packages, Dr Ian Henderson for stats advice, Dawn Lemke for her time and effort teaching me GIS programmes. Also thank you to Mike Tuohy for supplying orthophotographs of study areas.

Thank you to the Raptor Association of New Zealand for support and help with radio-telemetry equipment. I am particularly thankful to Dawne Morton for her cage traps and for company during roost observations and Steve Lawrence and Noel Hyde for technical advice and sharing my passion for raptors! Also thank you to the Ornithological Society of New Zealand for their generous funding and continual support. In particular, the members of the Wairarapa Branch for nurturing my skills as a young ornithologist. Thank you to the Massey University Graduate research fund, and the Ecology Group Development Fund for assistance with equipment and travel.

I am extremely appreciative of the staff and students of the ecology group who have been generous with their advice, support and humour over a coffee or three! Gracias to all the post grads for keeping me in supply of conversation and entertainment. Also for your support and friendship and encouraging my caffeine addiction! I endeavour to thank everyone however you know who you are and a lengthy list would only educe boredom for the other readers! The stream team deserve special praise for broadened my horizons in ecology and showing life exists beyond ornithology. A special thank you to the three magnificent girls who run the show, Barbara Just, Erica Reid, and Dianne Crow, for assistance organising finances and equipment and also the wonderful technicians Hayden Hewitt, Hamish Mack, Paul Barrett, Jens Jorgensen, Tracy Harris and Cathy Lake.

Thank you to Lucinda Birch, Paul Martinson and Brent Stephenson for capturing the beauty of raptors on film and canvas and supplying some of the photos for this thesis. To my flatmates Stew Taylor, Susan Greenwood, Richelle Marshall, and Shaun Bennett who put up with crazy bird rescue calls and injured birds. I would like to express my sincere gratitude and appreciation to the Bowie family and the Tankersley family for their hospitality over the many years and to Rebecca Tankersley, Scott Bowie, Justin Cook, Callum Kay, Leanne Scott, Ben Winder, Penny Aspin and Dawn Lemke for their wonderful contributions to my life.

Finally a very special thank you to my parents, Don and Gloria, for their love, support and sacrifices which got me here and for putting up with all the disgusting things associated with keeping raptors! Also thanks to my wonderful sisters Sarah, Nic, Mel and family for looking out for their younger brother! (*Cheers Circus approximans!*)

ABSTRACT

Between March 2000 and May 2001 138 Australasian Harriers were trapped, individually banded, measured, sexed and aged. Morphometric measurements and molecular sexing methods were used to identify the best way to accurately assign gender to harriers. Morphometric sexing is 96% accurate when based on six measurements; weight, back talon, culmen, middle talon, hallux and toe. Of these, weight, back talon and culmen are the most reliable indicators of sex. Molecular sexing applied to DNA from 11 birds proved to be an accurate means of sexing and is a first for this species.

Mammal (61.2%) and bird (36.2%) prey dominate the diet of the harrier at Pukepuke Lagoon, especially lagomorphs and small passerines. Mammalian prey in pellets peaked in August and again in December, was highest in the early-breeding season and lowest in the non-breeding season. Birds were most frequent in pellets in the non-breeding season (peaking in May and June) and least in the early-breeding season (August). Other prey averaged only 5.9% of the total prey in pellets over the year. Harriers are generalist feeders of live prey and carrion, but may become specialised when prey abundance and availability in the environment is high. Impact of harriers on economic, recreational, and threatened endemic species is discussed.

Eight harriers were radio-tagged and tracked intensively over seven months. Male home ranges averaged 405.51 ha in the breeding season and 669.71 ha in the non-breeding season. Female home ranges averaged 340.60 ha in the breeding season and 864.92 ha in the non-breeding season. In females, but not in males, there was significant difference between seasonal ranges. Range sizes and shapes varied between all individuals with no common pattern emerging. Breeding season range overlaps were scarce, but tended to be large and associated with closely nesting pairs. In the non-breeding season there were large overlaps in ranges of most birds. Range overlap was not related to age or sex. Temporal ranges overlapped little for most birds, except those nesting close together. For males and females pasture accounted for over 70% of the habitat in all ranges and seasons, but the birds utilised only 38% of pasture. Swamp accounted for less than 5% of the total habitat but was the most frequently used by harriers (41%).

Three communal roosts were observed for 27 evenings and six mornings. The earliest harrier, and the latest, landed in a roost 90 minutes and four minutes respectively before complete darkness. On average there were 39 minutes between the first and last harriers to land, and most landed shortly after sun moved below the horizon. The highest light reading for a harrier landing in a roost was 715.1 lux and the lowest 0.3 lux. High numbers of birds over roosts was associated with poor weather (wind and rain). Both the breeding and non-breeding season produced fairly similar positive linear increases in bird numbers as light intensity decreased. Differing habitat type and composition at the three roosts did not affect the general behaviour of harriers in response to changing light intensity and weather conditions. In New Zealand communal roosting by harriers may relate to a combination of foraging, social and resource pressures within the local area.

CONTENTS

CHAPTER 1: GENERAL INTRODUCTION, STUDY SITE, FIELDWORK AND METHODS.

CHAPTER 2: SEXING OF THE AUSTRALASIAN HARRIER: COMPARISON OF MORPHOMETRIC AND MOLECULAR METHODS.

CHAPTER 3: DIET OF THE AUSTRALASIAN HARRIER IN THE MANAWATU – RANGITIKEI SAND COUNTRY: A 25-YEAR COMPARISON.

CHAPTER 4: HOME RANGE, SPACING AND HABITAT USE OF THE AUSTRALASIAN HARRIER IN THE MANAWATU - RANGITIKEI SAND COUNTRY.

CHAPTER 5: COMMUNAL ROOSTING OF THE AUSTRALASIAN HARRIER IN THE MANAWATU-RANGITIKEI COASTLINE.

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

General Introduction

1

General Introduction, Study Site, Fieldwork and Methods.

1.1 BACKGROUND

Raptors or diurnal birds of prey form the order Falconiformes and are found globally in a wide range of habitats. The largest and most diverse group of raptors includes 223 species in the family Accipitridae, one of the largest avian families. This family contains those species commonly termed hawks, buzzards and eagles, together with more specialised species such as kites, old world vultures, cuckoo-hawks, sparrow-hawks, goshawks, and harriers (Kemp 1990). Collectively, harriers belong in the genus *Circus*, which includes the Australasian Harrier (*Circus approximans*), hereafter referred to as 'harrier' unless the usage is unclear.

New Zealand has seven native, five endemic and one introduced bird of prey (Turbott 1990). Of the four extant species, the New Zealand Falcon (*Falco novaeseelandiae*), Morepork (*Ninox novaeseelandiae*) and the Australasian Harrier are wide spread with the harrier being the most common (Heather and Robertson 1996). The Little Owl (*Athene noctua*) was introduced in the early 1900's from Germany and is found only in the South Island. Three diurnal and one nocturnal bird of prey are now extinct including the Eyles' Harrier (*Circus eylesi*), Haast's Eagle (*Harpagornis moorei*), Chatham Island Sea-Eagle (*Haliaeetus australis*) and the Laughing Owl (*Sceloglaus albifacies*) (Turbott 1990; Gill and Martinson 1991). There is doubt over the existence of the Chatham Island Sea-Eagle because of a lack of supporting fossil evidence (N. Hyde. pers. comm.), and the Laughing Owl (*Sceloglaus albifacies*) is now considered extinct since last reports were of a dead specimen recovered in 1914 (Heather and Robertson 1996).

1.1.1 Biology and Ecology

Identification

The harrier is a medium sized raptor with similar characteristics to small raptors, (e.g. kestrels and falcons) and large raptors (e.g. eagles and vultures) (Kemp 1990). The sexes are similar, although females (800-1200 gm, 55 cm) tend to be larger than males (600-850 gm, 50 cm) (Heather and Robertson 1996). Juveniles have dark brown eyes and plumage except for a white patch on the nape (Baker-Gabb 1985). As birds age their eye colour and plumage becomes paler. The oldest harrier recorded in New Zealand lived over 18 years (Heather and Robertson 1996).

Habitat, hunting, and food

Harriers are open country birds common in wetlands, farmland, high country tussock, scrubland, along forest margins, along riverbeds, and around the coast. They hunt by circling above the ground, or by slow quartering followed by a dive attack on unsuspecting prey. They also stoop over cover in order to flush prey, often hunting over drains, hedgerows, rank grass, swamps and edges of bush or open water (Baker-Gabb 1978). They take live prey and carrion consisting of mammals, birds, reptiles, amphibians, fish, and insects (Heather and Robertson1996).

Breeding

Breeding commences with courtship soaring and displays seen as early as June or July but most often between August and October. As the breeding season progresses courtship flights become more frequent, usually ending with the pair landing close to the chosen nest area (Baker-Gabb 1981). From October to November females start nest building usually on the ground or between 50 cm and 150 cm above ground level. Nests may be situated in swamps, rushes, bracken fern, rank grass, young pine plantations, grain crops or loose scrub (Baker-Gabb 1985). Nests are constructed of local coarse vegetation, usually with sticks and leaves forming a shallow platform. The nest is lined with soft fine vegetation such as grass stalks and raupo leaves but can also consist of wool or fur (pers. obs.).

In September to December 1-5 off white eggs are laid, which take the female c. 31-34 days to incubate before hatching. Initially only the female feeds the chicks although both parents hunt. When the chicks are older and able to tear their own food, prey is left

at the nest. Chicks fledge at c. six weeks old from December to February and remain with their parents for one to two weeks, however they may stay in the nest area for much longer (Baker-Gabb 1985). Little is known about juvenile dispersal from the breeding area or behaviour in the non-breeding season movements.

Social interaction

There is interaction between harriers in the breeding and non-breeding season, however, they are relatively silent except in the breeding season during courtship displays and defence (Heather and Robertson 1996). Some calling is heard in communal roosts during the non-breeding season where numbers usually between 10 and 50 birds converge at night. Harriers usually hunt alone, however several may work together when harassing large prey items such as Pukeko (pers. obs.). Territory size and interaction between harriers is relatively unknown and dispersal distances from banding records cover as far as 900 km (Appendix 1.1).

History and present status

The harrier was commonly know as Kahu in Maori mythology and appears in the story of Maui, where it is said that Kahu's plumage is the result of being scorched by the fire of Mahuika who tried to destroy Maui. Kahu was also believed to be a messenger used by tohunga to communicate with the gods (Riley 2001).

Worthy & Holdaway (1996) suggested that harriers were probably not part of the prehuman New Zealand fauna. However, there are some sub fossils and numerous midden records of *Circus approximans* from widely distributed sites in the North, South and Chatham Islands which suggest that they may have been here in very low numbers before the arrival of humans (Turbott 1990).

First human settlement in New Zealand is often set at AD800 (Davidson 1981) but maybe as early as AD2000 (Holdaway 1996), and before this New Zealand was predominantly forest covered (O'Brien 1981; Dawson and Lucas 2000). If the Australasian Harrier existed prior to human settlement it would probably have been confined to the lowland coastal swamps. The influence of the early Polynesian settlers followed by European settlement in the 1840's gradually extended the open country in land. Native forests retreated quickly into developing pastureland and with the

introduction of a variety of smaller mammals such as mice, rats and later lagomorphs (King 1995), the harrier flourished (Heather and Robertson 1996).

During the early to mid 1900's the Australasian Harrier was hunted and a bounty set by many Acclimatisation Societies as harriers were seen to be a major cause of the failure of many introductions of game birds (Oliver 1938; Gurr 1968; Heather and Robertson 1996). Presently the harrier has partial protection, however farmers and game bird hunters still commonly persecute them because they are suspected of attacking new born lambs, cast sheep and young game birds. Populations of harriers have been healthy on the mainland probably reflecting a general increase in prey numbers and species (Baker-Gabb 1985). Yet intensive grazing, decreasing prey abundance through disease and better pest control, and draining traditionally good swamp habitat for breeding may influence the population.

Distribution

The Australasian Harrier is the only member of the family Accipitridae, to breed in New Zealand. The Black Kite (*Milvus migrans*) is a vagrant to New Zealand but is not known to breed here, thus members of this large, cosmopolitan family of birds are poorly represented in New Zealand. Australasian Harriers are widespread and common throughout the New Zealand mainland, offshore islands and on the Chatham Islands. They visit the Kermadec Islands each winter and wander to The Snares, Auckland and Campbell Islands (Heather and Robertson1996). It is one of only two harrier species found in Australasia, the other being the Spotted Harrier (*Circus assimilis*) of Australia (Cupper and Cupper 1981; Simmons 2000). Beyond New Zealand the Australasian Harrier lives on mainland Australia, Tasmania, Fiji, New Caledonia, Vanuatu, Tonga, Society Islands, Loyauté and Wallis, and visits Norfolk and Lord Howe Islands and Samoa. It is known to be migratory in South Australia and Tasmania (Watling 1982; Marchant and Higgins 1993; Heather and Robertson 1996; Simmons 2000).

1.1.2 Evolution

Evolution of harriers (Circus spp.)

According to Wink (1998, cited in Simmons 2000) harriers diverged from the Accipiters five to seven million years ago and have the Goshawk (*Accipiter gentilis*) and Cooper's Hawk (*Accipiter cooperi*) as their closest relatives. Until recently only 13

species of harrier were commonly recognised containing three subspecies, but genetic research has suggested there could be 16 extant species (Simmons 2000). The three new species recognised are: The Madagascar Harrier *(C. macrosceles)* which is no longer a sub-species of the Reunion Harrier (*C. maillardi*); the Northern Harrier (*C. hudsonius*) which is now separate from the Hen Harrier (*C. cyaneus*); and the Papuan Harrier (*C. spilothorax*), separated from the Eastern Marsh Harrier (*C. spilonotus*) (Wink, 1998 cited in Simmons, 2000). Currently harriers are found on all continents except Antarctica. The sixteen species of harriers can be separated further into two phylogenetic groupings, the Steppe Harriers (commonly dry grassland harriers), and the Marsh Harriers to which the Australasian Harrier belongs.

Evolution of Marsh Harriers and the Australasian Harrier (Circus approximans)

The oldest ancestral harrier, the Long-winged Harrier (*C. buffoni*) from central and South America is believed (Simmons 2000) to have given rise to the Montagu's Harrier (*C. pygargus*), from which in turn arose the African Harrier (*C. ranivorus*) and about the same time the Australasian Harrier (*C. approximans*). Steppe Harriers appear to have also arisen from the Long-winged Harrier via the Spotted Harrier (*C. assimilis*). Thus the first harriers evolved in South America and not Europe as was originally thought (Simmons 2000).

Genetic research indicates that the Australasian Harrier gave rise to three separate species about 815,000 years ago. These include the Madagascar Harrier (*C. macroscele*) in Madagascar and the Comores; Reunion Harrier (*C. maillardi*) in the Reunion Islands; and the European Marsh Harrier (*C. aeruginosus*) widely spread in Europe, Western Russia and North Africa (Wink, 1998 cited in Simmons, 2000).

1.1.3 Taxonomy

The first specimens of Australasian Harrier were collected and formally described by the American Exploring Expedition from the Bay of Islands, New Zealand, in 1840 (Oliver 1930). Since then the taxonomy of the Australasian Harrier has been surrounded in confusion. In the 1930's five forms of the Australasian Harrier were described based on differences in body size and depth of plumage colour, the New Zealand form *Circus approximans drummondi* being the largest of the five (Oliver 1930). Soon after Amadon

(1941) suggested that there were not five forms, and distinguished instead two races. *C. approximans approximans* Peale distributed over many Pacific Islands, and *C. approximans gouldi* Bonaparte, found in Australia and New Zealand.

Vaurie (1965) suggested however, that the Australasian Harrier was a subspecies of the European Marsh Harrier (*Circus aeruginosus*). As a result literature published outside New Zealand often referred to the Australasian Harrier as *Circus aeruginosus gouldi* (Walters 1981; Blakers *et al.* 1984; Simpson and Day 1984) but most New Zealand ornithologists at the time still referred to the species as *Circus approximans gouldi* (Carroll 1968; Douglas 1970). Nieboer (1973; cited in Simmons 2000 pp21) suggested there were as many as 10 distinct species of harrier and recognised five subspecies of the Marsh Harrier, one being the Australasian Harrier. Baker-Gabb (1978) and Robertson (1978) used *Circus aeruginosus approximans* Peale combining the scientific names of the Australasian and European Marsh Harrier.

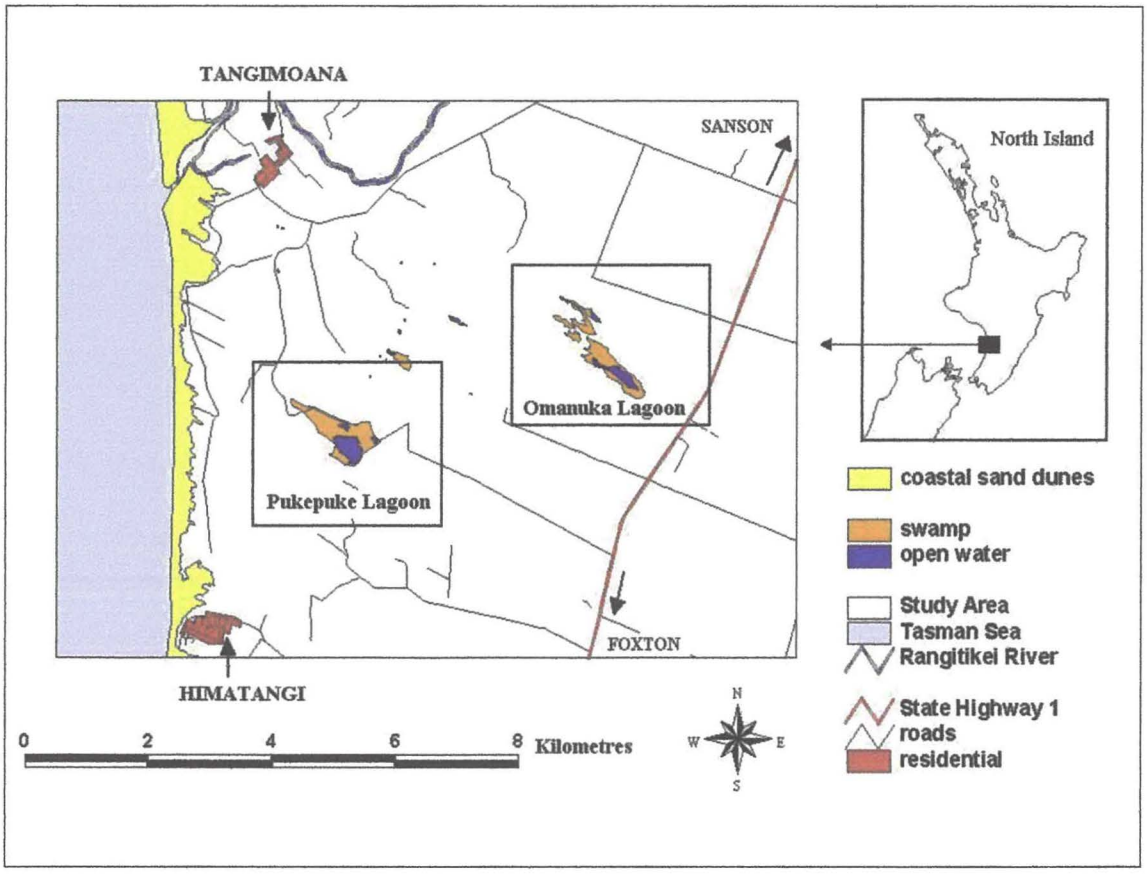
Ten years later Amadon and Bull (1988) gave full species status to the Australasian Harrier (*Circus approximans*) for New Zealand, Australia and the Pacific Islands. This view is supported by current reference literature (Baker-Gabb 1985; Amadon and Bull 1988; Sibley and Monroe 1990; Turbott 1990; Marchant and Higgins 1993; Heather and Robertson 1996) and is followed in the present study. Ornithologists before 1988 also argued that the Australasian Harrier should be a separate species because the plumage of both sexes was very distinct from the European Marsh Harrier (Baker-Gabb 1979). The confusion surrounding the taxonomy of the Australasian Harrier is epitomised by its specific name, *C. approximans*, meaning 'approximately like the Marsh Harrier'. As mentioned above, genetic research indicates that the Australasian Harrier gave rise to the European Marsh Harrier, thus Marsh Harriers apparently had their origin in the Southern Hemisphere (Wink, 1998 cited in Simmons, 2000).

1.2 PUKEPUKE LAGOON

Pukepuke Lagoon lies at 40° 20´S latitude and 175° 16´E longitude on the west coast of the lower North Island (Figure 1.1). Part of the wider Manawatu-Rangitikei sand country Pukepuke Lagoon is one of a series of shallow dune-lakes found along the

coastline (Cowie and Smith 1958). Its catchment covers approximately 30km^2 with Omanuka Lagoon lying to the north east (Ogden and Caithness 1982). It is less than 3km east from the sea (Figure 1.1), and 6.5m above mean sea level. The Lagoon includes 15ha of open water and 86ha of surrounding swamp (Figure 1.1) managed by the New Zealand Department of Conservation. As a protected wildlife area Pukepuke Lagoon has been a site of many ecological and biological studies (Caithness and Pengelly 1973; Gibbs 1973; Potts 1976; Baker-Gabb 1978; Robertson 1978; Moors 1979; Craig 1980; Moors and Lavers 1981; Ogden and Caithness 1982; Fordham 1983).

Figure 1.1 Map of the North Island (inset) showing the location of Pukepuke Lagoon and nearby Omanuka Lagoon. The lagoons occur between Tangimoana to the north, Himatangi to the south, and west of State Highway One.



The Manawatu region is characterised by a windy climate especially in exposed coastal areas where Pukepuke Lagoon is situated. The predominant wind flow is from the west or south-west and in well exposed coastal areas wind speeds average 15 to 18km/hr. Seasonal variation in wind speed is not great, but winds are generally lighter in strength from March through to August (Burgess 1986). Rainfall is reliable and varies between 900 and 1200 mm annually. The area does not experience extremes of temperature.

Sunshine hours increase towards the coast where an average of 2000 hours are recorded annually (Burgess 1986).

Pukepuke Lagoon lies between old and young dune complexes, the younger dunes bordering the coast and extending inland 0.4 - 6.4km (Cowie and Smith 1958). Quartz and feldspar minerals dominant the greywacke sand of the Manawatu-Rangitikei region. Ground down and deposited through alluvial and wind erosion from mainly the central ranges, the sands have been separated and deposited uniformly across the dune complex's (Cowie and Smith 1958). The young dune complex contains mostly unconsolidated areas with little plant cover. Most of these areas are now covered by well established pine plantations (*Pinus radiata*).

Plate 1.1 Pukepuke Lagoon (study area) facing north east showing open water, swamp, and dune hills.

Most of the study area is part of Tangimoana station, a primarily sheep and beef farm. Much of the station is in pasture with loose sandy topsoil where unconsolidated dunes are planted in pines as a means of erosion protection. Marram grass (*Ammophila arenaria*) and tree lupin (*Lupinus arboreus*) commonly occur in the dune hollows. The older dune complex has been established pasture for dairying for many decades, and

also borders Pukepuke Lagoon. Flax (*Phormiun tenax*) Raupo (*Typha orientalis*), Toetoe (*Cortaderia toetoe*), and Cabbage Trees (*Cordyline australis*) (Plate 1.1) dominate the swamp of Pukepuke Lagoon. The flora of Pukepuke Lagoon and surrounding sand country has been described by Carnahan (1957), Esler (1969; 1970; 1978), and Ogden and Caithness (1982). The fauna is described in chapter 3 which covering harrier diet.

1.3 FIELDWORK AND METHODS

1.3.1 Trapping method and design

Cage traps

Four cage traps, and two noose traps were used to catch harriers for banding and measuring or for attaching radio transmitters. Cage traps (Plate 1.2), 1.3m x 2m x 1.3m high, were adapted from those used by Hollom (1950). The cage frame was constructed of 5cm green plastic piping and the floor of the trap was open. Plastic material was chosen for its lightness and portability. The frames were covered with 5.5cm-gauge green wire netting. The wire was of 2.45mm thickness with a plastic coating to reduce damage to the fleshy covering of the upper mandible of the harrier, termed the cere. The walls and roof of the trap were assembled with nylon ties and could be stacked flat when disassembled for ease of transport. Trapped harriers were recovered through one end of the trap which also formed a door. A circular trap entrance in the roof of the trap allowed sufficient area for harriers to drop into the trap. The diameter of the circular entrance was 300mm and directly in the middle of the roof. 450mm long wires hung from the circumference of the trap entrance with the ends rounded to ensure they would not damage the eyes of harriers trying to escape, or fighting in the trap. The hanging wires formed a funnel to the entrance to discourage trapped harriers from escaping through the entrance. The hanging wires were slightly longer than the diameter of the entrance circle to prevent the hanging wires from swinging out and blocking the entrance for other harriers wanting to enter.

Plate 1.2 Cage Trap

Bait was largely determined by availability but consisted mostly of hares, rabbits and possums shot or trapped by either local hunters or myself. Hares were abundant around the coastal farmland of the Manawatu and it was not unusual to shoot more than 40 hares in one evening using night spotting gear (J. Cook. pers. comm.). Carcasses were cut open to make them more attractive to harriers, then placed at the bottom of the cage trap directly beneath the entrance. A heavy carcass prevented captured harriers from dragging the bait to the side of the trap. Lighter baits were staked firmly to the ground as harriers would often drag bait to the side of a cage trap when feeding. When this occurred, other harriers were then less likely to enter the trap. Instead they would pull part of the bait through the wire mesh of the cage and feed from outside the trap or walk around the bottom of the trap and never discover the entrance. Cage traps were placed near a fence enabling harriers to observe the entrance to the trap easily. Cage traps were set along frequented hunting locations assessed by direct observation of harriers hunting. The trapping sites chosen tended to be close to bodies of water or dense vegetation.

Noose traps

The modified noose traps (Plate 1.3) were used when harriers became harder to trap between June and August. They allowed me to trap birds which had become trap shy or were no longer interested in cage trap bait when other food became readily available. This trap design became important when capturing selected birds for radio tagging. All birds caught by the noose trap were recaptures, which suggests the cage trap was an effective method of trapping most harriers.

Plate 1.3 Noose mat for harriers shy of cage traps.

Noose traps were modifications of bal-chatris (Hollom, 1950) and were constructed of a wire mesh mat, 80cm x 100cm. The mat was constructed of 2mm thick wire mesh with a 2cm gauge. Forty pound breaking-strain nylon nooses were tied to the mat, designed to loop around the feeding harrier's legs (Plate 1.3). It was important that the mat did not make the bait too inconspicuous to harriers. Another requirement was to reduce trap shyness by harriers, which is why the bal-chatris cage was reduced to a simpler mat design.

The noose mat was staked firmly to the ground and placed in an area where target birds for radio tagging were believed to hunt regularly. Initially bait was placed under the mat but harriers were reluctant to stand on the mats so bait was then placed on top of the mat with nylon nooses surrounding it. This proved to be the most effective method of trapping using the noose mat. Harriers were inclined to land on the carcass but would frequently step into the nooses during feeding. It was difficult to judge if a harrier was caught until it attempted to fly off or struggled with its legs. Often other harriers would chase a feeding harrier off the trap, which resulted in the harrier pulling the nooses tight around its legs.

The advantages of the cage trap over the noose trap were (i) many harriers could be trapped in a single trapping day. Trapped harriers would also act as an attractive decoy for other harriers and as many as eight birds were caught in a trap at one time (ii) the trapped birds could be left unattended as they had considerable freedom within the trap. Because of this, the cage trap needed checking only twice daily.

The disadvantages of the cage traps were (i) they were large and bulky, which made transporting difficult, compared to smaller trap designs. (ii) they were effective only during parts of the year (February – June). (iii) they were obvious targets for inquisitive cattle and humans.

The main disadvantages of noose traps were that they needed to be kept under constant observation because a struggling bird can harm itself or become strangled in the nooses, and only one or two birds can be trapped at a time.

1.3.2 Banding

Trapping was carried out five times a week between February and July and a total of 138 birds were trapped, measured and banded. Captured harriers were placed in a banding mat (Plate 1.4) designed to restrain the bird and make measuring easier to perform. A traditional falconry hood (Plate 1.4) designed for Australasian Harriers was used during the entire banding process as a method of calming the bird and reducing stress. This technique is used widely by practising falconers both in New Zealand and internationally (Fox 1995).

Plate 1.4 Banding mat and traditional falconry hood used to restrain and calm harriers during banding and transmitter attachment.

A National Banding Scheme size L metal band was placed on the left leg of each trapped bird. For each bird trapped, nine Morphological measurements were taken, including: middle claw, toe, back claw, hallux, tarsus, beak, tail, wing and weight (Chapter 2, Figure 2.1 – 2.5). The birds were aged and sexed, where possible, and recapture weights of banded birds, if any, were taken. Sexing of harriers was based mainly on head and foot measurements, which showed considerably more variation between the sexes than other morphological measurements. This method of sex identification proved to be robust when subsequent DNA analysis of 11 birds showed no disagreement with the field sexing method (Chapter 2).

1.3.3 Radio Tracking Pilot Study

A pilot study was carried out in the summer of 1999-2000, prior to starting fieldwork, to develop effective skills in all aspects of radio telemetry. The same attachment technique, equipment and tracking method described in the experimental study (Chapter 4) was used in the pilot study. A transmitter was attached to a rehabilitated juvenile female New Zealand Bush Falcon (*Falco novaeseelandiae*). The bird was trained using

traditional falconry techniques and tracked on a regular basis during training and when released to hunt. She was finally released into the wild and tracked for a further 2 months before the transmitter detached when her tail feathers moulted. All of her training was carried out over open farmland, which is habitat typically used by harriers. Frequently, she would fly out of sight in pursuit of prey and had to be relocated solely by radio telemetry.

1.4 THESIS AIMS

Four data chapters are presented in this thesis, each resolving questions and adding to knowledge related to harrier biology and life history which is weak or absent in the current literature. The following text briefly explains the problems and weaknesses in the present knowledge and the aims of each chapter to solve questions arising as a result.

Chapter 1: Sexing

Although harriers show some reversed sexual dimorphism there is still confusion and uncertainty when determining sex in the field. The numerous overlaps in bodily measurements and lack of plumage colour differences make sex determination difficult. There are four measurements currently used to sex harriers, however, other combinations of bodily measurements many be more accurate at determining sex. With the innovation of molecular sexing methods for birds it is now possible to explore this technique for sexing the Australasian Harrier.

Aims

i) Identify the most effective morphometric measurements for accurately sexing harriers.

ii) Test the methods currently used to sex harriers in the field and develop a better sexing criterion, if needed, which will improve the criterion presently in use.

iii) Look for morphometric variations in harriers from different regions.

iv) Explore the possibility of using molecular methods to sex the Australasian Harrier.

Chapter 2: Diet

The misconception of harriers as slow cumbersome scavengers of carrion is a general view held by many observers. However, harriers also hunt live prey although the frequency of different prey and prey composition in the diet is poorly understood. Regional and seasonal variation may also occur as a result of prey fluctuations and regional prey abundance. Influences of changing habitat and prey abundance on diet over time has never been studied.

Aims

i) Describe the diet of harriers at Pukepuke Lagoon.

ii) Analyse seasonal variation in the diet of harriers at Pukepuke Lagoon.

iii) Compare the present diet with a 25-year-old diet study at Pukepuke Lagoon.

iv) Compare the present diet with six different diet studies from New Zealand.

v) Compare the present study with previous diet studies in different regions, habitats, and with different prey availability.

Chapter 3: Range, Spacing, and Habitat Use

Range, spacing and habitat use of the Australasian Harrier has never been accurately understood. Knowledge of range size, overlap and interaction between individual ranges is especially weak due to the inability to accurately study harrier movements. Habitat use, preference and availability within an individual range is also lacking from the literature. The innovation of new spatial analysis, location equipment, and range estimate techniques has allowed wintering behaviours such as spacing and habitat use to be accurately studied.

Aims

i) Determine the harriers home range.

ii) Determine the percentage of a range traversed on a regular basis (core range).

iii) Compare gender ranges during the breeding and non-breeding seasons.

iv) Compare habitat availability in harrier ranges with habitat utilisation, and discuss the effect of habitat on range size.

v) Examine both static and temporal range overlaps and interactions.

Chapter 4: Communal Roosting

Factors influencing roosting behaviour such as: light intensity, weather conditions, roost dynamics and season have not been studied for over 25 years and very few studies exist on communal roosting of Australasian Harriers. Comparison of roosts in different locations and of different composition has never been studied. Communal roosting by the Australasian Harrier is strictly a New Zealand phenomenon and the pressures eliciting communal roosting in closely related species are not relevant to harriers in New Zealand.

Aims

i) Examine the role of light intensity, weather conditions, and breeding and non-breeding season on the numbers and activities of harriers using communal roosts.

ii) Compare the behaviour of harriers at three different roosts in relation to roost dynamics.

iii) Discuss the role of communal roosting of harriers in New Zealand

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Sexing

2

Sexing the Australasian Harrier: Comparison of Morphometric and Molecular Methods.

2.1 INTRODUCTION

Raptors often show considerable sexual dimorphism, more correctly termed reversed sexual dimorphism (RSD) because, in contrast to most birds, the female is larger than the male (Olsen 1990; Dijkstra *et al.* 1998). One main hypothesis suggests that selection for RSD is strongest in agile raptors which actively pursue their prey but spend less energy searching, and weakest in raptors that spend more energy searching and do not actively pursue their prey (Schoener 1969; Fox 1977a; Simmons 2000). In line with this hypothesis the Australasian Harrier *(Circus approximans)*, which actively pursues live prey and searches for carrion, is considered a moderately sexually dimorphic raptor (Baker-Gabb 1978).

For many bird species morphological measurements successfully separate males from females where measurements of the two sexes do not overlap, or where the overlap is minimal (Jenkins and Veitch 1991; Pyke and Armstrong 1993; Armstrong 2001). Carroll (1970) and Fox (1977b) suggested that leg and foot measurements (principally tarsus and toe) are an adequate sexing measure for Australasian Harriers, and these have been used widely by New Zealand researchers (Pierce and Maloney 1989). Bill and wing measurements, taken as part of the banding scheme in New Zealand, have also been used for sexing. Until now, however, there has been no reliable way to differentiate Australasian Harrier sexes by measurements and overlaps cause confusion and error (Redhead 1969).

Some authors have used plumage characteristics in addition to morphometric measurements to reduce the error in assigning sex in Australasian Harriers (Redhead 1969; Baker-Gabb 1978; Pierce and Maloney 1989). Although male and female Australasian Harriers have similar plumage coloration, mature adult males and females differ in shades of grey and brown plumage. Males are light grey on the dorsal surface of the wings and almost white on the ventral body surface, bar a few dark specks. Females are light brown on both dorsal and ventral surfaces and have more dark specks than the males (Redhead 1969). Most males also have a pale sulphur yellow iris with a thin black outer ring which contrasts strongly with their yellow eye-ring (Baker-Gabb 1978). Although coloration in addition to the current morphometric measurements improves the success of sex assignment, a large proportion of birds continues to be wrongly sexed (Redhead 1969; Baker-Gabb 1978).

In recent years molecular sexing techniques have been used successfully on a wide range of avian species (Griffiths and Tiwari 1995; Lessells and Mateman 1996; Bradbury and Griffiths 1997; Lessells and Mateman 1998; Fridolfsson and Ellegren *et al.* 1999; Nesje and Roed 2000; Pruett *et al.* 2000) including the genus *Circus* (Griffiths *et al.* 1996; Griffiths *et al.* 1998), although the technique has never been developed for the Australasian Harrier (Huynen and Wong *Submitted*, Appendix 2.1). Sex identification by Random Amplified Polymorphic DNA (RAPD) has provided a useful way of discriminating between males and females. In birds males have a pair of identical sex chromosomes (ZZ) while females have one Z and one W chromosome (ZW) (Lessells *et al.* 1996). Consequently, all DNA sequences found in males also occur in females, however DNA sequences on the W chromosome are unique to females. The *Chromodomain-helicase-DNA-binding W-linked* gene or *CHD-W* is found on the W chromosome of most bird species including raptors from the genus *Circus* (Griffiths *et al.* 1996). A second gene, *CHD-Z*, similar to *CHD-W* is found on the Z chromosome and so is common to both sexes. Segments of these *CHD* genes are amplified using sequence specific DNA primers in a polymerase chain reaction (PCR). The DNA sequence of *CHD-Z* segments differs from that of *CHD-W* such that these segments can be digested using a restriction enzyme. The resulting DNA fragments are then separated according to size using gel electrophoresis (Griffiths *et al.* 1998). Sexes can then be distinguished as females showing two major DNA fragments and males showing one.

The aim of this study is to develop a reliable technique for sexing Australasian Harriers. To achieve this I analyse the current techniques to identify whether 1) the morphological measurements used by ornithologists are the most useful in separating the sexes, and 2) whether additional or different set of measurements give greater reliability when sexing Australasian Harriers. In addition, I explore the possibility of using molecular methods to sex the Australasian Harrier.

2.2 STUDY AREAS

2.2.1 Pukepuke Lagoon

Data were collected from two sites. The first, Pukepuke Lagoon, is situated at 40° 20´S latitude and 175° 16´E longitude on the West-Coast of the lower North Island (Figure 1.1). Part of the wider Manawatu-Rangitikei sand country it is one of a series of shallow dune-lakes found along the coastline (Cowie and Smith 1958). The lagoon is 3km from the sea, and 6.5m above mean sea level with a catchment of about 30km^2. The 86ha study site is surrounded by pasture, exotic forests and low-lying sand dunes and is managed by the Department of Conservation (Ogden and Caithness 1982). The flora of Pukepuke Lagoon and surrounding sand country has been described by Esler (1978) and Ogden and Caithness (1982).

2.2.2 Greytown

The second study site is an inland 26ha property in south Wairarapa, 3km north of Greytown, 41° 04´S latitude, 175° 29´E longitude, adjacent to the Waiohine River. The area is predominantly cultivated farmland surrounded by pasture and orchards and has been an annual trapping and banding site since 1992.

2.3 METHODS

2.3.1 Ethics

Massey University Animal Ethics Committee approved all methods involving the capture and handling of harriers. I carried out banding of harriers through the Raptor Association of New Zealand under banding permit 0285 issued by the New Zealand Department of Conservation. I also obtained authority to capture, handle and release harriers from the two study sites under section 53 and 56 of the Wildlife Act 1953 and section 38 of Wildlife Regulations issued by the New Zealand Department of Conservation.

2.3.2 Bird capture and data collection

Between February and July 2000 at Pukepuke Lagoon 138 harriers were captured using four cage traps described by Baker-Gabb (1978). Traps were separated by distances greater than 500m and placed near frequently visited hunting areas. Lagomorphs and possums, either shot or trapped locally, were used as bait. The birds were individually banded with standard L size stainless steel leg bands supplied by the New Zealand Department of Conservation.

Between 1992 and 2001 at the study site North of Greytown, 185 harriers were captured as part of a wider national banding scheme. All the birds were trapped between February and June for each year. Data from the Greytown harriers have been used as a comparison with the Pukepuke Lagoon birds. Birds from both localities were presumed to be unrelated due to the high rate of movement and dispersal of juveniles out of the natal areas soon after fledging (Heather and Robertson 1996), thus the data were considered to be independent.

Morphological measurements

I took nine measurements (Figure 2.1 – 2.5) commonly used in studies of raptors and other birds: weight, talon (middle and back), toe, hallux, tarsus, culmen (exposed upper mandible and fleshy cere), tail, and wing (Pepin 1985; Langham 1987; Brooker 1996; Wiklund 1996; Armstrong 2001).

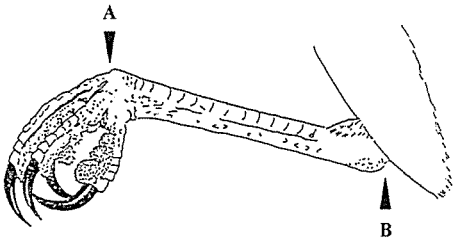


Figure 2.1 Tarsus from **A** to **B**

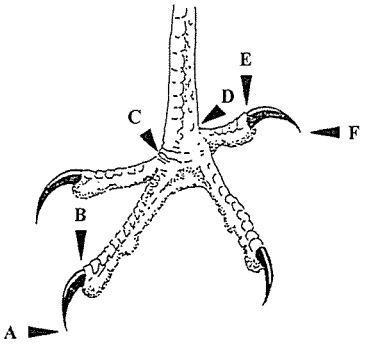


Figure 2.2 Middle Toe **A** to **C**;
Middle Talon **A** to **B**;
Back Talon **E** to **F**;
Hallux **D** to **F**

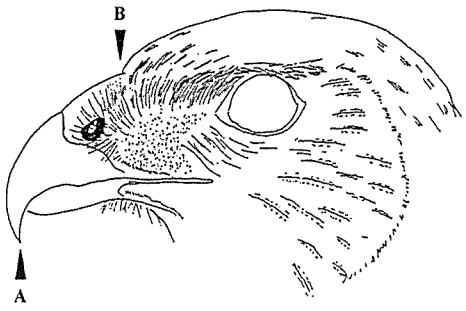


Figure 2.3 Exposed Culmen from **A** to **B**

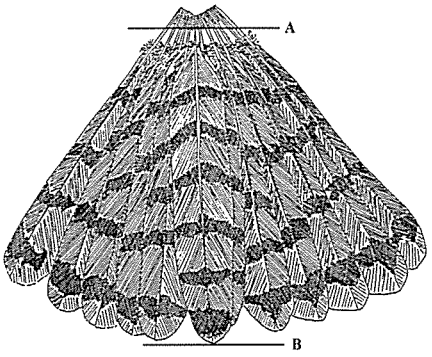


Figure 2.4 Tail **A** to **B**

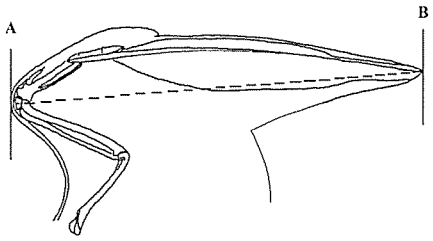


Figure 2.5 Wing **A** to **B**

Figures 2.1 – 2.5 *based on drawings in Anon. (1997). RANZ Training course 1997*

Weight was measured with 2kg Salter spring balance scales at 10-gram increments. Leg, foot and exposed culmen measurements were taken with vernier calipers to the nearest 0.01 mm. Tarsus length was taken from the notch on the proximal end of the tarsometatarsus to the start of the folded foot (Figure 2.1). Back talon and middle talon measurements were taken from the exposed claw of the hallux and middle toe (Figure

2.2). Hallux and middle toe included the toe and exposed talon (Figure 2.2). Exposed culmen measurements included the fleshy cere and exposed upper mandible (Figure 2.3). Tail (Figure 2.4) and wing (Figure 2.5) measurements were taken with a 1000mm ruler to the nearest 1.0mm. Tail measurements were taken by inserting the ruler between the two middle retrices and measuring from the base of the shafts to the tip of the longest tail feather with the tail closed. Wing measurements were taken with a folded wing from the carpal joint to the tip of the longest primary. In addition, I recorded plumage colouration (Carroll 1970; Fox 1977b; Baker-Gabb 1979). Harriers were usually held for ten minutes during the process and were released at the site of capture.

2.3.3 Statistical Analysis of Morphometric Data

Harrier banding at Greytown occurred irregularly over nine years between 1992 and 2001 and may have contributed to errors through lack of experience or practise when measuring. At Pukepuke Lagoon all the birds were banded in a single season and the measurements were therefore, probably less affected by error than those taken at Greytown.

The data from the two sites were pooled separately then standardised prior to analysis to compensate for the differential units and wide range of lengths. Back talon measurements were not collected from Greytown so are not part of the comparisons between the two sites.

Marchant and Higgins (1993) suggests that after fledging juveniles and adults are approximately similar in size to adults. Never the less, these two groups were initially separated and tested using canonical variate analysis (SAS 2000). No meaningful age-related differences were found at Greytown and Pukepuke Lagoon, thus adults and juveniles at the separate sites were pooled for analysis of sex.

Canonical variate analysis

Canonical variate analysis (SAS 2000) was used as a measure of the contribution made by each bodily measurement in separating the two sexes. Additionally, the analysis was used to determine which measurements contributed the most to the separation of the sexes. The analysis was carried out on the data from both banding sites to compare any

regional variation in morphology. The data from the two sites were used separately then standardised to compensate for the different units of measurement (e.g. grams and mm) and wide range of sizes of the different body parts that were measured. Full SAS output of these results can be found in Appendix 2.1 on CD-ROM.

Discriminant analysis

A discriminant analysis was used for each site on the standardised data to assess whether the bodily measurements gave significant determination of sexes, and if so, to develop a sex criterion. With the new criterion, misclassified birds were re-allocated to their correct sex. Full SAS output of these results can be found in Appendix 2.2 on CD-ROM.

Stepwise discriminant analysis

A stepwise discriminant analysis was used to test if a subset of the morphological measurements currently taken to sex harriers could be used reliably for sexing in the field to minimise handling time and stress. The analysis produced a new subset of measurements for the two study sites and their pooled data to determine if reasonable sexing could be achieved with fewer measurements. A discriminant analysis was then performed on the new subsets to see if they could be used as an acceptable group of measurements for sexing harriers. An acceptable error rate for the new subsets was set at $\leq$ 5% error rate of the original full compliment of measurements. A discriminant analysis was also performed on the four measurements currently used to sex harriers in New Zealand. Full SAS output of these results can be found in Appendix 2.3 on CD-ROM.

2.3.4 Molecular sexing technique

From the 138 birds trapped at Pukepuke Lagoon, 11 individuals had a feather removed from the breast for Random Amplified Polymorphic DNA (RAPD) sexing. The molecular sexing method was modified from Griffiths *et al* (1996). DNA was extracted from the base of freshly plucked breast feathers and amplified using two PCR primers, P2 and P8 (Griffiths *et al.* 1998). The sample of DNA was then run through gel electrophoresis and the sex specific genes dissolved using the restriction enzyme Hae III. Because the technique is also applicable to mammalian DNA including humans

(Lessells and Mateman 1996), feather samples from harriers were taken carefully so as not to contaminate the feather with human DNA. The molecular component of this research was carried out by Huynen and Wong (Institute of Molecular BioSciences, Massey University) (Appendix 2.1).

2.4 RESULTS

2.4.1 Separation of sexes by morphometric measurements

Canonical variate analysis

For both banding sites, weight had the largest positive canonical coefficient and thus most influence on the separation of sex (Greytown = 0.86 and Pukepuke Lagoon = 0.58, Table 2.1). At Greytown, middle talon had a relatively moderate coefficient suggesting it is a medium sexing measure. All other measurements for Greytown birds have a small influence on separating sex particularly tarsus, tail and wing.

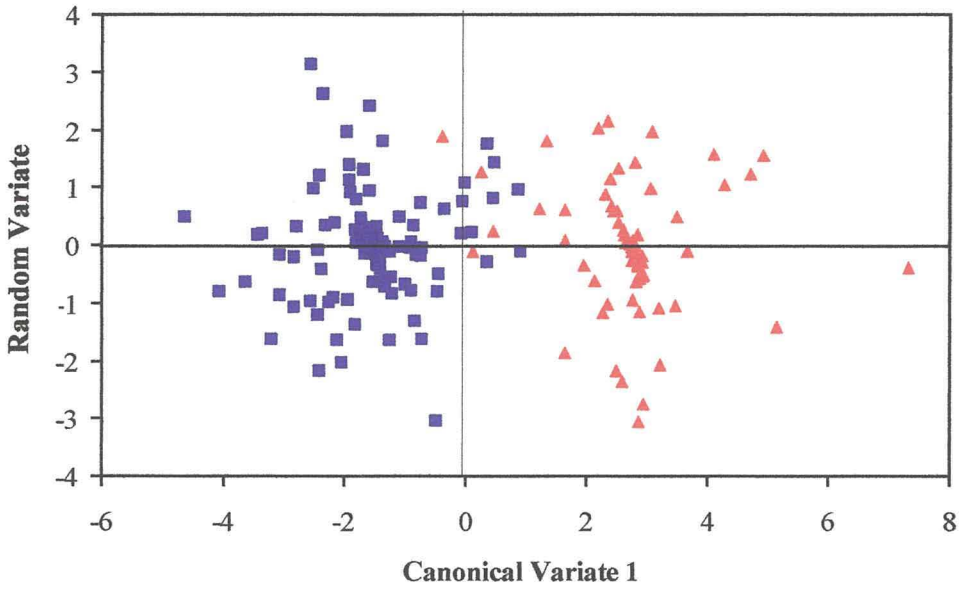
Table 2.1 Pooled Within-Class Standardised Canonical Coefficients for Greytown and Pukepuke Lagoon morphometric measurements showing the level of correlation within the first canonical variates. A high positive value suggests a strong indicator of sex.

	Greytown	Pukepuke Lagoon
Measurement	Standardised Coefficients	Standardised Coefficients
Middle Talon	0.213	-0.010
Toe	0.119	0.248
Hallux	0.176	0.219
Tarsus	-0.050	-0.079
Culmen	0.150	0.345
Tail	-0.113	0.180
Wing	-0.013	0.159
Weight	0.858	0.575

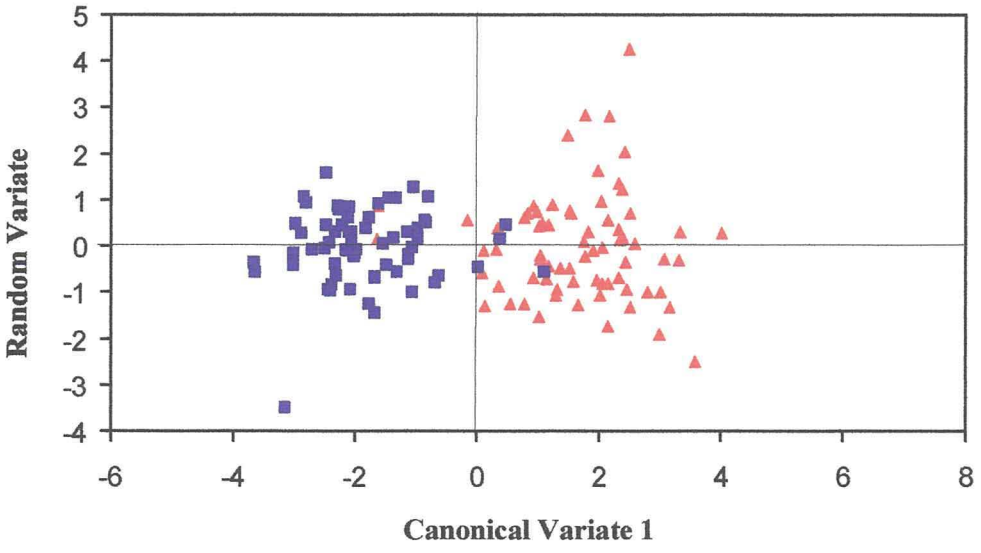
For Pukepuke Lagoon birds, weight, culmen, toe and hallux contribute most to the separation between the sexes, while tarsus and middle talon are poor measurements for sexing. The remaining measurements show low canonical coefficients and therefore have little influence on separation of sex (Figure 2.6).

Figure 2.6 Plot of Canonical Scores of Males (blue squares) and Females (red triangles) from Greytown **(a)** and Pukepuke Lagoon **(b)**.

a



b



A second canonical variate analysis was carried out on the Pukepuke Lagoon data, which included back talon, not available for the Greytown data. In this analysis back talon was the second largest (0.459) coefficient produced, following weight, suggesting it is a very good measurement for determining sex.

Discriminant analysis

From the pooled data of 323 harriers trapped at Greytown and Pukepuke Lagoon, 139 were identified as female and of these eight (5.8%) were misclassified (Table 2.2). Of the 184 birds identified as males, six (3.3%) were misclassified therefore a total of 4.3% of the birds in the pooled data were misclassified. Overall 3.2% of the Greytown birds were wrongly identified and 5.8% of those at Pukepuke Lagoon.

Table 2.2 Discriminant analysis of Greytown, Pukepuke Lagoon and pooled data showing the number of observations of assigned sex, the percentage classified into sex and number of misclassifications (shown as bold text).

		Greytown			Pukepuke Lagoon			Pooled Data		
		Female	Male	Total	Female	Male	Total	Female	Male	Total
Assigned Sex	Female	63	**4**	*67*	68	**4**	*72*	131	**8**	*139*
	%	94.0	6.0		94.4	5.6		94.2	5.8	
	Male	**2**	116	*118*	**4**	62	*66*	**6**	178	*184*
	%	1.7	98.3		6.1	93.9		3.3	96.7	
	Total	65	120	*185*	72	66	*138*	137	186	*323*
	%	35.1	64.9		52.2	47.8		42.4	57.6	

The discriminant analysis error rates produced from the eight measurements suggests Greytown females were higher (6.0 %) than the acceptable error rate of $\leq$5%, but Greytown males (1.7 %) fell well below the accepted error rate. Both sexes at Pukepuke Lagoon were slightly above the 5% error rate (males = 6.1 %, females = 5.6 %). Although all, with the exception of Greytown males, had slightly higher than acceptable error rates they can still be considered reasonably low. A smaller sample size for Greytown females may have led to a slightly higher error rate. Although there is a

difference in the error between the sexes in the pooled data, it is small (males = 3.3%, females = 5.8%) and might also be a result of unbalanced numbers (males n=184, females n= 139).

Stepwise discriminant analysis

The stepwise discriminant analysis produced similar but not identical subsets from the original eight measurements used above. For this reason, the error rates for each site may not collectively correspond to the pooled error rates.

Greytown

The stepwise discriminant analysis for Greytown produced a new subset of four measurements useful to separate the sexes: weight, middle talon, culmen and hallux. As mentioned measures of back talon were not available for Greytown. Using these measurements in a discriminant analysis, 67 birds were identified as females, four of which were misclassified. Of the 118 birds identified as males, four were misclassified (Table 2.3). Using a subset of four from the original eight measurements, of a total 185 harriers trapped and measured, at Greytown, eight (4.3%) were misclassified and of these 6.0% were females and 3.4% were males.

Pukepuke Lagoon

The Stepwise discriminant analysis from Pukepuke Lagoon produced a new subset based on five measurements: weight, back talon, culmen, tail and toe. A discriminant analysis of 138 harriers identified 72 as females (three misclassified) and 63 birds were identified as males (three misclassified) (Table 2.3). Of the 138 harriers trapped and measured at Pukepuke Lagoon, six (4.3%) were misclassified and of these 4.2% were females and 4.6% were males.

Pooled Data

In a stepwise discriminant analysis, the pooled data of the two sites produced a new subset based on five measurements: weight, hallux, culmen, middle talon and toe. From 139 birds identified as females using discriminant analysis, seven were misclassified while of the 184 birds identified as males, five were misclassified. From the total pooled data of 323 harriers trapped and measured, twelve (3.7%) were misclassified, 5.0% of the females, and 2.7% of the males.

The error rates from the new subsets for Greytown, Pukepuke Lagoon and the pooled data produced rates ≤ 6%. The new subset of Pukepuke Lagoon produced a smaller subset of five measurements although when back talon was removed from this analysis the Pukepuke Lagoon data behaved similar to Greytown. This indicates that back talon is an important measure and has a reasonably large influence on the analysis.

Table 2.3 Discriminant analysis based on new subset produced by stepwise discriminant analysis of Greytown, Pukepuke Lagoon and pooled data. The table shows the number of observations, the percentage classified into sex and number of misclassifications (shown as bold text).

		Greytown			Pukepuke Lagoon			Pooled Data		
		Female	Male	Total	Female	Male	Total	Female	Male	Total
Assigned Sex	Female	63	**4**	*67*	69	**3**	*72*	132	**7**	*139*
	%	94.0	5.97		95.8	4.17		94.9	5.04	
	Male	**4**	114	*118*	**3**	63	*66*	**5**	179	*184*
	%	3.39	96.6		4.55	95.4		2.72	97.2	
	Total	67	118	*185*	72	66	*138*	137	186	*323*
	%	36.2	63.8		52.2	47.8		42.4	57.6	

The measurements chosen from the two sites and the pooled data differed slightly but those present in two or more subsets were weight, culmen, toe, middle talon and hallux. Back talon also featured in the new subset at Pukepuke Lagoon but because it was absent from the Greytown data, it featured only in the Pukepuke Lagoon subset. However the results suggest back talon would also feature strongly in the Greytown data, had it been included.

Discriminant analysis of measurements currently used for sexing harriers.

Four measurements (bill length, tarsus, toe and wing) are currently required by the Department of Conservation to sex harriers in New Zealand. The discriminant analysis based on these four measurements produced a different error rate for the pooled data compared to collective error rates for the two study sites. This can be explained by the pooling effect on the data which produces a new sex criterion on which to base

misclassifications. Hence when site data were pooled, misclassifications at separate sites may not appear as misclassifications in the pooled data. Alternatively new misclassifications may appear when the data are pooled.

Greytown

Using wing, culmen, tarsus and toe measurements eleven of the 67 birds identified as females were misclassified, and of the 118 birds identified as males, eleven were misclassified. Thus of the total 185 birds banded at Greytown 22 (11.9%) were misclassified (16.4% of the females and 9.3% of the males, Table 2.4).

Table 2.4 Discriminant analysis based on a subset of four measurements (Wing, Culmen, Tarsus & Toe) presently used to distinguish sex, showing number of observations, the percentage classified into sex and misclassification estimates (bold text).

		Greytown			Pukepuke Lagoon			Pooled Data		
		Female	Male	Total	Female	Male	Total	Female	Male	Total
Assigned Sex	Female	56	**11**	*67*	67	**5**	*72*	121	**18**	*139*
	%	83.6	16.4		93.1	6.9		87.0	13.0	
	Male	**11**	107	*118*	**6**	60	*66*	**18**	166	*184*
	%	9.3	90.7		9.1	90.9		9.8	90.2	
	Total	67	118	*185*	73	65	*138*	139	184	*323*
	%	36.2	63.8		52.9	47.1		43.0	57.0	

Pukepuke Lagoon

Of the 72 birds identified as females five were misclassified, and of the 66 birds identified as males six were misclassified, thus of the total 138 birds banded at Pukepuke Lagoon eleven (8%) were misclassified (6.9% of the females and 9.1% of the males, Table 2.4).

Pooled Data

When data from both sites are pooled 18 out of the 139 birds identified as females were misclassified, and of the 184 birds identified as males, 18 were misclassified. Therefore

of the total 323 birds banded, 36 (11%) were misclassified (13.0% of the females and 9.8% of the males, Table 2.4).

There was no significant difference between the error rates from the discriminant analysis between the eight measurements used and the subset produced by the stepwise discriminant analysis. However when the pooled data comprising the four measurements currently used to sex harriers were separately compared to the data used in the two previous analyses, the p values were very similar and suggested some significant differences (8 measurements used, ANOVA, $F_{5,6} = 6.50$ $P \leq 0.08$; subset of 8 measurements, ANOVA, $F_{5,6} = 7.00$ $P \leq 0.07$). When error rates from all three analyses were compared a strong significant difference (ANOVA, $F_{5,6} = 471$ $P \leq 0.0002$) between the three error rates was found. Comparison between the eight measurements used in this study and the smaller sub set showed no significant difference.

2.4.2 Molecular and field estimate comparisons

The two primers, P2 and P8 were successful in amplifying the Australasian Harrier DNA and the restriction enzyme Hae III dissolved the sex specific genes from all 11 individuals (Huynen and Wong, *submitted.* Appendix 2.1). The results of the molecular sexing concurred with sexing of the same animals using field measurements. Of the 11 harriers sexed using the two methods, five were identified as female and six as male.

2.5 DISCUSSION

2.5.1 Morphometric analysis and its relevance

Canonical Variate Analysis

Of the nine morphometric measurements, weight had the greatest influence in separating males and females in both data sets and the pooled data. However, weight may not always reliably separate the sexes, because of weight fluctuations between seasons (Baker-Gabb 1978), individuals with different bodily condition, and fullness of crop at weighing. Therefore, the use of other measurements in combination with weight may produce better discrimination.

Although back talon measurements were not part of the Greytown data, the Pukepuke Lagoon data suggest that it may also have some significance in estimating sex. Culmen was also a significant separator of sex at Pukepuke Lagoon but was comparatively less so at Greytown, possible because of the strong influence of weight in the Greytown data. Weight was a better predictor of sex at Greytown than at Pukepuke Lagoon. The Greytown data were collected over 10 years, and therefore represent good and bad years. Pukepuke Lagoon data, however, were collected over only one year. There was little variation in the weights of the Pukepuke birds and therefore weight may have been less important in that analysis.

Wing and tail measures were unreliable indicators of sex because they fluctuate in individuals due to seasonal growth or feather damage. In both data sets Tarsus measurements did not contribute to the separation of the sexes, and hallux measurements had little effect, so both these measurements were unhelpful in determining sex.

Middle talon measurements gave conflicting results, having a considerable effect in the Greytown data but none in the Pukepuke Lagoon data, and therefore they were of no use as an indicator of sex. The fluctuation of middle talon in the canonical variate analysis may have been caused by measuring error during banding, because toe measurements are extremely difficult to take when harriers clench their feet. The vice-like grip, common in most raptors, including harriers (Fox 1978; Kemp 1990), made extension of the middle toe for accurate talon measurements hard to achieve. The Pukepuke Lagoon measurements were probably more accurate than those from Greytown because I had greater experience and practice handling captured birds when the former measurements were made. Raptor talons grow continuously (Fox 1995) and are susceptible to wear, which could explain some of the differences between the data.

Discriminant Analysis

The discriminant analysis of the original eight variables for both study sites and the pooled data gave low error rates across males and females. The reason for the slightly higher error rate for males at Pukepuke Lagoon is unclear, but nearly twice as many males were caught at Greytown (n=118) than at Pukepuke Lagoon (n=66), and more variation may have decreased the number of misclassifications. The number of females

from the two sites were similar and produce similar error rates.

Stepwise Discriminant Analysis

When restricted to new sub-sets of measurements assigned by the step-wise discriminant analysis, the error rate and number of misclassifications of sex for Pukepuke Lagoon is still slightly greater than Greytown. Although the sub-sets are similar, slight differences could reduce effects on the error rate for Greytown.

Little difference can be seen when comparing the number of misclassifications between eight measurements and their smaller subsets. This suggests that a smaller set of measurement can be used without compromising accuracy in sexing.

Discriminant Analysis using the four current morphometric measurements

The canonical variant analysis and discriminant analyses are based on analyses of the Pukepuke Lagoon and Greytown data. Thus, a comparison of the discriminating power of the four measures currently recommended by DoC with the new discriminators recommended in this study will be biased. This is because the same data used to develop the new discriminant function are used to test the predictive power of the new function. A further test of the two methods should be carried out on an independent set of data to test the effectiveness of the new measures suggested from Greytown and Pukepuke Lagoon in this study. However, there is strong biological and statistical support in this study to suggest that the four measures currently used to sex harriers are weak discriminators.

The evidence from the results suggests that the four measurements currently used to sex harriers are ineffective discriminator of sex. The difference in error rates between these four and the eight measurements (and the smaller sub set) used in this study was significant.

In the discriminant analysis using the four currently used measurements, males from both sites and from the pooled data produced very similar error rates, and this may be explained by the inclusion of wing and tarsus, which are poor indicators of sex. Females at Pukepuke Lagoon had a lower error rate than the females at Greytown, but the reason is unclear. Similarly unclear is the reason for the dramatic difference between sites

when comparing the three discriminant analyses.

The higher error rate found using current measurements to sex harriers can be accounted for by the smaller number of measurements recorded, the use of unreliable measurements and the absence of some measurements found in this study to be important for distinguishing sex. Hence a new set of measurements is recommended for sexing harriers reliably. This set of measurements is: weight, middle talon, culmen, hallux, back talon, and toe.

2.5.2 Plumage colour

Plumage colour alone is not a suitable method for sexing Australasian Harriers because there is no objective scale on which to base judgement. In other raptors, differentiating sex can be achieved by scoring categories of plumage variation (Blanco and Rodrigues-Estrella 1999). There is also wide variation of plumage colour within different age groups as well as within sexes of the Australasian Harrier. Furthermore, assessment of plumage colour may differ according to the bander, and the degree of regional and seasonal variation in plumage colour is unknown.

2.5.3 Molecular sexing techniques for *Circus*

Molecular sexing using similar methods to the present study has been applied to a wide range of avian orders, and has been successful in all orders bar Apterygiformes (Griffiths *et al.* 1998). Griffiths *et al* (1996) carried out molecular sexing of 28 European Marsh Harriers (*Circus aeruginosus*) and found that all 28 field estimates of sex concurred with the molecular sexing results based on blood samples. The Australasian Harrier is a close relative of the European Marsh Harrier (Simmons 2000), thus similar results in DNA sexing were expected in the present study. The results show that molecular sexing using primers P2 and P8, and the restriction enzyme Hae III can be used successfully on the Australasian Harrier, and suggest that the technique would be successful throughout the genus *Circus*. However, the method is expensive and time consuming compared to field estimates of sex when working with large numbers of individuals. For this reason RAPD sexing would not be desirable for the Australasian Harrier if reliable field estimates can be obtained. Although RAPD sexing has been

successful in many raptor species already (Griffiths *et al.* 1996; Fridolfsson and Ellegren 1999; Nesje and Roed 2000), the technique has limitations within the Falconiformes (Nesje and Roed 2000). A combination of plumage colour differences and appropriate morphometric measurements could achieve a similar result with less expense in time and resources.

2.6 RECOMMENDATIONS

The continued use of the four morphological measurements (bill length, tarsus, toe and wing) to sex Australasian Harriers should be reassessed. Morphometric sexing of Australasian Harriers should be based on six measurements; weight, back talon, culmen, middle talon, hallux and toe. Of these, weight, back talon and culmen are the most reliable indicators of sex. Australasian Harriers can be correctly sexed 96% of the time in the field by estimates and measurements based on a combination of plumage differences and the six morphometric measurements listed above, versus 89% if the current measurements are taken. Wing, tail and tarsal measurements should not be used at all because they are un-reliable indicators of sex. Wing, tail, and tarsus lengths overlap considerable between males and females, and feather lengths are weak indicators of sex because of seasonal growth and damage. Molecular sexing by the methods developed in this study should be used when resources permit and 100% accuracy is required.

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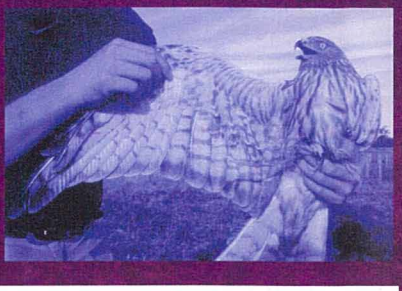
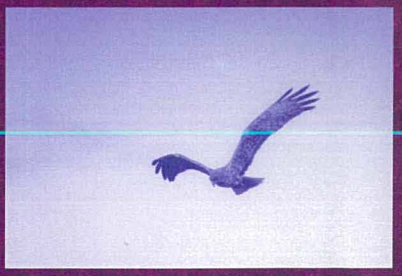
Diet





3

Diet of the Australasian Harrier in the Manawatu–Rangitikei Sand Country: A 25 - Year Comparison.

3.1 INTRODUCTION

Populations of Australasian Harriers on mainland New Zealand are healthy, mainly because of increases in prey numbers and species (Heather and Robertson 1996). However, fluctuating prey availability and abundance result from intensive grazing, draining of swamp areas, and local decreases in prey abundance through disease or better pest control (Baker-Gabb 1981). The harrier is commonly regarded as a carrion feeder, however, the composition of its diet includes both live and dead prey and the proportions may change over different seasons, time and geographical range (Baker-Gabb 1978).

In the early to mid 1900's the Australasian Harrier was hunted and a bounty set by many acclimatisation societies because harriers were seen as a major cause of failure of game bird introductions. The result of this attitude was that 200,000 harriers were killed over a 15-year period (Oliver 1938). At present the Australasian Harrier has partial protection, but farmers and hunters commonly persecute them because they are suspected of attacking new born lambs, cast sheep and young game birds. Harriers are culled in areas where intensive management of endangered species is still viable or harriers are known to be a risk to native fauna, including lizards and birds (Oliver 1930; Pierce 1987; Innes *et al.* 1999; Haselmayer and Jamieson 2001).

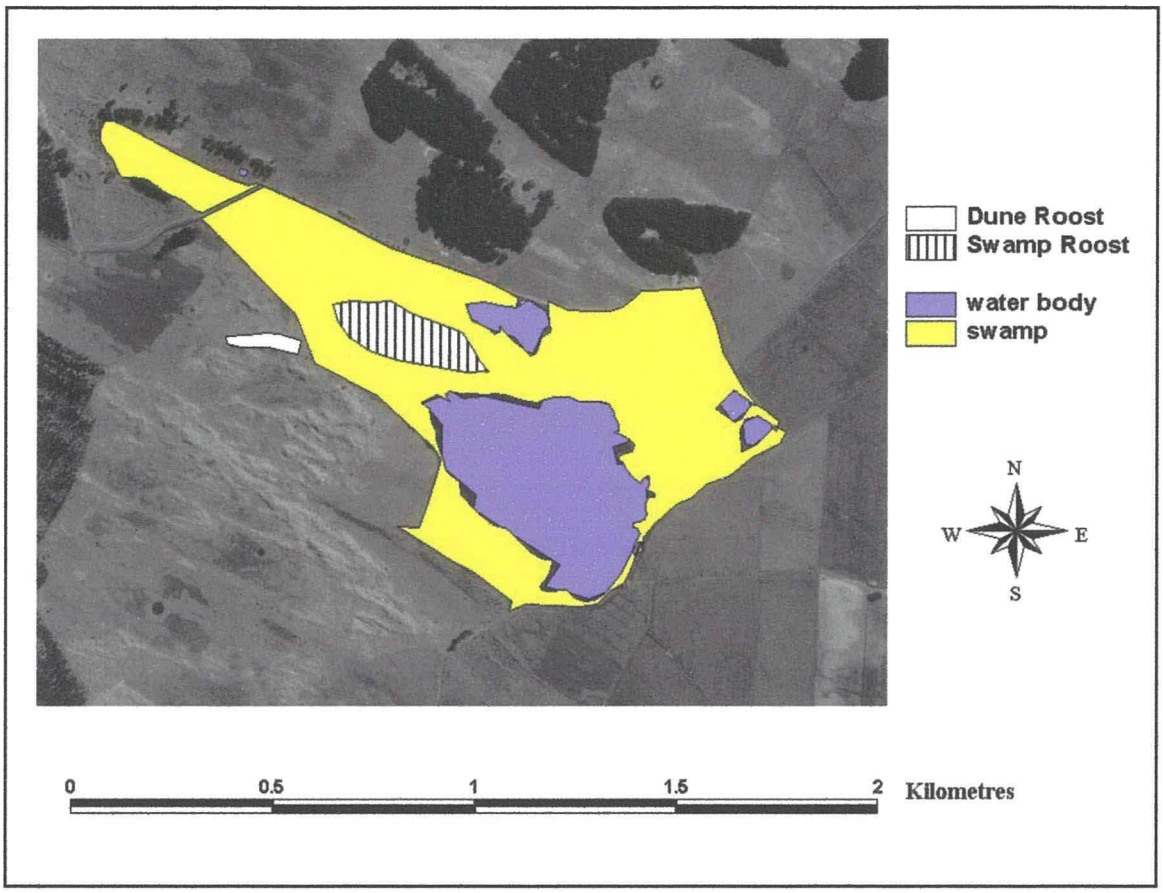
There have been six studies of the diet of the Australasian Harrier in New Zealand. Carroll (1968) examined the stomach contents of 124 harriers collected over three years from various New Zealand localities, and Redhead (1969) used remains of 129 stomachs and 20 pellets from the south east of the South Island. Douglas (1970) identified the prey in 99 pellets while Fox (1977) analysed 18 pellets from the eastern South Island hill country. Baker-Gabb (1978) analysed 344 pellets from Pukepuke Lagoon in the lower West Coast of the North Island. Pierce and Maloney (1989) analysed 239 stomachs and 779 pellets over three years from the Mackenzie Basin in central South Island.

This study aims to describe the diet of the Australasian Harrier at Pukepuke Lagoon on the west coast, southern North Island. I also assess the abundance of prey and carrion in the area. Similar research was carried out by Baker-Gabb (1978) between 1976 and 1977, and his results have been compared with this recent data. Factors involving changes to prey type and abundance have been considered in the comparison.

3.2 STUDY AREA

Pukepuke Lagoon is situated at latitude 40° 20´S and longitude 175° 16´E on the west coast of the lower North Island (Figure 1.1). Part of the wider Manawatu-Rangitikei sand country, Pukepuke Lagoon is one of a series of shallow dune-lakes found along the coastline. The lagoon is 3km from the Tasman Sea and 6.5m above mean sea level, with a catchment cover of about 30km^2 (Falla 1957; Cowie and Smith 1958; Esler 1970). The 86ha swamp and 15ha of open water (Figure 3.1) is surrounded by pasture, exotic forests and low-lying sand dunes and is managed by the Department of Conservation (Cowie and Smith 1958; Esler 1969; Esler 1970). Ogden & Caithness (1982) describe the flora of Pukepuke Lagoon.

Figure 3.1 Orthophotograph of Pukepuke Lagoon showing the location of the two communal roosts, main water bodies and swamp. Pellets were collected from the dune hill roost (solid white polygon). The larger swamp roost is shown as a vertical black lined polygon.



3.3 METHODS

Regurgitated pellets were collected at the end of each month from a communal roost used by resident harriers over a 12-month period from August 2000 to July 2001. The roost was situated in a network of farmed dune hills approximately 150m south west of a larger communal roost in the main swamp at Pukepuke Lagoon (Figure 3.1). Observations of captive harriers suggest that a single pellet is regurgitated once a day (Redhead 1968; Redhead 1969; pers. obs). The numbers of birds using the roost varied between season and weather conditions, reaching a maximum of approximately 40 birds.

3.3.1 Pellet Collection

When prey is ingested by raptors, it is broken down in the gizzard where digestive juices dissolve flesh and some small bone (Village 1990). The indigestible material is regurgitated as pellets consisting mainly of compacted fur, feather, large bone and other indigestible material (Plate 3.1).

Plate 3.1 Regurgitated pellets or castings of the harrier composed of small amounts of indigestible material usually fur, feather, bone and exoskeletons.

The method used for analysis of pellet content followed Day (1966). The air dried pellets were soaked in water before being teased apart with forceps on a shallow white plastic tray. The pellet contents were sorted according to the categories bone, feather, fur and other. Bones were used to identify how many individuals of the same prey type were present in a particular pellet. This worked especially well for small mammals and birds where multiple beaks or jaws were easily recognisable. Representative feather and fur samples were mounted on a glass slide in 70% ethanol, covered with a thin glass cover slip, and examined for differences in form and structure under a 400x component transition binocular microscope.

3.3.2 Prey Identification

Fur and feather samples from pellets were identified using Day's (1966) key. The key, based on British mammals, allowed identification of mammal hair to genus or species, but some New Zealand examples were missing (e.g. possum *Trichosurus vulpecula*). Feathers could be identified to family only. Fur and feather samples from species found at the study site were collected prior to analysis of the pellets to develop a slide library of potential prey items. This proved to be essential when identifying prey groups not explained by the key. Prey remains in pellets were often in low numbers, or damaged, which made identification difficult, thus the slide library in conjunction with the key enabled better identification of the prey.

When examining pellets great care was taken to ensure every different prey item was sampled, however, hairs and feathers present in low numbers may have gone unnoticed. Care was also taken to ensure each pellet was intact and discrete by storing pellets separately, and to record only primary prey of harriers, not animals consumed by the prey taken by harriers. For example, insectivorous birds and insects commonly occurred together in pellets. Usually secondary prey such as insects were found compacted in the remains of the crop or stomach of the harriers' food. Representative samples from each pellet were chosen based on clear areas of different colour or size to ensure all prey items within the pellet were identified. Pellets that appeared to contain a single prey item were sampled from different parts of the pellet as often different prey items were confined to discrete sections of the same pellet. In most cases these pellets consisted of large prey such as hares (*Lepus europaeus*) rabbits (*Oryctolagus cuniculus*) or possums.

3.3.2 Diet Analysis

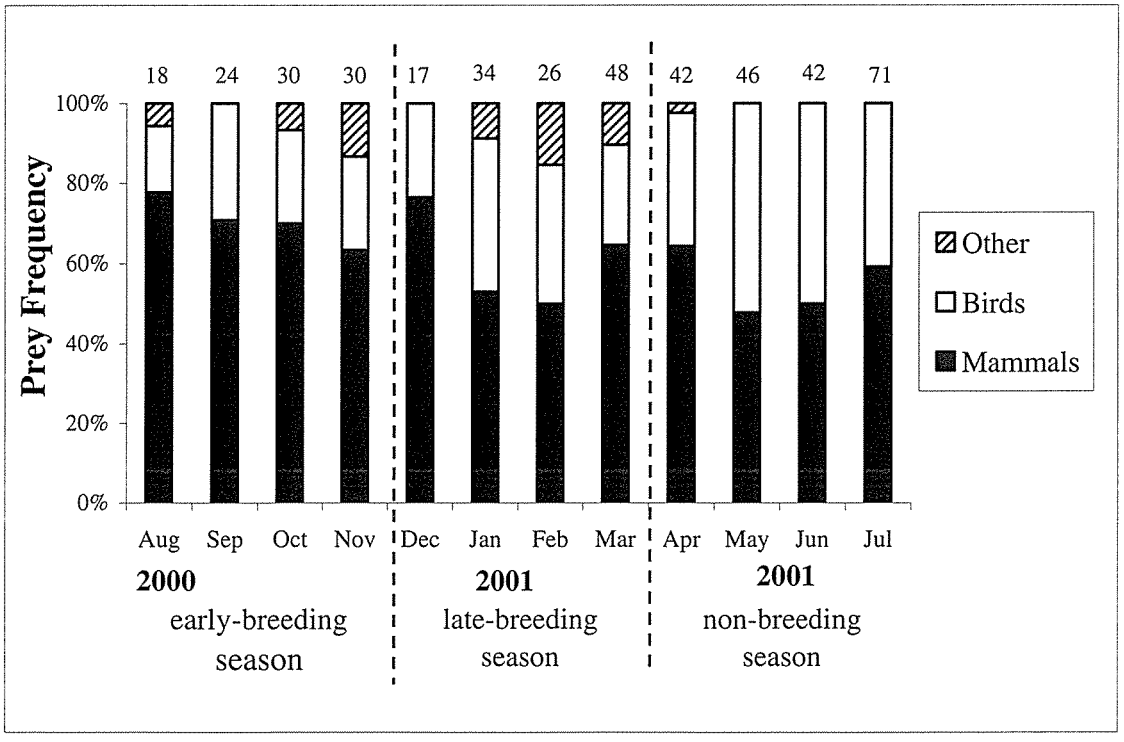
The prey were grouped into three categories: mammals, birds and other, and the importance of a particular prey item in the diet was expressed in terms of its numerical frequency and proportional frequency. The collection months were grouped into three biological seasons; early-breeding, from September to December, late-breeding from January to April, and non-breeding from May to August. For testing the significance of variation in prey and in season, one-way ANOVA (SAS 2000) was used. A log-linear model was fitted for multiple comparisons and interactions of prey type and season.

Dietary patterns were tested with seasonal and monthly data, as well as with prey groups and the animals comprising each prey group using Chi-squared (SAS 2000).

3.4 RESULTS

From a total of 312 pellets analysed, 415 prey items were identified and allocated to 14 types. Poorly represented prey types were merged into larger groups for statistical analysis because they represented a minor component of the diet. Prey types were scored on presence or absence, and multiple prey items from the same species were counted accordingly. The occurrence of the three main prey groups (mammals, birds, other) for each month is listed in Appendix 3.1 and summarised in Figure 3.2. The occurrence of the three prey groups varied significantly by season (One-way ANOVA, $F_{2,3} = 39.58$, $P \leq 0.01$). The most frequently occurring types of prey were passerines (22.7%) followed closely by lagomorphs (21.9%) (Appendix 3.1). Anseriformes, rats, sheep, possums and mice ranged between 7.0% and 10.4%.

Figure 3.2 Percentage occurrence of three main prey groups (mammals, birds and other) in the diet of the Australasian Harrier collected from August 2000 to July 2001 at a communal roost at Pukepuke Lagoon. Months are separated (vertical dashed lines) into three biological seasons, early-breeding, late-breeding and non-breeding. Columns contain the proportion of prey remains from pellets collected during each month. The sample of pellets collected is shown at the top of each monthly column.



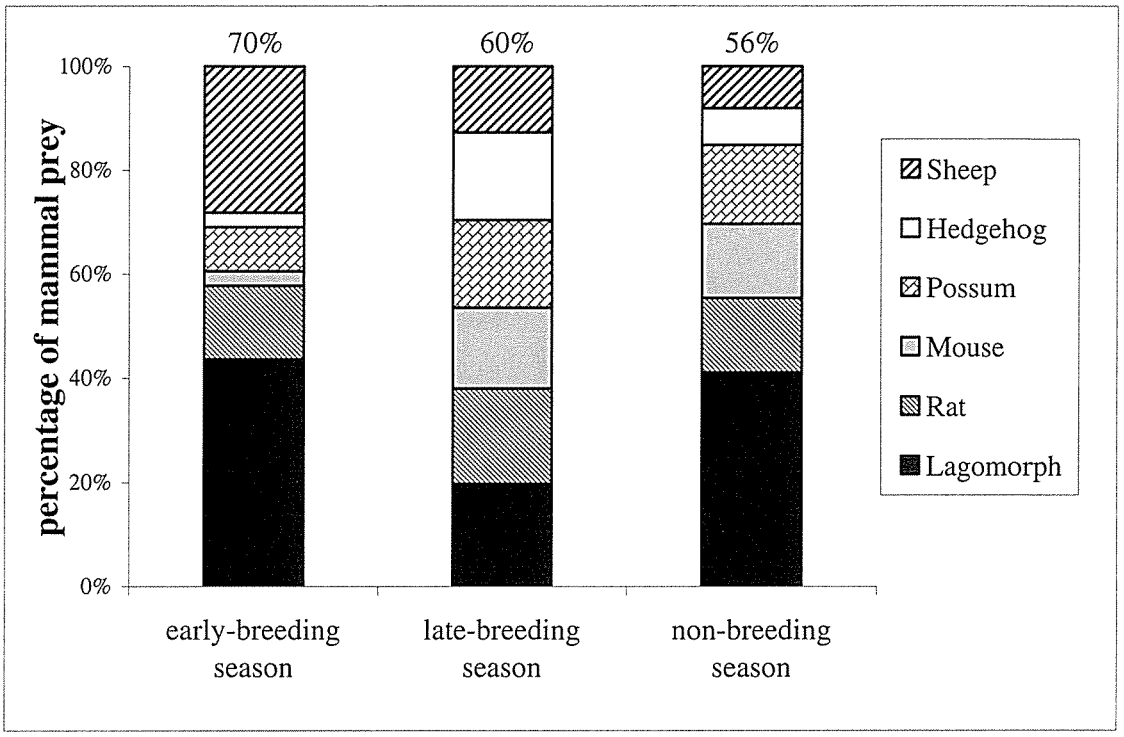
Significant variation in both biological seasons ($\chi 2 = 22.4$, dif = 3, $P \leq 0.01$) and prey groups ($\chi 2 = 200.5$, dif = 3, $P \leq 0.01$) and their interaction ($\chi 2 = 32.9$, dif = 9, $P \leq 0.01$) indicates that 1) there are differences in the total number of prey types in the diet each season, 2) the proportion of each prey categories varies from season to season, and 3) some of the prey categories are more common than others across the whole year. The output from the Chi-squared test suggests that variability of the diet may not be explained by broad seasonal or prey groupings but rather by some specific prey types and monthly time intervals (Appendix 3.1-3.4 on CD-ROM). Proportional bar plots of monthly and individual prey types are shown in Appendix 3.2-3.4.

3.4.1 Mammal Prey

There was significant variation between the six specific types of mammalian prey identified in the harriers diet (1-way ANOVA, $F_{5, 6} = 3.76$, P=0.03). However, variation over the three seasons was not significant (1-way ANOVA $F_{2, 3} = 0.01$, P=0.99). Mammalian prey formed between 48-78% for all pellet composition over the twelve months peaking in August and again in December (Figure 3.2). Total mammalian prey identified in pellets averaged 61.2% over the entire year. The months between and including August and December encompass most of the breeding season. Mammal fragments occurred more frequently in the early-breeding season than the post-breeding and non-breeding season but this difference was not significant. Mammalian occurrence in pellets was highest in the early-breeding season (70%) and lowest in the non-breeding season (56%) (Figure 3.2). The lowest monthly totals of mammalian prey occurred in February, May and June (Figure 3.2).

Lagomorphs (35.8%) were the most frequently occurring mammalian prey followed in all seasons by rats (15.4%) and sheep (15.0%). Possum (13.8%), mice (11.4%) and hedgehogs (8.7%) made up the smallest proportion of the total mammalian diet (Appendix 3.1-3.2).

Figure 3.3 Percentage of mammalian prey occurring in pellets collected from a communal roost at Pukepuke Lagoon between August 2000 and July 2001. Percentages were calculated from frequency of occurrences in pellets for early-breeding, late-breeding and non-breeding seasons. The proportion of mammalian prey found in the total diet for the three seasons is shown above their respective columns as a percentage.

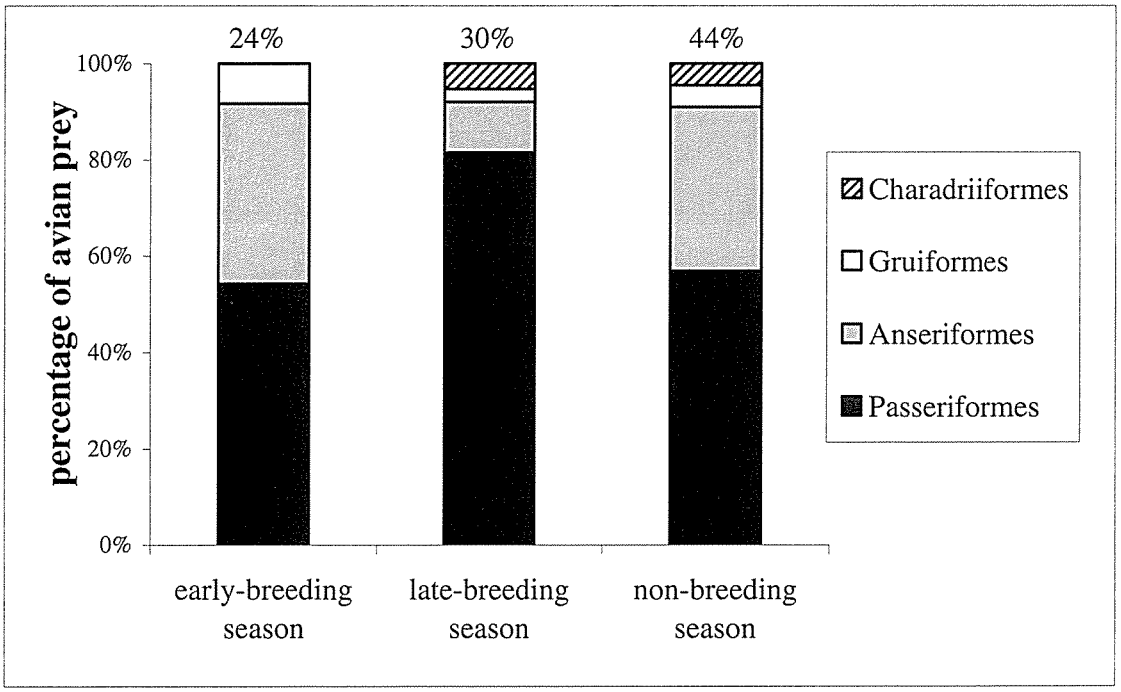


In the early-breeding season lagomorphs formed 40% of the total mammalian prey (Figure 3.3). Sheep were the second most frequent item, accounting for c.30% of the prey in pellets. Sheep and lagomorphs were the only mammalian prey found in August (Appendix 3.3). Sheep dominated September and lagomorphs August and November, and the two had similar frequencies in October. Rats and possums accounted for c.10% of the early-breeding season diet. Hedgehogs and mice represent only a small proportion of the overall mammalian diet composition (<5%) in the non-breeding season. The late-breeding season showed equal proportions (20%) of all major mammalian prey categories suggesting a large variation in the prey taken in these months (Appendix 3.3). In the non-breeding season there were similar proportions of the six mammalian prey categories and again, lagomorphs are the dominant prey type. Most mammalian prey types have an even spread of occurrence in pellets over the four months of the non-breeding season with the exception of hedgehogs, which have highest proportions in April, and sheep, which have highest proportions in July (Appendix 3.2).

3.4.2 Bird Prey

Total avian prey identified in pellets averaged 36.2% over the entire year. Passeriformes (62.7%) were more frequent than any other birds, and almost twice as frequent as Anseriformes (28.7%). Charadriiformes and Gruiformes accounted for only 8.7% of birds in the diet. There was highly significant variation between the four specific types of avian prey (one-way ANOVA, $F_{3, 4} = 18.80$, $P<0.01$) however, variation between early-breeding, late-breeding and non-breeding season was not significant. Birds identified in pellets had an average frequency of 36.2% over the 12 months. Their remains in pellets were least frequent (16.7%) in August and peaked (>50%) in May and June (Figure 3.2). These two months were dominated by Anseriformes which coincided with duck shooting season. Birds in pellets were most frequent in the non-breeding season and least frequent in the early-breeding season (Figure 3.4).

Figure 3.4 Percentage of avian prey occurring in pellets collected from a communal roost at Pukepuke Lagoon between August 2000 and July 2001. Percentages were calculated from frequency of occurrences in pellets for early-breeding, late-breeding and non-breeding seasons. The proportion of avian prey found in the total diet for the three seasons is shown above their respective columns as a percentage.



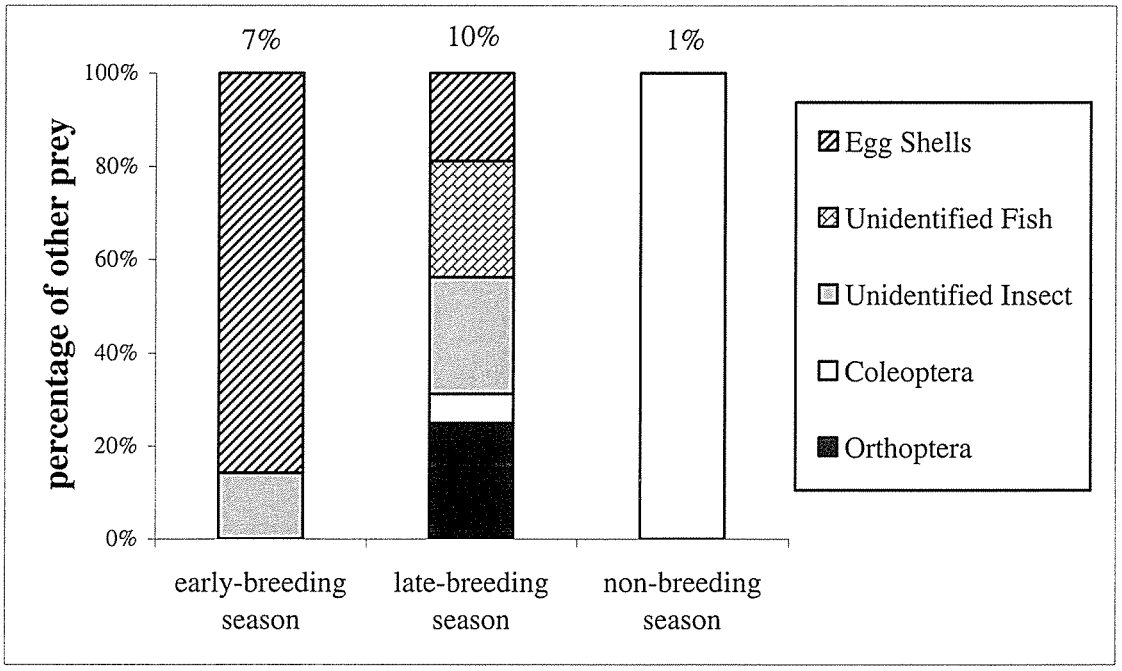
Passeriformes constituted a high proportion of the birds in the diet, especially in the late-breeding season (86%) (Figure 3.4). Passeriformes were the only birds identified in August, December and January and were also frequent in February, March, April and

July (Appendix 3.3). Anseriformes were frequently eaten in the early-breeding (38%) and non-breeding (34%) seasons, respectively, but were not a larger component in the late-breeding season (11%). Anseriformes and Passeriformes were the main bird prey overall and were inversely related to each other in most months (Appendix 3.3). Charadriiformes and Gruiformes were collectively less that 10% of the total avian prey in all seasons, with Charadriiformes present only in late-breeding and non-breeding seasons (Figure 3.4) and only in pellets from seven of the twelve months sampled (Appendix 3.3).

3.4.3 Other Prey

Prey items not of mammalian or avian origin were categorised as other prey (Figure 3.5) and averaged only 5.9% of the total prey occurring in pellets over 12 sampling months. Insects and eggshells dominated the 'other' category, mainly in the early-breeding season. There was no significant variation between the five types of other prey and no significant variation over the early-breeding, late-breeding and non-breeding season.

Figure 3.5 Percentage of other prey occurring in pellets collected from a communal roost at Pukepuke Lagoon between August 2000 and July 2001. Percentages were calculated from frequency of occurrences in pellets for early-breeding, post breeding and non-breeding seasons. The proportion of other prey found in the total diet for the three seasons is shown above their respective columns as a percentage.



Other prey accounted for 7% of the total diet in the early-breeding season and was almost entirely represented by bird eggs (86%) with the remainder (14%) being unidentifiable insects (Figure 3.5). Eggshells were found in all months of the early-breeding season except September, and insects occurred only in October (Appendix 3.4). Late-breeding season pellets contained the highest percentage (10%) of other prey with all prey types being represented to some extent. Orthoptera, unidentified insects and fish dominated the late-breeding season, occurring in similar (25%) proportions. Eggs (19%) and Coleoptera (6%) make up the remaining prey proportions for this season. No prey items from this group were found in December and only eggshells were found in January (Appendix 3.4). Unidentifiable insects dominated February but Coleoptera were also present. Orthoptera and unidentifiable fish had equally shared proportions in March and a small proportion represented unidentifiable insects. The non-breeding season was composed exclusively of Coleoptera, which were found only in April (Appendix 3.4). This represented 1% of the total pellet composition during the non-breeding season which suggests that 'other' prey items did not play a major role in the diet of harriers in this or any other season when compared to mammalian and avian prey.

3.5 DISCUSSION

Significant variation between and within seasons and prey groups suggest that at Pukepuke Lagoon harriers eat a wide variety of prey items, and some prey types were taken more regularly and in higher frequency than others. Probably large prey items such as sheep, adult lagomorphs and possums, Anseriformes and Gruiformes were consumed as carrion but smaller prey items such as rodents and Passeriformes were most probably caught alive. This suggests that the harrier is an opportunistic feeder eating carrion and live prey from a wide range of prey groups, and that both are important in the diet. Generally, live prey is taken more frequently in spring and summer, and carrion more often in the winter.

Mammal (61.2%) and bird (36.2%) prey dominate the diet of the Pukepuke Lagoon harriers, especially lagomorphs (21.3% of total annual diet) for mammals, and small passerines (22.0% of total annual diet) for birds. It is likely that passerines mainly

comprised small (<100grams) species, because Australian Magpies (*Gymnorhina tibicen*) were the only large passerines in the study area. These birds often attack harriers, especially in the breeding season, and may occur in the diet only as carrion. Lagomorphs appear to be the most consistently dominant food group throughout the year but become less important in the late-breeding season when other prey items, such as small passerines, become increasingly available. Lagomorph frequencies were lowest in December when frequencies of mice, hedgehogs and passerines peaked, suggesting harriers take a wider variety of smaller prey during the breeding season. This may reflect the abundance of these prey types during the breeding season, which coincides with breeding activities of many animals. Rats and possums were reasonably frequent throughout the year suggesting that they, like lagomorphs, are a stable food item for the harrier. Predictably, sheep are common in the winter and spring months which coincides with the appearance of many dead lambs.

Charadriiformes and Gruiformes accounted for a small proportion of the avian prey, which suggests that these birds were probably scarce in numbers or were difficult prey to hunt. A colony of over 1000 Black-backed Gulls (*Larus dominicanus*), situated close to the communal roost, may have contributed to Charadriiformes in the carrion diet of the harriers, as adult and chick gull carcasses were frequently found in and around the colony. Defence around the gull colony was strong and intruding harriers were quickly chased out of the immediate area suggesting adult Black-backed Gulls would have rarely been taken alive. Presumably harriers could easily take Black-backed Gull eggs and chicks from temporarily unsupervised nests, as reported from other Black-backed Gull colonies (Carroll 1968). Harriers have, however, been known to attack adult Black-billed Gulls (*Larus bulleri*) (Cooper 1991). I have seen harriers harassing adult Mallards (*Anas platyrhynchos*) and Pukeko (*Porphyrio porphyrio*), and once an adult male harrier tail-chasing an adult Canada Goose (*Branta canadensis*). All these attacks were unsuccessful.

Remains of Gruiformes were found in small numbers in the pellets and may have been from Pukeko, because this species was the only representative of the group seen at Pukepuke Lagoon. Duck shooters hunted Pukeko during May, thus injured or un-recovered Pukeko may have been a source of food for harriers. Pukeko chicks were seen in relatively large numbers during the breeding season and may have formed part of the

live prey diet of harriers. Australian Coots (*Fulica atra*) were not seen at Pukepuke Lagoon and were not considered part of the harrier diet during this period. Baker-Gabb (1981) observed prions (*Pachyptila* sp.) in the diet of harriers, the result of a storm event leaving ten prion carcasses in the study area, but none were found in this study.

Food items in the diet category 'other prey' occurred more frequently in the early-breeding and late-breeding seasons but were very scarce in comparison to mammals and birds. 'Other prey' foods are strongly influenced by season, for instance many insects, and items such as bird eggs are scarce in the non-breeding season. Harriers were seen successfully hunting carp (*Carassus auratus*) at Pukepuke Lagoon (pers. obs.) and have been recorded capturing other fish (Habraken 1979). Numerous carp remains at harrier nests (Appendix 1.2b) suggest they were under represented in pellet remains.

Simmons (2000) suggests that the most likely cue for breeding in harriers is the availability of prey. Breeding times for harriers may be dependent on the breeding cycles of smaller prey items such as passerines and mice, or the abundance of easily available prey. Newton and Marquiss (1981; 1982) found that in sparrowhawks (*Accipiter nisus*) the onset of breeding occurred when prey first became easier to catch, so maximum food demands of chicks and availability of food coincided. Daan and Dijkstra (1982) suggested that early stages of juvenile fledging coincided with maximum availability of prey, thus making food easily available for inexperienced juveniles and potentially increasing their rate of survival.

3.5.1 Inaccuracy in Prey Identification and Analysis

It is likely that soft invertebrates, fish, amphibians and reptiles were under-represented in pellets because they leave few indigestible remains. Baker-Gabb (1978) found that these items in harrier pellets were relatively less frequent than observations of their capture by harriers in the field. Field observations in this study of kill sites and of remains at nests also suggest that these groups were under-represented in the pellets collected.

Grasses, seeds and other vegetation were often found in pellets but regarded as the stomach content of other prey consumed. Carroll (1968) found that vegetation accounted for 42% of the total stomach content of 124 harriers and suggested that most

was inside the gut of the prey, and the remainder was eaten accidentally. Captive harriers and falcons (*Falco novaeseelandiae)* frequently consume grass while feeding on prey (pers. obs). Carroll (1968) found that fresh plant material in harrier stomachs was often clover, grass leaves and moss. Balfour and MacDonald (1970) suggest that vegetation may be intentionally swallowed to aid in digestion in other species of the genus *Circus*.

It was extremely unlikely that pellets of other species of birds were confused with those of harriers. Other raptors are uncommon in the Manawatu sand country (Falla 1957; Gill 1976; Baker-Gabb 1978) and no other raptors were observed during the field work. Other New Zealand raptors such as New Zealand Falcon and Morepork (*Ninox novaeseelandiae*) produce much smaller pellets than the Australasian Harrier (Fitzgerald 1965; Fox 1977; Stephenson 1998). Black-back Gull (Larus dominicanus) pellets were found in a nearby gull colony but differed in size and texture from those of the harrier (Fordham 1963) and no gull pellets were found in or near the harrier roost. Other pellet-producing species were seen infrequently at Pukepuke Lagoon and rarely observed near the harrier roost for any length of time. Only harriers were seen using roosts during regular evening observations at communal roost (Chapter 5).

3.5.2 Diet study comparisons

There was significant difference (ANOVA, $F_{23, 24}$ $P < 0.01$) between composition of diet in this research and the six previous diet studies. Carroll (1968) recorded similar percentages of birds (34%) compared to this study (36%) (Appendix 3.5), in the stomach content of 124 harriers from numerous locations around New Zealand. Carroll's (1968) study included eggs as part of the bird component of the harrier diet. Eggs were not considered in the bird diet of harriers and this could account for the small discrepancy in the percentage of birds found between both studies. In contrast, mammals accounted for 36% of the total prey found by Carroll (1968) compared to 60% in this study. The differences in mammalian percentages may be due to the large numbers of lagomorphs in the coastal sand dune country of the Manawatu. Carroll (1968) found a larger number of insects, particularly Orthoptera, increasing the value of 'other prey' to 30% compared with 6% in this study 6%.

In the south east of the South Island, Redhead (1969) found mammals to be the most common (47%) in the diet of the harrier followed closely by birds (36%) and to a lesser extent other prey (18%) (Appendix 3.5). The frequency of mammals and birds in the diet seem to concur with the findings of this study, however mammals occurred in slightly lower proportion in Redhead's (1969) analysis. The analysis of stomach and crop content by Redhead (1969) may explain the higher proportions of other prey compared to this study. Many easily digestible prey items would not occur in pellet remains but could be present in stomach and crop content.

Douglas (1970) found that mammals, particularly hares, heavily dominated (83%) the diet of harriers (Appendix 3.5), in eastern South Island hill country. Douglas's (1970) study was carried out in an area with a large population of hares, and also coincided with another study in the same general area which involved killing large numbers of hares. These were all used by harriers for food.

Fox's (1977) study consisted of 18 South Island harrier pellets and found 53% of the prey was mammalian origin and 47% birds (Appendix 3.5). No other prey categories were present in the analysis. Although similar diet assessment techniques were used, the small numbers of long term data make comparisons between the two studies difficult.

Pierce and Maloney (1989) found that on average rabbit remains occurred in 98.5% and 70% of pellets and stomach content from two respective study areas in the Mackenzie Basin (Appendix 3.5). This occurrence is much higher than the present study probably because of the very high rabbit population and lack of rabbit control in Pierce and Maloney's study area at the time of the study. During the Pierce and Maloney (1989) study, rabbits were controlled through poisoning resulting in an increase in alternative prey, specifically skinks and hedgehogs, although the numbers of lagomorphs taken after poisoning was still much higher than in this study.

Baker-Gabb's (1978) study at Pukepuke Lagoon provides material for a significant comparison with the present study. Baker-Gabb recorded similar species composition and seasonal trends to those found in this study (Appendix 3.5), where the winter diet of harriers tended to be dominated by mammalian prey. However, the diet became more varied with a strong influence from birds, especially passerines, in the non-winter

months. Other prey items, not mammalian or avian, occurred in low numbers but were most obvious in the non-winter periods, when they become increasingly available.

In comparison to this study, Baker-Gabb (1978) found that in the years 1976-1977 mammals accounted for 46% and birds 41% of the total prey items from prey remains at nest sites and pellets from communal roosts. The present research accessed diet solely on pellet composition and not on prey remains. Although observations of prey remains at nest sites were made, only one nesting pair was successful. Redpath *et al* (2001) suggest that assessment of diet by pellets alone tends to be biased towards small prey and to underestimate large prey. However, this does not explain why more mammals were found in this study compared to Baker-Gabb (1981). Many small prey items, such as passerines, hedgehogs and fish, occurred in small numbers in pellets but were abundant at nest sites. Hence a bias towards large, not small, mammalian prey may have occurred in pellet remains, accounting for the difference in diet shown by this study and Baker-Gabb's (1981). A combination of the two diet assessment techniques may be needed to fully evaluate harrier diet.

This study shows harriers are generalist feeders of both live prey and carrion, with a tendency towards lagomorphs and introduced passerines, and broadly resembles findings of previous studies. The diet comparisons summarised above suggest that harriers in New Zealand have a diverse and flexible diet (Carroll 1968; Redhead 1969; Baker-Gabb 1981) which concurs with the findings of this study. Douglas (1970) and Pierce and Maloney (1989) differ in their diet conclusions, finding harriers specialising almost specifically on lagomorphs. In both of these studies, however, hares and rabbits were abundant and carcasses were available in high numbers due to intensive culling programmes. This suggests harriers generally have a varied diet, tending towards lagomorphs and passerines, but may become specialised when prey abundance and availability in the environment is high.

3.5.3 Impact of harriers on economic, recreational and threatened endemic species.

Pukepuke Lagoon is managed by the Department of Conservation mainly for waterfowl, and predictably a higher occurrence of waterfowl in the diet was found compared to

other Australasian Harrier diet studies (Carroll 1968; Redhead 1969; Douglas 1970; Fox 1977; Pierce and Maloney 1989). At Pukepuke Lagoon it is common to find the remains of shot ducks with only the breast muscles removed. This material is available as carrion for harriers, along with birds shot but never recovered by hunters. The percentage of Anseriformes in the harrier diet was similar in this study (10% of total prey taken) and that of Baker-Gabb (1981) (7% of total prey taken). More over, his study observed no harriers taking adult ducks or ducklings. Although it is probable that harriers do take the occasional duckling, the large proportion of Anseriformes are most probably taken as carrion.

Harriers are commonly accused of, and killed for, attacking and killing healthy new born lambs. There is no doubt that harriers feed off dead lambs. However, harriers were never seen attacking live lambs, and in all cases harriers attended lambs that were already dead. Carroll (1968) found no evidence of harriers attacking live lambs, similar to findings in this study, but suggested they feed on carcasses immediately after death. Black-backed Gulls were also seen in large numbers in the study area and were seen frequently feeding on lamb carcasses. Although both harriers and Black-backed Gulls use lambs as food neither species has been recorded killing animals larger than young hares or rabbits (Carroll 1968) and both species may be incapable of killing a new born lamb when it is protected by its mother.

Harrier predation on threatened endemic species, or their disturbance of them, has become a management concern for many recovery programmes where the numbers of a species have become critically low (Treadgold 2000). Depending on the rarity of the species, their susceptibility to predation, and the size, shape, and composition of their home range, there may be no other option in such situations than to cull the numbers of harriers. Although this may aid the survival of small populations of key species, it is not a long term solution because harrier movement to new areas is influenced by natural dispersal and changes in prey type and abundance, especially by juveniles (Pierce and Maloney 1989). Therefore recruitment to replace culled individuals would be expected to be relatively quick. A long term solution may come in the form of a behavioural deterrent achieved through a wider understanding of harrier diet and behaviour patterns.

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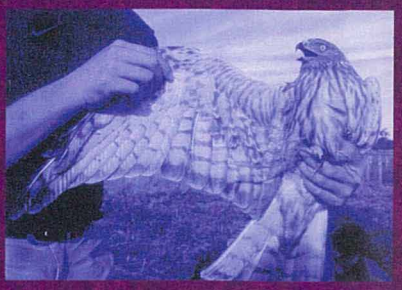
Spacing



4

Home Range, spacing and habitat use of the Australasian Harrier in the Manawatu-Rangitikei sand country.

4.1 INTRODUCTION

Although Australasian Harriers (*Circus approximans*) are common in New Zealand (Heather and Robertson 1996), little is known about harrier ranging behaviour and habitat use. Baker-Gabb (1978) estimated distances moved by harriers based on observational data of banded birds (Baker-Gabb 1978) that focused mainly on spring and summer breeding territories. Less is known about the harrier's behaviour in winter (Gurr 1968), when activities are not driven by pressures such as breeding. Knowledge of winter foraging patterns, time budgets and communal roost behaviour is also lacking because these aspects have been largely unstudied.

Radio-telemetry has been used with great success in providing valuable ecological and life history information for many raptor species throughout the world (Walls and Kenward 1995; Hodder *et al.* 1998; Kenward *et al.* 1999; Amar *et al.* 2000; Burton and Olsen 2000; Kenward *et al.* 2000; Tornberg and Colpaert 2001). This technique has also been widely used for many New Zealand birds (McLennan *et al.* 1987; Imber *et al.* 1994; Taborsky and Taborsky 1995; Stephenson 1998; Armstrong *et al.* 1999), however, radio telemetry studies on New Zealand raptors are poorly represented. Early studies of harrier spacing were limited by lack of appropriate tools to follow birds with large home ranges, but with the advent of radio-telemetry and improvements in transmitters (smaller size and better distance reception) this type of focused research is now possible. In this study radio-telemetry is used to determine size, shape and structure of the range in the harrier.

The study was designed to achieve the following aims: 1) Determine the Australasian Harrier's maximum home range size at Pukepuke Lagoon and surrounding area. 2) Determine what percentage of its home range is traversed on a regular basis (core range). 3) Compare and contrast gender range sizes during the breeding and non-breeding seasons. 4) Compare habitat availability in harrier ranges with habitat utilisation, and discuss the effect of habitat on range size 5) Examine both static and temporal range overlaps and interactions.

4.2 STUDY AREAS

4.2.1 Pukepuke Lagoon

Data were collected from Pukepuke Lagoon, (40° 20´S latitude and 175° 16´E longitude) on the West Coast of the lower North Island (Figure 1.1). Part of the wider Manawatu-Rangitikei sand country Pukepuke Lagoon is one of a series of shallow dune-lakes found along the coastline (Cowie and Smith 1958). The lagoon is 3km from the sea, and 6.5 m above mean sea level with a catchment covering about 30km^2. The Lagoon includes 15ha of open water and 86ha of surrounding swamp managed by the New Zealand Department of Conservation. Pasture, exotic forests and low-lying sand dunes dominate the surrounding area. The flora of Pukepuke Lagoon and surrounding sand country has been described by Esler (1969, 1970), and Ogden and Caithness (1982). Harriers were trapped, radio-tagged and released at Pukepuke Lagoon, however most ranged outside the boundaries of the Lagoon.

4.2.2 Other areas

The habitat surrounding the boundaries of Pukepuke Lagoon is dominated by pasture for grazing sheep, beef and dairy cattle (Cowie and Smith 1958). The north west side of Pukepuke Lagoon is dominated by pine plantations (*Pinus radiata*) of various ages, which were once part of the sand dune habitat of the nearby coastline. Numerous patches of swamp, harvested pine plantations, and dune hills are also present, but cover relatively small areas compared to the dominant habitats of pasture and growing pines (Esler 1978).

4.3 METHODS

4.3.1 Radio telemetry

Transmitters

Eight single-stage tail-mounted transmitters were produced to prescribed specifications (see below) by Sirtrack Ltd, Havelock North New Zealand, and attached to four adult female, two adult male, and two juvenile male harriers in June 2000. The study was carried out from June 2000 to January 2001.

Each transmitter measured c.30 x 12 x 8mm and weighed c.6g which was less than the 2.5% of total body weight recommended (Kenward 2001) for tail mounted attachment to flying birds. The aerial comprised 170mm of flexible plastic coated pleated wire. Mounting holes (2mm) usually employed for a harness were drilled into each end of the transmitter, but were used instead for threads to attach the transmitter to tail feathers (Plate 4.1).

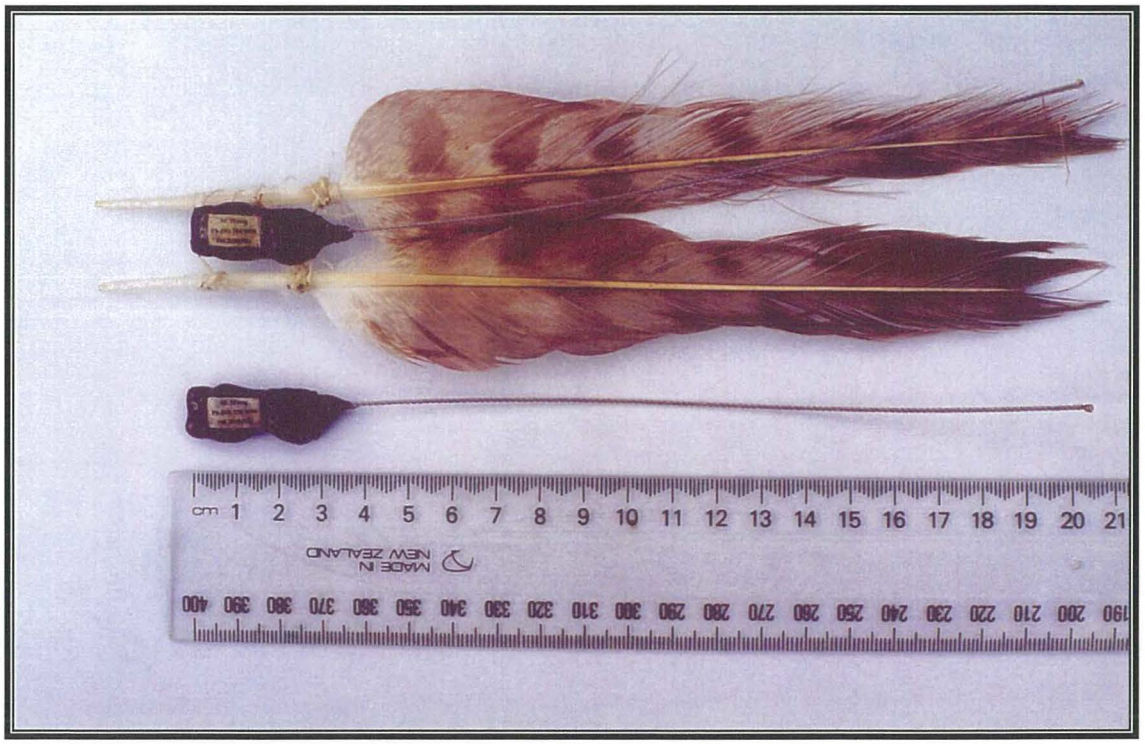
An activity-sensing device was built into the transmitter to record the harrier's tail posture and indicate its activity. This was achieved with a mercury tilt-switch set at an angle of 18° from horizontal. The transmitter produced 2 pulse rates, 30ppm and 50ppm, and sent changing pulse rates to the receiver as it moved through the pre-set angle. Between the position of 0° and 18° from horizontal, the pulse transmitted was 50ppm. When the transmitter moved below 18° from horizontal the pulse rate fell to 30ppm. Observations and photographs of body and tail positions of harriers in captivity and in the wild over ten years provided an estimate of the tilt angle while performing predetermined behaviours. This estimate proved extremely accurate (pers. obs.): During the eight months of radio tracking in every occasion that visual contact with a bird was made, the behaviour and body position of the bird gave the same activity indication as the pulse rate signal from the receiver. Free flight signals were dominated by 50ppm pulse rates and perched signals by 30ppm pulse rates. Feeding generated continuous variation between 50ppm and 30ppm. When a harrier was incubating or sitting on its tarsi a 50ppm pulse rate resulted but, in contrast to the signal from a bird in flight, the direction of the signal from a sitting bird did not change. From these varying activity pulses, I made assessments of behaviour when the harriers were not in view.

An average pulse rate of 40ppm was used to estimate transmitter life span at 4.5 months on the assumption that the transmitters would spend equal time transmitting the two pulse rates. However, the birds spent relatively more time on the ground than flying, therefore the 30ppm pulse rate occurred more often than expected, and a life span of 7 months was achieved for some of the transmitters.

Transmitter Attachment

Tail-mounted transmitters were chosen to fulfil the following requirements of this study: (i) A life span of several months including winter, spring and part of the summer. This relatively short life span reduced the weight of the battery and therefore the weight of the whole transmitter. The recommended weight of a tail-mounted transmitter is a maximum of 2.5% of the harrier's body weight (Kenward 2001). (ii) Have little or no adverse effects on harrier survival, behaviour, and moulting in that order.

Plate 4.1 Single stage tail-mounted radio transmitter attached to the two central rectrices of eight Australasian Harriers at Pukepuke Lagoon for the purpose of following their movements and behaviour from July 2000 to February 2001. Transmitters recovered after moulting of tail feathers.



The tail-mounted transmitters were sewn to the bases of the two central rectrices using rot-proof nylon thread (Plate 4.1). The harrier was cast in a banding mat and hooded with a traditional falconry hood (Plate 1.4) to keep it calm and reduce struggling during the process. The two central rectrices used for transmitter attachment were separated from the rest of the tail by a cardboard separator taped lightly to the tail. This enabled the tail to stay in position during the attachment process, even if the harrier struggled. It also made delicate sewing easier and prevented excess glue dripping onto other tail shafts. Some of the down feathers were either patted down with warm water or trimmed away to make sewing and gluing easier. The feather shafts were not pierced as this could have weakened them. Because the bases of the two central rectrices are close to the uropygeal gland, making them oily and less able to accept glue, the proximal ends of the shafts were roughened with a small nail file to create a platform for a stronger bond. The thread was wound around the feather shafts, tied, and the knot glued with quick drying adhesive to form a strong bond. Transmitter attachment time was approximately 15 minutes per bird and had no apparent harmful effects on the harriers.

Tracking

Prior to starting fieldwork on harriers, a pilot study was carried out in the summer of 1999-2000 with a rehabilitated juvenile female New Zealand Falcon (*Falco novaeseelandiae*) to develop effective skills in all aspects of radio telemetry. The same attachment technique, equipment and tracking method described in the experimental study was used in the pilot study.

Radio-tagged harriers were located using the method described by Kenward (2001), and tracked with a 3-element yagi antenna and Teleonics TR-4 portable receiver (Sirtrack, NZ). A Global Positioning System (Garmin GPS-12) handheld unit was used to record the geographic positions of the tagged birds. The GPS had a maximum error rate of 15m from the physical position although field observations suggested an error rate of less than 15m, and consistently less than 10m. The location of individually tagged birds was recorded in the field with a tape recorder and later transferred onto spreadsheets for analysis.

Tagged harriers often moved out of receiver range when the receiver was at a low vantage point, but it was usually possible to receive signals at high vantage points such as dune hills. Once a signal was received, a visual observation of each bird was sought. If visual observations were not possible, estimates were made by cross bearings to locate the bird's position within 20m. The cross-bearings were taken from high open areas to avoid signal interference. Position estimates were also taken if a bird was resting in dense vegetation or roosting at night. During the day visual sightings were easily achieved because harriers are nervous in the presence of people, and would take flight well before they were approached closer than 20m.

Travel around the study area was on foot and on a Yamaha 300 cc 4-wheel motorbike. Travelling on foot was appropriate when the terrain was unsuitable for the bike, or the bike might have disturbed the birds. Much of the area was farmed, so tracking on foot was the best method to limit disturbance of farm activities, but it took longer to locate the birds.

Ground searches were supplemented by flights in a single engine Cessna in each of the months November 2000, January and February 2001, to find two radio-tagged juvenile males which could not be located in the immediate study area. Location estimates of radio-tagged birds from aerial searches are very accurate and have been used successfully for other radio-tagging raptor studies (White and Nelson 1991; Marzluff *et al.* 1994). If located from the air, ground searches of the approximate area were then carried out to pin point the tagged bird. Aerial searches began close to the study area and worked outwards into a wider area encompassing c. 600 km^2.

4.3.2 Data Recording

The sampling regime for the radio-tagged harriers was based on methods described by Kenward (2001). One to two daytime fixes were taken daily for each bird, five days a week, between July 2000 and February 2001. If a tagged bird was not found on any particular day a larger search effort was made the following day to locate it. Individuals were located at least once a day and if possible twice with a minimum six-hour interval between observations of any one bird, thus all fixes were independent.

Once a tagged bird was sighted, I recorded the time, location, activity, habitat and weather. Activity, habitat and weather information was recorded using numerical scores (Appendix 4.1). I took fixes throughout the day so that all daylight hours were covered, and individual birds were observed for varying lengths of time. Only details of the initial sighting were recorded, however, because it was possible that the subsequent behaviours of tagged harriers may have been influenced by the presence of the observer.

Table 4.1 Gender and age of eight radio-tagged Australasian Harriers tracked from Pukepuke Lagoon and surrounding areas from June 2000 to February 2001.

Radio-tagged birds	*Sex*	*Age*
TX 2	Female	Adult
TX 6	Female	Adult
TX 8	Female	Adult
TX 10 *	Female	Adult
TX 4	Male	Juvenile
TX 12	Male	Juvenile
TX 14	Male	Adult
TX 16 *	Male	Adult

***TX 10* * and *TX 16* * formed a pair during the 2000-2001 breeding season**

Four females and four males (including two juveniles) were tracked in the study (Table 4.1). The two juveniles dispersed from Pukepuke Lagoon prior to the breeding season. The remaining six harriers were all adults which bred in the area, two of them forming a pair.

4.3.3. Data Analysis

Radio-tagging data were separated into breeding and non-breeding seasons for range analysis. The non-breeding season period extended through June to the end of August, and the breeding season from September to January.

Range Size

Spacing data for radio-tagged harriers were analysed with the computer software package RANGES V (Kenward and Hodder 1996). An autocorrelation analysis was initially carried out on each harrier's fixes to test if the recording method used produced a time interval that prevented the problem of non-independent fixes. The accuracy of fixes produced by the GPS (to within 10m of the true position) meant that a fix resolution of 20m could be set. This resolution size resulted in RANGES V setting a boundary strip of 10m around a fix in its calculation of polygon edges and areas (Kenward and Hodder 1996).

Minimum Convex Polygon (MCP) analysis, which is used extensively in studies of home range (Kenward 2001), was used to estimate the home range of the eight radio-tagged birds. In the analysis, home range is defined as an area repeatedly traversed by an animal, including excursive areas represented by outlying fixes. The core area (core range) of a home range is defined as the area repeatedly traversed on a regular base's (Kenward 2001). The core range is revealed when excursive areas, represented by outlying fixes, are removed (Kenward 2001). One-way ANOVA (SAS 2000) was used to look at the effect of breeding and non-breeding season on home range and core range sizes for male and female harriers.

An increment plot analysis was applied to range fixes of tagged birds to test if the full extent of their range was revealed. This was indicated when a plateau in the increment plot was reached.

Utilisation plots were created for radio tagged birds to decide what percentage of fixes defines a core range. Percentage of area defined as core was estimated from marked decreases in the slope of the distribution curve. When ranges were small, no obvious slope discontinuity in the utilisation plot could be distinguished thus the core and home ranges where very similar in size. The utilisation plots of combined seasonal range for the eight radio tagged harriers are shown in Appendix 4.2. Utilisation plots were also used to find core ranges for breeding and non-breeding season.

Overlap

'Static interaction' is the physical spacing of geographical areas showing overlap between two or more ranges (Kenward and Hodder 1996). Static interactions were measured as proportions of overlapping habitat of radio-tagged harriers using spatial analysis in the geographical information system (GIS) computer package ARCVIEW 3.2 (ESRI 1999).

Interaction through time between individuals with overlapping ranges is commonly referred to as 'temporal interaction' (Kenward and Hodder 1996). Temporal interactions were examined using the dynamic interactions option in RANGES V. Dynamic interaction analysis gives a single cohesion index for the tendency of pairs of animals to be close together in a time period, thus the probability of ranges overlapping through time can be estimated (Kenward and Hodder 1996). The method used for analysis of temporal range overlap is described by Kenward *et al.* (1993). Two individuals that do not share a static overlapping range should show a probability close to zero as they would be neither attracted to, nor avoid, each other. Likewise, animals whose ranges overlap but seldom encounter each other because they rarely visit the same place at the same time, would also show a probability close to zero. Median distances between individuals and temporal interaction probabilities were analysed using Jacob's Index in RANGES V (Kenward and Hodder 1996).

Habitat Use

Six types of habitat were identified and separated using ARCVIEW 3.2 (ESRI 1999) from an orthophotograph of the study area and surrounding lands taken in August 2000. The six habitat types identified were; open water, dune hills, forest, long grass, pasture and swamp. Home range estimates using the MCP's produced in RANGES V were used to set habitat boundaries for each radio-tagged bird. Percentages of habitat available and used were calculated for breeding and non-breeding home ranges. Habitat utilisation was calculated as the percentage of radio fixes that a harrier was observed in a particular habitat type. ANOVA (SAS 2000) was used to look at the significant differences of habitat utilisation and availability for male and female harriers.

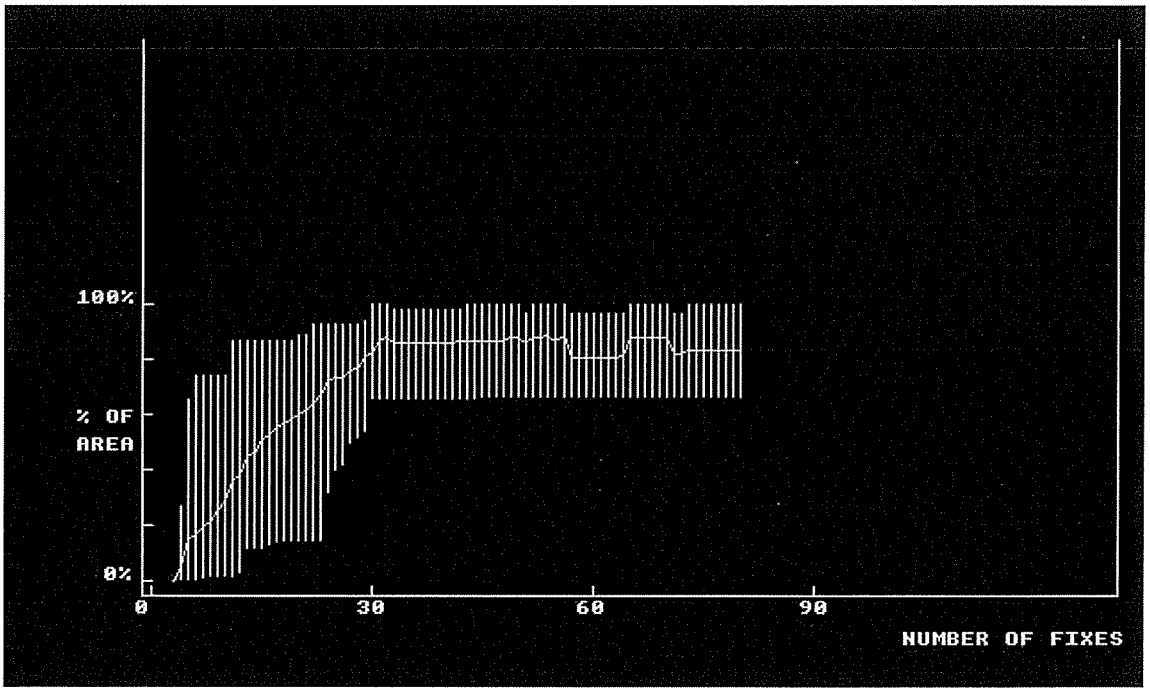
4.4 RESULTS

4.4.1 Home and core range size and shape

Incremental plots were compared and in all cases the outer minimum convex polygons (MCP) home range area reached an asymptote after approximately 30 fixes (Figure 4.1).

The sizes difference of male home and core ranges in the breeding (One-way ANOVA, $F_{3,4} = 4.50$, $p \leq 0.17$) and non-breeding (One-way ANOVA, $F_{1,2} = 1.13$, $p \leq 0.33$) season were not significantly different. In contrast, female home and core ranges in the breeding (One-way ANOVA, $F_{3,4} = 12.98$, $p \leq 0.01$) and non-breeding season (One-way ANOVA, $F_{3,4} = 10.60$, $p \leq 0.02$) were significantly different (Table 4.2).

Figure 4.1 RANGES V (Kenward and Hodder 1996) incremental plot analysis displaying the upper and lower limits and average (solid line) percentage of area revealed in relation to number of fixes for eight radio tagged Australasian Harriers at Pukepuke Lagoon. Full extent of ranges revealed by plateau at approximately 30 range fixes using data from minimum convex polygons.



There were no significant differences between the breeding and non-breeding home range size in males (One-way ANOVA, $F_{1,2} = 0.40$, $p \leq 0.56$). Likewise there were no significant differences in male core ranges between the breeding and non-breeding seasons (One-way ANOVA, $F_{1,2} = 1.41$, $p \leq 0.30$). In contrast, female breeding and non-breeding range size was significantly different for both home (One-way ANOVA, $F_{3,4}$

= 5.90, $p \leq 0.05$) and core (One-way ANOVA, $F_{3,4} = 6.77$, $p \leq 0.04$) ranges.

Females had smaller core ranges than males in both seasons. The non-breeding season core range differences were not significant (One-way ANOVA, $F_{3,4} = 1.41$, $p \leq 0.28$), however breeding season core ranges were (One-way ANOVA, $F_{3,4} = 10.80$, $p \leq 0.03$). Full SAS output of results can be found in Appendix 4.1 – 4.2 on CD-ROM.

Table 4.2 Home range and core range areas (ha) of male and female Australasian Harriers for the breeding (September – January) and non-breeding (June - August) season at Pukepuke Lagoon June 2000 – January 2001. Means (*number of individuals*) and ranges are shown. The non-breeding season included two juvenile males that were not present during the breeding season. All adults attempted to breed.

		Male	*Female*
Home Range (ha)	Non-breeding	669.71 (*4*)	864.92 (*4*)
		114.05-1147.69	358.37-1272.22
	Breeding	405.51 (*2*)	340.60 (*4*)
		245.44-565.58	128.62-521.26
Core Range (ha)	Non-breeding	338.70 (*4*)	148.65 (*4*)
		65.35-600.97	54.58-239.86
	Breeding	65.12 (*2*)	28.57 (*4*)
		53.90-76.34	21.71-46.03

Ranges varied greatly in shape, showing no general pattern between individuals or seasons. However, the breeding season home ranges of harriers (Figure 4.2) tended to be somewhat elongated and the non-breeding season (Figure 4.3) home ranges more circular. Home and core range sizes tended to be smaller in the breeding season and larger in the non-breeding season.

Figure 4.2 Nest location, home range shape and core range shape for six radio-tagged adult Australasian Harriers at Pukepuke Lagoon during the breeding season (September 2000 – January 2001). Breeding pair of TX 10 (female) and TX 16 (male) is shown.

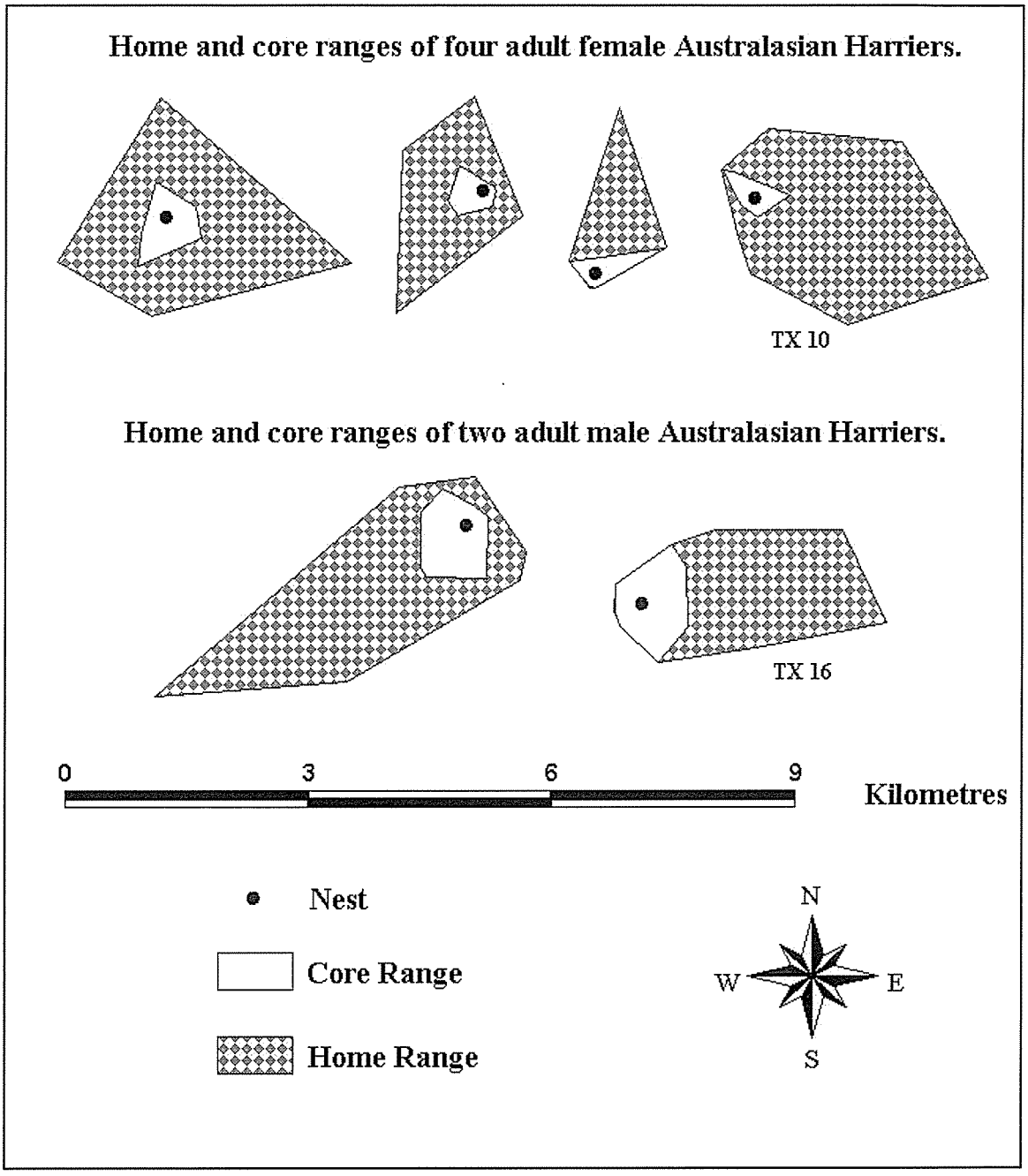
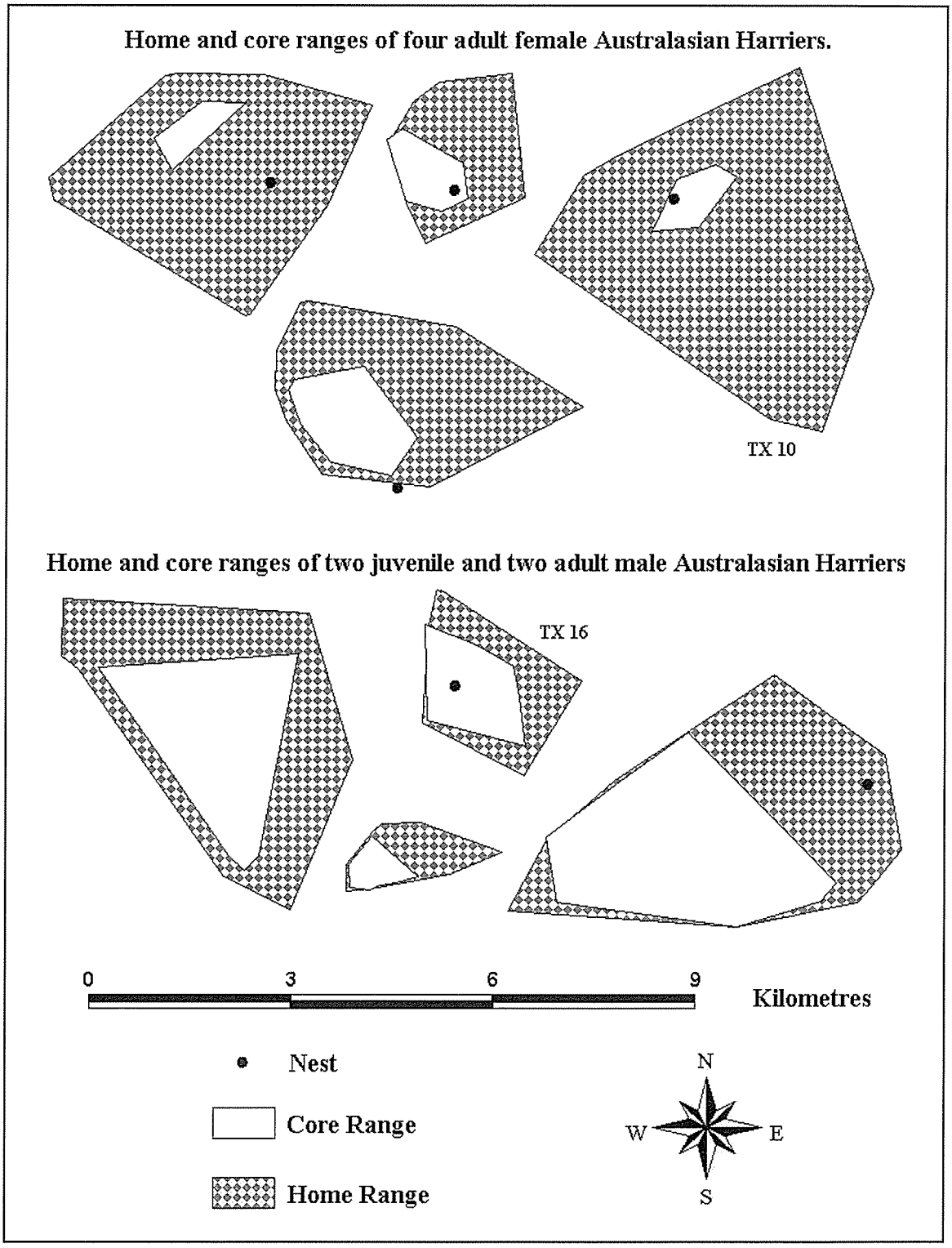


Figure 4.3 Nest location, home range shape and core range shape for eight radio-tagged Australasian Harriers at Pukepuke Lagoon during the non-breeding season (June – August 2000). Two juvenile males with out nest locations are shown as well as breeding pair of TX 10 (female) and TX 16 (male).



4.4.2 Range overlap

Static Interactions: Breeding Season

During the breeding season overlaps between birds core ranges (7.76%) or home ranges (11.20%) were scarce, however overlaps present tended to be large (Table 4.3). Three of the four adult females and one of the two adult males bred within the boundaries of Pukepuke Lagoon. The core and home ranges of the pair TX 10 (female) and TX 16 (male) overlapped considerably. TX 16's core range overlapped a large (86.7%) proportion of TX 10's core range. However, TX 10 almost completely surrounded TX 16's home range, which may have been accounted for by the male's persistent territory defence, restricting its home range during the breeding season. TX 10's home range was the largest of the pair and she displayed the second largest home range of all the females. Moreover her home range expanded when the chick was approximately three weeks old. During this time the male continued to carry out most of the nest defence and was never far from the nest.

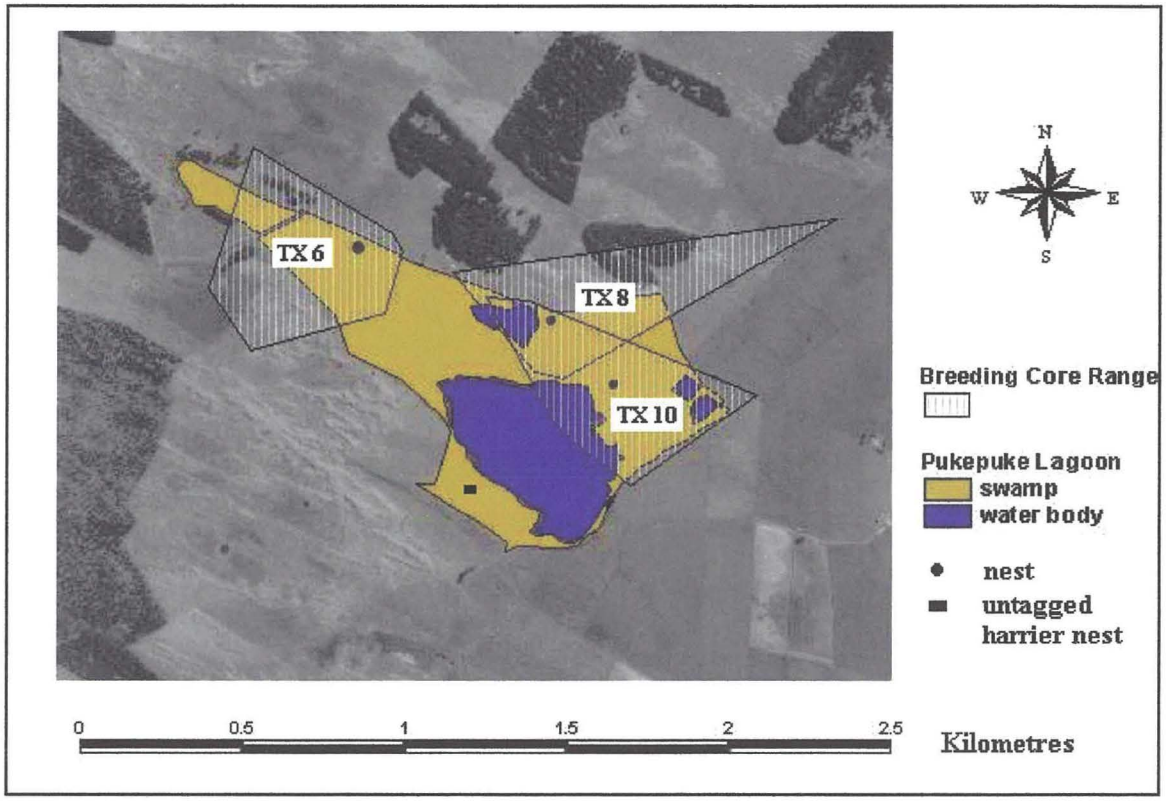
Table 4.3 Core and home range overlaps of six radio-tagged adult Australasian Harriers during the breeding season (September 2000 – January 2001) at Pukepuke Lagoon. The ranges of birds shown in the left-hand column overlapped those of the birds in the top row represented as percentage of range overlap (core/home). TX 10 and TX 16 were the only radio-tagged birds to form a pair, all others paired with non radio-tagged partners.

	TX 2	*TX 6*	*TX 8*	*TX 10*	*TX 14*	*TX 16*
TX 2	-	0/0	0/9.9	0/0	0/10.7	0/0
TX 6	0/0	-	0/0.6	0/0	0/0	0/0
TX 8	0/2.7	0/0.3	-	25.3/8.3	0/0	18.9/6.1
TX 10	0/0	0/0.2	23.5/33.5	-	0/19.3	35.0/97.1
TX 14	0/12.5	0/0	0/0	0/20.9	-	0/46.5
TX 16	0/0	0/0	43.4/11.7	86.7/46.1	0/20.4	-

TX 8 nested approximately 200m from the nest of TX 10 and 16, and substantial overlap between these three birds occurred (Figure 4.4.). This suggests that some segregation of core areas exists but there may also be high tolerance for other pairs nesting close by. TX 6 nested approximately 850m and 700m respectively from the nest's of TX 8 and the pair consisting of TX 10 and TX 16. TX 6 had little overlapping breeding home range and no core range overlap with the other three birds breeding at Pukepuke Lagoon. The remaining radio-tagged birds nested away from Pukepuke

Lagoon and had little or no overlap of breeding ranges. The core ranges of all birds, except pairs within 200m of another nesting pair, had no overlap with other birds suggesting that there is greater segregation in the core areas.

Figure 4.4 Breeding proximity and core range (vertical barred polygons) of three adult female Australasian Harriers nesting at Pukepuke Lagoon in the 2000-2001 breeding season. TX 6 nesting Northwest of the main water body with no overlapping core range. TX 8 nesting north of the main water body and overlapping TX 10's core range. The nest of TX 8 and TX 10 is separated by approximately 200m. Only one nest from a non radio-tagged pair of harriers was discovered at Pukepuke Lagoon, south west of the main body of water.



Static Interactions: Non-breeding Season

I found large overlaps in the core (mean = 11.05%) and home (mean = 31%) ranges of most radio-tagged birds (Table 4.4) in the non-breeding season. There was no apparent relationship between age or sex and overlapping ranges, as all groups tended to overlap to some extent in core and home ranges. Birds whose ranges never overlapped did not share the same territory at any stage of the study. For this reason, and because of the lack of evidence suggesting a relationship between range overlap and age/sex groups, they were not considered as exclusions from neighbouring ranges. Core ranges overlapped little for all individuals, with the exception of TX 10 & 16, suggesting that there is some segregation of core areas but it is not as evident in the non-breeding season.

Table 4.4 Percentage of core and home range overlaps during the non-breeding season (June – Late August 2000) for the eight radio-tagged Australasian Harriers at Pukepuke Lagoon. The ranges of birds shown in the left-hand column overlapped those of the birds in the top row represented by percentage of range overlap (core/home).

	TX 2	*TX 6*	*TX 8*	*TX 10*	*TX 4*	*TX 12*	*TX 14*	*TX 16*
TX 2	-	0/39	0/72	0/9	8/55	0/0	5/30	0/13
TX 6	0/14	-	25/35	0/7	9/29	5/59	0/7	0/16
TX 8	0/57	66/80	-	0/13	36/59	1/24	4/30	9/23
TX 10	0/11	0/25	0/20	-	0/13	5/98	1/27	36/96
TX 4	28/54	58/81	90/73	0/10	-	9/67	3/16	4/32
TX 12	0/0	6/20	1/4	10/9	2/8	-	0/5	14/19
TX 14	16/33	0/23	11/41	14/24	3/18	0/50	-	17/40
TX 16	0/4	0/14	6/9	99/24	1/10	17/49	4/11	-

Temporal Interactions

Attraction and avoidance interactions between harriers refer to temporal interaction probabilities produced using Jacob's Index in RANGES V (Kenward and Hodder 1996). Ranges overlapped little in time for most birds, except those nesting close together, thus neutral interactions (i.e. probability = close to 0) would be expected (Table 4.5). The breeding season produced high attraction between TX 10 and TX 8, explained by the close proximity of their nest sites. Similarly, it would be expected that TX 6 would also have a reasonably high attraction with these two females because it nested fairly close (800m) to them. Although the probability scores with TX 6 and the two closely nesting females tend slightly towards attraction they can be considered close to zero and therefore reflect neither attraction nor avoidance. It would be expected that the breeding pair of TX 16 and TX 10 would have a high attraction because breeding season demands a certain amount of close interaction, however this does not seem to be the case (+0.10). Observations of interactions were high for this pair when the female was at the nest, however fixes of the female in the nest were omitted from the analysis which would explain the resulting low interaction value. The negative probability seen in the pairing of TX 14 with TX 6 and TX 8 suggests there is avoidance among these pairings. However, their home ranges during the breeding season never overlapped, thus this result must be considered as neither avoidance nor attraction. All other parings showed neutral temporal interactions.

Table 4.5 Temporal interaction of six radio-tagged adult Australasian Harriers during the breeding season (September 2000 – January 2001) at Pukepuke Lagoon. The Figures represent the probability of two radio-tagged individuals being attracted to, or avoiding each other where their corresponding ranges overlap (–1 = high avoidance, +1 = high attraction, 0 = neither attraction nor avoidance).

	TX 2	*TX 6*	*TX 8*	*TX 10*	*TX 14*	*TX 16*
TX 2	-					
TX 6	0.04	-				
TX 8	0.03	0.18	-			
TX 10	0.03	0.07	0.59	-		
TX 14	0.04	-0.23	-0.14	0.02	-	
TX 16	0.03	0.02	0.01	0.10	0.07	-

Table 4.6 Temporal interaction of eight radio-tagged Australasian Harriers during the 2000 non-breeding season at Pukepuke Lagoon. The non-breeding season included the two juveniles (TX 4 and TX 12) which did not form breeding territories, dispersing prior to breeding season. The figures represent probabilities that two radio-tagged individuals are attracted to or avoid each other where their ranges overlap (–1 = high avoidance, +1 = high attraction, 0 = neutral attraction / avoidance).

	TX 2	*TX 6*	*TX 8*	*TX 10*	*TX 4*	*TX 12*	*TX 14*	*TX 16*
TX 2	-							
TX 6	0.02	-						
TX 8	-0.09	0.15	-					
TX 10	0.04	0.03	0.06	-				
TX 4	0.08	-0.20	0.06	0.09	-			
TX 12	0.03	-0.02	0.22	-0.02	0.04	-		
TX 14	0.00	0.00	-0.05	-0.06	0.07	0.06	-	
TX 16	0.01	0.00	0.07	0.27	0.00	0.07	0.07	-

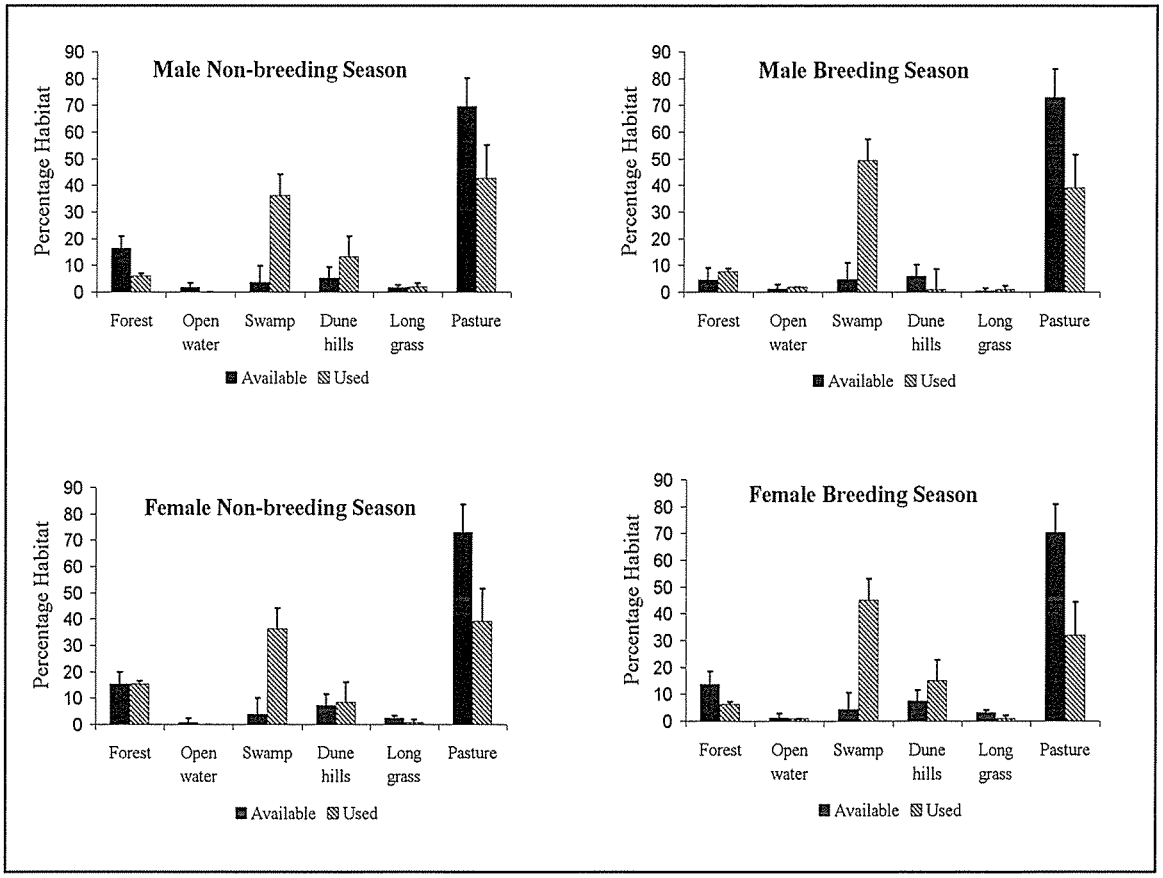
Although all pairings appear to have neutral temporal interactions in the non-breeding season (Table 4.6), there are some points worth mentioning. TX 4 and TX6 share a slight avoidance (-0.20), which might result from dispersal pressure on juveniles by adults (parents) from natal areas. This juvenile did not disperse from Pukepuke Lagoon (suspected natal area) until well into the breeding season, which may have increased the probability of negative interaction with adults. In contrast TX 12 has a slight attraction with TX 8 (+0.22). This juvenile dispersed from Pukepuke Lagoon (suspected natal area) three days after the first breeding activities in adults were observed. Dispersal

could have reduced any negative interaction the bird might have received, if it had stayed in the area for longer. TX 10 and 16 also show a moderate attraction (+0.27) and this might be explained by pre-breeding season interaction and early pair bonding.

4.4.3 Habitat Use

Males and females shared similar habitat composition for both the breeding and non-breeding season (Figure 4.5). Pasture accounted for over 70% of the habitat in all ranges and seasons however only 38% ±2.3 of pasture was utilised by harriers (Figure 4.5). The difference between pasture availability and use by harriers in the non-breeding season was not significant for males (One-way ANOVA, $F_{3,4} = 1.64$, $p \leq 0.25$) but was for females (One-way ANOVA, $F_{3,4} = 6.65$, $p \leq 0.04$). The use of pasture habitat in the breeding season was significantly less than that available for both males (One-way ANOVA, $F_{1,2} = 30.75$, $p \leq 0.03$) and females (One-way ANOVA, $F_{3,4} = 7.13$, $p \leq 0.04$).

Figure 4.5 Habitat availability and habitat use by male and female Australasian Harriers in the breeding (September 2000 – January 2001) and non-breeding (June – August 2000) season at Pukepuke Lagoon. Habitat availability (solid bars) is the percentage of habitat present in the home range, and habitat used (hatched bars) is the percentage of radio fixes in each habitat type. Habitat types are forest (mainly pine), open water, swamp, dune hills, long grass (non-grazing pasture), and pasture.



Forest habitat types accounted for approximately 12.5% of range composition in all ranges except male breeding range (4.5%). Although the amount of forest available and used by each sex differed slightly this was not significant in either males (non-breeding: One-way ANOVA, $F_{3,4} = 2.49$, $p \leq 0.17$; breeding: One-way ANOVA, $F_{3,4} = 1.03$, $p \leq 0.42$) or females (non-breeding: One-way ANOVA, $F_{3,4} = 0.03$, $p \leq 0.88$; breeding: One-way ANOVA, $F_{1,7} = 1.83$, $p \leq 0.22$). There were no significant differences in forest usage between sexes in the breeding season (One-way ANOVA, $F_{5,6} = 0.18$, $p \leq 0.69$) and although females used slightly more forest habitat in the non-breeding season this was also not significant (One-way ANOVA, $F_{7,8} = 2.21$, $p \leq 0.19$). There was no significant difference in forest use between seasons for males (One-way ANOVA, $F_{3,4} = 1.21$, $p \leq 0.33$) and females (One-way ANOVA, $F_{3,4} = 1.10$, $p \leq 0.33$).

Available swamp habitats were similar between sexes and season ranges, accounting for less than 5% of the total habitat. Although swamp represented a small proportion of the available habitat, it was the most frequently (41% ±3.3) used. The difference between available and used swamp habitat in the breeding season was significant for females (One-way ANOVA, $F_{3,4} = 11.31$, $p \leq 0.02$) but not males (One-way ANOVA, $F_{1,2} = 5.96$, $p \leq 0.13$). The non-breeding season shows a reversal of this with males (One-way ANOVA, $F_{3,4} = 8.36$, $p \leq 0.03$) using significantly more swamp habitat than is available and females (One-way ANOVA, $F_{3,4} = 3.93$, $p \leq 0.09$) showing similar but not significant differences. Although differences between use and availability of swamp habitats are just non-significant, for males in the breeding season and females in the non-breeding season, the overall trend suggests harriers frequent swamp areas all year.

There were no differences between available and used habitat for both sexes and seasons for the remaining habitat types of open water, dune hills and long grass. Harriers, therefore, reflected by their use the relatively small proportions of area covered by these habitats.

4.5 DISCUSSION

4.5.1 Home Range

The home range of the Australasian Harrier at Pukepuke Lagoon varied between sexes and seasons. During the non-breeding season females had larger ranges than males, and this could be accounted for by their larger body mass. Peery (2000) for instance, suggested that home range size in raptors increased with body mass and energetic requirements. In addition to this, Harestad and Bunnell (1979) hypothesised that as home range area increased to meet the energetic requirements of the larger female, more unsuitable habitat would be encountered, producing an even greater demand for increased range.

In the breeding season the home range of females reduced sharply and their core ranges were significantly smaller during this period. As is typical of accipiters, females generally have a larger range than males in the non-breeding season but this is reversed in the breeding season (Burton and Olsen 2000). At Pukepuke Lagoon females were seen to roost in many locations away from their breeding ranges in the non-breeding season, however, they returned to roosts close to nest sites each night during the pre-laying period and this may have reduced their ability to range further (pers. obs). The females stayed close to their nests during incubation and early chick development, which may also have restricted their range. Only one out of eight eggs laid by radio-tagged females hatched, despite all females incubating for the full period. The female that produced a chick stayed close to the nest until approximately three weeks after hatching, and the chick fledged at six weeks. Only one radio-tagged bird (TX 2) nested in long grass and shared a small portion of its breeding home range with one other adult male (TX 14) but their core ranges did not overlap. Her non-breeding range was the largest of all the harriers tracked in the study and did not include substantial areas of swamp.

The MCP analysis used to estimate range sizes is sensitive to points on the periphery of a range, thus it produces ranges that include areas seldom, or never, visited (Harris *et al.* 1990). Consequently MCP's produced in this study may over-estimate the true home-range area of an individual. Because the sample sizes were small, the results may also

under represent the span of range size exploited by Australasian Harriers, thus the results are conservative in terms of range size variability in the population. They are, however, indicative of harrier ranges in coastal dune lands. Direct observation of the location of radio tagged harriers throughout the study gave approximate field worker estimates of ranges size which were consistent with the ranges produced by the MCP analysis.

During the spring months it was often possible to see harriers cover the full extent of their range in a matter of hours, their ability to cover large distances being aided by rising thermals. Although harrier altitudinal range has not specifically been covered in this or any other study it is probable that the ability to fly high influences their range size and dispersal ability. Harriers frequently became difficult to observe from the ground when flying in thermals and it was necessary to hear their courtship calls in order to locate them. Pilots from the Feilding Gliding Club report sightings of harriers riding thermals at altitudes of 4 - 6,000 ft (c. 1200-1800m), and one harrier flying at an estimated 8,000 ft (c. 2400m) was observed from a glider (J. Peart pers. comm.). Glider pilots often use harriers as visual indicators of rising thermals in order to gain altitude themselves (J. Peart pers. comm.). Flying at these altitudes is unstudied in Australasian Harriers, however food location, distribution, courtship displaying and social interactions may all influence this behaviour. It is unknown which age and sex groups use thermals to reach altitudes over 4,000 ft (c. 1200m) but observations from the ground suggest there are no specific group trends in this behaviour. Frequently adult harriers are noticed flying in thermals during courtship displays and their calling tends to catch the attention of the observer.

The only other study on the spacing behaviour of the Australasian Harrier in New Zealand (Baker-Gabb 1978) comprised data from 212 wing-tagged individuals. Fortnightly visual observations of those birds present over 18 months, were used to estimate home and core ranges.

Estimates of home and core ranges utilising radio tracking data from this study produced home ranges which are almost two-thirds smaller than those found by Baker-Gabb (1978) (Table 4.7). A possible explanation for the discrepancy is that in the present study the home range estimates during breeding were based on adults only,

while Baker-Gabb combined adults and juveniles in his analysis. Juvenile dispersal during the breeding phase probably biased and produced much larger home range estimates in Baker-Gabb's (1978) study. A similar range size in the non-breeding season would be expected for both studies. However, the present study again produced smaller home range estimates. Comparisons of core range in the breeding season is not possible as they are not given in Baker-Gabb's (1978) study.

Table 4.7 Comparison of home and core range studies of the Australasian Harrier at Pukepuke Lagoon in the breeding and non-breeding season form 1978 (Baker-Gabb) and 2001. Baker-Gabb's (1978) estimates of range size are based on wing tagged observations of harriers compared with this study, based on radio tagging data of eight individuals. Averages for core and home range for all birds are given in this study.

		Baker-Gabb (1978) wing tagged observations	**Radio-tracking (2001)**
Non-breeding Range	Home Range	900 ha	763 ha
	Core Range	N/A	566 ha
Breeding Range	Home Range	900 ha	373 ha
	Core Range	300 ha	158 ha

For all measurements of range, radio tracking seems to produce smaller estimates (Table 4.7). A possible explanation for the difference is that radio telemetry produces conservative but accurate estimates of home range and is a reliable indicator of range size (Hodder *et al.* 1998; Kenward 2001).

4.5.2 Overlapping static ranges

The small amount of range overlap in the breeding season suggests that there is little interaction with neighbouring harriers. Core area overlaps were seen between the only radio-tagged breeding pair and an adult female (TX 8) who nested near by. The distance between these two nests, and their overlapping core ranges, suggests that there is some tolerance, or advantage to pairs nesting close together. Arroyo (2001) found colonial breeding of Montagu's Harriers (*Circus pygargus*) in Europe decreased the individual costs of defence in terms of risks taken, and enhanced defence efficacy. Arroyo (2001) also suggested alarm calls from Montagu's Harriers triggered neighbouring birds to join in defence. Observations of nest defence by Australasian Harriers showed that although

alarm calls from several birds were frequently heard when a potential predator intruded, only one bird participated in defence. It is possible that the predators observed were not significant enough to elicit group defence. This behaviour, however, has not been recorded in the literature.

Baker-Gabb (1978) suggested that it is common to find harriers nesting in close proximity, observing the average 'nearest neighbour' distance amongst 19 nests to be 910m and the closest 300m. The closeness of nests at Pukepuke Lagoon may have been due to competition for good breeding resources resulting from the lack of available swamp area. Simmons (2000) noted that wetland areas in North America have larger proportions of successful Northern Harrier (*Circus hudsonius*) nests than drier habitats more accessible to predators. Close nesting may be the result of competition for good breeding habitat, traditionally wetlands, as three of the four females nested at Pukepuke Lagoon. Only one of these nests was successful in rearing a chick, a 0.25 reproductive success from four nests, compared with Baker-Gabb's (1978) study which produced a 1.05 reproductive success from 19 nests. Predators were not the cause of failure in the remaining nests in this study.

Numerous overlaps of non-breeding ranges suggest greater interaction between harriers when territories are less vigorously defended. In the breeding season virtually no overlapping ranges occurred, excepting closely nesting pairs. This is common in other raptors (Dawson and Mannan 1991). The opposite is seen in the non-breeding season with almost all radio-tagged individuals showing some degree of range overlap. In the non-breeding season the increase in range size seems to complement the greater overlap. This may also support the hypothesis of habitat limitation and amount of overlap during the breeding season.

4.5.3 Overlapping temporal ranges

As expected, greatest temporal interaction was observed from birds in close proximity to each other during the breeding season. Mutual avoidance by closely nesting females, competing for similar resources and attracting potential predators (closely nesting harriers) to their young, might have been expected. This, however, did not seem to be the case. The strongest attraction was seen between two nesting females (+0.59).

Female harriers nesting in close proximity to each other may be compelled to keep a close watch on other females as potential predators of eggs or chicks. The close proximity (200m) of nests may also have meant that avoidance was impossible, and the behaviour of females staying close to the nest through much of the breeding season produced a positive temporal interaction.

Most temporal interaction in the non-breeding season seemed to be reasonably neutral with little trend towards either attraction or avoidance. The slight exceptions may be due to the displacement of juveniles from the natal area by adults. Dispersal of juveniles, before being displaced by adults, was considered to be a factor of attraction rather than avoidance between adults and juvenile in the non-breeding season because juveniles would not be subjected to any territorial behaviour by adults. Positive interaction in the non-breeding season by an adult male and female could be explained by them later forming a breeding pair. This suggests that breeding pairs may have formed earlier than the first observations of courtship and defence. Baker-Gabb (1978) observed harriers soared in thermals as early as July and suggested that males used this opportunity to display plumage. This may be true for some individuals in some years. Observations in the present study, however, suggest many adult harriers are still moulting during this period. I suggest that rather than a display of plumage, a display of flying and consequent hunting ability to provide for the female and young in the upcoming breeding season may be the purpose of flying thermals as early as possible. Because the sample of intensively studied harriers at Pukepuke Lagoon was not large, the results of dynamic interactions in this study should be seen as indicative.

4.5.4 Habitat Use

Swamp habitat was used extensively (41%) by harriers compared with the amount available (< 5%) and was clearly a preferred habitat type. Its use by females was increased in the breeding season by the nesting of three of the four females in the swamp. Two males were tracked during the breeding season and, unlike females, they were not restricted by incubation duties and were frequently seen over many other habitats in the breeding season. This may account for the lack of significant use of swamp by males compared to females during the breeding season.

In contrast to swamp, pasture formed an extensive habitat type, but was relatively little used by harriers. The lack of cover for small invertebrates in pasture could force potential prey to either utilise areas of heavy vegetation cover, or restrict their use of pastoral habitat to nocturnal periods. The behaviour of prey may reduce the attractiveness of pasture as hunting areas for harriers.

Harriers used pine forests in all seasons to a small extent and in this habitat small birds are probably the main prey type. Harriers often take small birds on the wing and passerines form a substantial part of their diet (Gibb 1970; Baker-Gabb 1981; Cooper 1991). Analysis of regurgitated pellets from the study area (Chapter 3) revealed that birds made up 37% of the total diet and 60% of the birds identified were passerines. Harriers are also known to hunt over large stands of forest in search of bird prey (Innes *et al.* 1999) similar to the behaviour of the only true forest-hunting harrier, the Reunion Harrier (*Circus maillardi*), in the Reunion Islands off the east coast of Madagascar (Simmons 2001). Although the available and used forest habitats were very similar, the proportion of forest actually used is hard to assess. Often harriers were observed following forest margins and were recorded as using forest habitat because it was difficult to establish whether forest, or the surrounding area, was the habitat primarily being utilised. Forest edges are difficult to measure and were not defined as a distinct habitat in the analysis.

4.5.5 Summary of findings and Future Research

The findings of this study provide new information on the life history and behaviour of the Australasian Harrier with implications for conservation of harriers and, therefore, other animals that are its prey. Aspects of harrier movements, spacing and habitat utilisation contribute to conservation issues such as predator-prey relationships affecting some of New Zealand's rare and endangered species (Pierce 1987; Innes *et al.* 1999; Treadgold 2000). Harrier biology has also become a management concern for many recovery programmes where numbers of the focal species have become critically low. Harrier ranges reach a maximum of around 1,000 ha and the ranges of many birds may overlap within an area. During the breeding season of most birds, harrier ranges reduce in size and breeding pairs become territorial. Thus, culling resident pairs may be a beneficial short-term solution for protecting other important nesting birds. Harrier

recruitment to replace culled individuals is relatively quick because the birds are very mobile over large areas. Deterring harriers in the long-term from entering localised areas may be achieved through a wider understanding of harrier habitat use, interaction patterns and ranging behaviours in different areas.

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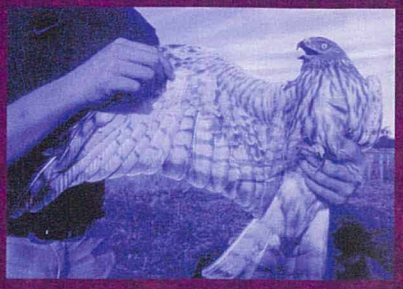
Communal Roosting



5

Communal roosting of the Australasian Harrier on the Manawatu-Rangitikei coast.

5.1 INTRODUCTION

Although communal roosting is a common behaviour in many species of raptors, including the Australasian Harrier (Gurr 1968; Hedley 1976), the ecological factors influencing this behaviour are not obvious. Four major selective forces have been proposed to explain the presence of communal roosting by Australasian Harriers: (i) protection from predators (ii) a chance for solitary birds to meet mates (iii) establishment of an information centre for food finding (iv) a trait inherited from a migratory close relative (Beauchamp 1999).

The Australasian Harrier in New Zealand appears to lack some of the pressures that elicit communal roosting in other species of raptors (Chester *et al.* 1990; Thompson *et al.* 1990; Parker *et al.* 1995; Beauchamp 1999; Arroyo 2001) such as migration and predatory nest defence. The Australasian Harrier does not migrate in New Zealand but does communally roost. It is however one of the few Australian raptors known to migrate. The species is found in the north, east, south-east and south-west of Australia but only birds in the south, and in Tasmania, are usually migratory (Cupper and Cupper 1981; Marchant and Higgins 1993). The Australasian Harrier does not usually roost communally in Australia and therefore appears to be solely a New Zealand phenomenon. (Sharland 1958).

Few harrier roosting studies existed and the influence of environmental parameters is poorly represented in these studies (Baker-Gabb 1978, Gurr 1968, Hedley 1976, Stead 1932). Environmental parameters such as light intensity, weather conditions, and

seasonal changes may influence communal roosting behaviour and numbers attending a roost (Baker-Gabb 1978, Gurr 1968). The geography, habitat composition, size, and structure of communal roosts may also influence the behaviour of harriers at roosts, however uncertainty exists over the influence these environmental parameters have on roosting behaviour.

This research examines the communal roosting of harriers along a stretch of New Zealand coast adjoining farmland, and considers some factors known to influence roosting behaviour such as; light intensity, weather conditions, roost dynamics, and season. It also discusses the pressures that elicit communal roosting in closely related species, and the possible role of communal roosting in the Australasian Harrier.

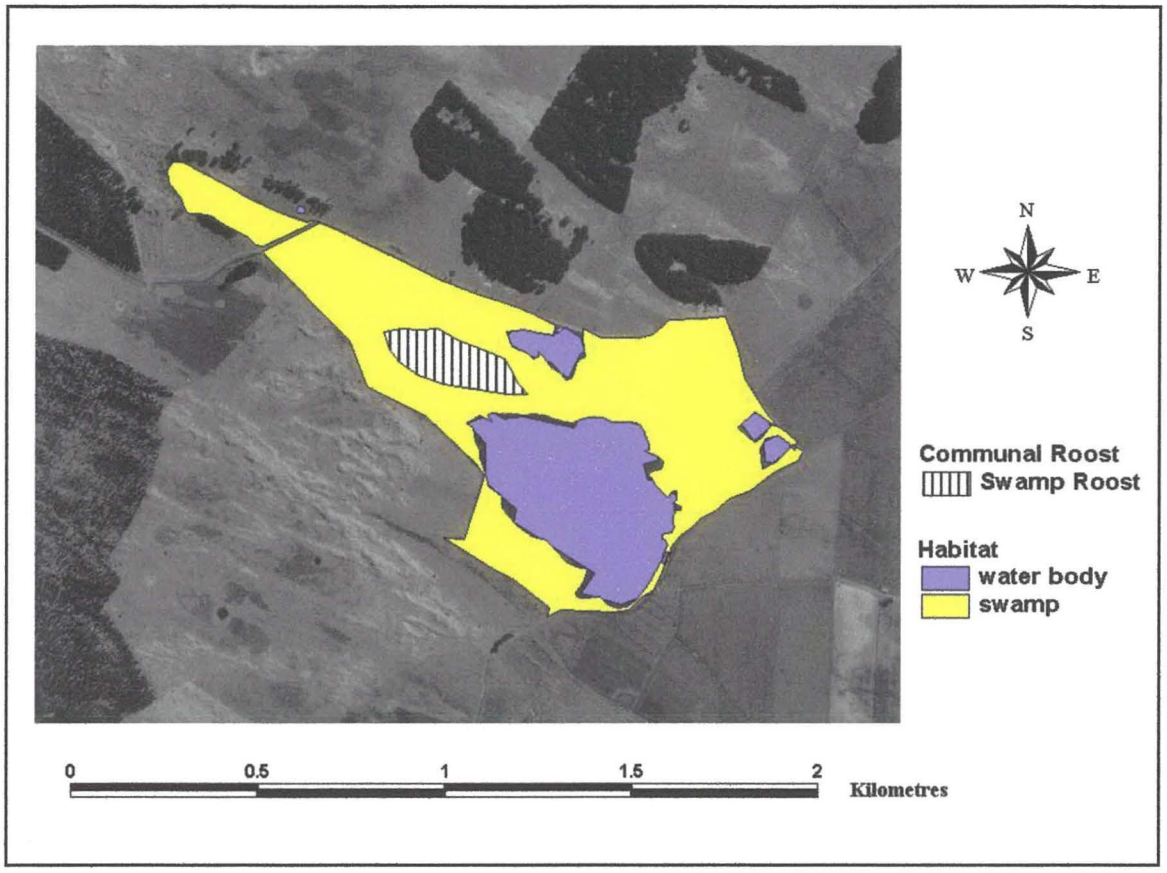
5.2 STUDY SITES

5.2.1 Pukepuke Lagoon

Pukepuke Lagoon lies at 40° 20´S latitude and 175° 16´E longitude on the west coast of the lower North Island (Figure 1.1). Part of the wider Manawatu-Rangitikei sand country Pukepuke Lagoon is one of a series of shallow dune-lakes found along the coastline (Cowie *et al.* 1958). The lagoon is 3km from the sea, and 6.5m above mean sea level with a catchment covering c. 30km^2. The Lagoon includes 15ha of open water and 86ha of surrounding swamp managed by the Department of Conservation (Figure 5.1). Pasture, exotic forests and low-lying sand dunes dominate the surrounding area. The surrounding habitat is dominated by pasture for grazing sheep, beef and dairy cattle. The north west side of Pukepuke Lagoon is dominated by Pine plantations (*Pinus radiata*) of various ages, which were once part of the sand dune habitat of the nearby coastline. Numerous patches of swamp, harvested pine plantations, and dune hills are also present, but cover relatively small areas compared to the dominant habitats of pasture and growing pines. The prevailing winds come from the south west and are strongest in late autumn, winter and spring. The communal roost found at Pukepuke Lagoon covers c. 4ha and is located in swamp dominated by flax (*Phormium tenax*), raupo (*Typha orientalis*), cabbage trees (*Cordyline australis*) and to a lesser extent toetoe (*Cortaderia toetoe*). The flora of Pukepuke Lagoon and surrounding sand

country has been described by Esler (1978) and Ogden and Caithness (1982).

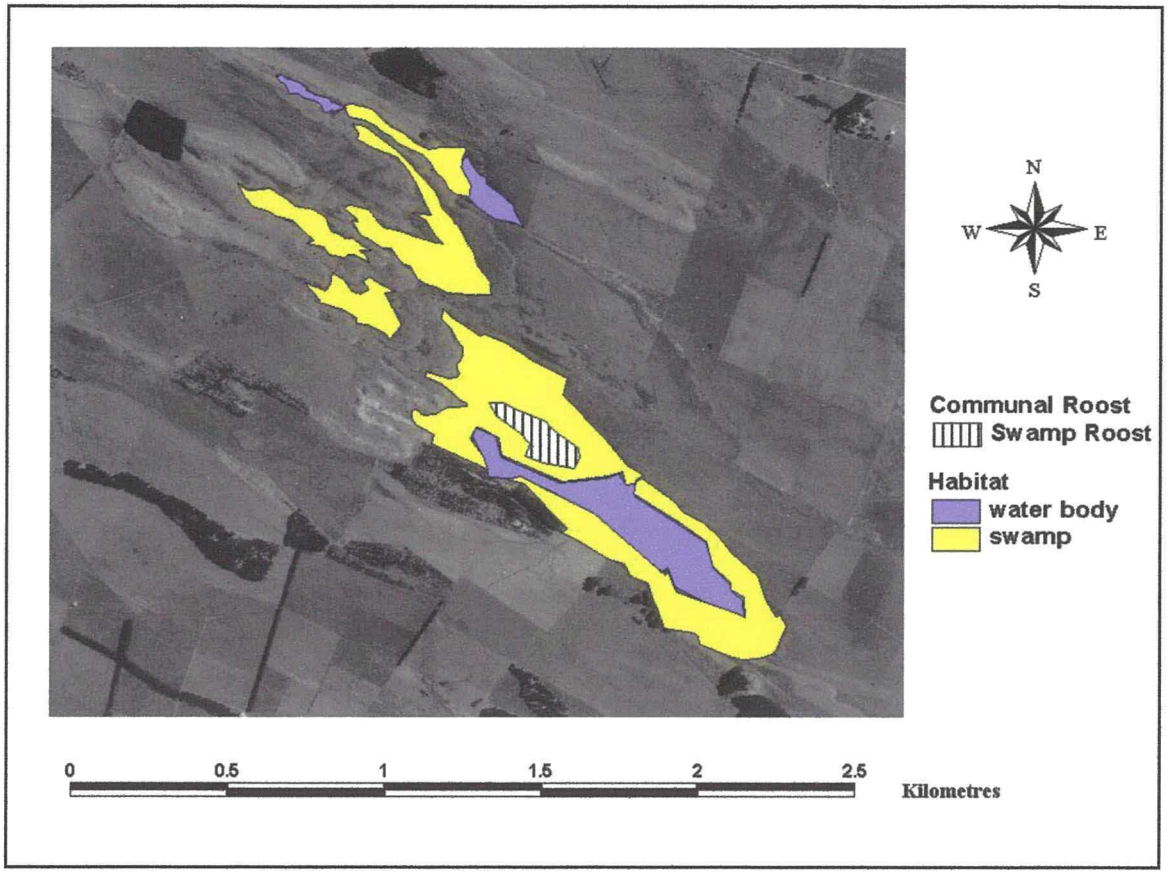
Figure 5.1 Orthophotograph of Pukepuke Lagoon communal roost located in raupo/flax swamp. Surrounding habitat dominated by pasture, pines blocks and dune hills.



5.2.2 Omanuka Lagoon

Omanuka Lagoon is situated c. 5.2km east north east of Pukepuke Lagoon (Chapter 1, Figure 1.1) and the climate, lagoon size, composition of vegetation and surrounding habitat is very similar. The swamp is mostly raupo with patches of cabbage trees and flax. Willow trees (*Salix sp.*) also feature around the margins of the main body of water. Omanuka Lagoon is situated in a dune hollow on the eastern side of a dune complex and is surrounded by pastures for grazing sheep and cattle. The lagoon comprises 12ha of open water and c. 50ha of surrounding swamp (Figure 5.2). The roost covers c. 4ha, lies completely in raupo, and is sheltered from prevailing south west winds by 25m high dune hills and adult pine plantations to the west and the south respectively.

Figure 5.2 Orthophotograph of Omanuka Lagoon communal roost located in raupo swamp. Surrounding habitat dominated by pasture, pines blocks and dune hills.



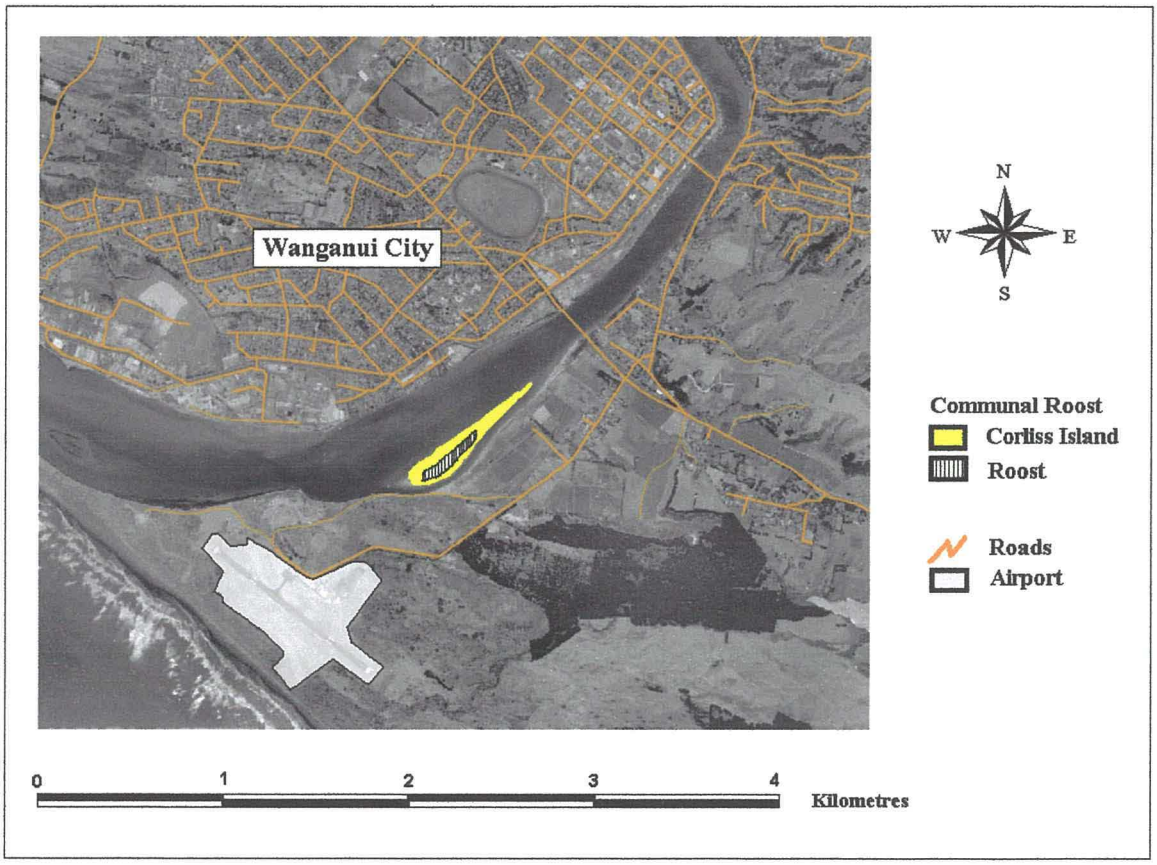
5.2.3 Corliss Island (Wanganui)

Three harrier roosts were studied along the Manawatu-Rangitikei coastline. The smallest roost was located on Corliss Island (40° 05′S latitude and 175° 05′E longitude), a long narrow island c. 1150m x 110m with an area c. 8ha on the lower Wanganui River (Figure 5.3). Corliss Island is 3km up stream from the mouth of the Wanganui River, which flows into the Tasman Sea on the west of the lower North Island. The communal roost is 500m from the nearest urban settlement and 2.5km south of the centre of Wanganui city.

Corliss Island is, therefore, surrounded by the Wanganui River and further surrounding habitat consists of a large grass hill to the south, pasture to the east, coastline to the west and Wanganui City to the north. A well established row of c. 30m high pine trees (*Pinus radiata*) grows along the north west margin of Corliss Island. Patches of flax (*Phormium tenax*) surrounded by various swamp and coastal grasses on the southern side dominate most of the island. During low tide sand and mud flats are exposed

around the southern and eastern edges of the island. Deposited driftwood is common on the south east end of the island and is frequently used as perches by harriers before roosting. The prevailing winds blow from the coastline on the western side as the southern and northern winds are blocked by hills to the south and pines trees to the north west. The communal roost occupies an area of c. 2.5ha in swamp grass on the south west side of Corliss Island.

Figure 5.3 Orthophotograph of Corliss Island communal roost (located in swamp grass) and surrounding habitat, on the Wanganui River.



5.2 METHODS

Three communal roosts were monitored at three week intervals over seven months during early and late breeding season (August 2000-February 2001). Observations of harriers at roosts were made in the evening and morning from a distant vantage point which did not disturb the normal activities of the birds. 27 evening observations at roosts began one hour before sunset and continued until birds were no longer visible. Six observations were made in the morning beginning 30 minutes before sunrise and

continued for two hours.

Observations from each roosting session were recorded with a tape recorder, later transferred onto spreadsheets for analysis. The date and weather conditions including wind direction, wind strength, precipitation and cloud cover, were noted at the beginning of each roost observation. Light intensities were recorded with a photometer as the harriers arrived at the roost, as well as the birds age and sex. In very low light conditions, observing arrivals and departures and distinguishing age and gender was impossible. Harriers were counted only if they landed in the roost, however, as all light faded any harriers flying over the roost were counted as roosting birds unless directly observed flying away from the roost. Binoculars (50 x 12) were used to count harriers when low light conditions made seeing harriers with the naked eye impossible. However, binoculars restrict peripheral vision to a large extent thus rapid scanning over the roost was important because birds would move quickly across a roost, especially in strong winds. Scanning, with binoculars, from right to left covering the entire roost was therefore carried out quickly to avoid counting a bird twice.

Measurements of the number of harriers flying over a roost were taken at intervals of 10 lux until the light intensity reached zero. Light levels were usually 3-4000 Lux at the start of each roost observation but faded rapidly about 30mins before complete darkness. The average and range of arrival and landing times of harriers for the three roosts were compared. A linear regression analysis was carried out for estimating the average light intensities at which harriers arrived at roosts.

The weather condition at each roost observation was categorised into two broad groups; 'fine weather' conditions were defined as no precipitation and average wind speed less than 10m/s; 'poor weather' conditions were defined as presenting precipitation and or wind speed greater than 10m/s. Cloud cover was omitted from analysis, as this did not appear to influence the arrival or numbers of harriers.

Seasonal influences were categorised into breeding and non-breeding season. Breeding was determined from the first observations of vigorous defence of breeding areas as harriers came into roost. This period was from November 2000 to January 2001 when the first females began incubating, and chicks were small (and most vulnerable) through

to fledging in late January. Breeding pairs were also most active in defence during this period. Non-breeding season included all other months not in the breeding season from August 2000 to February 2001. The influence of seasonal and weather conditions on arrival times and numbers of harriers at roosts was examined using linear regression analysis. Seasonal and weather data from the three roosts was combined as individually there were to few observations.

5.4 RESULTS

5.4.1 Roost site characteristics

Roosts varied in area depending on in numbers of birds using them. Pukepuke Lagoon and Omanuka Lagoon were composed of similarly large sized areas of swamps (86ha and 50ha respectively), while the total area of Corliss Island was only 8ha. Pukepuke Lagoon and Omanuka Lagoon had similar sized roosts (c. 4ha) while the Corliss Island roost was almost half the size (c. 2.5ha) of the other two roosts.

Harrier roosts were situated on the ground and comprised of several 'roosting bowls' consisting of flattened plant material forming an oval shaped hollow in the vegetation. The surrounding vegetation was usually high around the bowl adding shelter to the roosting bird. Evidence of a freshly used bowl consisted of white down feathers attached to vegetation, fresh white and black droppings usually clustered at one end of the oval shaped bowl, and occasional cast pellets of indigestible food remains (Plate 5.1). Although many harriers used the same roost, there was no evidence to suggest that there was more than one bird occupying the same roost bowl. Adjacent bowls were sometimes as close as one metre apart, but usually only one fresh pellet was found in a bowl suggesting that harriers did not share bowls. No harriers were seen to land in a bowl already occupied by another bird.

Plate 5.1 Roosting bowl in of a communal roost at Pukepuke Lagoon

5.4.2 General behaviour of roosting harriers at three roost sites

Harriers were observed flying in a straight line towards the roost from distances of 2km away. On evenings were wind facilitated soaring, as many as 16 individual birds were counted at one time flying over the roost at varying heights. The number of birds flying over the roost fluctuated rapidly as harriers landed and others flew into the roost area. Harriers, which had previously landed, sometimes rose again out of the roost to soar, chase other harriers, or fly a short distance and land again in, presumably, a more preferred roosting spot.

Pukepuke Lagoon and Omanuka lagoon had similar numbers of birds using the roost in each season, ranging between approximately 10 and 50 birds. Corliss Island had approximately 10 to 15 birds using the roost in all seasons. On average most harriers arrived at the roost 40 minutes before complete darkness. The earliest a harrier landed in a roost for the evening was 90 minutes before complete darkness and the latest four minutes before complete darkness. On average there were 39 minutes between the first and last harrier to land in a roost. The light intensity decreased rapidly when the sun

moved below the horizon and most harriers landed shortly after this. The highest light reading for a harrier landing in a roost was 715.1 lux and the lowest was 0.3 lux.

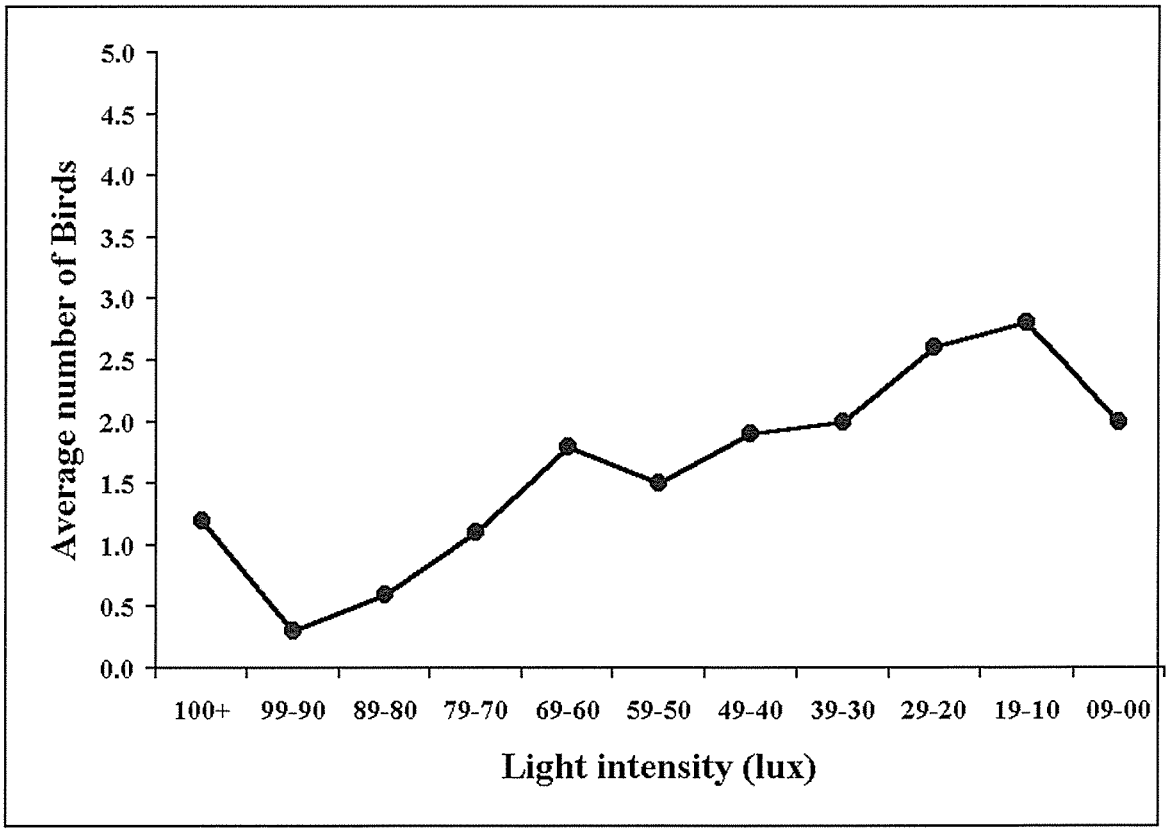
A total of 27 evening observations and five morning observations were collectively made at the three communal roosts. Fifteen evening and five morning observations were from Pukepuke Lagoon where a more intensive study on Australasian Harriers was based.

5.4.2 Influence of light on roosts

Pukepuke Lagoon

On average there was 37 mins (range 66-16 mins) between the first and the last harrier to land at Pukepuke Lagoon roost. The first harrier entered and landed in the roost 75 minutes before complete darkness and the latest 4 minutes before complete darkness. The light intensity between the first and the last harrier to land at Pukepuke Lagoon roost ranged between 590.3-0.3 lux.

Figure 5.4 Average numbers of harriers flying over Pukepuke Lagoon roost as light intensity (lux) decreases from 15 evening observations (August 2000 – February 2001).

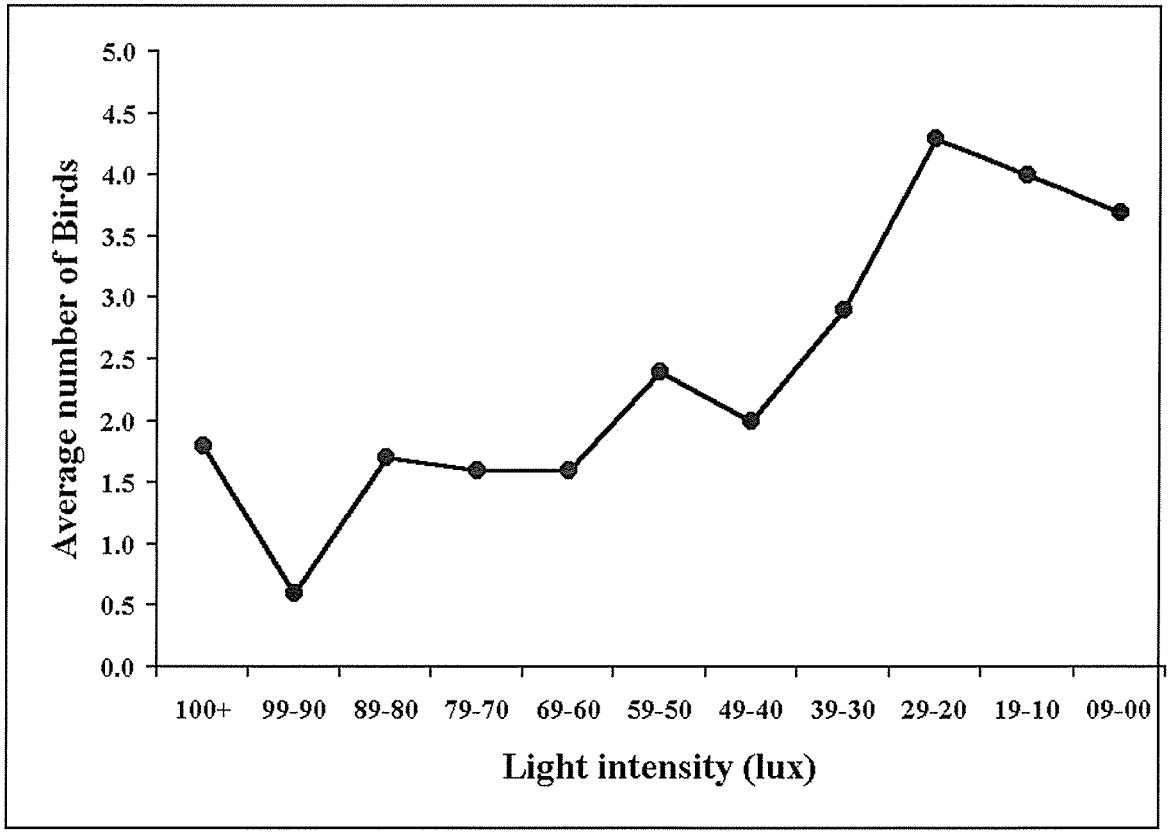


The numbers of harriers flying over the roost at any one time ranged between 0 and 13 birds (Figure 5.4). On average the highest number of harriers were seen over the roost between 10 and 20 lux with a rapid decline closer to zero lux. A steady linear increase from 99-90 lux to 19-10 lux is seen in Figure 5.4.

Omanuka Lagoon

Six evening observations were made from Omanuka Lagoon. On average there was 47 mins (range 81 – 21 mins) between the first and the last harrier to land at Omanuka Lagoon roost. The first harrier landed in the roost 95 minutes before complete darkness and the latest 5 minutes before complete darkness. The light intensity between the first and the last harrier to land at Omanuka Lagoon roost ranged between 590.6-0.6 lux.

Figure 5.5 Average numbers of harriers flying over Omanuka Lagoon roost as light intensity (lux) decreases from 6 evening observations (August 2000 – February 2001).



The numbers of harriers flying over the roost at any one time fluctuated according to weather condition month and light intensity and ranged between 0 and 16 birds. On average the highest number of harriers were seen over the roost between 29-20 lux with an even shallow decline closer to zero lux (Figure 5.5). A steady cumulative increase is

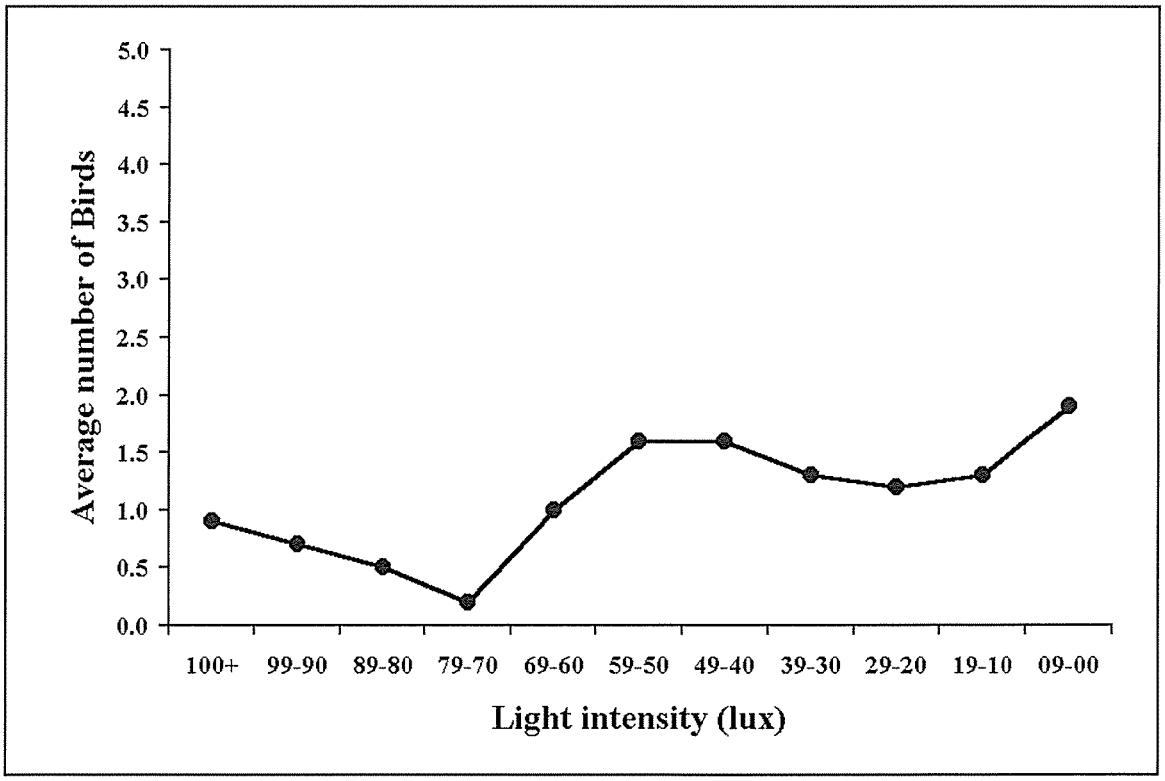
seen from 99-90 lux to 29-20 lux.

Corliss Island

Six evening observations were made from Corliss Island roost. At Corliss Island there was on average 36 mins (range 18-59 mins) between the first and the last harrier to land in the roost. The earliest and last harriers landing in the roost was 95 mins and 6 mins respectively before complete darkness. The light intensity between the first and the last harrier to land at the Corliss Island roost ranged from 715.1-1.8 lux.

The numbers of harriers flying over the roost ranged between 0 and 10 birds. On average the highest number of harriers were seen over the roost when the light intensity was between 9-0 lux. The lowest number of birds occurred between 79-70 lux, with a steady increase to between 40-59 lux and another decrease in bird numbers between 29-20 (Figure 5.6).

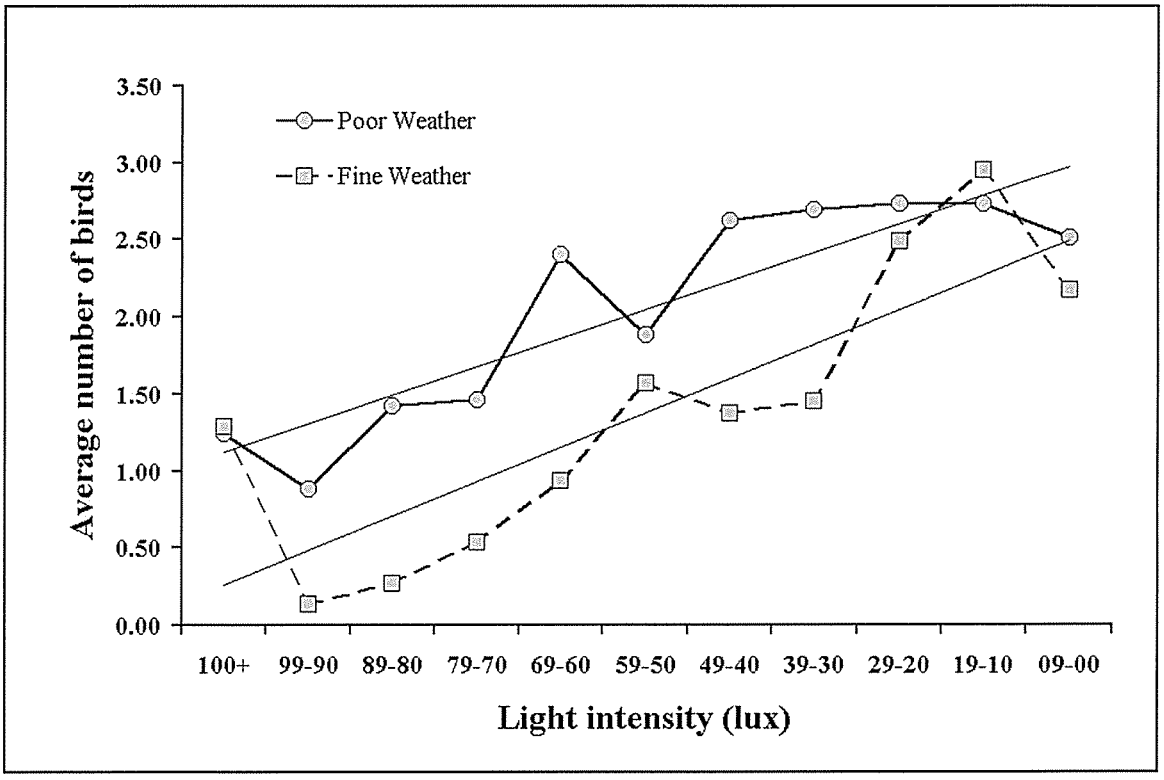
Figure 5.6 Average numbers of harriers flying over the communal roost on Corliss Island, Wanganui River mouth, as light intensity (lux) decreases from 6 evening observations (August 2000 – February 2001).



5.4.3 Influences of weather on roosts

Data from the three roosts were combined and averaged from 12 poor and 15 fine evening roost observations. The weather conditions on eight of the fifteen evening observations at Pukepuke Lagoon were record on evenings of 'fine weather'. The remainder of the Pukepuke Lagoon roost observations were on evenings of 'poor weather'. Four 'poor weather' observations and two 'fine weather' observations were recorded for both Omanuka Lagoon and Corliss Island.

Figure 5.7 Effect of poor and fine weather conditions on the average number of birds flying over three evening roosts (Pukepuke Lagoon, Omanuka Lagoon and Corliss Island) as light intensity (lux) decreases. Poor weather conditions defined as precipitation and/or wind speed greater than 10m/s. Fine weather conditions defined as no precipitation and average wind speed less than 10m/s. Solid linear trend lines are shown for each.



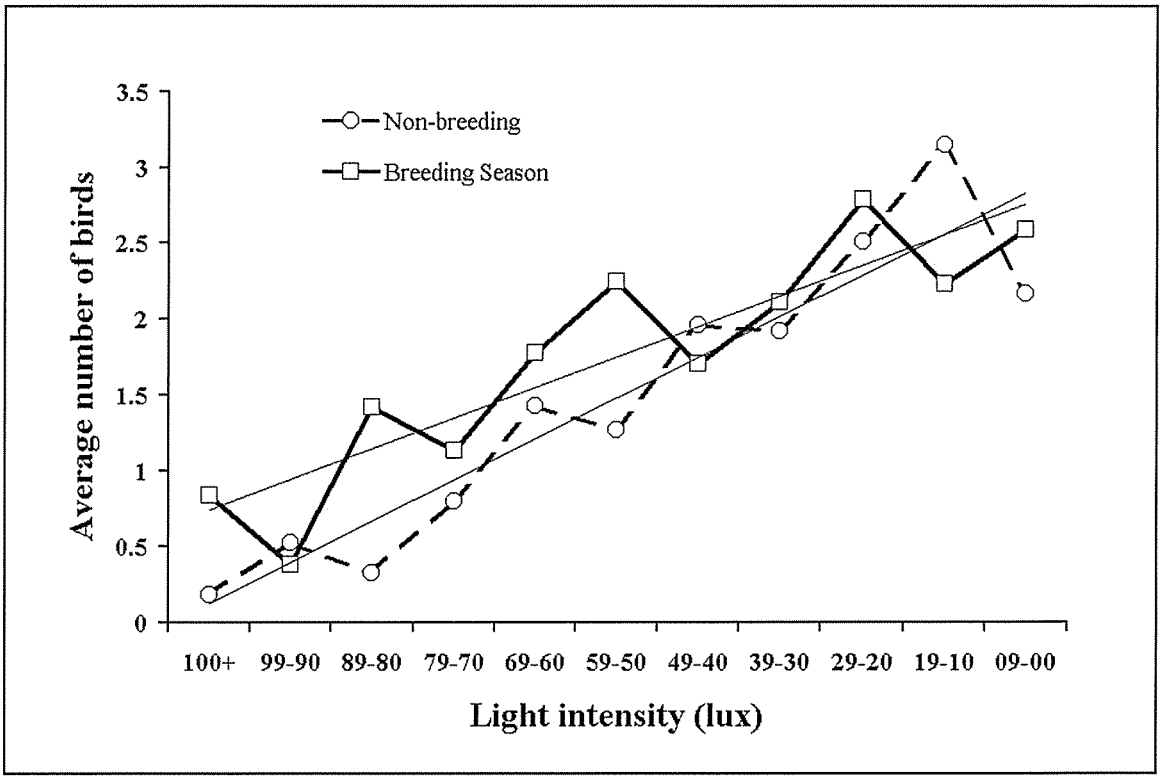
'Poor weather' tended to facilitate a higher average number of birds soaring over a roost than 'fine weather', extending across a wider range of light intensities (Figure 5.7). A steady increase in harrier numbers with a peak at 49 lux is found in 'poor weather' conditions. 'Poor weather' reached a plateau for numbers of birds over a roost between 49 and 10 lux with a slight decrease as the light intensity reached zero. 'Fine weather' elicited a slower return of birds to the roost, reaching a peak at 19-10 lux before a final

steep decrease as light intensity reached zero. Hence a higher average number of birds were seen soaring over a roost for long periods of time in 'poor weather'.

5.4.4 Seasonal influence on roosts

Both breeding and non-breeding season produced fairly similar positive linear increases in bird numbers as light intensity decreased (Figure 5.8). During breeding the average numbers of birds at the roost was slightly higher over most light intensities, suggesting more birds were using the roost, or were flying over the roost for longer before settling. The non-breeding season was associated with a lower average number of birds attending the roost over most light intensities except between 19 and 10 lux.

Figure 5.8 Influence of season on average bird numbers flying over three evening roosts (Pukepuke Lagoon, Omanuka Lagoon and Corliss Island) as light intensity (lux) decreases. Breeding season (November 2000 - January 2001). Non-breeding season (August-October 2000 and February 2001). Solid linear trend lines are shown for each.



5.5 DISCUSSION

Pukepuke and Omanuka Lagoon roosts were similar in habitat composition, surrounding habitat, location, protection from prevailing winds and size. Corliss Island was very different from the other two roosts in many aspects including harrier numbers attending the roost and roost characteristics and composition. However the general behaviour of harriers in response to changing light intensity and weather conditions, were similar in all three sites. There was no specific time that harriers appeared at the roost, however most entered the roost area as light was fading. Most birds were seen flying over the roost shortly before complete darkness and continued until visibility was virtually non-existent. Similar observations were made by Baker-Gabb (1978).

The erratic nature of the plot of birds approaching the Corliss Island roost (Figure 5.6) can be explained by the size of the data compared to the two other roosts. Corliss Island roost covered a relatively smaller area and constantly had fewer birds roosting throughout the study. This is obvious in Figure 5.6 in comparison with the numbers approaching Pukepuke or Omanuka Lagoon roosts. However there is a similar positive correlation between bird numbers and decreasing light intensity in all three roosts. Corliss Island roost constantly had fewer birds than the other two roosts studied which may have been affected by its location, habitat composition and surrounding habitat, structure, size, and protection from prevailing winds.

Unlike Pukepuke and Omanuka Lagoon, Corliss Island was located on the coast and was more susceptible to coastal winds from the west. There was no protection from surrounding habitat to the west, thus, unlike Pukepuke and Omanuka Lagoon, it was very exposed in poor weather conditions. The plant cover at Pukepuke and Omanuka Lagoon roosts was dense, in some places 2-3m high, adding to protection from wind and precipitation. The main vegetation on Corliss Island was comparatively shorter, less dense, and composed mostly of swamp grasses, which provided limited protection in poor weather. Although most observations of communal roosts in the literature are from large swamps, Hedley (1976) observed a roost in a hay paddock. However, he did not find large numbers like those found in swamps by Stead (1932) or Gurr (1968). Corliss Island is situated very close to urban Wanganui City (Figure 5.3), which is uncommon for harrier roosts and exposes it to human disturbance. Although access to the island is

difficult, a gravel road approximately 50m from the roost is frequently used by vehicles travelling to and from a speedway located less than 1km from the roost. The Wanganui Airport is also only a short distance away (c. 1km) and may be an additional source for disturbance.

An old communal roost closer to the Wanganui Airport, since abandoned, was known to have a similar number of birds as the Corliss Island roost (D. Morton *pers comm.*). It is possible that other small roost sites exist near by, which would reduce the numbers visiting Corliss Island. Only two communal roosts were discovered close to Pukepuke Lagoon (Pukepuke and Omanuka Lagoon roosts). Both were located in large areas of swamp, which is common and widely distributed along the south west coastal sand dune country (Cowie and Smith 1958).

5.5.1 Effects of weather on communal roosts

Poor and fine weather conditions seemed to produce similar peaks in numbers of birds at a roost. However, comparison of weather conditions in Figure 5.6 suggest that either more harriers were using roosts during poor weather or harriers were spending more time flying over the roost before landing. In most observations during poor weather, high winds were common and would facilitate soaring over roosts. Some individuals were observed soaring for 15 minutes at various altitudes, only settling into the roost once the light had almost faded. Soaring would be difficult in fine weather as wind and thermal lift would not aid in flight, and would require more energy. Harriers already grounded in a roost were more inclined to take to the wing when large numbers of harriers were flying above the roost.

5.5.2 Effects of season on communal roosts

Breeding and non-breeding season attendance at roosts were very similar, suggesting there is little influence on numbers of birds and arrival times between seasons. The numbers of birds over a roost in the breeding season averaged slightly higher than the non-breeding season which contradicts what has been commonly believed (Baker-Gabb 1978) however the difference was small. Although the whole breeding season was sampled only part of the non-breeding season was sampled. Thus data from a complete

year of observations may reveal a higher average number of harriers in the non-breeding season as months not sampled may have increased the average number of birds seen over a roost. Observations suggest that weather, not season, plays a greater role in numbers of birds attending roosts.

All three roost sites overlapped breeding territories of nesting pairs of harriers. The first observations of breeding territory defence by nesting individuals were seen as early as late August, however vigorous defence of breeding areas when harriers came into roost was not seen until November when the first females began incubating. This defence continued till most juveniles had fledged towards the end of January. Although defence by nesting territory holders was obvious during high light intensity, defence activity ceased as light intensity decreased, allowing individuals to enter the roost without harassment. This may explain the relatively similar numbers of harriers using the roost in both the breeding and non-breeding season.

The numbers of birds observed at the three communal roosts were small in comparison to those recorded elsewhere (Stead 1932; Gurr 1968; Heather and Robertson 1996). However numbers from this study are not uncommon for communal roosts in general (Hedley 1976; Baker-Gabb 1978) and may have been more accurate counts. The numbers observed at the three roosts were based on observations of harriers over a roost at particular light intervals not on how many birds were observed landing. This was significant because early in the study it was discovered that harriers often lifted from a roosting spot, only to re-enter after soaring, making over-estimations of roosting numbers extremely easy. It was also difficult to keep record of activities of any one particular individual during roost observations, because large numbers would congregate over the roost carrying out different behaviours. Also harriers would be departing or arriving at the roost adding to the difficulty. Hence the actual numbers of birds using any particular roost are very difficult to count accurately when numbers are high.

Harriers appeared as the light intensity faded below 100 lux therefore counts greater than 100 lux were combined and averaged. Lux readings were only taken when harriers were sighted at light intensity readings over 100 lux, because the occurrence of harriers over this light intensity were infrequent and did not warrant 10 lux interval recordings.

This, therefore, explains the decrease in harrier numbers from 100+ lux at the three roosts (Figures 5.4, 5.5 and 5.6).

The distances travelled by birds to use a roost were unknown, but studies of harrier range by the author (Chapter 4), suggest it is not uncommon for communal roosts frequented by individuals to be on the periphery of their range. Observation of known radio-tagged individuals suggest that roosting times varied between birds however most appeared within approximately 30minutes of complete darkness. One adult female carrying a radio tag was observed frequently entering the roost approximately 60 minutes before complete darkness. She had a very small range and spent much of her time in or around the roost area. It was observed that harriers were capable of covering large areas of their range quickly, so flying to a roost would have been easy for them. However, weather conditions, and possibly season, may have been factors influencing entry times.

Although communal roosting is a common phenomenon in New Zealand it does not feature much in the early literature, and the factors eliciting the behaviour are not mentioned. Communal roosting is displayed by six other *Circus* species including the Hen (*C. cyaneus*), Long-winged (*C. buffoni*), European, Eastern and African Marsh (*C. aeruginosus, C. spolonotus and C. ranivorus*), Montagu's (*C. pygargus*), and Pallid (*C. macrourus*) and is well documented (Watson 1977; Baker-Gabb 1978; Fernandez 1992; Clarke *et al.* 1997; Beauchamp 1999; Green and Etheridge. 1999; Simmons 2000; Arroyo 2001; Fefelov 2001).

The present and developing theories for communal roosting can be applied to many *Circus* species but few are applicable to the Australasian Harrier in New Zealand. The presence of nearby companions has been found to reduce energetic demands in other birds (Du Plessis *et al.* 1994), however, Australasian Harriers do not share the same roost bowls, thus no thermoregulatory benefit would be gained. Communal roosting has been suggested (Eiserer 1984) to dilute individual predation risk, however the Australasian Harrier in New Zealand has no natural predators and does not communally roost in Australia where predators are more abundant. Gurr (1968) stated that communal roosting added little protection from intruding predators, noting that roosting harriers could be approached to within a few metres at night. Migratory patterns elicit communal

roosting of the European Marsh and Montagu's Harrier when they gather in large assemblies in preparation for movement from an area (Meinertzhagen 1956). The Australasian Harrier is, however, known to commonly migrate in Australia but the literature indicates that it does not roost communally (Sharland 1958). Increased foraging efficiency is gained by unsuccessful birds following companions to food patches (Ward and Zahavi 1973). Observations of morning roost departures suggests harriers tended to head out in many different directions and were not followed. Baker-Gabb (1978) also found similar behaviour by harriers at morning roosts. The most prominent prey item in the diet of harriers was lagomorphs and high numbers (60+ individuals) were shot in one night of hunting (J. Cook *pers. comm.*). In coastal Rangitikei - Manawatu region local farmers shot hares and rabbits which were available as carrion for harriers. Buckley (1996) suggests communal roosts act as information centres for food finding, especially those supporting large numbers of birds, however small roosts also exist. Caccamise and Morrison (1988) proposed communal roosts are aggregations of birds close to rich foraging patches. Pukepuke and Omanuka lagoon could be rich foraging patches supporting a relatively large biomass compared to surrounding habitat (Chapter 3, 4). This may explain the smaller numbers of harriers attending the Corliss Island roost which appears to occupy an area with a small local biomass.

In New Zealand communal roosting by harriers is common. Possibly the roosting behaviour of the Australasian Harrier has been secondarily lost in locations where it is not observed (Beauchamp 1999). Alternatively it may have evolved either for the first time or again as a result of influencing factors. The factors eliciting the behaviour remain unclear, however some are more likely than others to apply to the Australasian Harrier. A possible function of communal roosting by harriers in New Zealand may relate to a combination of foraging, social and resource pressures within the local area. Further research on inland, as opposed to coastal, communal roosts could increase understanding of roost selection and composition. Information on relatedness, social interactions at roosts and individual foraging behaviours of known harriers could also prove rewarding.

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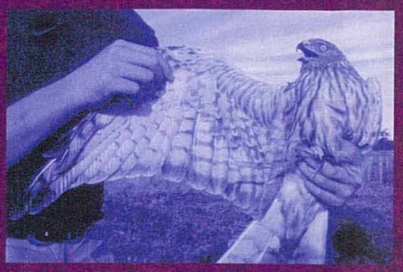

Synthesis

6

Synthesis.

This research has dealt with aspects of Australasian Harrier behaviour and ecology, some previously unstudied. Morphometric sexing of harriers is difficult due to overlaps between bodily measurements of males and females. Morphometric sexing has provided accurate identification methods for future field studies of Australasian Harriers. The results strongly suggest that the criterion presently used to sex harriers in New Zealand performs poorly against the newly developed criterion. The statistical and molecular analyses used in this study have practical implications for future sex-based harrier research. Molecular sexing of birds is a recent technique that has been applied to the Australasian Harrier for the first time. A manuscript on molecular sexing harriers has been submitter for publication.

Harriers are generalist feeders, with a tendency towards lagomorphs and introduced passerines. The wide variety of prey types in the diet of harriers at Pukepuke Lagoon suggest they take a range of live prey as well as carrion. This is contrary to the common belief that harriers are predominantly carrion feeders, lacking the speed, agility and 'strategic' thought processes needed for hunting live prey. This study and others suggest harriers in New Zealand have a diverse and flexible diet but may become specialised when prey are abundant and available in the local area. Consequently harriers could have impacts on some economic and recreational resources, and threatened endemic species. Culling harriers as a means of protecting these resources and threatened species might, however, provide only a short term solution because harriers are very mobile.

Temporal and static ranges overlap when harriers exploit profitable food resources. A high concentration of prey may lead to individual territories overlapping, however, social interactions in communal roosts suggest there is some benefit to territory sharing. High quality habitats offer prey species greater food, protection, and breeding benefits

that can directly relate to higher prey densities. Habitat quality may also influence the size and shape of harrier ranges. For instance, high quality habitats, offering more prey could influence the size of a harrier range because only a small area would be needed to find sufficient food. Although harriers have no natural predators in New Zealand, habitats which are difficult for predators to access may be selected, especially by breeding harriers.

Habitats which offer protection from harsh environmental conditions may also be preferred by harriers. Communal roosting of harriers occurs only in New Zealand and may relate to a combination of social, foraging and resource pressures in the local area. Harriers that use communal roosts all share part of their range area with many other roosting birds. This collection of birds in one small area of their range may simply be explained by the harrier's need to seek shelter during unfavourable weather conditions. However, communal roosting occurs in all weather conditions and seasons, suggesting the behaviour could have multiple functions such as transferring information about food, and promoting other social interactions.