The feeding ecology of the Adelaide Rosella *Platycercus elegans adelaidae* in cherry growing districts of the Adelaide Hills

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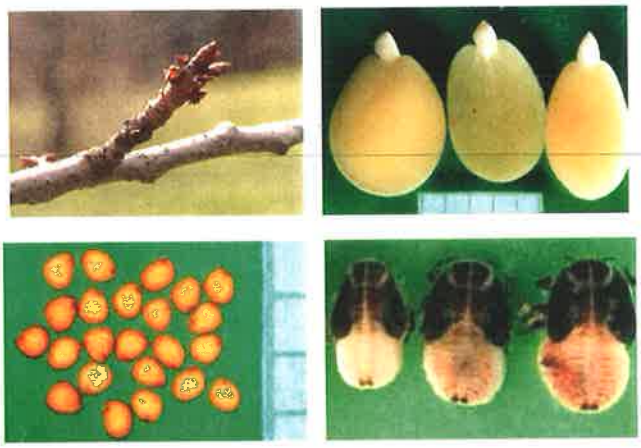

Thesis submitted for the Degree of Master of Science

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December 2003

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ABSTRACT

The Adelaide Rosella *Platycercus elegans adelaidae* has been one of the main bird pests of commercial cherry (*Prunus avium*) orchards in the Adelaide Hills. The greatest effect on production has been prior to fruit development through destructive feeding on dormant flower buds in autumn and winter and on flowers in spring. This is the only bird species that has been recorded in Australia to feed on and damage cherry flower buds. Although more than fifty varieties of cherries are commonly grown in the Adelaide Hills, severe damage to buds and flowers by rosellas has usually been restricted to one variety or its derivatives. Rosellas also feed on ripening and ripe cherry fruit.

The specific aims of this study were to:

- gather baseline information on diets of Adelaide Rosellas around cherry orchards at different times of the year;
- determine the importance of cherry primordia relative to other foods in the diet, and
- investigate some of the factors that might influence food use and food choice (e.g. energy content of foods, accessibility of foods) as precursors for proposing management strategies for reducing damage to cherry buds caused by rosellas.

The diets of Adelaide Rosellas were determined principally from crop contents, complemented by opportunistic field observations of feeding birds. Adelaide Rosellas in the Adelaide Hills are predominantly seed-eaters but supplement their diet at times with other foods such as fruit, bulbs, buds and insects. The birds are generalists, feeding on a wide range of foods. The high proportion and variety of non-indigenous foods in the diet of the rosellas sampled indicate that they can be highly adaptable in their foraging behaviour and that they probably forage opportunistically according to the seasonal availability of foods.

Adelaide Rosellas consumed a greater volume and number of food items in autumn than in other seasons. The higher quantity of food consumed in autumn was to a large extent attributable to the availability of apples at this time of year. A lesser number of food items and volume of food were consumed by rosellas in summer when seeds and insects were usually more abundant compared to autumn. Non-indigenous foods comprised the bulk of the diet throughout the year but were of least

importance in summer possibly reflecting the relative availability of these and indigenous foods. Weeds were an important food source in all seasons, providing seeds, buds and bulbs to the diet, but were of greatest importance in spring. Fruit pulp represented a large component of the diet based on the volume consumed although it is likely to be of lesser relative importance than seeds in terms of the total energy contribution to the diet.

Rosellas damaged flower buds of cherry for the sole purpose of removing and eating flower primordia. Although significant levels of cherry bud damage occurred within the study area, flower primordia were a food of minor importance in the diet in terms of the volume consumed relative to other foods. Cherry primordia were absent in the diet in summer and occurred in negligible amounts in autumn and spring. In winter, primordia comprised less than 2% by volume of all foods but were consumed by 43% of birds in the sample.

Apple (*Malus sylvestris*) flesh was the most frequently occurring food item (39% of birds) followed by the seeds of sub-clover *Trifolium subterraneum*, apple, wild radish *Raphanus raphanistrum*, and fat hen *Chenopodium album*. The foods of greatest importance based on volumetric proportions in birds' crops were apple flesh (18% of all foods), wild radish seed (9%), apple seed (9%), *Trifolium* spp. seed (mainly sub-clover; 8%) and olive (*Olea europaea*) fruit (5%).

Insects represented only 1.4% of the diet by volume of all foods but were recorded in the crops of 41% of all birds. On a seasonal basis, the order Hemiptera was the major insect group represented in the diet. The percent contribution of all hemipteran insects to the volume of insect material in the diets was highest in summer (93% of all insects) and lowest in winter (58%). The Psylloidea (jumping plant lice and lerp insects) were the main component of hemipteran insects in the diet in each season except summer. Triozid nymphs (Psylloidea) were the dominant insect group in winter and spring and were represented by two species *Schedotrioza marginata* and *S. multitudinea*.

There were seven foods that each comprised more than 10% of the diet by volume in at least one season. Of these foods, three collectively represented 42% by volume of the summer diet, three represented 48% of the autumn diet, three represented 51% of the winter diet and four foods represented 49% of the spring diet. Seasonally, the most important foods by percentage volume were soursob bulb in spring (16%), cherry fruit in summer (20%) and apple fruit in autumn and winter (27% and 18% respectively). The seasonal peak in consumption of apple fruit was autumn (27% by volume) when cherry fruit was not recorded.

Based on general observations of relative abundance and availability of foods in relation to their representation in the diet, selection for cherry flower primordia by rosellas was low and may therefore be considered a food of relatively low importance. The dietary information collected during this study indicated several food sources of high dietary importance (e.g. apples, sub-clover, and soursobs *Oxalis pes-caprae*) with promising potential for use as an alternative food source to divert feeding activity of rosellas from cherry trees.

The opportunity to maximise energy intake (or net energy gain) during bud feeding appeared to be a key factor influencing varietal preference by rosellas. Although the energy density (J mg^{-1} dry mass) of cherry flower primordia did not differ significantly between the heavily damaged variety (William's Favourite) and two lesser damaged varieties (Lustre and Makings), the difference in mean energy content per bud was significant, due to the difference between varieties in number (means of 3.8, 3.0 and 2.5 respectively) and dry weight of primordia per bud. This difference provides rosellas with the opportunity to increase the rate of energy intake, thereby influencing their choice between varieties. The differences in the estimated rate of energy intake between the three varieties broadly corresponded with bud damage levels observed for each of these varieties within the same orchard at Basket Range over a five-year period (1988 to 1992). Measurements of bud density for the three varieties indicated that the bud feeding rate may also differ between varieties, reflecting the observed varietal differences in mean number of primordia and mean energy content per bud. Thus, bud density differences indicated that feeding on buds of William's Favourite compared to the other varieties was energetically more profitable than differences in bud energy content alone suggested.

Although cherry buds were not a staple part of rosellas' diet this food was possibly sought when birds were able to meet their minimum daily energy requirement from more energetically profitable foods. I propose a number of reasons as to why rosellas feed on cherry buds in orchards when other foods may be available:

- Cherry buds are an abundant, relatively constant and predictable food resource;

- Some varieties (e.g. William's Favourite) provide the opportunity for increasing foraging profitability;
- Despite the small size and low energy content of buds as individual food units, high harvesting rates are possible (due to bud and primordia density and the bill structure of rosellas allowing a higher rate of energy intake compared to some other foods such as seed of salvation jane *Echium plantagineum* or wireweed *Polygonum aviculare*);
- As a tree crop, feeding on cherry buds allows birds to avoid the higher risk of predation when feeding on the ground, particularly in wet conditions;
- Cherry trees may provide birds with the opportunity to manage their daily energy expenditure: for example, basking in the leafless canopy in winter as a form of behavioural thermo-regulationrequires less effort to avoid predation compared to ground feeding and provides the opportunity to continue feeding when weather conditions are adverse for ground feeding;
- There is no competition for this food resource by cohabiting species; and
- Cherry buds may provide minor nutrients that occur in very low amounts, or are not present, in other foods.

A further consideration is the availability of other food resources in the orchard pasture, and the close proximity to favoured roosts or day-time resting sites, which may increase the attractiveness of cherry orchards to rosellas.

A habitat manipulation experiment involving the cultivation of small replicate plots supporting soursob plants to expose bulbs elicited a significant feeding response by rosellas. At each field site there was an increase in rosella visits to treated plots following the exposure of soursob bulbs to the surface by hand tilling. On plots that were not cultivated there was no change in visitation by rosellas. These results indicated that soursobs, as an important food source of rosellas and a widespread and common weed in the Adelaide Hills, might be of value as a decoy food for reducing feeding damage to cherry trees at certain times of the year. Soursob bulbs are not normally accessible to rosellas. As rosellas do not dig for bulbs, access to them depends on cultivation or other disturbance to the soil to bring the bulbs to the surface.

The use of decoy foods appears to show some promise as a control strategy, particularly where rosellas are causing damage to trees within cherry orchards that are uneconomic to protect with netting. In these situations habitat modification in order to change existing patterns of foraging behaviour is worth consideration. As foraging generalists, rosellas have a diverse diet for meeting their daily energy requirements throughout the year. A number of food sources of rosellas identified in this study were common weed or pasture species (e.g. soursob, wild radish, sub-clover) that could be promoted or manipulated through particular farm cultural practices, possibly involving a modest investment of time and effort by the orchard manager. As the orchard pasture may represent an important foraging resource for rosellas, the effect of its composition on bud damage levels is worthy of further investigation. Apples and cereal grain (e.g. oats or barley) are suggested as potential decoy foods; and sub-clover (as a sown pasture) and William's Favourite cherry trees are suggested as potential cultivated decoy crops. A summary is given of the type of experiments that could be carried out in order to develop practical control measures for rosellas that damage buds in commercial cherry orchards.

As a general principle, measures to discourage feeding at the susceptible crop should be counter-balanced by measures to encourage feeding at other sites. With the exception of exclusion netting, the use of any control technique should therefore be integrated with other measures to ensure that the orchard to be protected is made as unattractive to birds as possible, and that attractive alternative feeding sites are available. This approach may need to be adopted over a large area involving possibly several properties. For each locality and situation, the attributes of the orchard that rosellas utilise as a food source should be evaluated in relation to the key environmental resources that the population requires to survive during the period when trees are vulnerable to feeding damage. From this understanding more effective management strategies can be developed and implemented.

DECLARATION

This thesis contains no material that has been accepted for the award of any other degree or diploma in any university and, to the best of my knowledge and belief, it contains no material previously published or written by another person except where due reference or acknowledgment is made.

I give my consent to this thesis being made available for photocopying and loan.

T.M. Reynolds

5th December 2003

ACKNOWLEDGEMENTS

I thank my supervisor, Dr David Paton of the Department of Environmental Biology, University of Adelaide, for his encouragement and constructive advice during this project. I also thank Professor Michael Tyler of this Department for his support and encouragement.

I am grateful to Dr Ron Sinclair of the Animal and Plant Control Commission, Department of Primary Industries and Resources SA, for suggesting this research project, and for his ongoing encouragement and advice. I also thank Peter Bird from the same agency for his advice during the project and his assistance in the field.

I am grateful to a number of commercial cherry growers for allowing me access to their orchards during the field studies, in particular Doug and Bill Bishop (Basket Range), Colin Bungay (Cherryville), Jeff, Barry and Bob Green (Montacute), Don and Vic Willsmore (Uraidla), Don Pellew (Ashton), Bill Cooksley (Marble Hill) and Harley Mason (Forest Range).

I thank Keith L Taylor from the Australian National Insect Collection, CSIRO Division of Entomology, Canberra for identifying the Psyllidae insect material and Gary Taylor from the Department of Crop Protection, Waite Agricultural Research Institute, University of Adelaide for identifying the Triozidae insect material. I also thank Dr Elwood Zimmerman, Curator of Weevils Emeritus, Australian National Insect Collection, for identifying the Curculionidae specimens. Other insect material was identified with the assistance of staff from the Entomology Unit, South Australian Research and Development Institute. Alison Frensham provided assistance with some statistical analyses. Other people who provided advice in the early stages of this project included John Long and Peter Mawson of the Agriculture Protection Board of Western Australia. I thank Piers Brissenden and Amy Blaylock from the Department of Environmental Biology at the University of Adelaide for their assistance with aspects of the laboratory work. I also thank Yvonne Steed for her support during the writing of the manuscript.

The field and laboratory studies were initially supported by the Animal and Plant Control Commission, Primary Industries and Resources South Australia. National Parks and Wildlife SA, Department for Environment and Heritage, issued permits for the collection of birds within the study area. Further study support was provided by the Department for Transport and Urban Planning. This research project was also made possible through the provision of a Higher Education Contribution Scheme Exemption Scholarship by the University of Adelaide.

1 GENERAL INTRODUCTION

There are many examples where birds have been identified as pests of agricultural crops due to their impact on crop yields. Bomford (1992) noted that the most significant damage inflicted by birds in Australia is to germinating cereal, ripening sunflower and fruit crops. A number of parrots (Psittacidae) have been reported to attack cultivated crops. Parrots that have been implicated with damage at varying levels in agricultural crops include Galahs *Cacatua roseicapilla* on wheat in New South Wales (Jarman and McKenzie 1983); White-tailed Black Cockatoos *Calyptorhynchus baudinii*, Western Rosellas *Platycercus icterotis*, Port Lincoln Parrots *Barnardius zonarius* and Red-capped Parrots *Purpureicephalus spurius* on apples and soft fruits in south-western Western Australia (Long 1985); Cockatiels *Nymphicus hollandicus* on sorghum and millet (e.g. Forshaw 1981); Long-billed Corellas *Cacatua tenuirostris* on cereal grains in western Victoria (Temby and Emison 1986); and Adelaide Rosellas *Platycercus elegans adelaidae* on cherry crops in South Australia (Sinclair and Bird 1987; Reynolds 1991; Fisher 1991, 1993). Whilst losses to industries as a whole are generally low in Australia, they are distributed patchily in space and time such that individual growers may experience severe losses (e.g. Allen 1990; Emison 1990).

Many commercial growers experience some level of fruit loss or damage due to birds, estimated to be around $4 million in South Australia's cherry, apple and pear crop in 2000[1]. In the Mount Lofty Ranges, a number of common birds including Red Wattlebirds *Anthochaera carunculata*, Adelaide Rosellas, Musk Lorikeets *Glossopsitta concinna* and Rainbow Lorikeets *Trichoglossus haematodus* are considered to be significant pests of vineyard and orchard crops (e.g. Taylor 2001). Levels of fruit damage and abundance of these four species are perceived by vignerons and horticulturalists to be increasing (Graham *et al.*, 1999). Adelaide Rosellas are not considered to be a major pest of apples and pears by growers in the region, although in a recent field survey including orchard sites, feeding behaviour by this species was regularly detected (Taylor 2001). Taylor (2001) suggested that growers largely tolerate fruit damage by rosellas as the natural distribution of the species has historically covered the apple and pear growing region.

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[1] Parliamentary Hansard, 27 March 2001

Birds have been regarded by cherry growers to be a serious problem in the Adelaide Hills for a long period of time and it has been estimated that losses exceed 15% of gross annual returns to the industry in South Australia (Sinclair 1989a). Several bird species, including the Silvereye *Zosterops lateralis*, Red Wattlebird, Little Raven *Corvus mellori*, Common Starling *Sturnus vulgaris*, Blackbird *Turdus merula*, lorikeets and the Adelaide Rosella, have been implicated in damage to cherry fruit, but many growers have considered damage levels to be of little economic significance (Sinclair and Bird 1987).

In cherry orchards of the Adelaide Hills, the Adelaide Rosella has been recognised as the main avian pest species (Sinclair and Bird 1987). The rosellas damage dormant flower buds mainly during winter, flowers in the spring and fruit during summer. During the current study, when information was collected on diets of Adelaide Rosellas (1985 to 1992), damage by this species to dormant flower buds was recognised as the factor having the greatest impact on cherry production (Sinclair and Bird 1987). The destructive method of feeding by rosellas on flowers also contributed to production losses, unlike nectarivorous birds such as Silvereyes and honeyeaters which leave the flower undamaged when feeding. Sinclair and Bird (1987) reported that severe bud and flower damage caused by rosellas was usually restricted to one particular variety of cherry, William's Favourite, which at that time was also one of the most widely grown varieties in the region producing almost 40% of the gross returns to the local industry (Sinclair, 1989). Some trees of this variety lost over 90% of potential production through bud losses alone. An assessment of 20 cherry orchards in the Adelaide Hills during the 1986 - 1987 season showed that levels of damage varied widely between orchards and between trees within orchards (Sinclair and Bird 1987).

No birds other than Adelaide Rosellas are known to feed on and cause damage to cherry flower buds. Rosellas remove the whole bud from fruiting spurs leaving only a few scales on the spur. Individual birds can remove one bud per second and may feed continuously for several minutes without a break (Sinclair and Bird 1987). The benefit that rosellas gain from feeding on cherry buds compared to other foods in their environment, or the particular attraction of the buds of William's Favourite compared to buds of other varieties, had not been clearly understood prior to this study.

1.1 TAXONOMY OF THE ADELAIDE ROSELLA

The Crimson Rosella *Platycercus elegans* (Gmelin, 1788) is endemic to eastern, south-eastern and southern Australia and is the largest of the rosellas. Crimson Rosellas are medium sized broad-tailed parrots, represented by seven subspecies. There is marked geographical variation in the colour of the plumage among all subspecies however a blue cheek patch is common to all ages of all subspecies.

The seven subspecies comprise three clearly distinguishable groups, the crimson, Adelaide and yellow groups. Three subspecies form the Adelaide group and appear intermediate in coloration between subspecies *P.elegans elegans* and *P. elegans flaveolus* (Higgins 1999). Within the Adelaide group *P.elegans fleurieuensis* occurs on Fleurieu Peninsula, *P.elegans adelaidae* Gould, 1841 along the Mount Lofty Ranges from just south of Adelaide northwards to about Clare, and *P.elegans subadelaidae* from the southern Flinders Ranges southwards to near Gladstone. Subspecies of the Adelaide group intergrade in a cline of decreasing red in plumage from south to north.

Populations that are the subject of this study have usually been assigned to the subspecies *P. e. adelaidae* Gould, 1841. An alternative view (Schodde and Mason 1997) is that the central Mount Lofty Ranges birds are intergrades *between P. e. fleuriensis* and *P. e. subadelaidae* and that the name based on them, *P. e. adelaidae* Gould, 1841, is therefore indeterminable. Clearly, the systematics of the Adelaide Rosella complex requires further study. Birds within the geographic range of *P. elegans adelaidae* also exhibit great variation in plumage (Higgins 1999).

1.2 GENERAL BIOLOGY OF CRIMSON ROSELLAS

1.2.1 Habitat

The Adelaide Rosella frequents a variety of timbered habitats. It occurs in forested valleys throughout the Mount Lofty Ranges and in open forest, trees growing along watercourses or beside country roads, cultivated farmlands and orchards (Forshaw, 1981), and is particularly common within ecotones between native woodland or forest and agricultural land (i.e. pasture or orchards) (R. Sinclair pers. comm.[2]).

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[2] Dr RG Sinclair, Animal and Plant Control Commission, Adelaide.

1.2.2 Movements

The Crimson Rosella, including all subspecies, is sedentary or resident throughout its range, (e.g. Forshaw 1981; Ford and Paton 1976). Of 3964 banded in Australia (1953 to 1996), 98.5% of 454 recoveries were less than 10 km from the banding site (Higgins 1999). In the Mount Lofty Ranges adult rosellas usually are encountered in pairs or parties of up to four or five, and immatures tend to band together in flocks that seem to wander locally (Forshaw 1981).

1.2.3 Social organisation and behaviour

Adult Crimson Rosellas are nearly always found singly or as mated pairs, and sometimes gather in small groups (Higgins 1999). Sub-adults typically form larger flocks. For all ages, flocks tend to be largest when feeding on the ground. Flocks of sub-adults move locally and disperse at the start of the breeding season. Mated pairs spend most of the day alone, tending to join other pairs only in morning and late afternoon. Groups of sub-adults tend to stay together throughout the day (Aslin 1978). Pairs defend small territories around the nest site during the breeding season (Krebs 1997). There is no reported information on the size of home ranges. However, Brereton (1971) suggested that individuals, pairs and groups have loosely defined, permanent, all-purpose home ranges that overlap with others and that agonistic behaviour only occurs if birds meet at preferred sites.

Crimson Rosellas are active, noisy and conspicuous and are arboreal and terrestrial, feeding in trees and shrubs and on the ground (Higgins 1999). Birds roost in tall trees, often in various *Eucalyptus* (Higgins 1999), sometimes in thickets of *Melaleuca* (Marchant 1992). They go to roost just before last light (Aslin 1978) and leave the roost at about sunrise (Magrath and Lill 1983; Torcello 1990). In morning and evening, birds bask on exposed perches (Aslin 1978; Torcello 1990). During the heat of the day birds loaf in shade, either among inner foliage or on branches below the canopy (Forshaw 1981; Aslin 1978). The main rest period is around midday in summer and early morning in winter (Torcello 1990).

1.2.4 Breeding

All subspecies nest in natural hollows, usually *Eucalyptus*, in forests or woodlands (Higgins 1999; Aslin 1978) but there are recent observations of Adelaide Rosellas nesting in roofs of houses (Paton, pers. comm.[3]) and using artificial nest boxes (Clarke 1988). Nesting takes place during September to December. Eggs are laid on decayed wood dust lining the bottom of the hollow (Forshaw 1981). Clutch size is four or five, rarely up to seven (Higgins 1999). The incubation period is 19 days and only the female broods. The fledging period is approximately 5 weeks (Forshaw 1981). Breeding success throughout the range of the Crimson Rosella has been estimated at 2.2 young fledged per nest (Higgins 1999). In the Adelaide Hills Adelaide Rosellas generally hatch around the beginning of November, with young first appearing out of the nest in early December (R. Sinclair and P. Bird, pers. comm.[4])

1.2.5 Feeding ecology

Crimson Rosellas forage in pairs or small flocks (Higgins 1997); on the ground or in shrubs and trees (Forshaw 1981). Birds rarely feed on the ground in forests, but often do so in more open areas (Higgins 1999). In rural areas, they feed along roadsides, and in farmland, among grass or on low weeds, such as thistles, dock and onion grass growing in pasture and also on spilt grain (e.g. Bridgewater 1934; Aslin 1978).

There are limited references in the literature to foods eaten by the Adelaide Rosella. Feeding records that have been reported are mostly qualitative and incidental to multiple species investigations. They are often based on direct field observations rather than studies of stomach contents. More reports have been published of foods eaten by birds of the crimson group in eastern States than for birds of the more geographically restricted Adelaide group. Summaries of the foods consumed by Crimson Rosellas are given by Forshaw (1981) and Higgins (1999). Barker and Vestjens (1989) list 25 foods from "stomach contents" (food material found in the oesophagus, crop or gizzard) for *P. elegans* (*P. flaveolus* and *P. adelaidae*) based on a search of the avian literature for notes on bird foods to 1980. A general description of the diet of Crimson Rosellas given by Forshaw (1981) is "...seeds of grasses, shrubs and trees, especially eucalypts and acacias, as well as fruit, berries, nuts, buds, blossoms, nectar, and insects and their larvae." Reynolds (1991) presented data on frequency of food items recorded from the crops of 67 Adelaide Rosellas

[3] Dr DC Paton, Department of Environmental Biology, University of Adelaide.
[4] Dr RG Sinclair and PL Bird, Animal and Plant Control Commission, Adelaide.

taken from cherry orchard properties in the Adelaide Hills during winter (when peak damage to cherry buds generally occurs) between May 1985 and August 1990.

Bridgewater (1934) analysed the individual crop and stomach contents of 41 Crimson Rosella specimens collected from north-eastern Victoria (Shire of Mansfield) between August 1932 and August 1933. The most frequently occurring items in the crops or stomachs were as follows: *Trifolium subterraneum* seed (21 crops), apple pulp (14), *Trifolium* sp. seed (8), Cercopidae nymphs (8), *Eucalyptus* sp. seed (7) and *Cirsium arvense* seed (6). Apple pulp (mean 2.2 mL; range 0.25-7 mL) and *Trifolium subterraneum* seed (10 crops with 50 or more seeds including one crop with 400 seeds) were each the most important food items by quantity in 10 bird samples. Unidentified seeds were recorded in 19 crops. Apple pulp was recorded in crops collected from January to June and *Trifolium subterraneum* seed for all months except December. Insect material was recorded in a total of 21 crops. Cherry pulp was an important item in two crops (December and January).

Lea and Gray (1935) examined the crop or stomach contents of 38 Adelaide Rosellas collected from an area extending from Mount Remarkable to Cape Jervis between the months of January and August. This study was limited to general descriptions of food items. Seed material was identified in 35 birds, "vegetable matter" in 15 birds and insect material in 4 birds. Taxonomic identifications of seed material were limited to the following: *Solanum nigrum*, 'wheat' (*Triticum aestivum*) and *Trifolium glomeratum* (Second Valley, April); *Acacia* sp. and 'Compositae' pappus (Encounter Bay, January); *Xanthorrhoea spatha* (Encounter Bay, August); and *Solanum* sp. (Mount Remarkable, July). Invertebrate material included small larvae (Second Valley in April); 'coccid insects' possibly from galls (Blackwood in March); and 'caterpillars' (Mount Remarkable in July).

Paton *et al.* (1988) observed that the Crimson Rosella in South Australia eats the immature seeds of olives and the flesh of fallen olive fruit. They noted that the birds did not carry the stones away from the tree and concluded that the birds could not be held responsible for the dispersal of olives.

In a study of the feeding ecology of the Crimson Rosella in a temperate wet eucalypt forest in autumn and winter of 1981 (Sherbrooke Forest Park, south central Victoria), Magrath and Lill (1983) recorded 45 types of foods in the diet. Food records were based on 262 feeding observations of adults in autumn and 229 in winter. Field observations were supported by examination of feeding debris from the foliage of *Eucalyptus regnans* (i.e. buds, galls and fruits which had been opened and whose contents had been removed). The diet as a whole consisted almost entirely of insects and reproductive parts of plants. Items forming more than 5% of the diet by percentage foraging time in either season included *Eucalyptus regnans* flower buds, gall insect larvae, beetles (on *Acacia dealbata*), *A. melanoxylon* seed, *Dicksonia antarctica* sori and *Pomaderris aspera* shoots (pith). Only one food item recorded was non-indigenous, the seed of the herbaceous weed deep-rooted catsear *Hypochaeris radicata*.

Lepschi (1993) recorded foods eaten by Crimson Rosellas in eastern New South Wales from incidental observations made during the period 1986 to 1992. The habitats in which field observations were made were not described but possibly included a range of natural, semi-natural and altered habitats. A total of 90 foods were identified representing 82 species of plants, however there were no invertebrates recorded. Foods were identified in the following categories: seed, flowers, flower buds, fruit, leaves, leaf midrib, stems and exfoliating outer bark. Most foods were seeds (66 spp.) followed by flowers or flower buds (9 spp.). A total of 25 foods were from indigenous plants (25 spp.), 23 foods from native plant species (22 spp.) not indigenous to the observation area and 42 foods were from introduced species (35 spp.). Feeding on flower buds was recorded for two *Acacia* species. Rosellas were also observed feeding on the flowers of two *Prunus* species (apricot *P. armeniaca* and cherry-plum *P. cerasifera*).

Brown (1984) reported that the Green Rosella *Platycercus elegans* ssp. *caledonicus*, a widespread Tasmanian endemic species, is primarily an arboreal feeder and a great opportunist and successful exploiter of man-altered habitats, taking a wide variety of food plants, both native and introduced. Feeding observations of Green Rosellas in a variety of habitats, including sclerophyll forest, rainforest, heath, orchard, pasture and agriculture, garden, hedgerow, and roadside revealed that seeds and fruits were taken most frequently, followed by buds and shoots, flowers, leaves and insects. Orchard species taken included cherry (seed and fruit) and apple (seed and fruit; buds and shoots). In 'pasture and agriculture' habitat many pasture weeds were taken including chickweed, dandelions, various grasses and thistles. As introduced food plants such as seeding grasses, dandelion, thistles and apples were highly seasonal in availability, Brown (1984) suggested these were collectively unlikely to provide a year round food source, thus it was necessary for

Green Rosellas to rely on native food sources as their mainstay. The diurnal pattern of feeding behaviour of the Green Rosella described by Brown (1984) is similar to that observed for the Adelaide Rosella. Generally, the main periods of feeding activity are undertaken from shortly after daybreak when birds leave the roost, until mid-morning, and again from late afternoon until just before they return to roost at dusk. Rosellas are generally quiet whilst feeding and when on the ground move quietly and methodically over the feeding area. There are usually long periods of inactivity during the middle of the day when the birds sit quietly in the shade. In the Adelaide Hills during winter, however, rosellas are often seen resting in the leafless canopy of deciduous trees. Flock sizes are highly variable but it is more usual to encounter larger groups during autumn and winter (particularly when feeding on the ground) than in the warmer months.

1.3 CONSERVATION

Wyndham and Cannon (1985) have made the following assessment of the conservation of the rosella complex in Australia: "None of the rosellas…appears to be in immediate danger of extinction and all the rosellas have substantial parts of their range in areas that are used for agriculture or range-land grazing. Generally, suitable food for rosellas has remained plentiful. There has been, and doubtless will continue to be, extensive clearing and mortality of trees over much of the range of the rosella complex. Trees, particularly eucalypts, are important to rosellas as sources of food, for nest sites and for shelter. In most places ample trees remain to ensure the continued survival of the rosellas. However, there could be some localised extinctions, possibly even complete loss of a sub-species, in areas that are extensively cleared or where disease causes widespread mortality of eucalypts".

Given that populations of Adelaide Rosellas persist in heavily modified landscapes, food availability is unlikely to be a significant factor limiting the conservation of the subspecies. The declining number of large hollow-bearing eucalypts in agricultural districts may be of greater importance particularly for individual populations, given the obligate nesting requirement of rosellas for natural tree hollows that are provided by large eucalypts. Although presently considered a relatively common taxon over its geographic range, Adelaide Rosellas may be at risk where small, isolated populations occur within heavily cleared landscapes (such as the eastern slopes of the Mount Lofty Ranges; R. Sinclair, pers. comm.[5]) that are subject to ongoing decline, destruction and fragmentation of limited breeding habitat.

1.4 PEST MANAGEMENT

The broad approaches used for the control of pest birds in commercial fruit crops in South Australia have typically been population reduction and deterrence measures, and more recently, exclusion netting made more feasible due to the availability of long-life plastics. In a review of Australian research on bird pests, Bomford and Sinclair (2002) recognised that "many growers resort to scaring devices or shooting, approaches that are relatively inexpensive and require little effort or expertise". They also noted that most evaluations of scaring and population reduction approaches have concluded that such approaches are usually not effective.

The use of exclusion netting is possibly the only effective approach used to date for protecting cherry crops from pest birds, including rosellas. There are situations though where netting is not economically beneficial, particularly for older fruit orchards with tall trees and wide tree spacings. Netting may sufficiently alter the crop micro-climate to require higher insecticide and fungicide use, and unless well erected and maintained, the net structure may trap birds resulting in damage to fruit and possible mortality of the trapped birds (R. Sinclair, pers. comm). Where netting is not economically viable, habitat manipulation to reduce the attractiveness of crops to birds is worthy of consideration, although there has been little adoption of this approach by growers in Australia (Bomford and Sinclair, 2002).

Knowledge of the ecology of the pest bird species and of the crop to be protected is important for the development of effective damage control measures (e.g. Kozicky and McCabe 1970; Ford 1990; Jarman 1990a,b). Although the nature and extent of damage by rosellas to commercial cherry crops in the Adelaide Hills has received some attention (i.e. Sinclair and Bird 1987; Fisher 1991, 1993), insufficient knowledge of the ecology of rosellas has hindered the development of control measures that have been as successful as netting where economically viable.

The energy demands and dietary habits of a bird population have a major influence upon potential impact of birds within agricultural systems (Wiens and Dyer 1977).

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[5] Dr RG Sinclair, Animal and Plant Control Commission, Adelaide.

Given that birds eat primarily to obtain energy (Kendeigh *et al.* 1977), a fundamental aspect of the feeding ecology of a species is the composition of the diet. Information on the use of food resources and factors underlying diet selection are therefore of relevance to developing effective strategies to manage and conserve animal populations.

1.5 STUDY OBJECTIVES

This study was initiated in the late 1980s in response to concern from orchardists about frequent or high production losses attributed to Adelaide Rosellas within a number of commercial cherry orchards in the Adelaide Hills. Prior to the commencement of this study the nature and extent of damage to cherry trees by rosellas was generally well recognised within the industry but the factors influencing this behaviour were not understood. The potential to develop effective management strategies for rosella populations has been limited by insufficient information on important aspects of their biology, in particular their feeding ecology. The broad aim of this study therefore was to develop a greater understanding of aspects of the biology of rosellas relevant to population management and mitigation of crop damage in commercial cherry orchards in the Adelaide Hills.

Adelaide Rosellas have a diverse diet and they use many other food resources during the winter period when damage to cherry buds occurs (Reynolds 1991). Without an understanding of the relative importance of cherry buds in the diet, opportunities for influencing foraging behaviour of rosellas by manipulating their environment may be difficult to evaluate and realise. The potential to change foraging behaviour in an agriculturally valuable crop may be largely influenced by the relative importance of the food in the diet of the pest species and the availability of alternative food resources within its habitat. If the vulnerable crop, such as cherry buds, represents a highly sought after or preferred food source of the pest species, exclusion netting may be one of the few available management options. If, however, cherry buds are a minor or unimportant part of the seasonal diet then there may be greater potential to influence feeding patterns and to control damage by manipulating alternative food resources within their habitat.

The principal basis of this study was a dietary analysis from which were developed further investigations concerning particular aspects of rosella feeding ecology. The investigations presented here on rosella feeding ecology are principally based on two levels of biological inference, food use and food choice, involving the integration of field and laboratory observations and feeding experiments. Given the difficulties in quantifying available resources in studies of food exploitation, food choice was considered in general terms for selected foods only. An important issue in studies of food exploitation is the need to relate changes in bird behaviour to changes in available resources. In this study a field experiment was conducted involving the manipulation of a food resource to evaluate behavioural responses. Food choice and foraging behaviour were also considered within the general framework of foraging theory to assist in identifying spatial and temporal patterns by which rosellas obtain food.

The specific aims of this study were to:

- gather baseline information on diets of Adelaide Rosellas around cherry orchards at different times of the year;
- determine the importance of flower primordia from cherry buds relative to other foods in the diet, and
- investigate some of the factors that might influence food use and food choice (e.g. energy content of foods, accessibility of foods) as precursors for proposing potential management strategies for reducing damage to cherry buds by rosellas.

2 PATTERN AND EXTENT OF DAMAGE TO FLOWER BUDS OF CHERRY TREES IN THE ADELAIDE HILLS

2.1 INTRODUCTION

Floral buds on cherry trees (*Prunus avium*) are borne on spurs arising from the main branches. Floral initiation takes place in summer after the crop is harvested (Westwood 1978). Buds occur in-groups of 3 to 12 buds in a whorled arrangement, with the central bud usually being vegetative (Fisher 1991). The floral buds usually produce two to four flowers and each cherry flower normally produces one fruit (Westwood 1978). The heavily damaged variety William's Favourite (Plate 1) produces on average four flower primordia per bud (range 1-9) (Sinclair and Bird 1987). The timing of fruit maturation in the Adelaide Hills varies according to variety and locality. Harvesting of the fruit of early maturing varieties usually commences in the first week of November in orchards in the warmer, lower altitude, western part of the study area (i.e. Montacute and Norton Summit districts). Harvesting of late maturing varieties extends to late January or early February in the cooler, higher altitude, central and eastern parts of the study area (i.e. Basket Range, Uraidla, Ashton and Lenswood).

Bud feeding usually commenced in late March and ceased in late August (pers. obs.), just prior to bud burst. Rosellas usually fed on the flowers over the period of several weeks when different varieties flowered within a typical commercial orchard. They also fed on ripening and ripe fruit until the end of the season in early February.

The method of feeding on buds by rosellas first involves removal of a whole bud from a bud group that is borne on a fruiting spur (Plate 1). The bud is held between the upper and lower mandibles whilst the tongue manipulates the bud. An incision is made to the outer bud scales, possibly using the sharp edge of the lower mandible, in order to expose the flower primordia group inside. The primordia group is excised and the outer bud scales discarded.

Plate 1. Undamaged and damaged buds on fruiting spurs of William's Favourite cherry trees; and cherry primordia found in crops of rosellas.

Fruiting spurs of William's Favourite cherry trees were photographed at Bishop's Orchards, Basket Range in late winter. The order of descriptions given is from left to right.
Top row: Undamaged floral bud whorl on lateral fruiting spur; Bud whorls damaged by rosellas on a low, declining branch.
Second row: Fruiting spurs with floral buds removed by rosellas (note terminal vegetative buds are undamaged).
Bottom row: Two fruiting spurs with damaged floral buds; Cherry primordia found in the crop of an Adelaide Rosella taken from a cherry orchard in the Adelaide hills (1mm graduations on scale).

Sinclair and Bird (1987) first reported that severe damage to buds caused by rosellas was usually restricted to only one commercial variety of cherry in the Adelaide Hills, "William's Favourite", where more than fifty varieties were commonly grown. They recognised that damage of this type to cherries or any other fruit was unknown elsewhere in Australia, but had similarity overseas to Bullfinch *Pyrrula pyrrhula* damage to certain varieties of pears in England (Newton 1964; Summers and Jones 1976).

Sinclair and Bird (1987) monitored bud damage to William's Favourite trees in 20 commercial cherry orchards over the 1986 -1987 season. They found that in half of the orchards trees of this variety had on average less than 10% of buds damaged, and in a quarter of the orchards more than 60% of the buds were damaged. In the most severely affected orchard more than 90% of buds were removed by rosellas, after which feeding shifted to other varieties resulting in up to 50% damage on some trees. Fisher (1991; 1993) monitored bud loss for several cherry varieties at two orchards in the Adelaide Hills in 1991 (this included data that I collected for the current study). He noted that William's Favourite and Black Douglas (a derivative of William's Favourite) trees were more heavily damaged than trees of Lustre (Plate 2) or Makings varieties, and that most of the buds on high branches were removed before the branches lower in the tree were damaged by rosellas. The seasonal pattern of damage in the orchards involved removal of most of the buds on preferred varieties before some buds of other varieties were taken.

The investigations reported here extend previous studies by monitoring individual trees of several varieties in one orchard over a number of years and comparing levels of damage to several varieties at more than one location in the same year.

Two investigations were conducted on the varietal and temporal patterns of feeding damage to the flower buds of cherry trees by rosellas. The first involved monitoring bird damage to buds of individual trees of several cherry tree varieties in one orchard immediately prior to flowering in five consecutive seasons. The purpose was to determine whether rosellas fed preferentially on the buds of certain varieties in a consistent pattern over a period of several years.

The second investigation involved an assessment of bud damage to the most common cherry varieties in each of two orchards in order to compare damage levels attributable to different rosella populations within the same year.

Plate 2. Cherry orchards and cherry trees in the Adelaide Hills.

The order of descriptions given is from left to right.
Top row: Orchard prior to flowering at Norton Summit, 25/9/92; Orchard in flower at Montacute, 9/10/92. Second row: Narrow, un-sprayed vegetated strip between sprayed tree rows in winter at Norton Summit; Diverse suite of annual weed species growing in a wide, unsprayed strip between tree rows at Forest Range just after initial bud burst, 23/9/92. Third row: 'Williams Favourite' cherry tree with typical branching pattern of long interlocking spurs; 'Lustre' cherry tree showing arrangement of fruiting spurs on upper branches; 'Lustre' cherry tree showing typical vase shape. Bishop's Orchards, Basket Range.

2.2 METHODS

2.2.1 Data collection

In the first investigation, individual trees of four cherry varieties in one commercial orchard at Basket Range (Bishop's; refer Fig. 3.3) were monitored for extent of bud loss immediately prior to flowering in each year from 1988 to 1992. All healthy, mature trees of the following varieties were monitored over this period: Lustre (32 trees), Makings (39), Opal (48) and William's Favourite (34). The trees were individually assessed immediately prior to the period of rapid bud swelling which preceded flowering (i.e. "bud burst"). The assessments were thus carried out within two weeks of the commencement of flowering, in five successive years on the following dates: 9 September 1988, 12-13 September 1989, 12-13 September 1990, 13-14 September 1991, and 16-17 September 1992. As bud feeding generally finished in late August (pers. obs.) these assessments undertaken in September allowed measurement of total losses for all varieties for subsequent comparison of bud predation across varieties.

In the second investigation, bud damage to a total of 252 trees were assessed in Bishop's orchard at Basket Range on 16-17 September 1992, the most common varieties being William's Favourite (35 trees), Lustre (37), Makings (36) and Opal (57). This was compared to bud damage in an orchard at Cockatoo Flat near Cherryville (Bungay's orchard, 5.6 km north of Bishop's orchard; refer Fig. 3.3) where a total of 122 trees of the varieties William's Favourite (58 trees), Lustre (39) and Tartarian (25) were assessed on 17-18 September 1992. The assessments were undertaken within two to three weeks of the onset of flowering. This investigation thus sought to compare bud damage levels caused by geographically separate rosella populations within the same year.

Fisher (1993) observed that bud loss on heavily damaged varieties such as William's Favourite initially occured on the high branches and only became significant for the lower branches as the season progressed. A similar progression of damage also appeared to occur on the less favoured varieties, Lustre and Makings (pers. obs.). However, this pattern usually emerged in the late stages of bud development when the bud resource of William's Favourite became severely depleted. This predictable pattern of damage contributed to the efficacy of the visual estimation method.

Each tree was visually assessed for the extent of bud loss. Estimates of bud loss for each tree were recorded based on seven damage classes (Table 2.1). The estimate of damage for individual trees was based on the proportion of the total number of buds produced on the tree that had been removed by birds. Bud damage estimates were scored according to the following damage classes:

Table 2.1. Indices for percentage of damaged cherry buds based on visual estimates.

Damage index	Percentage of buds damaged
1	nil or negligible
2	>0 & < 5%
3	5 - 25%
4	25 - 50%
5	50 - 75%
6	75 - 90%
7	90 - 100%

All varieties, each with a minimum of 25 trees in each of the orchards were monitored for bud damage. The data collected on bud losses in these investigations were used to determine by simple comparison any differences or patterns based on varieties, years and orchards.

Within each cherry orchard there was a mixture of black-fruiting and white-fruiting varieties (recognised by the colour of the fruit when ripe), comprising trees of varying age. Both orchards had in common mature trees of the black fruiting varieties (William's Favourite, Lustre and Makings). The most common varieties in the orchard at Cockatoo Flat were William's Favourite (WF), Lustre and Tartarian. Orchard pasture management on each property was based on sod culture (pasture management) rather than cultivation, the latter being a more widespread practice in the district in the 1970s. Each orchard also occurred within the foraging range of a population of rosellas that were known to forage heavily on buds over the autumn - winter bud dormancy period. At both sites, a track (Cockatoo Flat) or road (Basket Range) bounded one side of the orchard, and modified native vegetation (eucalypt woodland) adjoined other sides. Native vegetation however was more extensive within the broader landscape at Cockatoo Flat.

2.2.2 Data analysis

The tree counts based on bud damage class for each variety were initially recorded as the proportion of trees in each of the seven classes shown in Table 2.1 (Figs. 2.1 and 2.3). The number of trees in each bud damage class for each variety were aggregated for the five-year observation period (1988 – 1992) and expressed as a proportion of the total number of trees assessed (Fig. 2.2).

2.3 RESULTS

2.3.1 Variation over time in loss of buds to four cherry varieties at Bishop's orchard, Basket Range

Each year during the period 1988 to 1992 at Bishop's orchard, Lustre, Makings and Opal varieties received relatively little damage to buds, whilst William's Favourite trees had consistently high levels of damage (Figure 2.1).

The majority of Lustre trees had 0-5% bud damage (Damage Index 2) in four of the five years (1989-1992). However in 1988 over 50% of trees were recorded in the lowest damage class with nil or negligible damage. No trees were recorded in the highest damage class during the monitoring period, and in only one year (1991) were any trees recorded with 75-90% damage.

The distribution of damage classes for Makings trees was similar to those for Lustre, with the dominant damage class in each year being 0-5% (Damage Index 2), except for 1988 when over 60% of trees showed nil or negligible bud damage. No trees were recorded in the two highest damage classes (75-90% or 90-100%) during the monitoring period.

There was a broader distribution of trees recorded within all bud damage classes for Opal trees each year compared to Lustre and Makings. In each year only a small proportion of trees were recorded in damage classes 50-75% or greater. The highest proportion of trees with nil or negligible damage was recorded in 1988 which was consistent with that for Lustre and Makings in the same year.

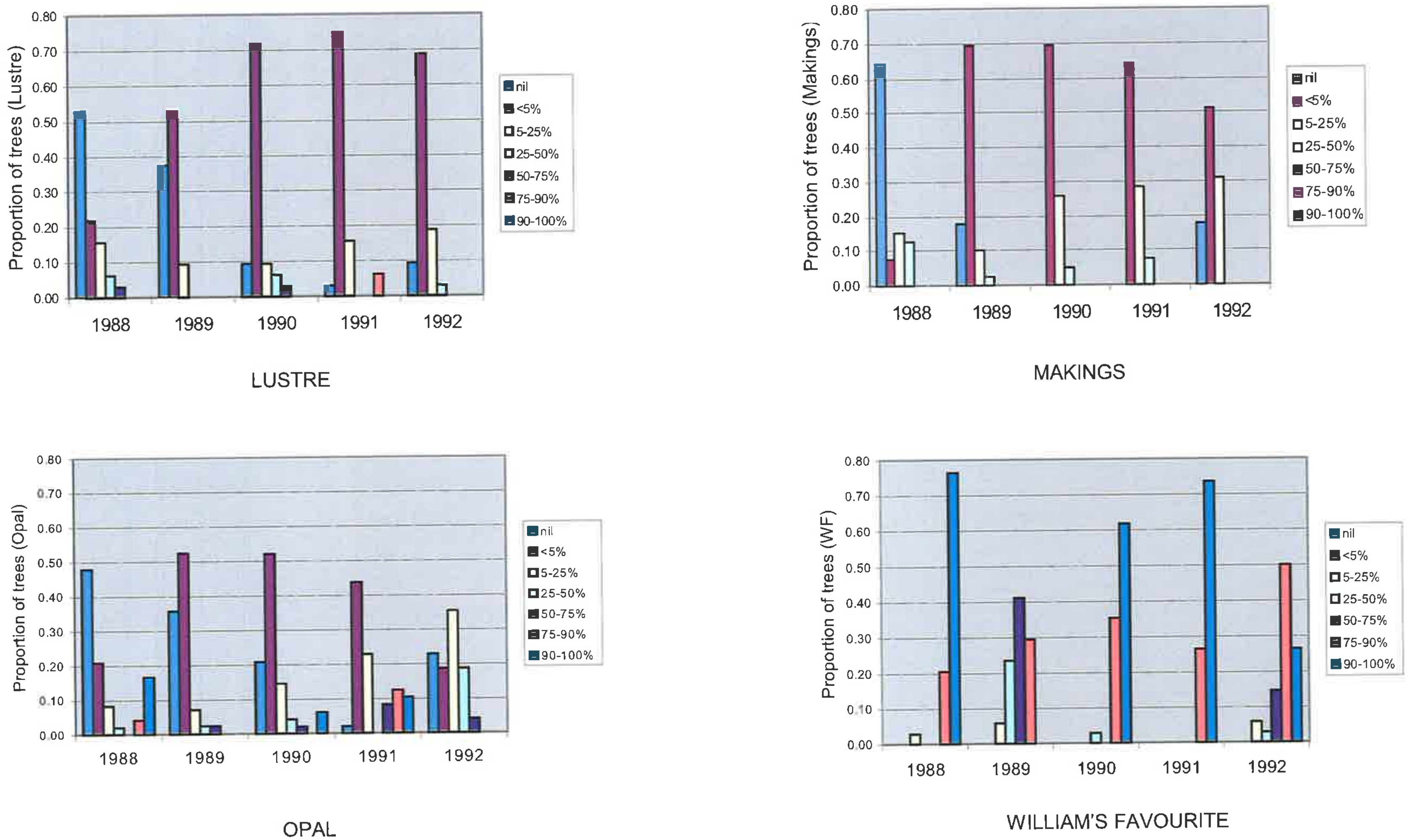

Figure 2.1. Proportion of trees recorded in each of seven bud damage classes for four cherry varieties (Lustre (32 trees), Makings (39), Opal (48) and William's Favourite(34)) in each year from 1988 to 1992 in Bishop's orchard at Basket Range. The key to bud damage classes is given on the right of each figure.

The most frequently recorded bud damage classes in each year for William's Favourite trees were 50-75% or higher. In three of the five years (1988, 1990 and 1991), the majority of trees were recorded in the 90-100% damage class. No trees were recorded with less than 5% damage in the five-year period.

Over the five-year period the distribution of bud damage classes for the William's Favourite trees was strongly biased towards the higher damage classes (Figure 2.2). The contrary pattern was observed for the other three varieties (i.e. a stronger bias towards lower damage classes for Lustre and Makings compared to Opal).

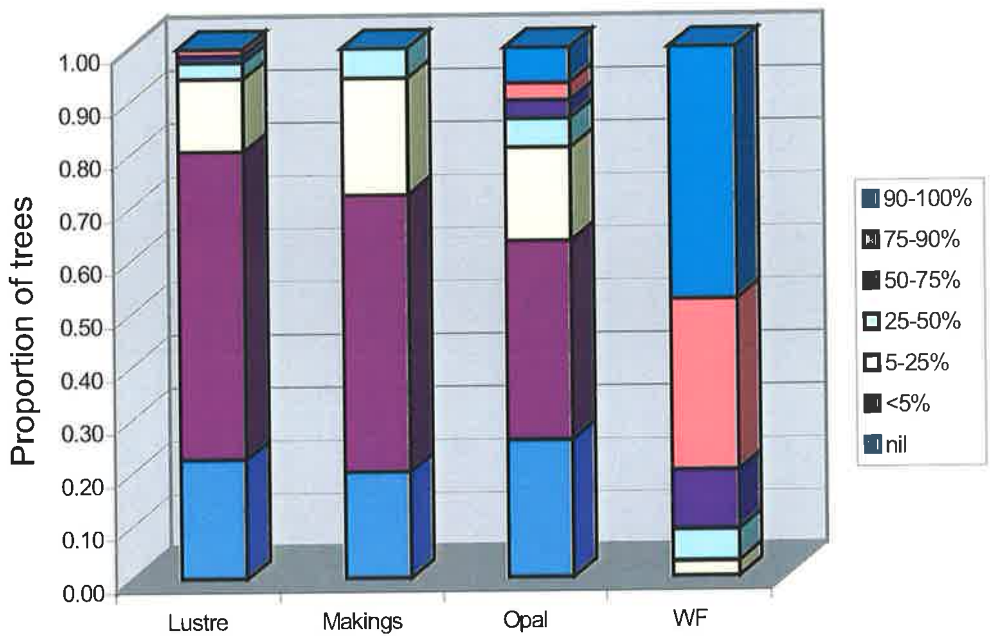

Figure 2.2. Overall proportion of cherry trees in each bud damage class averaged over five years (1988-1992).

In each year a total of 32 Lustre, 39 Makings, 48 Opal (42 in 1989) and 34 William's Favourite (WF) trees were assessed. The key to bud damage classes is given on the right of the figure.

2.3.2 Comparison of bud damage to varieties of cherries in two orchards (Basket Range and Cherryville) in 1992

Rosellas in both orchards exploited buds of the William's Favourite variety (WF) to a greater extent than buds of other varieties (Figures 2.3 and 2.4). A greater proportion of WF trees were recorded in the highest damage class (90-100%) in the Cherryville orchard than in the Basket Range orchard (91% compared to 26%). The distribution of damage classes was similar between orchards for Lustre with the highest proportion of trees at both locations scored in the 0-5% damage class (Damage Index 2). At Cherryville, the feeding damage to buds of Tartarian trees was intermediate between that of WF and Lustre. Moderate overall levels of bud damage to Tartarian trees were distributed broadly across the range of damage classes with 20% or more of the trees exhibiting damage in each of the 25-50%, 75-90% and 90-100% damage classes, whereas only 3% of Lustre trees were recorded in each of these classes. At Basket Range the distribution of tree damage scores amongst the damage classes was similar for three varieties, Lustre, Makings and Opal where the highest proportion of trees was recorded in the three lowest damage classes.

A comparison of WF trees with other varieties in each orchard based on visual assessment indicates distinct, separate peaks in the distribution of trees amongst bud damage classes. Between 30% and 40% of non-WF trees at each location exhibited damage in the 0-5% damage class (Damage Index 2). However, a greater proportion of trees at Cherryville received higher levels of bud damage than at Basket Range. At Cherryville 91% of WF trees exhibited 90-100% damage whereas at Basket Range 94% of WF trees were recorded with damage distributed more widely across the three highest damage classes (50-75%, 75-90% and 90-100%).

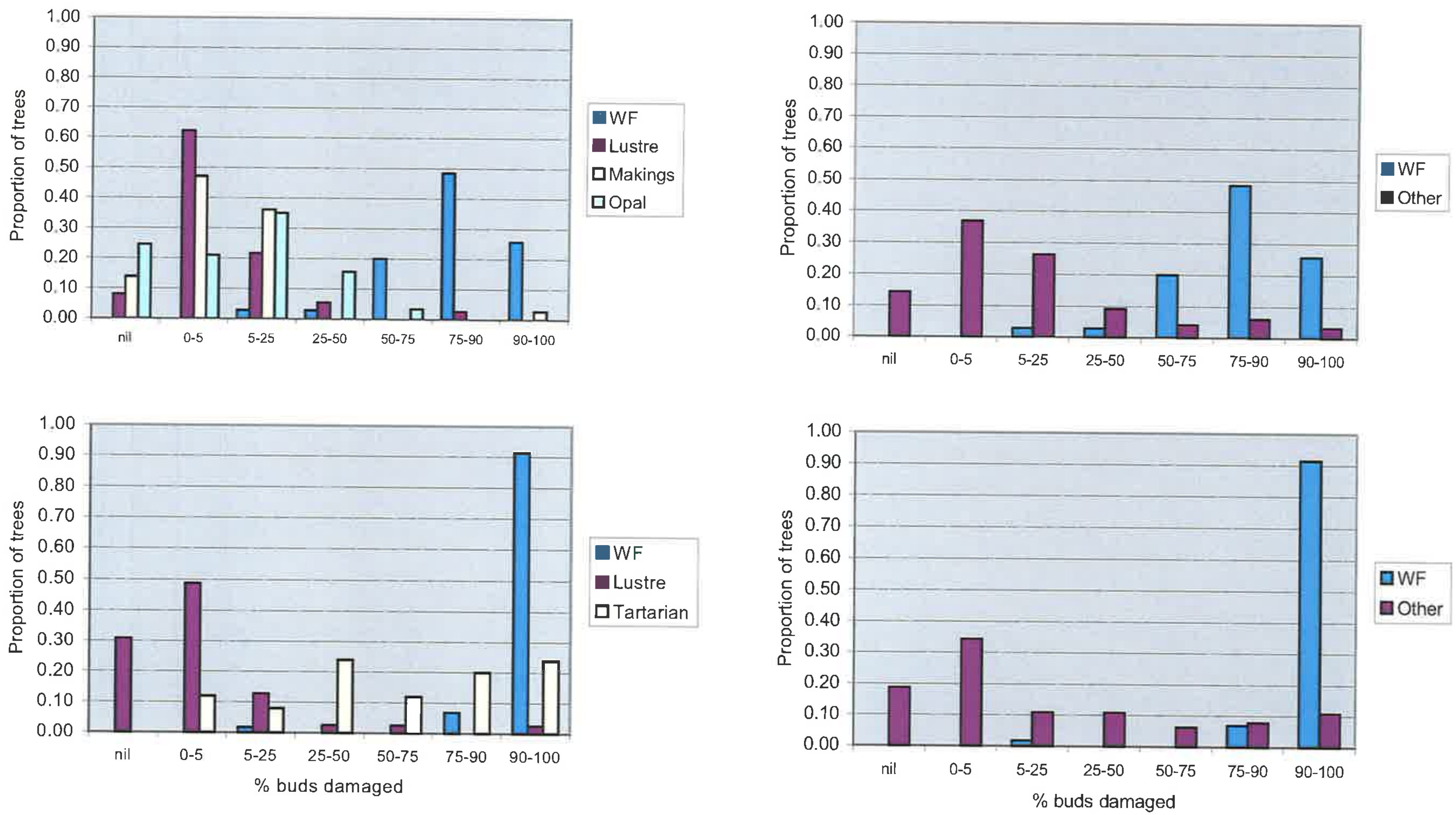

Figure 2.3. Distribution of bud damage within seven damage classes for the main cherry varieties at Bishop's orchard (252 trees), Basket Range and Bungay's orchard (122 trees), Cherryville in 1992.

Bishop's orchard is represented by the top figures and Bungay's orchard by the bottom figures. The grouping of scores for nine non-WF varieties at Basket Range and two varieties (Lustre and Tartarian) at the Cherryville site is represented by 'Other' in the figures (refer to key on the right-hand side of figures). At Basket Range 35 WF, 37 Lustre, 36 Makings, 57 Opal and 87 trees of other varieties (18 Wix, 17 Napoleon, 14 Delta, 10 Black Douglas, 14 Rufus and 14 Sam) were assessed. At Cherryville 58 WF, 39 Lustre and 25 Tartarian trees were assessed. Note: 'WF' = William's Favourite (all sites).

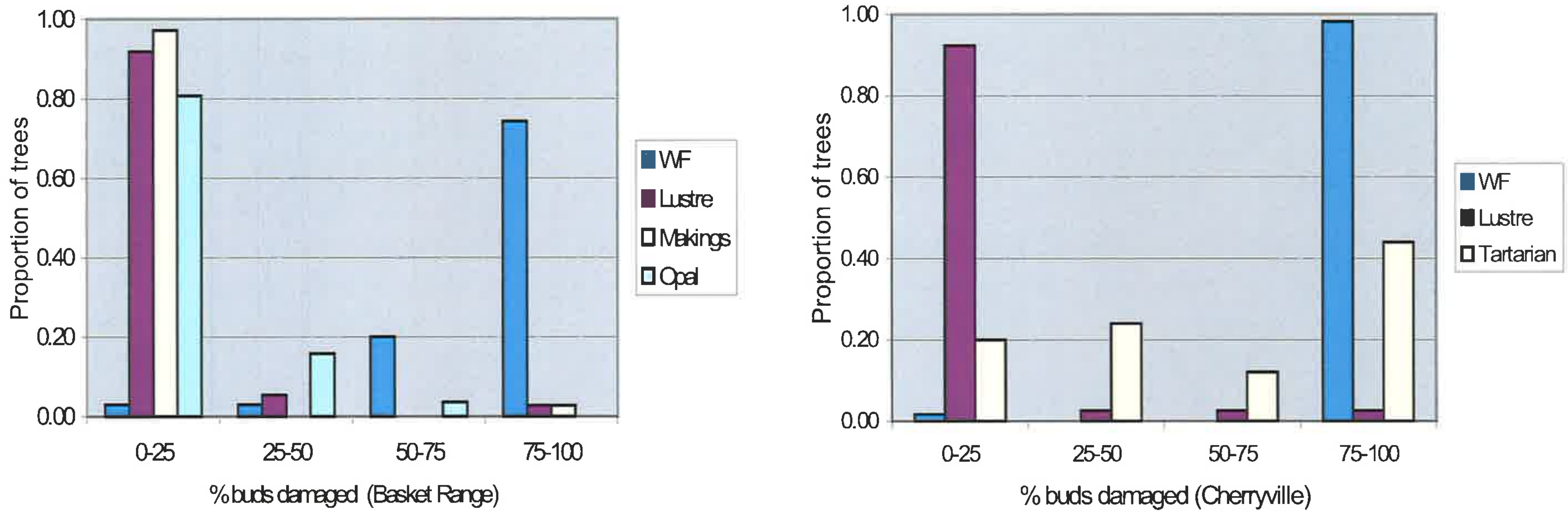

Figure 2.4. Distribution of bud damage within four (aggregated) damage classes for the main cherry varieties at Bishop's orchard, Basket Range and Bungay's orchard, Cherryville in 1992.

The 0-25% and 75-100% damage classes in this figure were derived from grouping scores in the nil, 0-5 and 5-25% classes and the 75-90% and 90-100% classes respectively. At Basket Range 35 William's Favourite (WF), 37 Lustre, 36 Makings and 57 Opal trees were assessed. At Cherryville 58 WF, 39 Lustre and 25 Tartarian trees were assessed (refer to the key on the right of each figure).

2.4 DISCUSSION

The data presented here indicate that trees of William's Favourite at Basket Range received a disproportionately high level of damage to buds compared to Lustre, Makings and Opal, indicating a particular order of preference by rosellas for the buds of different cherry tree varieties that each provided an abundant resource of buds. The data also indicate that within each variety monitored over the five-year period at Basket Range there is a reasonably consistent pattern of damage between years involving relatively minor fluctuations in the distribution of bud damage classes within the sample of trees between years. This investigation thus indicated that the foraging behaviour of one population of rosellas in relation to a cherry bud food resource was reasonably consistent over a period of several years.

A comparison of orchards at two localities (Basket Range and Cherryville) in the same year showed a similar pattern of damage amongst non-William's Favourite trees based on seven bud damage classes compared to William's Favourite trees. The main difference between localities was the higher proportion of William's Favourite trees recorded in the highest damage category (90-100%) at Cherryville. This investigation has shown that different populations of rosellas can exhibit similar patterns of damage to cherry buds with respect to four common cherry varieties.

As the bud damage estimates were recorded at the end of the bud development period it is evident that a significant resource of flower buds of a number of other varieties was under-exploited by rosellas compared to William's Favourite, indicating that the birds may exercise varietal preference. Thus, when William's Favourite trees were present, rosellas appeared to feed preferentially on the buds of this variety despite the abundance of buds from other varieties within the same orchard, as also shown by Sinclair and Bird (1987) and Fisher (1991; 1993).

These results suggest there are other factors that influence choice by rosellas. Such factors might include differences in nutritional quality of flower primordia between varieties, position of trees within orchards or varietal differences in bud density or bud-group density. In the two orchards studied, cherry buds of all varieties appeared to be a super-abundant resource given that a large resource of potentially edible buds, albeit of less preferred varieties, remained undamaged by rosellas at the end of the bud development period each year. This abundance of buds of all varieties may therefore permit rosellas to feed selectively, particularly during the earlier stages of bud development when the resource of undamaged buds of preferred varieties is relatively high. Thus it might be expected that an increasing proportion of trees of less favoured varieties should begin to exhibit damage in the higher damage classes later in the bud development period as the bud resource on William's Favourite trees becomes increasingly depleted by rosellas. Such a pattern of damage is similar to that reported by Fisher (1993). This can be compared to choice tests or "cafeteria" trials (Pinowski and Drodz 1975) whereby an animal is offered a variety of potential foods of equal availability and subsequent diet selection is monitored, demonstrating that as favoured foods are depleted the animal must choose less preferred foods.

There were differences in the spatial distribution of trees of each variety within the orchard at Cherryville, for example a greater proportion of William's Favourite trees occurred at the periphery of the orchard (i.e. adjacent to open areas) compared to trees of the Lustre variety. This may have had an influence on the foraging behaviour of rosellas, including food choice. However, at Basket Range there was no such bias in the spatial distribution of trees of either variety. Furthermore, the pattern of damage to Lustre relative to William's Favourite was similar at both the Cherryville and Basket Range orchards. These observations suggest that position of trees within the orchard was not a significant factor in varietal selection.

This chapter confirms that losses of buds for certain varieties can be very high whilst buds of other varieties remain largely undamaged, and demonstrates that this pattern is broadly consistent between years and between different rosella populations. Why do rosellas select one cherry bud variety in preference to another? Given that extraneous factors such as position of trees within an orchard or food availability do not appear to significantly influence varietal selection by rosellas, intrinsic attributes of the buds of each variety may be of greater importance in determining food selection (refer Chapter 4). Optimal foraging theory argues that birds often select food based on the energy gained relative to the time and effort required to harvest the food item (e.g. Pyke *et al.* 1977; Krebs 1978). Bud density may therefore be a factor that influences foraging efficiency, and if differences in density occur between varieties this could explain observed patterns of varietal selection by rosellas.

Fisher (1991; 1993) observed that differences in bud density between varieties corresponded with differences in damage levels, and suggested that attributes of tree structure affecting bud density may be important in determining varietal preference of Adelaide Rosellas in cherry orchards. Fisher (1991) conducted taste trials using captive rosellas in order to investigate varietal differences in bud damage observed in the field, but the results suggested that taste plays a minor role in determining varietal bud preference. Fisher (1993) suggested that the buds of favoured varieties might yield a higher energetic reward for the bird than less damaged varieties, and that investigations should be conducted on the timing of growth and development of buds, focusing on energy content and the size of primordia, as well as the chemical composition of buds in order to explain varietal preference.

As yet, no studies have considered other attributes of cherry buds such as primordia density and energy content that may differ between tree varieties and have the potential to influence bud selection. This will be considered in a later chapter. Before varietal preference and influencing factors can be properly considered greater information on the foods that rosellas use throughout the year is necessary. Without an understanding of the importance of cherry buds compared to other foods in the diet the factors that influence the use of buds by rosellas may be difficult to determine. In the following chapter the diets of Adelaide Rosellas taken from cherry orchard properties where bud damage was known to occur are investigated.

3 DIETS OF ADELAIDE ROSELLAS IN THE STUDY AREA

3.1 INTRODUCTION

Limited information has been reported on the diet of the Adelaide Rosella, particularly in orchards where the birds are considered a pest. The only reported dietary study for Adelaide Rosellas in cherry orchards is one based on examination of the crop contents of 67 birds collected during winter in the Adelaide Hills (Reynolds 1991). A study by Lea and Gray (1935) was based on examination of the crop or stomach contents of 38 birds collected from Mount Remarkable (southern Flinders Ranges) to Cape Jervis (southern Mount Lofty Ranges). Dietary studies of Crimson Rosellas in various parts of south-eastern Australia have been reported by Bridgewater (1934), Magrath and Lill (1983) and Lepschi (1993). A detailed account of the feeding ecology of Crimson Rosellas is given in Chapter 1 (Section 1.2.5).

This dietary study was undertaken to determine the food used by Adelaide Rosellas at a number of typical commercial cherry orchard properties in the Adelaide Hills. In particular, I sought to:

- identify patterns of food use by rosellas in relation to temporal (e.g. seasonal) and biological (i.e. age and gender) factors;
- determine the importance of cherry primordia in relation to other foods in the diet of rosellas; and
- provide a basis for further investigations on food choice and food availability in order to identify possible factors influencing food choice and foraging behaviour by rosellas.

3.2 METHODS

The diets of rosellas were determined principally from crop contents, complemented by opportunistic field observations of feeding birds. Since the identification of food items being consumed in the field was often difficult to achieve with confidence, the following assessment of diet is based mainly on an examination of the contents of crops from birds shot under permits issued by the National Parks and Wildlife SA (Department for Environment and Heritage).

3.2.1 Description of study area

Adelaide Rosellas were collected for food analysis from a number of commercial cherry orchard properties (in and adjacent to orchards) in the Adelaide Hills within the Mount Lofty Ranges, just east of the city of Adelaide in South Australia. The study area extends from Montacute (34° 54' S) in the north to Uraidla and Carey Gully in the south (34° 58' S), and from Norton Summit in the west (138° 43' E) to Lenswood in the east (138°49' E).

The study area has a Mediterranean climate characterised by cool wet winters and comparatively warm, dry summers (Figures 3.1 and 3.2). In the eastern part of the study area (Lenswood Research Centre) the mean daily maximum temperatures for each month over winter range from 11.4°C to 12.5°C and the mean daily minimum temperatures range from 6.0°C to 6.7°C. In summer, the mean daily maximum temperatures for each month range from 23.3°C to 25.7°C and mean daily minimum temperatures range from 11.6°C to 13.5°C. The winter months are the wettest three-month period of the year. In winter, the monthly rainfall means range from 134.1 mm to 151.4 mm (17.7 to 20.1 mean number of rain-days), compared to 28.8 – 44.2 mm (5.7 – 9.1) in summer. The annual mean rainfall is 1027.7 mm with rain falling on a mean of 156.5 days per year.

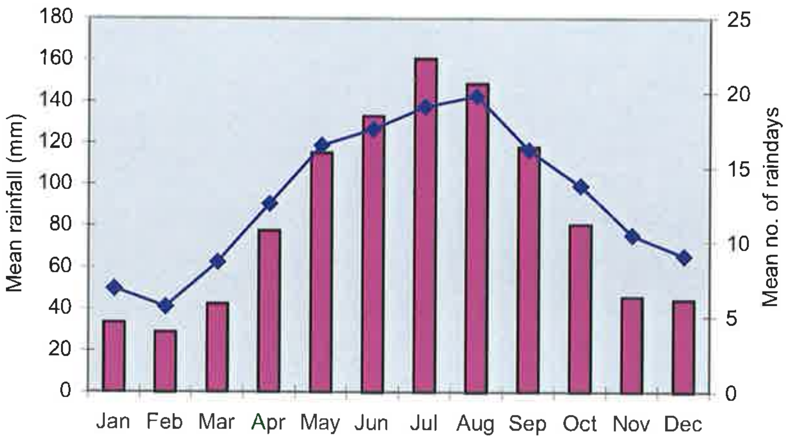

Figure 3.1. Mean monthly rainfall in mm (dots) and mean number of rain-days (bars) for each month at Lenswood Research Centre in the Mount Lofty Ranges.

Lat. 34.95° S, long. 138.81° E; elevation 452 m. Source: Bureau of Meteorology (2001). Climate averages - long term mean values of weather data, 1967-2000.

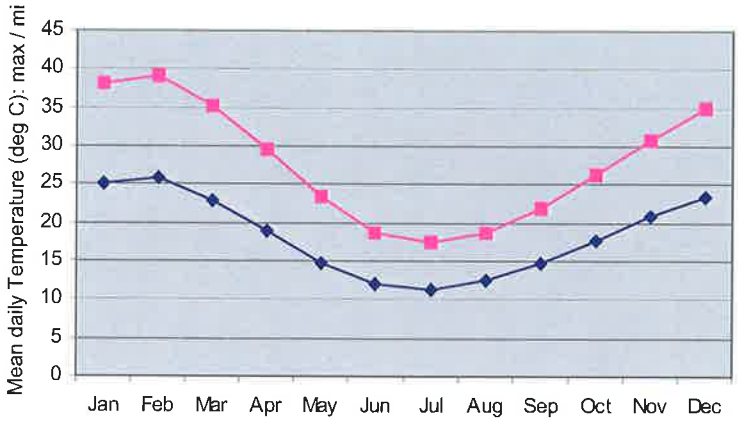

Figure 3.2. Mean daily maximum temperature and mean daily minimum temperature (°C) for each month at Lenswood Research Centre in the Mount Lofty Ranges.

Lat. 34.95° S, long. 138.81° E; elevation 452 m). Source: Bureau of Meteorology (2001). Climate averages - long term mean values of weather data, 1967-2000.

The 18 commercial orchards from which birds were collected in the study area were typically situated on hill slopes (Plate 2). Orchards in the study area ranged in altitude from 220m to 550m: Basket Range 400-490m; Forest Range 500-550m; Uraidla 500-550m; Ashton 450-500m; Lenswood 470-550m; Marble Range 450-500m; Montacute 300-400m; Norton Summit 320-470m; Carey Gully 450-500m; and Cockatoo Flat 220-250m.

The pattern of land use was broadly similar in all districts within the study area, being predominantly horticulture and market gardening, and some rural residential, and agriculture and mixed farming (Table 3.1; Figure 3.3). The vegetation cover was predominantly exotic (tree crops, annual vegetable crops, viticulture and floriculture), with remnant stands of four native plant communities: *Eucalyptus obliqua* woodland, *E. obliqua - E. fasciculosa* woodland, *E. leucoxylon - E. viminalis* woodland, and *E. fasciculosa - Allocasuarina verticillata* low woodland (Table 3.1; Figures 3.3 and 3.4). *E. obliqua* woodland was the most common and widespread remnant community, and occurred in all districts. *E. obliqua - E. fasciculosa* woodland and *E. fasciculosa – A. verticillata* low woodland only occurred in the northern part of the study area including the Montacute and Cockatoo Flat districts. *E. leucoxylon - E. viminalis* woodland occurred only in the Montacute, Cockatoo Flat, and Basket Range districts.

Figure 3.3. Types of land-use within the Adelaide Hills study area.
Cherry orchards where Adelaide Rosellas were collected for dietary analysis (1985 to 1992) are represented as Study Sites and identified by orchard codes (refer legend).

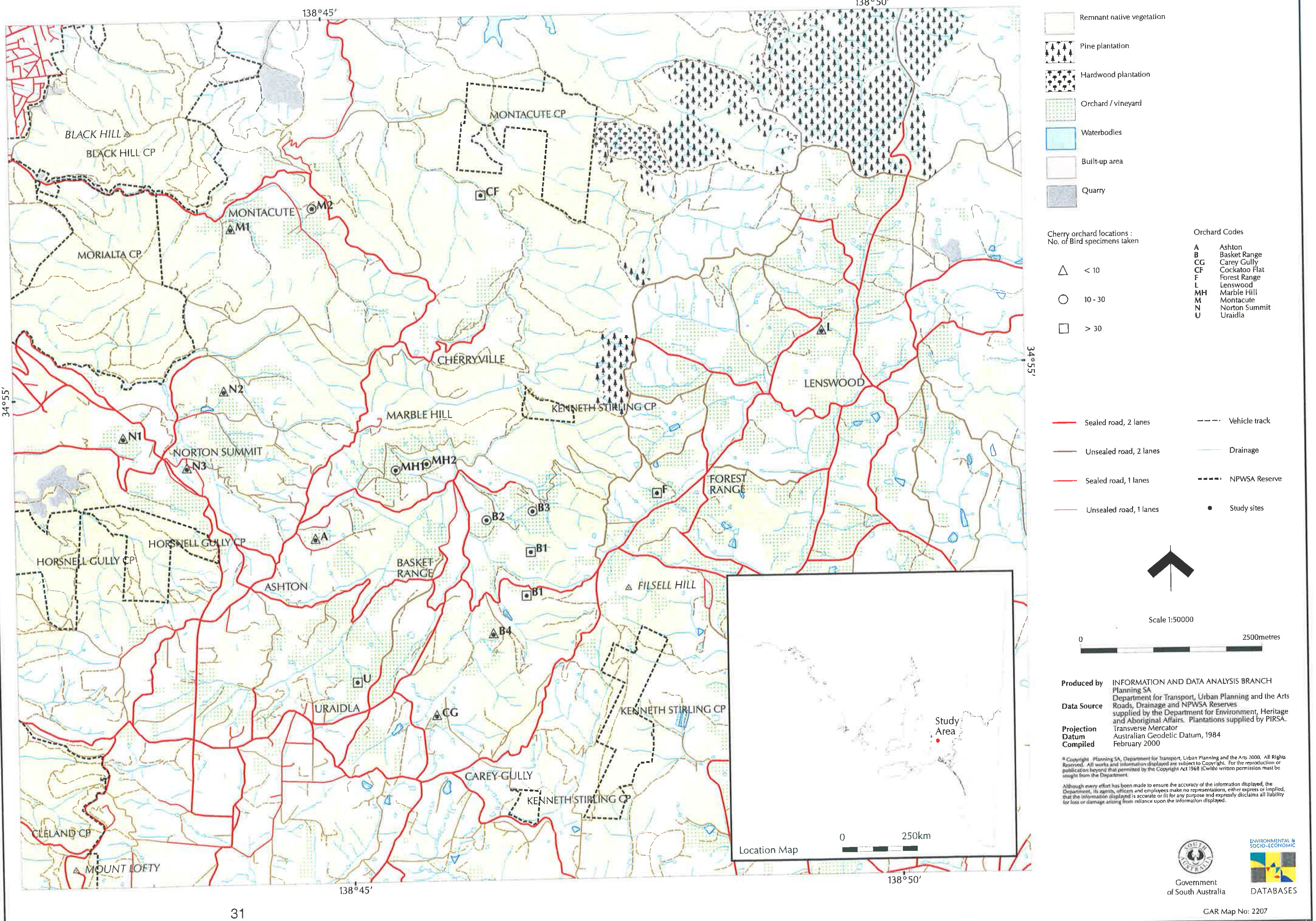

Figure 3.4. Remnant native vegetation associations within the Adelaide Hills study area. Cherry orchards where Adelaide Rosellas were collected for dietary analysis (1985 to 1992) are represented as Study Sites and identified by orchard codes (refer legend).

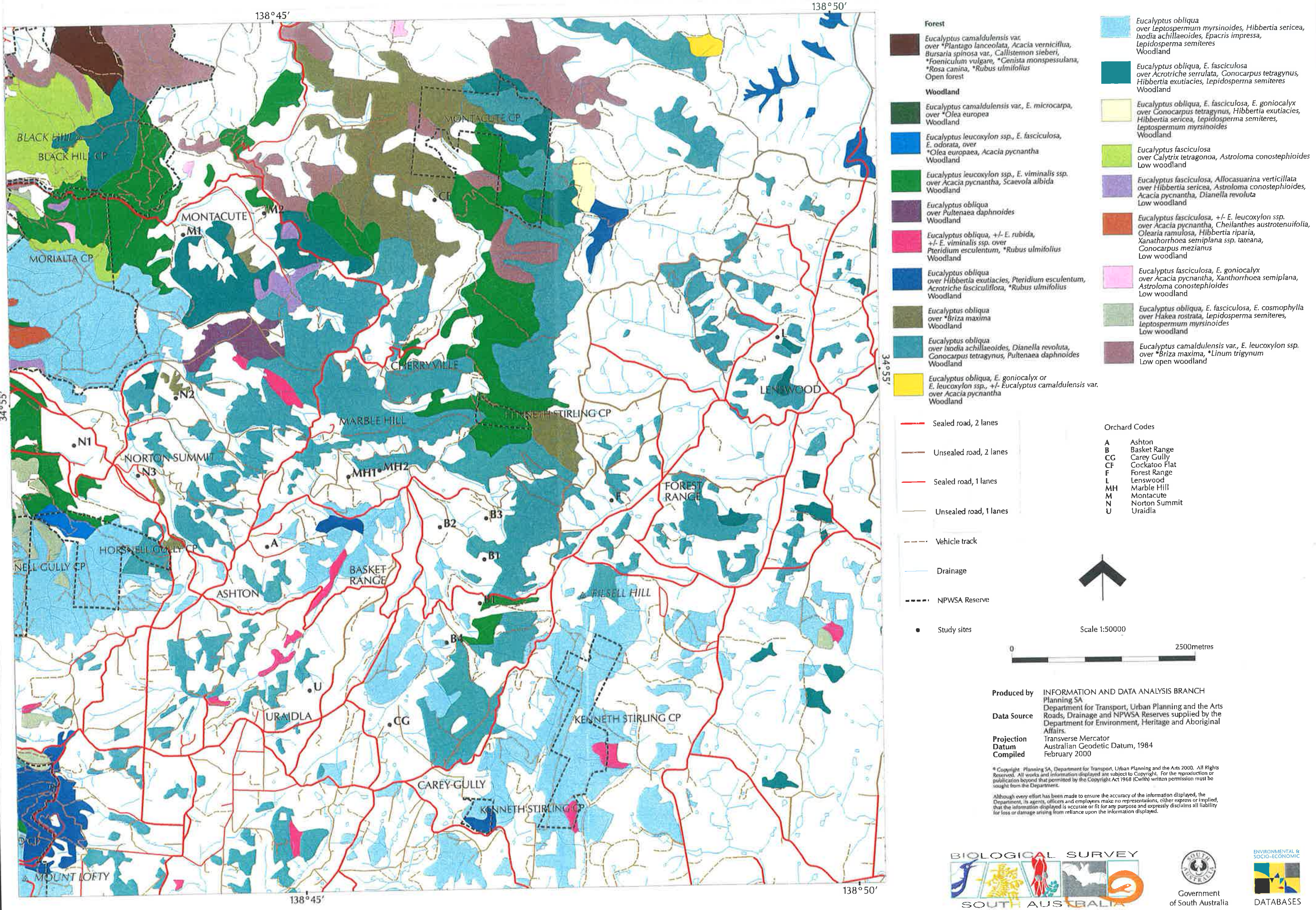

Table 3.1. Districts in the Mount Lofty Ranges from which Adelaide Rosellas were collected between 1985 and 1992 for dietary analysis showing summary of land-use and vegetation.

Principal land-use types and vegetation types for each district are listed in descending order of land area occupied. Information is based on Land-use cover and Floristic Vegetation cover compiled by Planning SA, 2000.

District (No. of orchards)	Predominant land-use types	Predominant vegetation types
Basket Range (5)	Horticulture & Market Gardening Rural Residential Agriculture & Mixed Farming	Exotic (tree crops, improved pastures, annual crops) *Eucalyptus obliqua* woodland *Eucalyptus leucoxylon - E. viminalis* woodland
Uraidla (1)	Agriculture & Mixed Farming Horticulture & Market Gardening Rural Residential	Exotic (tree crops, improved pastures, annual crops) *Eucalyptus obliqua* woodland
Cherryville (1)	Horticulture & Market Gardening Vacant Other Recreation (conservation reserve)	Exotic (tree crops, improved pastures, annual crops) *Eucalyptus obliqua* woodland *Eucalyptus leucoxylon - E. viminalis* woodland *E. fasciculosa - Allocasuarina verticillata* Low woodland
Marble Hill (2)	Horticulture & Market Gardening Vacant; Rural Residential	Exotic (tree crops, improved pastures, annual crops) *Eucalyptus obliqua* woodland
Forest Range (1)	Horticulture & Market Gardening Rural Residential; Vacant	Exotic (tree crops, improved pastures, annual crops) *Eucalyptus obliqua* woodland
Montacute (2)	Rural Residential Agriculture & Mixed Farming Livestock and Poultry Horticulture & Market Gardening	Exotic (tree crops, improved pastures, annual crops) *Eucalyptus obliqua - E. fasciculosa* woodland *Eucalyptus leucoxylon - E. viminalis* woodland *E. fasciculosa - Allocasuarina verticillata* low woodland
Norton Summit (3)	Rural Residential Horticulture & Market Gardening Vacant	Exotic (tree crops, improved pastures, annual crops) *Eucalyptus obliqua* woodland *Eucalyptus leucoxylon - E. viminalis* woodland
Carey Gully (1)	Rural Residential; Agriculture & Mixed Farming; Vacant; Forestry	Exotic (tree crops, improved pastures) *Eucalyptus obliqua* woodland
Lenswood (1)	Horticulture & Market Gardening; Rural Residential; Vacant	Exotic (tree crops, improved pastures, annual crops) *Eucalyptus obliqua* woodland *Eucalyptus obliqua - E. fasciculosa* woodland
Ashton (1)	Rural Residential; Vacant Horticulture & Market Gardening	Exotic (tree crops, improved pastures, annual crops) *Eucalyptus obliqua* woodland

3.2.2 Collection and storage of crops

A sample of 333 Adelaide Rosellas was collected from the study area between July 1985 and September 1992. Aggregated monthly totals (number of birds) were as follows: January (32), February (26), March (26), April (27), May (27), June (25), July (29), August (28), September (32), October (26), November (26) and December (29).

Birds were obtained from 18 commercial orchards in 10 districts of the Adelaide Hills: Basket Range, Forest Range, Lenswood, Uraidla, Carey Gully, Ashton, Marble Hill, Norton Summit, Cockatoo Flat and Montacute (Table 3.2). All orchards occurred within a 6 km radius of Cherryville. Crop contents were obtained *post-mortem* from rosellas shot in and around orchards.

Approximately 91% of birds in this sample were obtained from 10 orchards in 5 districts (i.e. Basket Range, Uraidla, Cherryville, Marble Hill and Forest Range) representing 91% of all foods by volume. The highest proportion of birds (34%) was obtained from five orchard properties at Basket Range representing 36% of all foods by volume (Table 3.2). The majority of birds were obtained from orchardists who shot birds under destruction permits issued by National Parks and Wildlife SA.

Table 3.2. Distribution of Adelaide Rosella specimens taken from commercial orchards within the Adelaide Hills study area for dietary analysis.

These data are based on a total of 333 birds taken from 18 orchards within 10 districts from 1985 to 1992.

District	No. of orchards	No. of birds	Percentage of all birds	Percent volume of foods
Basket Range	5	112	33.6	34.3
Uraidla	1	64	19.2	21.3
Cherryville	1	59	17.7	20.8
Marble Hill	2	36	10.8	9.4
Forest Range	1	32	9.6	5.5
Montacute	2	12	3.6	2.3
Norton Summit	3	6	1.8	2.7
Carey Gully	1	6	1.8	2.7
Lenswood	1	5	1.5	1.1
Ashton	1	1	0.3	0.1

Crop contents were removed from shot birds, in the laboratory either soon after being shot, or after the birds had been stored in a freezer. The contents were then stored in 70% ethanol for subsequent analysis. Before being dissected, a range of morphological measurements was obtained from each bird including bill length, bill width, wing length, wing span, tail length and body weight (not presented here). Age was determined from the condition and moult pattern of primary and secondary feathers. Gonads were examined during dissection to establish gender. The age and gender of birds were determined for investigating their relationship with diet (see below). Birds were aged to the nearest month up to the age of 13 months when the first moult occurs using the assumption that hatching occurs at the beginning of November. After this first year, only a minimum age could be confidently assigned to a bird based on plumage characters, notably by evidence of incomplete moult in the flight feathers. In this study birds were thus identified as juvenile up to the age of 12 months, and as adults at 13 months of age or older.

3.2.3 Measurement and analysis of crop contents

Analysis of seasonal variations in food use was based on a sample of 333 shot birds obtained over a period of seven years from 1985 to 1992. Crop contents were removed from 87 birds in summer, 80 in autumn, 82 in winter, and 84 in spring. The data from each month in these seasons were aggregated.

The data were expressed as percentage frequency of occurrence and percentage volume. The percentage frequency of occurrence of individual foods is the percentage of all crops containing that particular food, regardless of volume (i.e. "percentage of crops" for a given food item). This value was calculated by counting the number of crops that contained a particular food and dividing the number by the total number of crops examined for a particular time period or sample of birds. Statistical tests (Analysis of Variance and Tukey – Kramer HSD) were performed to determine differences between various food data samples based on season or gender.

Volumetric data were obtained using the aggregate volume method (e.g. Martin *et al.* 1946; Frith *et al.* 1974; Norman and Mumford 1982; Temby and Emison 1986) then expressed as a percentage ("percent volume"). The value for a particular food was calculated by summing the volume of all occurrences of the food and dividing this number by the volume of all foods from crops for a particular time period or sample of birds, then expressing this value as a percentage. According to Hyslop (1980) volumetric techniques probably give the most representative measure of bulk and may be applied to all food items.

Non-food items such as charcoal, bark and amber, were separated from the food component of crop samples before measuring the volume of food items. The total volume of crop food contents and volume of each of the separable components was determined by measurement involving the liquid displacement of each food item or group of items sorted from crop contents in a graduated measuring device (described by Inglis and Barstow 1960). This displaced volume was thus equal to that of the food items.

To minimise errors in the estimate of volume based on displacement, excess surface water or preserving liquid was removed from food items by blotting them on fine-grade filter paper then briefly air-drying. When food items could not be physically separated for volumetric measurement, indirect volumetric estimation was employed. This was achieved by visually calibrating food items in a crop sample against a volumetric standard selected from the sample.

Crop contents were initially sorted into fractions comprising items of similar size using screens. The volumetric proportion of each food item within a fraction was determined either by further separating of the fraction into individual foods and measuring the volumetric displacement or by the visual calibration technique described above. When dealing with small amounts of food, greater accuracy is obtained by comparative judgement than by measurement (Davison 1940).

A reference collection of seeds and other potential foods from the study area was made in order to assist in the identification of food items encountered in crop samples. Examples of foods recorded in crops are shown in Plates 3, 4 and 5. Items not immediately identifiable were either sub-sampled, hand drawn or photographed and assigned a reference code so that they could be recognised in subsequent samples. Many larger seeds were de-husked by rosellas so it was necessary to prepare de-husked samples of most seed types in the reference collection as most texts usually rely on characteristics of the husks or testa of seeds for positive identification (e.g. Anon. 1952; Anon. 1974; Flood 1986). As crop samples were stored in 70% alcohol it was not possible to grow plants from seeds to assist in identification.

Psylloidea were identified by KeithTaylor (CSIRO Division of Entomology) and Gary Taylor (University of Adelaide), Curculionidae by Dr Elwood Zimmerman (CSIRO Division of Entomology), and other insects by staff of the Entomology Unit, South Australian Research and Development Institute and the South Australian Museum.

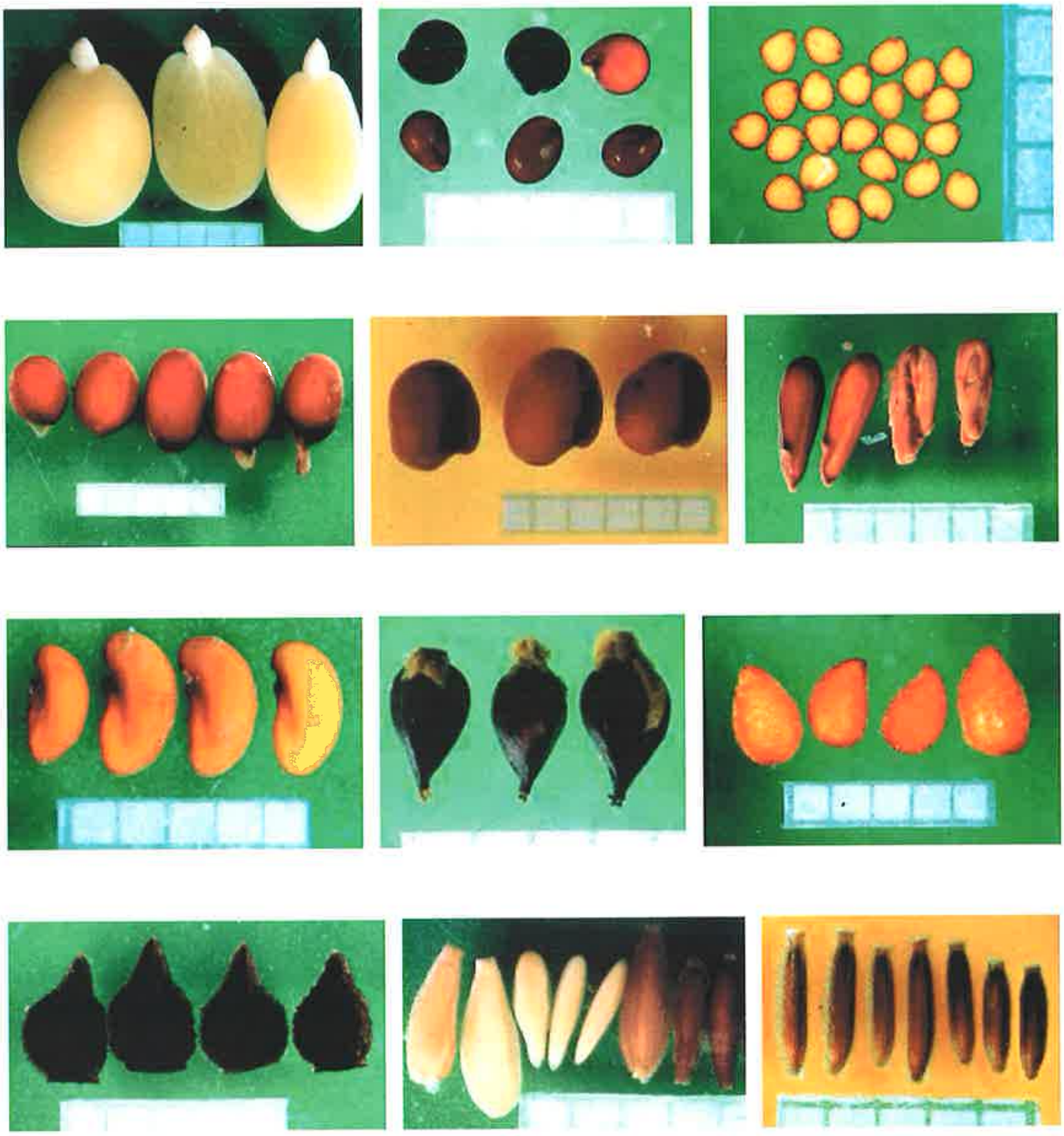

Plate 3. Some foods recorded in crops of Adelaide Rosellas collected in and around cherry orchards in the Adelaide Hills between 1985 and 1992.

A scale with 1mm graduations is shown in all photographs. Foods are seeds unless stated otherwise. The order of descriptions given is from left to right. An asterisk (*) indicates items that were obtained from a rosella crop.
Top row: dehusked *Malus sylvestris*; *Chenopodium album* (top) and *Amaranthus cruentus* (bottom); *Cerastium semidecandrum*.
Second row: *Raphanus raphanistrum**; *Trifolium subterraneum*; *Erodium moschatum**.
Third row: *Medicago arabica**; *Polygonum aviculare*; *Rubus fruticosus** (achene).
Fourth row: *Echium plantagineum*; *Sonchus oleraceus** (dehusked and with husks); *Senecio vulgaris*.

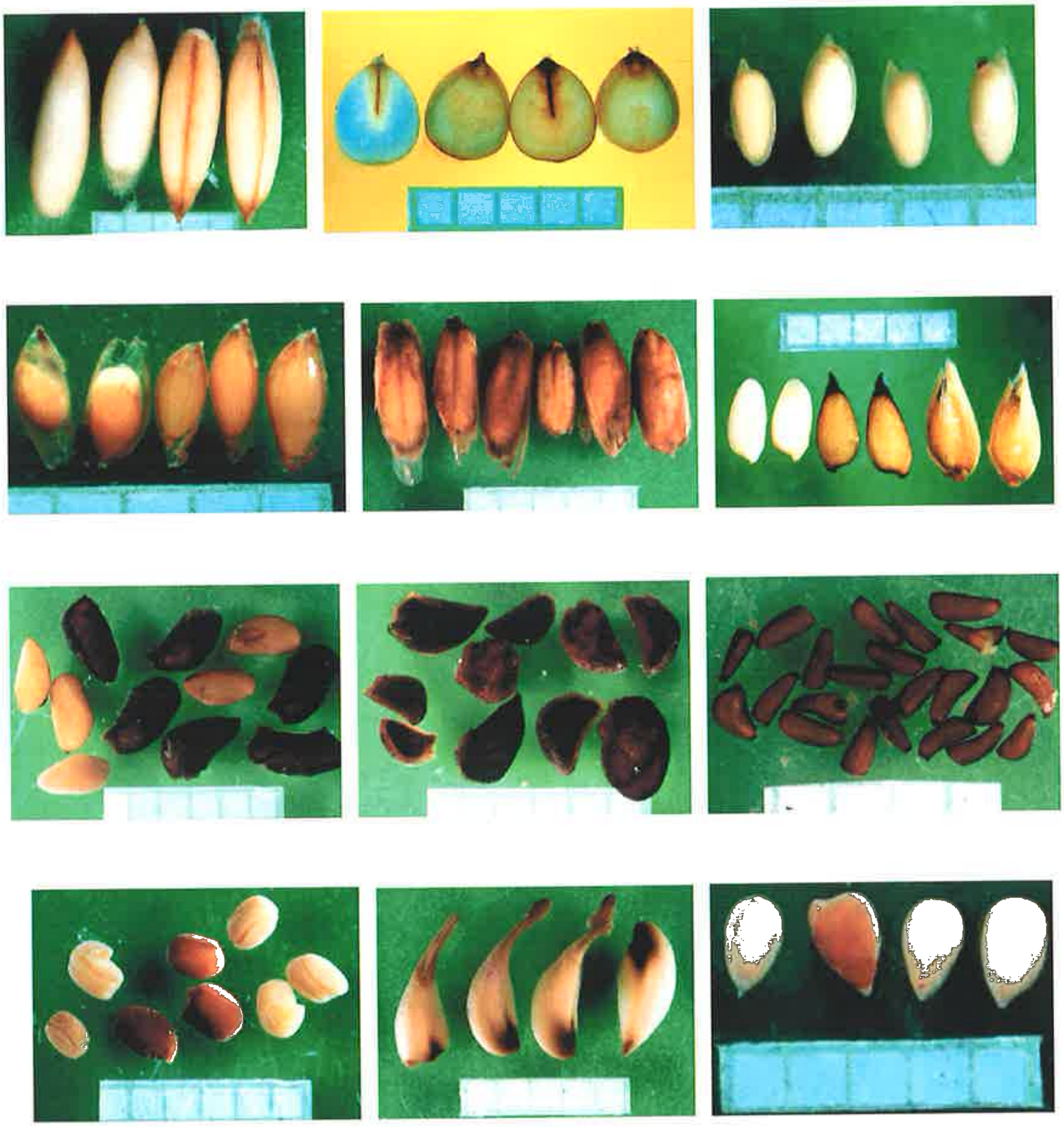

Plate 4. Some foods recorded in crops of Adelaide Rosellas collected in and around cherry orchards in the Adelaide Hills between 1985 and 1992.

A scale with 1mm graduations is shown in all photographs. Foods are seeds unless stated otherwise. The order of descriptions given is from left to right. An asterisk (*) indicates items that were taken from a rosella crop.
Top row: *Avena barbata*; *Briza maxima*; *Poa annua*.
Second row: *Digitaria aequiglumis**; *Lolium* sp.*; *Phalaris* sp.
Third row: *Eucalyptus obliqua* (five dehusked); *E. baxteri*; *Melaleuca armillaris*.
Fourth row: *Geranium molle*; *Acacia* sp. (aril); *Veronica persica* (four dehusked).

Plate 5. Some foods and food plants of Adelaide Rosellas in cherry growing districts of the Adelaide Hills.

The order of descriptions given is from left to right. An asterisk (*) indicates items that were taken from a rosella crop.
Top row: Undamaged and chewed mature *Melaleuca armillaris* fruits, Norton Summit, 25/9/92; Husks of sour-sob bulbs (*Oxalis pes-caprae*) eaten by rosellas, Basket Range, November 1992. Second row: *Poa annua* plant (winter grass), Forest Range 23/9/92; Cherry flower primordia from crop of an adult male bird, collected 12/8/85 (a scale with 1mm graduations is shown).
Third row: Flower buds on *Oxalis pes-caprae* plants (sour-sob) chewed by rosellas, Forest Range, 23/9/92; *Oxalis pes-caprae** (flower primordia; scale with 1mm graduations); *Taraxacum officinale* flower head damaged by rosellas, 23/9/92.

3.2.4 Sexing of birds

Sexing is an important prerequisite to many ecological and behavioural studies (Renner and Davis 1999). The gender of 300 Adelaide Rosella specimens was determined in the laboratory from examination of the gonads. Despite variation in plumage pattern between individuals, there were no consistent or reliable patterns of differences between the sexes of rosellas that would readily allow the determination of gender. The gender of a further 23 birds was unable to be determined from the examination of specimens. A step-wise discriminant analysis was then performed on a range of external morphometric data obtained from 300 birds of known sex in order to determine the best set of variables for discrimination. The discriminant function was then formulated based on the chosen variables of length and width of upper mandible, and upper to lower mandible span, and then applied to data obtained from the 23 birds of unknown sex. Consequently, of the sample of 323 birds, 132 were indentified as female and 191 as male[6]. These data were then used to investigate possible relationships between gender and food use in the bird sample.

3.2.5 Field observations of food use

During the course of the field study opportunistic observations of rosella feeding activity, in particular food use, were recorded to complement the crop analysis. Feeding observations were recorded from six land-use types: orchard, orchard pasture, other (adjacent orchard), roadside, native vegetation, and ornamental garden.

Feeding on cherry buds was commonly observed in a number of orchards. Feeding damage to specific varieties, in particular William's Favourite, had previously been monitored over the course of a season by Sinclair and Bird (1987) and Fisher (1991, 1993).

Over a six-day period in 1998 (August 10th to 16th) in a cherry orchard at Basket Range, continuous observations of foraging behaviour of rosellas on cherry buds were carried out. After a period of inactivity, foraging in the afternoon usually commenced between 4.00 p.m. and 4.30 p.m., with the greatest intensity of activity

[6] A further 10 birds were not sexed where the range of morphometric measurements could not be made. These birds however were included in the dietary analysis where gender relationships were not the subject of investigation (i.e. n = 333).

occurring in the period between 4.30 pm and 5.30 pm. Feeding usually ceased by 5.40 p.m., just prior to dusk. Observation periods were thus chosen to coincide with these periods of bird activity.

3.3 RESULTS

3.3.1 Frequency of foods

In the sample of 333 birds collected between 1985 and 1992 a total of 1942 food items and were recorded (Table 3.3). Within this bird sample 73 non-food items (amber, bark or charcoal) were also recorded. Rosellas fed on 172 foods from 149 species of plant or insect. Some species were a source of more than one food. For example, sour-sob *Oxalis pes-caprae* was represented in the diet by flower buds, bulbs and lower stem tissue. "Seeds" were the most common Food Group representing 97 (56%) of all foods within at least 20 families, and comprising 1216 (63%) of all food items. Rosellas also fed on at least 33 species of insects from 6 orders, fruit from 8 plant species and flower buds from 7 plant species. The frequency of occurrence of each food recorded in crops is given in Appendix 1.

The dietary study also shows that individual birds fed on a variety of foods in a feeding session. Five foods or more occurred in 61.0% of crops and at least 9 foods occurred in 68 or 20.4% of crops. Only 12.6% of crops contained two foods or less. Half of the sample (168 birds or 50.5%) had 3,4,5 or 6 foods in the crop.

Table 3.3. Number of foods according to major food groupings found in the crops of Adelaide Rosellas taken from cherry orchards in the Adelaide Hills between 1985 and 1992.

These data are based on examination of the crop contents of 333 birds. A species may be represented in more than one Food Group, e.g. soursob is represented in "bulbs", "flower buds" and "vegetative" [5] Food Groups.

Food Group	Number of foods	Number of food items	Minimum number of families represented
seeds	97 [1]	1216	20
kernel	6 [2]	19	3
bulb	3 [2]	48	1
flower parts	7 [2]	110	5
fruit	8 [2]	238	3
vegetative[5]	4 [2]	46	1
insect	47 [3]	265	6[4]
Total	172	1942	

[1] 96 spp.
[2] corresponds to the number of species
[3] at least 33 species, some represented by adult and immature stages
[4] represents Orders only
[5] non-reproductive parts of plants

"Seeds or kernels" were the most frequently occurring Food Groups based on total numbers of food items recorded in the crops in each season (Figure 3.5). "Seeds or kernels" comprised at least 59% of food items recorded for any one season, including up to 71% of all items in summer. Other frequently recorded items were in the following food groups: "flower parts" (13% in winter), "fruit flesh" (18% in summer) and "insects" (14% in autumn).

Most birds used "Seeds or kernels" in each season (Figure 3.6), being recorded in at least 90% of the crops examined. On a seasonal basis, other highly represented Food Groups were "fruit flesh" (eg 78% of birds taken in autumn) and "insects" (48% of birds taken in autumn and spring respectively).

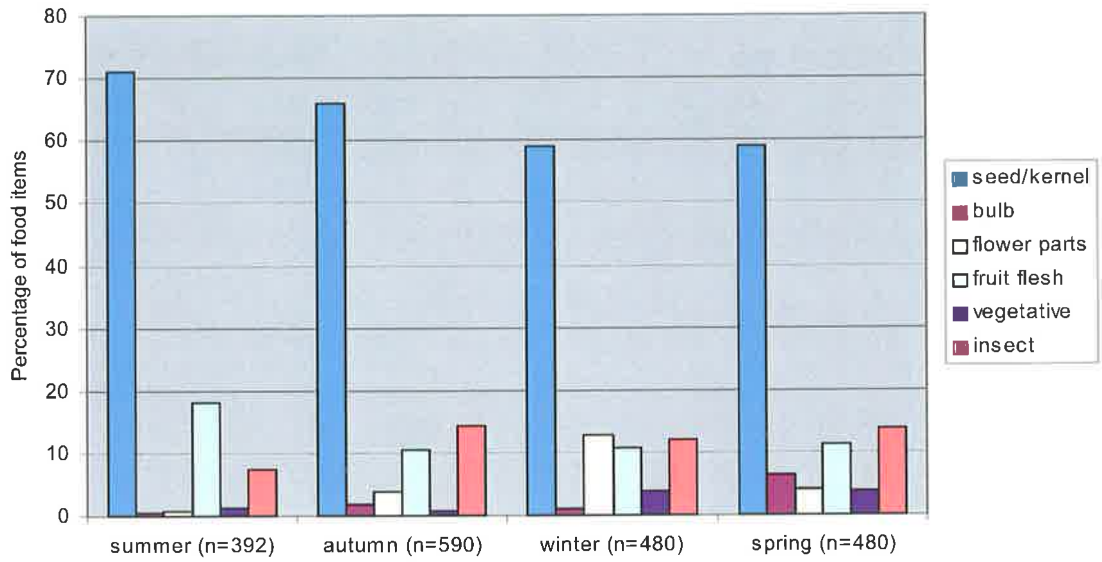

Figure 3.5. Percentage of food items in the crops of Adelaide Rosellas that belonged to six possible food groups in each season.

Crop contents were recorded from birds taken in and around cherry orchards between 1985 and 1992. These data are based on 392 items recorded in summer (87 birds), 590 items in autumn (80 birds), 480 items in winter (82 birds) and 480 items in spring (84 birds). The six food groups are shown on the right of the figure.

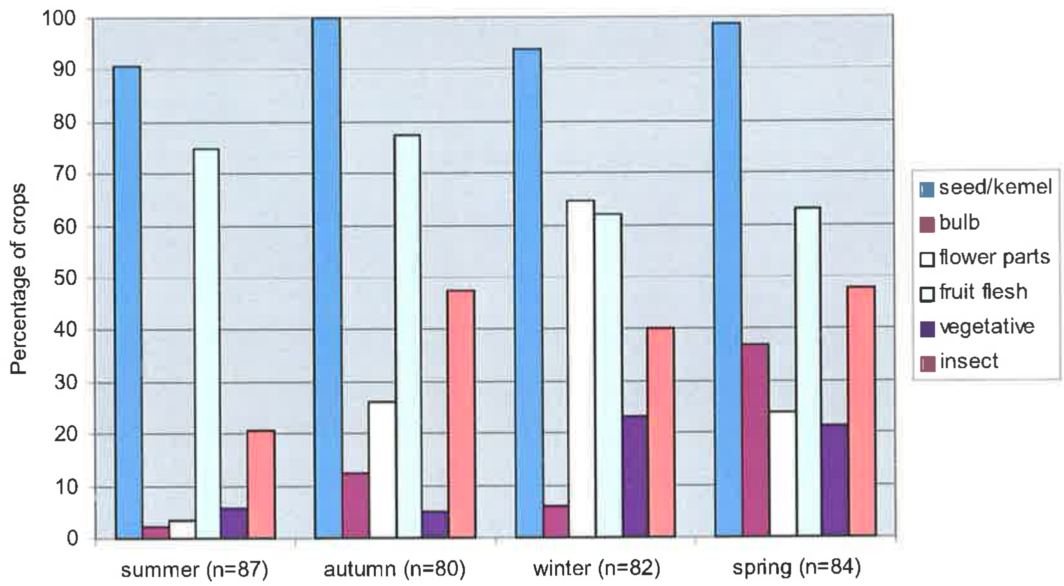

Figure 3.6. Percentage of crops of Adelaide Rosellas in which foods were recorded belonging to six possible food groups in each season.

Crop contents were recorded from birds taken in and around cherry orchards between 1985 and 1992. These data are based on 87 birds collected in summer, 80 in autumn, 82 in winter and 84 in spring. The six food groups are shown on the right of the figure.

The mean number of foods per crop (Table 3.4) was lowest in January (4.2 items) and highest in May (7.7). The mean number of foods per crop over all months was 5.8, and for each of the months November to February, the mean was less than five food items per crop. On a seasonal basis, mean number of foods per crop (Table 3.5) was lowest in summer (4.5) and highest in autumn (7.4); winter and spring were similar (5.9 and 5.7 respectively).

Table 3.4. Mean number of foods per crop from Adelaide Rosellas taken in each month of the year during the period 1985-1992 in and around cherry orchards in the Adelaide Hills. Non-food items were represented by amber, bark or charcoal.

Month	Number of crops	Number of non-foods per crop Mean ± s.e.	Number of foods per crop Mean ± s.e.
January	32	0.4 ± 0.11	4.2 ± 0.4
February	26	0.2 ± 0.08	4.6 ± 0.6
March	26	0.2 ± 0.07	6.8 ± 0.6
April	27	0.1 ± 0.06	7.6 ± 0.7
May	27	0.1 ± 0.06	7.7 ± 0.7
June	25	0	5.4 ± 0.6
July	29	0.03 ± 0.03	5.9 ± 0.6
August	28	0.1 ± 0.06	6.3 ± 0.6
September	32	0.2 ± 0.06	6.0 ± 0.4
October	26	0.4 ± 0.10	6.2 ± 0.4
November	26	0.4 ± 0.10	4.9 ± 0.7
December	29	0.5 ± 0.11	4.7 ± 0.5
All months	333	0.2 ± 0.02	5.8 ± 0.2

Table 3.5. Seasonal variation in number of foods recorded per crop from Adelaide Rosellas taken in each season during the period 1985-1992 in and around cherry orchards. Data shown are means ± standard error (s.e.).

Sample period	Number of crops	Number of foods per crop mean ± s.e.
summer	87	4.5 ± 0.3
autumn	80	7.4 ± 0.4
winter	82	5.9 ± 0.3
spring	84	5.7 ± 0.3
all seasons	333	5.8 ± 0.2

In the sample of 323 birds of known sex the mean number of foods per crop was similar for females (5.8 ± 0.2; n=132) and males (5.9 ± 0.2; n=191) but differed significantly between seasons (Table 3.6).

Table 3.6. Mean number of foods per crop for each season of male and female Adelaide Rosellas collected in and around cherry orchards between 1985 and 1992.

A two way analysis of variance revealed no significant difference between the sexes (F=0.07; df=1, 315; p=0.78) and no interaction between sexes and season (F=2.24; df=3, 315; p=0.08) but there was a significant difference between seasons (F=14.4; df=3, 315; p<0.0001). A Tukey-Kramer HSD test revealed that the number of foods per crop in autumn was significantly greater than all other seasons, and those in summer significantly less than all other seasons. The number of foods per crop in spring and winter were similar. Number of crops examined are shown in parentheses.

	Number of foods per crop mean ± s.e. (n)				
Sample	summer	autumn	winter	spring	all seasons
female	4.2 ± 0.4 (37)	8.0 ± 0.6 (35)	5.1 ± 0.5 (30)	5.9 ± 0.5 (30)	5.8 ± 0.2 (132)
male	4.7 ± 0.4 (46)	7.0 ± 0.5 (44)	6.3 ± 0.5 (47)	5.6 ± 0.4 (54)	5.9 ± 0.2 (191)
both	4.5 ± 0.3 (83)	7.4 ± 0.4 (79)	5.8 ± 0.4 (77)	5.7 ± 0.3 (84)	5.8 ± 0.2 (323)

The majority of food items recorded in the total sample of birds (n=333) were not indigenous to the study area (Figure 3.7). Non-indigenous foods were recorded in the crops of all birds taken in each season, except summer when 91% of crops contained non-indigenous foods. On a seasonal basis indigenous foods were recorded in as few as 44% of crops (winter) and as many as 68% of crops (autumn).

The proportion of non-indigenous food items to all food items in the diet was similar between seasons ranging from 69% in summer and autumn to 79% in winter (Figure 3.9). The only native seed sources of importance in the diet were from the "tree crops" *Eucalyptus* spp. and *Acacia* spp. (Table 3.7). Eucalypt seed (*E. obliqua*, *E. baxteri*, *E. viminalis* or *Eucalyptus* sp.) occurred most frequently in autumn (50% of birds) and *Acacia* seed (from *A. pycnantha* or other *Acacia* sp.) occurred only in 28% of birds taken in summer. The lowest representation of native seed in the diet was in winter, a time of the year when intensive feeding on the buds of cherry trees occurred.

Table 3.7. The most frequently occurring seeds from indigenous species in the diet of Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992.

	Percentage occurrence in crop samples			
Food	Summer	autumn	winter	spring
Eucalyptus obliqua / *baxteri*	13.8	37.5	6.1	14.3
E. viminalis	5.7	11.3	0	4.8
Eucalyptus sp. (unidentified)	0	1.3	2.4	0
Acacia pycnantha	25.0	0	0	0
Acacia sp. (unidentified)	2.0	0	0	0
Eucalyptus spp.	19.5	50.0	8.6	19.0
Acacia spp.	27.6	0	0	0

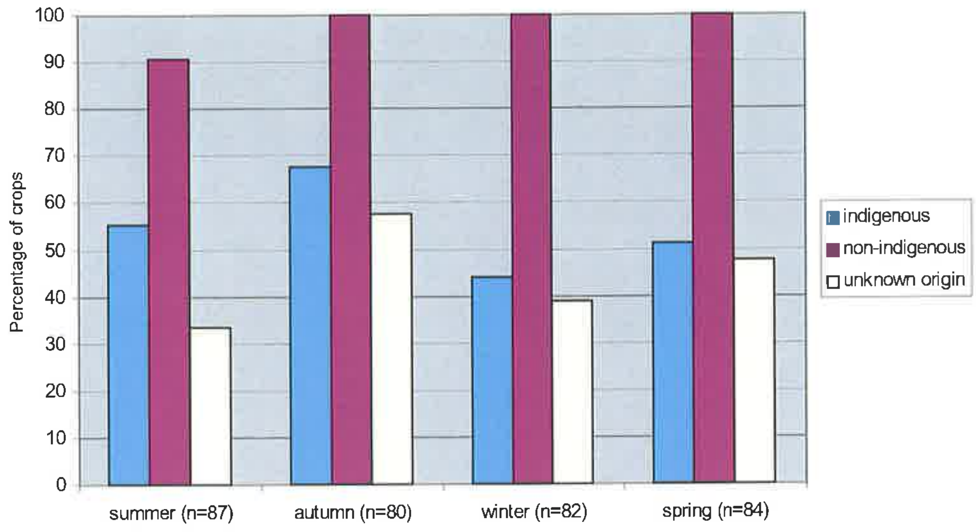

Figure 3.7. Percentage of crops containing indigenous and non-indigenous food types for Adelaide Rosellas collected in and around cherry orchards between 1985 and 1992.

The number of crops examined in each season are given in parentheses. The food types are shown on the right of the figure.

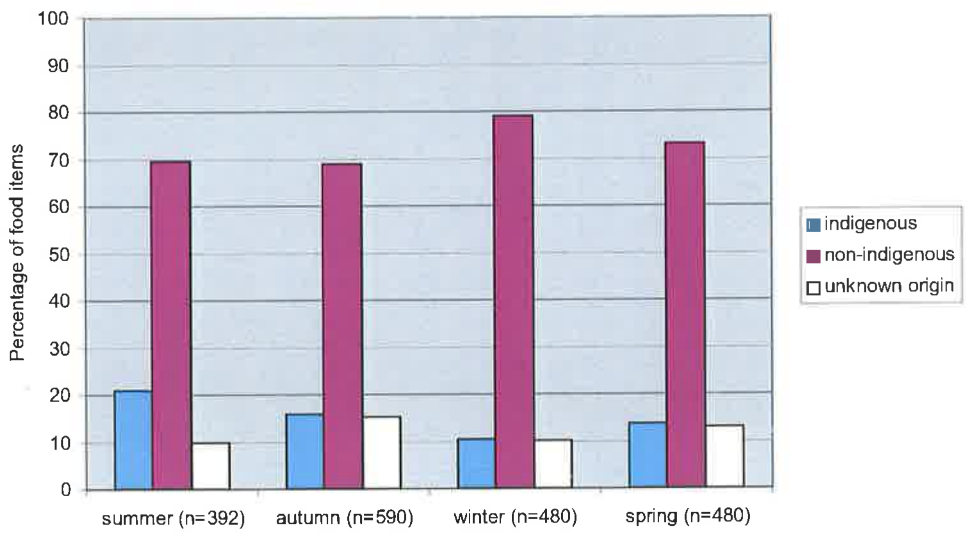

Figure 3.8. Food types recorded in the crops of Adelaide Rosellas collected in and around cherry orchards between 1985 and 1992, expressed as a percentage of all food items recorded for each season.

The total number of food items recorded for each season are shown in parentheses. The number of crops examined in each season were as follows: summer (87), autumn (80), winter (82) and spring (84). The food types are shown on the right of the figure.

The frequency of individual foods recorded in each season in the sample of 333 Adelaide Rosellas taken from cherry orchards in the Adelaide Hills during the period from 1985 to 1992 is also given in Appendix 1. Twenty foods individually occurred in more than 10% of all birds (n=333) collected from all months of the year (Table 3.8). Non-food items (i.e. amber, bark or charcoal) were found in 21% of crop samples and unidentified seeds were recorded in 19% of crops.

Apple flesh (i.e. the fleshy pericarp) was the most frequently occurring food item (39% of crops; present all months except November) followed by the seeds of sub-clover (24%; all months except October), seeds of apple (22%; all months except November), seeds of *Raphanus raphanistrum* (21%; all months except December), and seeds of *Chenopodium album* (21%; all months except October to February). The most frequently occurring flower buds in crops were from sweet cherry (17%; present each month from March to September) and sour-sob (13%; present each month from July to October).

Insects were recorded in 38% of crops. Immature stages of the Psylloidea (plant lice) occurred in 35% of crops, represented by nymphs of Psyllidae: Spondyliaspidinae and Triozidae.

Table 3.8. Individual foods occurring in more than 10% of all crops from a sample of 333 Adelaide Rosellas taken in around cherry orchards between 1985 and 1992.

			Months recorded in crops (✓)											
Food	Percentage of crops	No. of crops	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Malus sylvestris (flesh)	39.0	130	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Trifolium subterraneum (seed)	23.7	79	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Malus sylvestris (seed)	21.9	73	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Raphanus raphanistrum (seed)	21.0	70	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Chenopodium album (seed)	21.0	70			✓	✓	✓	✓	✓	✓	✓			
Plantae: Non-food item (amber, bark or charcoal)	20.7	69	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
Plantae: unidentified seed	18.6	62	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Eucalyptus obliqua / E.baxteri (seed)	17.7	59	✓	✓	✓	✓	✓		✓	✓		✓		✓
Polygonum aviculare (seed)	17.1	57	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Prunus avium (flower bud)	17.1	57			✓	✓	✓	✓	✓	✓	✓			
Briza spp. (seed)	14.7	49	✓	✓	✓	✓	✓		✓		✓		✓	✓
Poa annua (seed)	14.7	49	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓
Rubus fruticosus (achene)	14.7	49		✓	✓	✓	✓	✓	✓	✓				✓
Oxalis pes-caprae (bulb)	13.8	46		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Prunus avium (flesh)	13.5	45	✓	✓									✓	✓
Oxalis pes-caprae (bud)	12.9	43							✓	✓	✓	✓		
Stellaria media (seed)	12.3	41	✓						✓	✓	✓	✓	✓	
Spondyliaspidinae: (nymph or lerp)	11.7	39	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	
Triozidae: *Schedotrioza multitudinea* (nymph)	11.7	39						✓	✓	✓	✓	✓	✓	✓
Hypericum perforatum (seed)	11.7	39	✓	✓	✓	✓	✓	✓		✓			✓	✓
Avena sp. (seed)	11.4	38	✓		✓		✓				✓	✓	✓	✓
Lepidoptera: immature stage	11.1	37		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	

In autumn and winter, apple fruit was the most frequently recorded food item (58% and 55% of birds respectively) and was found in over 20% of birds in spring and summer (Table 3.9). Apple seed was present in the diet through all seasons and was most frequently recorded in autumn and winter (26% and 38% of birds respectively). From September to November (spring), soursob bulbs were the most frequently occurring food (36% of birds) but in other seasons it was a relatively minor food in the diet, particularly in summer and winter. The seed of sub-clover *Trifolium subterraneum* was a prominent food in the diet particularly in autumn (48% of birds), summer (24%) and winter (20%). Fat hen *Chenopodium album* seed was another prominent food in autumn and winter, occurring in 40% and 44% respectively of birds examined for these seasons. The seed of wild radish *Raphanus raphanistrum* was eaten by birds in all seasons and was recorded in 28% of crops in winter. Flower buds of soursob *Oxalis pes-caprae* were a frequently recorded food in winter and spring (30.5% and 21.4% of crops respectively). Seed of blackberry *Rubus fruticosus* was found in 31.3% of crop samples taken in autumn, but was not recorded in spring. The seed of wireweed *Polygonum aviculare* was a frequently occurring food in autumn and winter (33.8% and 23.2% of birds respectively) but in other seasons occurred in less than 10% of birds examined.

Cherry fruit (i.e. the fleshy mesocarp) was the most frequently recorded food in summer (37% of birds) but did not appear in the diet in other seasons. Cherry flower primordia were highly represented in the diet in autumn (24% of birds) and winter (43% of birds).

Seeds of 16 grass species were also found in crop samples. Seed of two native grasses (*Stipa* sp. and *Danthonia* sp.), two cultivar species (wheat and barley) and twelve weed grass (non-cultivar) species were identified. The latter species were the most frequently occurring grasses in the diet. The seed of wild oat *Avena* sp. was a prominent food in spring and summer (22.6% and 18.4% of birds), but was not recorded in the crops in winter. The quaking grasses, *Briza maxima* and *B. minor*, appeared in the diet in all seasons but were more prominent in summer and autumn (23.0% and 26.3% of crops). Rye grass *Lolium* sp. and winter grass *Poa annua* seeds were found in crops from each season with rye grass seeds prominent in winter (17.1% of crops) and winter grass seeds prominent in winter and spring (19.5% and 27.4% of crops).

Seasonally, the most frequently occurring native foods in the diet, other than insects, were the seeds of messmate stringybark *Eucalyptus obliqua* or brown stringybark *E. baxteri*, (37.5% of birds in autumn), and seeds of golden wattle *Acacia pycnantha* which were recorded in 25% of birds in summer but not recorded in other seasons.

Insects appeared in the diet in all seasons. The insect component of the diet was dominated by immature stages of Psylloidea, represented by the Spondyliaspidinae and two *Schedotrioza* species (Triozidae). In winter *Schedotrioza* spp. nymphs were found in the crops of 32.5% of birds and one species of *Schedotrioza*, *S. multitudinea*, was recorded in 29.8% of crops in spring. In autumn the main insect groups in the diet were nymphs of Spondyliaspidinae (25% of crops) and lepidopteran larvae (23.8% of crops).

Non-food items (amber, bark or charcoal) were also recorded in crops. In spring and summer non-food items were recorded in over 30% of crops examined, but in autumn and winter a markedly lower proportion of crops contained non-food items (13.8% and 3.7% respectively).

Table 3.9. Individual foods occurring in more than 10% of all crops in any season for the sample of 333 Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992.

Food items are seeds unless otherwise indicated. The number of crops examined was 87 collected in summer, 80 in autumn, 82 in winter and 84 in spring.

SUMMER		AUTUMN		WINTER		SPRING	
Food	**% crops**	**Food**	**% crops**	**Food**	**% crops**	**Food**	**% crops**
Prunus avium (fruit)	36.8	*Malus sylvestris (fruit)*	57.5	*Malus sylvestris* (fruit)	54.9	*Oxalis pes-caprae* (bulb)	35.7
Non-food item (amber, bark or charcoal)	31.0	*Trifolium subterraneum*	47.5	*Chenopodium album*	43.9	Non-food item (amber, bark or charcoal)	33.3
Acacia pycnantha	25.3	*Chenopodium album*	40.0	*Prunus avium* (bud)	42.7	*Cerastium semidecandrum*	33.3
Trifolium subterraneum	24.1	*Eucalyptus obliqua/E.baxteri*	37.5	*Malus sylvestris*	37.8	*Stellaria media*	31.0
Briza spp.	23.0	*Polygonum aviculare*	33.8	*Oxalis pes-caprae* (bud)	30.5	Triozidae: *Schedotrioza multitudinea* (nymph)	29.8
Malus sylvestris (fruit)	21.8	*Rubus fruticosus*	31.3	*Raphanus raphanistrum*	28.0	*Poa annua*	27.4
Avena sp.	18.4	*Hypericum perforatum*	27.5	Plantae: unidentified seed	25.6	*Malus sylvestris* (fruit)	23.8
Rubus fruticosus	17.2	*Briza* spp.	26.3	*Polygonum aviculare*	23.2	*Avena* sp.	22.6
Raphanus raphanistrum	14.9	*Malus sylvestris*	26.3	*Trifolium subterraneum*	19.5	*Arctotheca calendula*	22.6
Eucalyptus obliqua/ E.baxteri	13.8	*Spondyliaspidinae*: (nymph or lerp)	25.0	*Poa annua*	19.5	*Oxalis pes-caprae* (bud)	21.4
Senecio vulgaris	13.8	*Hypochoeris radicata*	25.0	Triozidae: *Schedotrioza marginata* (nymph)	18.3	*Raphanus raphanistrum*	19.0
Medicago spp.	12.6	Plantae: unidentified seed	23.8	*Lolium* sp.	17.1	*Oxalis pes-caprae* (stem)	19.0
Rubus fruticosus (fruit)	12.6	Lepidoptera: immature stage	23.8	*Oxalis pes-caprae* (stem)	17.1	Plantae: unidentified seed	17.9
Hypericum perforatum	11.5	*Prunus avium* (bud)	23.8	*Stellaria media*	17.1	*Malus sylvestris*	15.5
Spondyliaspidinae: (nymph or lerp)	11.5	*Raphanus raphanistrum*	22.5	Lepidoptera: immature stage	15.9	*Prunus avium* (fruit)	15.5
Hypochaeris radicata	10.3	Diptera: immature stage	18.8	*Amaranthus cruentus*	15.9	*Erodium moschatum*	15.5
Poa annua	10.3	Non-food item (amber, bark or charcoal)	13.8	Triozidae: *Schedotrioza multitudinea* (nymph)	14.6	*Eucalyptus obliqua/E.baxteri*	14.3
		Sonchus oleraceus	13.8	*Rubus fruticosus*	11.0	Insecta: unidentified, immature stage	11.9
		Oxalis pes-caprae (bulb)	12.5	*Anagallis arvensis*	11.0	*Sonchus oleraceus*	10.7

3.3.2 Volumetric measurements of food items

The percent volume of each food recorded in crops is given in Appendix 2. The volume of food measured within individual crops ranged from 0.05 mL to 12.30 mL. Up to 18 different foods were recorded in a single crop. The seasonal range of crop volumes recorded was 0.05 – 5.40 mL (summer), 0.40 – 12.30 mL (autumn), 0.10 – 9.40 (winter) and 0.10 – 8.45 (spring). Figure 3.9 shows that as the number of foods per crop increases the volume of food per crop tends to increase. The majority of crops with three foods or less contained less than 1.0 mL food volume. As the number of foods per crop increased there was generally a diminishing proportion of crops within the lowest crop volume class (0 – 1.0 mL). Within the smallest crop volume class 72 crops (21.6% of all crops, or 57.6% of this volume class) contained at least four foods and 50 crops contained at least 5 foods.

The mean volume of food per crop (± s.e.) ranged seasonally from 1.35 ± 0.12 mL in summer to 3.15 ± 0.27 mL in autumn for both sexes (Table 3.10). For all seasons mean volume per crop was 2.31 ± 0.18 mL for females and 2.09 ± 0.14 mL for males compared to 2.17 ± 0.11 mL for birds of both sexes.

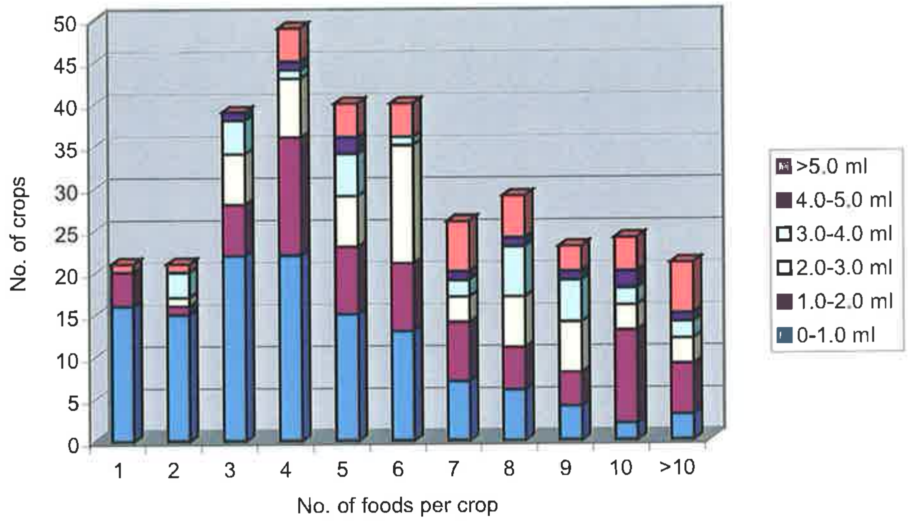

Figure 3.9. Relationship between the volume of food in crops and the number of foods in a crop.

These data are based on a sample of 333 Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992. The number of foods per crop were grouped into 11 possible "crop food number" classes and individual crop volumes were grouped into one of six possible volume intervals to show the relationship between volume and number of foods per crop. The crop volume classes are shown on the right of the figure.

Table 3.10. Mean volume of food in the crops of Adelaide Rosellas taken in and around cherry orchards between1985 and1992, in each season and for each sex.

A two way analysis of variance revealed no significant difference in volume of food per crop between the sexes ($F = 1.07$, df=1, 315; $p = 0.302$) and no interaction between gender and season ($F = 0.48$, df=3, 315; $p = 0.696$) but there was a significant difference between seasons ($F = 12.60$, df=3, 315; $p < 0.001$). A Tukey-Kramer HSD test revealed that the volume of foods per crop in autumn was significantly greater than in all other seasons, and the volume in summer significantly less than spring. There was no significant difference in the volume of foods per crop between spring and winter, nor between summer and winter. The values given in this table are mean volume of food in mL ± standard error and number of birds (n). A total of 323 sexed birds were analysed.

	Volume (mL) of food per crop mean ± s.e. (n)				
	summer	autumn	winter	spring	all
female	1.25 ± 0.15 (37)	3.45 ± 0.41 (35)	2.30 ± 0.42 (30)	2.30 ± 0.32 (54)	2.31 ±- 0.18 (132)
male	1.42 ± 0.17 (46)	2.91 ± 0.35 (44)	1.99 ± 0.25 (47)	2.08 ± 0.28 (30)	2.09 ± 0.14 (191)
both	1.35 ± 0.12 (83)	3.15 ± 0.27 (79)	2.11 ± 0.22 (77)	2.15 ± 0.21 (84)	2.17 ± 0.11 (323)

Seeds or kernels were the most important food type for each season based on percent volume (Figure 3.10). By volume, the highest representation of seeds or kernels in the diet was in winter (70% of all foods) and lowest was in spring (44%). The contribution of "bulbs" to the diet was minor or negligible in all seasons except spring where "bulbs" represented 16% of food items by volume. This was almost entirely represented by one food, the bulbs of sour-sob *Oxalis pes-caprae*. "Fruit flesh" was a significant food type particularly during summer and autumn when it represented one third of the diet by volume. "Flower parts" comprised 4% of the diet in winter and 5% in spring but this food type was only present in negligible amounts in other seasons. Insects or invertebrates were also a minor food group based on percent volume, and were most prominent in the diet in summer (2.2%).

In the sample of 333 birds from all months there were five foods that each represented more than 5% of the volume of all food items (i.e. 76) - apple fruit (18.3% by volume of all foods), wild radish seed (9.4%), apple seed (8.6%), *Trifolium* spp. seed (8.4%; mainly sub-clover) and olive fruit (5.1%). A further 16 foods each comprised between 1% and 5% by volume of all foods, and another 55 foods each contributed less than 1% to the total volume. In each season, individual foods comprising at least 1% of the total volume collectively represented over 90% of the volume of all foods (Table 3.11).

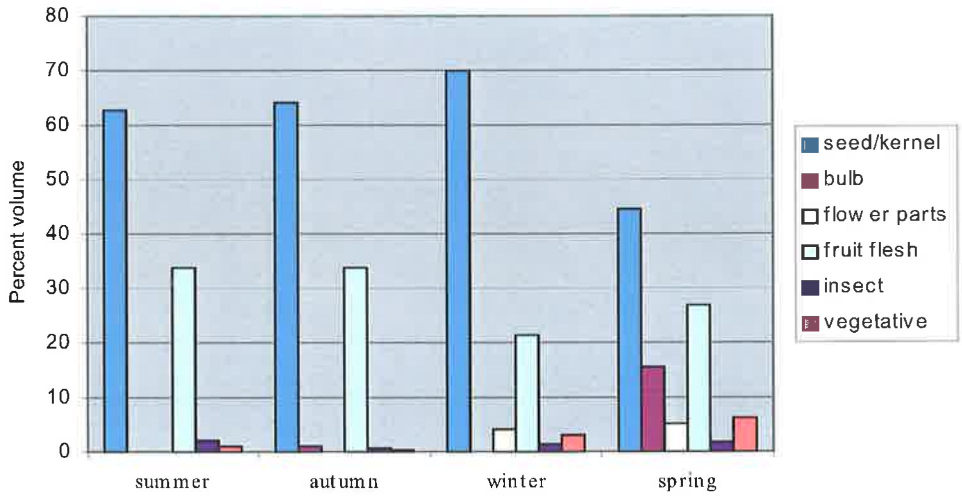

Figure 3.10. Percent volume of foods eaten in each season by Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992 based on six Food Groups.

The total number of crops examined from each season were 87 in summer, 80 in autumn, 82 in winter, and 84 in spring. The types of foods are shown on the right of the figure.

Table 3.11. The number of foods eaten by Adelaide Rosellas that each contributed at least 1% by volume of all foods in each season, and the percent volume of the seasonal diet that these foods collectively contributed.

These data are based on the crop contents of a total of 333 birds collected in and around cherry orchards between 1985 and 1992. The total numbers of foods recorded in each season were summer (53), autumn (59), winter (45) and spring (53).

Sample	No. of foods ≥1% by volume	Total percent volume contributed by these foods
summer	20	93.8
autumn	17	93.4
winter	15	91.5
spring	18	93.1

There were seven foods (cherry flesh, apple flesh, soursob bulb, *Trifolium* seed, apple seed, olive flesh and wild radish seed) that each comprised more than 10% of the diet by volume in at least one season (Figure 3.11). Of these foods, three foods represented 41.9% by volume of the summer diet, three foods represented 47.6% of the autumn diet, three foods represented 51.4% of the winter diet and four foods represented 49.1% of the spring diet.

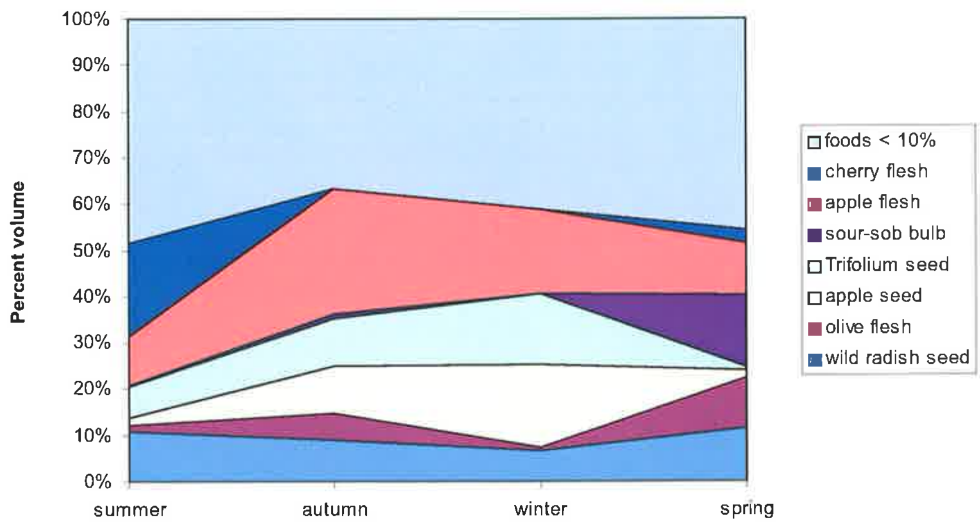

Figure 3.11. Percent volume of seven food groups that represented at least 10% by volume of foods in any season for Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992.

The seven food groups are shown on the right of the figure. The area curve for each food is based on four values representing pooled data for each season. The group "foods <10%" comprised a different suite of foods in each month or season, none of which contributed greatly at any one time. The total number of crops examined for each season were 87 in summer, 80 in autumn, 82 in winter and 84 in spring.

Seasonally, the most important foods by percentage volume (Figure 3.11) were soursob bulb in spring (15.6%), cherry flesh in summer (20.1%) and apple flesh in autumn and winter (27.0% and 18.2% respectively). The seasonal peak in consumption of apple flesh was autumn (27% by volume) when cherry flesh was not recorded.

In summer, four foods represented 50% of the diet by volume: cherry fruit (20.1%), wild radish *Raphanus raphanistrum* seed (11.0%), apple fruit (10.8%) and seeds of *Acacia pycnantha* (8.1%). Cherry fruit and seed of *A. pycnantha* were not recorded in the autumn diet when apple fruit was the principal food eaten based on volume, representing 27% of all foods. Apple seed (10.3%) and seed of *Trifolium* spp. (10.2%; mainly sub-clover) were two other prominent foods in autumn. Apple fruit and apple seed (18.2% and 17.9%) dominated the winter sample with *Trifolium* spp. seed (mainly sub-clover) also a prominent food (15.2%). Soursob bulb (15.6%) was the most consumed food by volume in spring followed by wild radish seed (11.5%), apple fruit (11.1%) and olive fruit (10.9%).

Each food in the diet was grouped within one of four possible food source categories: "weeds" (i.e. alien broad-leaf and non-agricultural grass species), "horticultural" (commercial horticultural crops, i.e. apple fruit, apple seed, cherry fruit, cherry flower primordia), "native" (plant foods indigenous to the study area) or "other" (e.g. pasture species, insects) (Table 3.12). "Weeds" formed a greater portion of the diet (41.9% by volume) than any other food category. Seasonally, weeds were of greatest importance in spring and summer when 64.0% and 39.5% of the diet by volume respectively were represented by this food source. "Horticultural" foods were the major dietary component in autumn (37.5%) and winter (38.1%), represented mainly by apple fruit and seed, and a lesser extent by cherry primordia. Native foods were a minor component of the diet in all seasons but were most prominent in summer (13.5% of all foods by volume).

Table 3.12. Contribution by volume of indigenous and non-indigenous food sources to the seasonal diet of Adelaide Rosellas collected in and around cherry orchards between 1985 and 1992.

The food sources in the first column are: 'weeds' (ie alien broad-leaf and non-agricultural grass species), 'horticultural crops' (commercial horticultural crops, i.e. apple fruit, apple seed, cherry fruit, cherry flower primordia), 'indigenous' (foods indigenous to the study area, including plants and insects), and 'other' (e.g. pasture spp., other insects). The percent volume of all foods in each of the categories is shown for each season. The total number of crops examined for each season were 87 in summer, 80 in autumn, 82 in winter and 84 in spring.

	Percent volume of foods from each food source				
Food source	summer	autumn	winter	spring	all months
Introduced					
weeds	39.5	35.1	30.3	64.0	41.9
horticultural crops	32.6	37.5	38.1	15.9	31.4
Indigenous					
plants or insects	13.5	5.0	1.1	2.8	4.9
Other	14.4	22.4	30.5	17.3	21.8

The percentage volume of non-indigenous foods (Figure 3.12) was lowest in summer (81.9%) and highest in winter (95.0%). Indigenous foods, however, comprised only 1% of the diet in winter and up to 17% of the diet in summer by aggregate volume.

All indigenous foods excluding invertebrates (i.e. seed) represented 13.3% by volume of the diet in summer (mostly *Acacia* spp.), 4.7% in autumn (mostly *Eucalyptus* spp.), and less than 1.5% in spring (Table 3.13). Foods of indigenous species represented only 1.05% of the diet in winter and comprised seeds (0.19%) and psyllid insects (0.86%). The highest seasonal representation of cherry primordia in the diet was in winter when foods of indigenous species were the least represented.

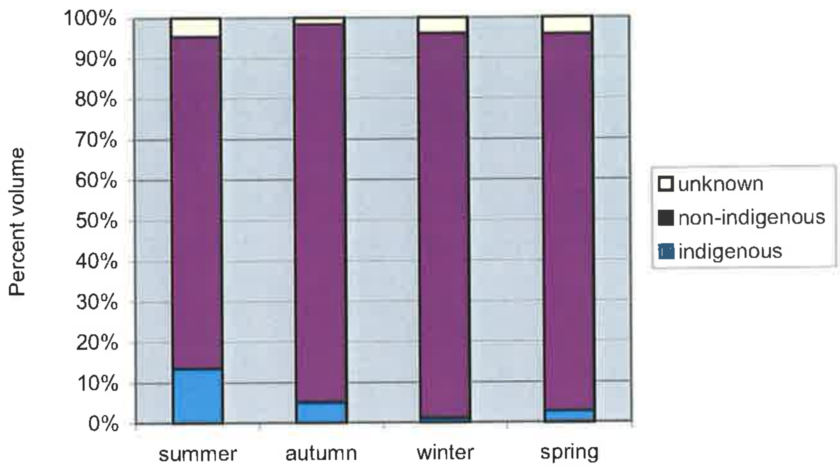

Figure 3.12. Contribution of indigenous and non-indigenous foods to the diet of Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992 based on the percentage volume of all foods.

The food categories are shown on the right of the figure. The total numbers of crops examined for each season were 87 in summer, 80 in autumn, 82 in winter, and 84 in spring.

Table 3.13. Percent volume of major foods from indigenous species in the diet of Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992.

The total numbers of crops examined for each season were 87 in summer, 80 in autumn, 82 in winter and 84 in spring.

	Percent volume			
Food	summer	autumn	winter	spring
Acacia sp., seed/aril	2.9	0	0	0
Acacia pycnantha, seed/aril	8.13	0	0	0
Danthonia sp., seed	0.07	0	0	0.03
Eucalyptus obliqua / baxteri, seed	0.35	1.6	0.14	0.56
Eucalyptus viminalis, seed	0.35	1.48	0	0.46
Eucalyptus sp., seed	0	0.03	0.05	0
Geranium solanderi, seed	0.87	0.04	0	0.21
Oxalis perennans, seed	0	0.33	0	0.04
Stipa sp., seed	0.64	1.19	0	0
Bursaria spinosa, seed	0	0.02	0	0
ALL native seeds	13.31	4.69	0.19	1.30
psyllid (nymph or lerp)	0.22	0.33	0.86	1.47
ALL native foods	13.53	5.02	1.05	2.77

3.3.3 Prominent foods in the diet

Several food sources are examined below in some greater detail given their prominence in the diet or the impact potential of rosellas on the food source. The food sources investigated here are apples (seed and flesh), soursob plants (bulbs, flower buds and stem tissue), cherry buds (flower primordia) and insects.

Apple

The accessibility of commercially grown apples throughout the study area to rosellas was generally reflected by the crop contents. Apple flesh was the most important food item recorded, based on the overall volumetric percentages (18%). Apple flesh was the major food item in autumn (27% of food by volume) occurring in 58% of crops from this sample (Figure 3.13). In winter, apple flesh was again the major food item (18% of food by volume), occurring in 55% of crops from this sample. Mean volume of apple flesh per crop sample was 0.40 ± 0.05 mL compared to 2.17 ± 0.11 mL for all foods. On a seasonal basis the mean volume of apple flesh per crop was highest in autumn and winter. There was a significant difference in mean volume of apple flesh consumed per bird (female only) between autumn and each of the other seasons, and between male and female birds (Table 3.14).

Seasonally, apple seed was more prominent in the diet in autumn and winter than in other seasons. In autumn and winter 26% and 38% of birds respectively fed on this food compared to 16% and 9% respectively in spring and summer. Apple seed was one of only five foods that individually represented at least 5% of all foods by volume in the diet analysis. On a seasonal basis, apple seed comprised only 1.7% by volume of foods in each of spring and summer. However, in autumn and winter, apple seed comprised 10% and 18% respectively of all foods by volume (Figure 3.13). There was no significant difference in mean volume of apple seed consumed per bird between male and female birds, but seed consumed in each of autumn and winter differed from other seasons (Figure 3.14).

Table 3.14. Mean volume of apple flesh recorded in crops of male and female Adelaide Rosellas collected in and around cherry orchards between 1985 and 1992.

These results are based on a sample of 323 birds of known sex. Analysis of variance (ANOVA) revealed a significant difference in mean volume of apple flesh per bird between seasons ($F=9.835$; df = 3, 315; $p<0.0001$), between sexes ($F=6.389$, df = 1, 315; $p=0.012$) and a significant interaction between sexes and season ($F=2.938$; df = 3, 315; $p=0.034$). A Tukey-Kramer HSD test revealed that the mean volume of apple flesh per crop differed significantly between male and female. This test also showed that the means were significantly different between autumn and each of the other seasons. However there was no significant difference between winter, spring or summer. Analysis of variance (ANOVA) also revealed a significant difference, for females, in mean volume of apple flesh per bird between seasons ($F=7.410$; df = 3, 128; $p=0.0001$). Using ANOVA for males, there was no significant difference between seasons ($F=1.649$; df = 3, 187; $p=0.180$). A Tukey-Kramer HSD test also showed no difference between seasons. Volumetric measurements shown are mL ± s.e. Number of birds (n) is given in parentheses.

	Volume (mL) of apple flesh in crops mean ± s.e. (n)				
	summer	autumn	winter	spring	all birds
all	0.14 ± 0.04 (83)	0.86 ± 0.17 (78)	0.40 ± 0.09 (78)	0.24 ± 0.09 (84)	0.40 ± 0.06 (323)
female	0.13 ± 0.19 (37)	1.31 ± 0.19 (35)	0.54 ± 0.21 (30)	0.30 ± 0.21 (30)	0.57 ± 0.11 (132)
male	0.15 ± 0.12 (46)	0.50 ± 0.12 (43)	0.31 ± 0.12 (48)	0.21 ± 0.11 (54)	0.17 ± 0.03 (191)

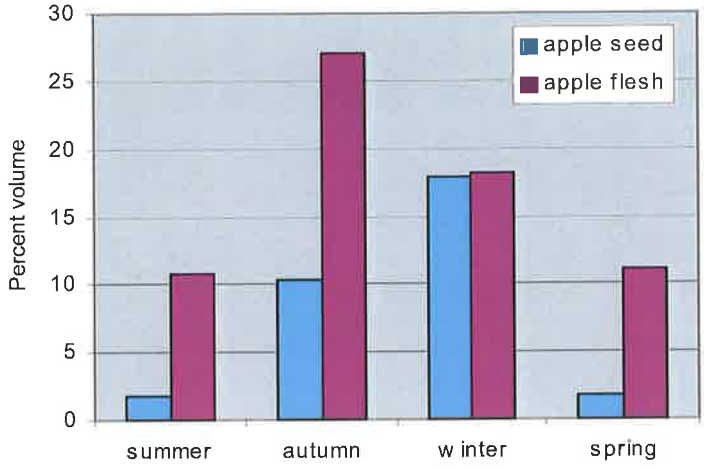

Figure 3.13. Volumetric proportions of apple seed and apple flesh in the crops of Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992.

Volumetric proportions of each food are based on all foods recorded in each seasonal period. The total numbers of crops examined from birds taken in each season were 87 in summer, 80 in autumn, 82 in winter and 84 in spring.

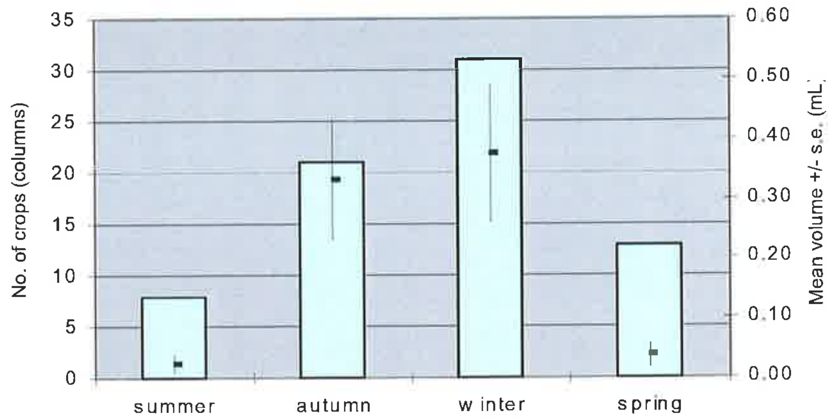

Figure 3.14. Mean volume of apple seed in crops and number of crops with apple seeds for 323 Adelaide Rosellas of known sex collected in and around commercial cherry orchards between 1985 and 1992.

Analysis of variance revealed a significant difference in mean volume of apple seed per crop between seasons (F=5.159; df = 3, 315; p=0.0017), no difference between sexes (F=1.420; df = 1, 315; p=0.2343) and no interaction between sexes and season (F=1.744; df = 3, 315; p=0.1579). A Tukey-Kramer HSD test revealed that the mean volume of apple seed per crop differed significantly between the following seasons: winter and spring, winter and summer, autumn and spring, and autumn and summer, with seed being more prominent in crops in autumn and winter. The mean volume of apple seed did not differ between autumn and winter or between spring and summer.

Soursob

The broad-leaf weed soursob *Oxalis pes-caprae*, a common plant of orchard pastures within the study area, was also a prominent food source for rosellas, with birds consuming the bulbs, stem tissue and flower buds of the plant.

Bulbs of the soursob plant were recorded in the diet in all months except January and December. This food was present in 46 birds (19 female, 27 male) or 14.2% of the total sample of crops from 323 sexed birds. The mean volume of bulbs consumed was 0.86 ± 0.21 mL for females and 0.56 ± 0.15 mL for males compared to the mean of 0.68 ± 0.13 mL for birds of either sex (Table 3.15).

Sour-sob bulbs were the most important food item in spring based on percent volume (16% of all foods in spring) when it was present in 36% of crops examined (Figure 3.15). Of the 46 birds that fed on soursob bulb, 61% were recorded in the months of September and October. Apple fruit was second in importance to soursob bulbs in spring based on volumetric measurements of crop contents (11.1% by volume). Soursob bulbs were only a minor food by volume in other seasons, represented by trace amounts in summer and winter (Figure 3.16). In autumn soursob bulbs comprised only 1% by volume of all foods although it was recorded in 12.5% of samples.

Rosellas also fed on the flower buds and the stem bases of sour-sob. Birds fed on buds only in winter and spring when buds were recorded in the crops of 38 birds or 11.8% of the total bird sample (n=323 sexed birds; Figure 3.15). In winter, although 30% of birds fed on buds, this food accounted for only 2% by volume of the winter diet. Just over 21% of birds fed on buds in spring contributing 5% to the diet by volume. Sour-sob stem did not occur in the diet in summer, and in autumn, less than 3% of birds fed on stem bases. In winter and spring, 17% and 19% of birds respectively fed on stem bases. However, relative volumes for stem bases in the diet were low (3% and 6% of all foods for each season).

Table 3.15. Mean volume of soursob flower bulbs in crops of Adelaide Rosellas based on the sample of birds that consumed bulbs.

Volumetric measurements were based on birds taken in and around commercial cherry orchards between 1985 and 1992.

	Volume (mL) mean ± s.e.	No. of crops that contained bulbs.
female	0.86 ± 0.21	19
male	0.56 ± 0.15	27
both sexes	0.68 ± 0.13	46

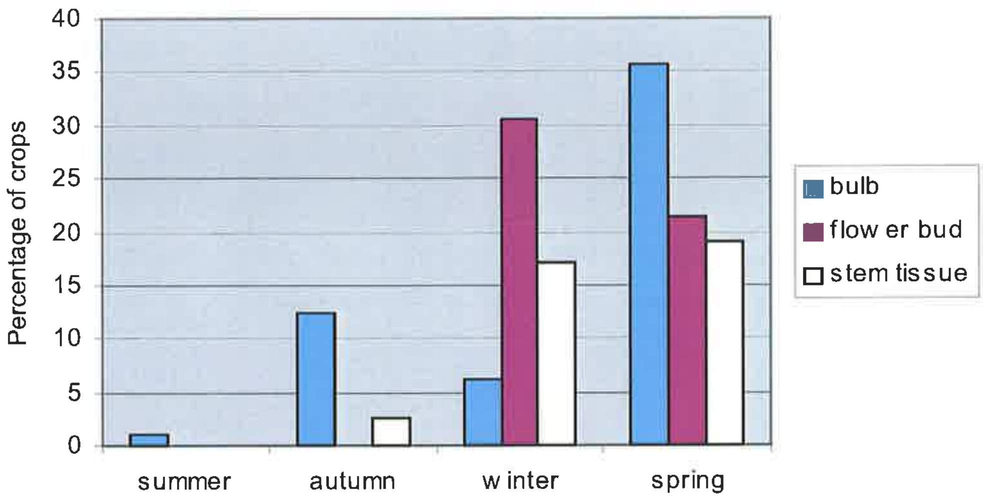

Figure 3.15. Percent occurrence of soursob parts in the crops of Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992.

Percent occurrence of each of three soursob foods eaten by birds for each seasonal period are shown. The total numbers of crops examined from birds in each season were 87 in summer, 80 in autumn, 82 in winter and 84 in spring.

Table 3.16. Mean volume of soursob flower buds in crops bas sample of Adelaide Rosellas that consumed buds.

Birds examined were taken in and around commercial cherry orchard: 1985 and 1992.

	Volume (mL) mean ± s.e.	No. of crops containing buds
female	0.18 ± 0.08	14
male	0.39 ± 0.03	24
both sexes	0.31 ± 0.10	38

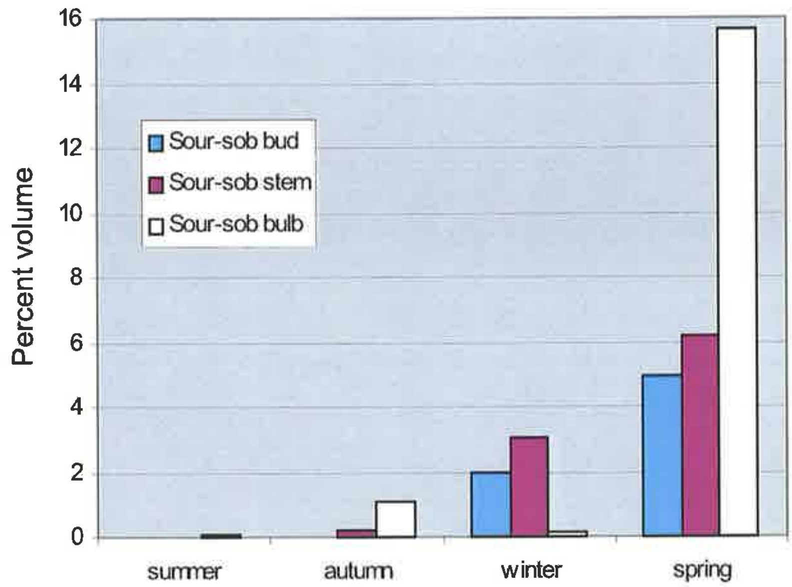

Figure 3.16. Volumetric proportions of soursob buds, bulbs and stems in the crops of Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992.

Volumetric proportions of each food are based on all foods recorded in each seasonal period. The total numbers of crops examined from birds taken in each season were 87 in summer, 80 in autumn, 82 in winter and 84 in spring.

Cherry buds

Cherry bud development begins soon after fruit maturation in December and January and finishes at bud burst in late August to early September, depending on variety and locality. Cherry flower primordia were found in 16.7% of crops in the sample of 323 birds and were recorded in crops for seven months of the year, from March to September. Numbers of primordia were counted in a small proportion of crops. Four crops collected in May and June each contained between 12 and 50 primordia. Another crop from a sub-adult (first year) male bird collected in late June contained 1245 primordia representing 0.99 mL by volume. Two crops collected in August contained 168 (0.15 mL) and 357 primordia (0.40 mL) respectively.

As I was not able to distinguish between cherry varieties from visual examination of ingested flower primordia, it was assumed that most primordia found in crops were taken from buds of varieties that received consistently high levels of feeding damage during the study period, in particular William's Favourite and related varieties.

Flower primordia were absent in the diet in summer and occurred in negligible amounts in autumn and spring (0.1% and 0.2% by volume). Primordia, however, comprised 1.9% by volume of all foods in winter. This coincided with the lowest representation of native foods in the diet.

For the period from March to September during which rosellas foraged on cherry buds, 188 birds were collected including 79 females and 109 males. In this sample, 54 birds (28.7%) had fed on cherry buds including 25 females (31.6%) and 29 males (26.6%). Of the 54 birds that fed on primordia, there were 35 juvenile (first year) birds including 15 females and 20 males and 19 adult birds including 10 females and 9 males.

The difference in volume of cherry primordia consumed between male and female birds or between juvenile and adult birds of either sex was not significant (Table 3.17).

Table 3.17. Mean volume of cherry primordia in the crops of Adelaide Rosellas that consumed primordia (n=54).

Birds were taken in and around cherry orchards in the Adelaide Hills between 1985 and 1992. Analysis of variance revealed that there was no significant difference in mean volume of primordia per bird between sexes (F=3.0955; df = 1, 52; p=0.0846), or between adult and juvenile (F=0.2449; df = 1, 52; p=0.6228). A Tukey-Kramer HSD test revealed that there was no significant difference in mean volume of primordia per bird between sexes or between ages.

		Volume (mL) of cherry primordia per crop	
Bird sample		mean ± s.e.	No. of birds that consumed primordia
juvenile or adult			
	female	0.03 ± 0.03	25
	male	0.10 ± 0.03	29
male or female			
	juvenile	0.05 ± 0.04	35
	adult	0.07 ± 0.03	19

Although the frequency of cherry primordia in the diet was relatively high, particularly in winter (43% of birds; Figure 3.17), this food had a lower representation in the diet based on quantity or percentage volume (Figure 3.18). In the winter sample when cherry primordia were more highly represented than in other seasons, this food comprised less than 2% by volume of the sample (compared to 18% for apple flesh or apple seed).

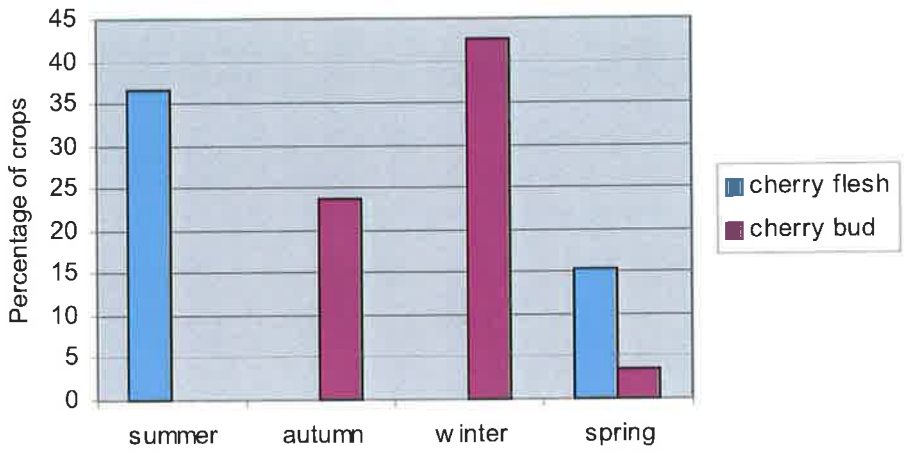

Figure 3.17. Percent occurrence of cherry flesh and cherry flower primordia in crops of Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992.

Percent occurrence of each food is based on the number of birds with cherry flesh or flower primordia in their crops relative to all birds in each seasonal period. The total numbers of crops examined from birds taken in each season were 87 in summer, 80 in autumn, 82 in winter and 84 in spring.

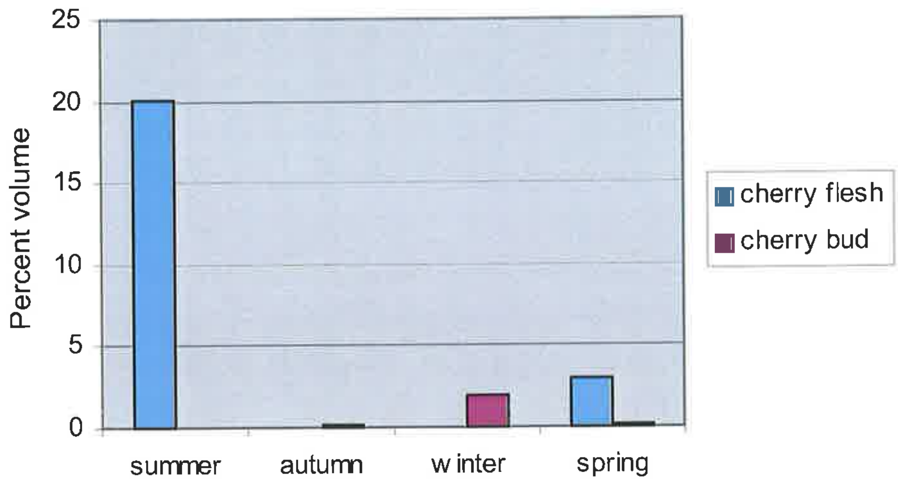

Figure 3.18. Volumetric proportions of cherry flesh (fruit pulp) and cherry flower primordia in crops of Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992.

Volumetric proportions of cherry foods are expressed as a percentage of the total volume of food recorded in each season. The total numbers of crops examined from birds taken in each season were 87 in summer, 80 in autumn, 82 in winter and 84 in spring.

For the birds that consumed cherry primordia (n=54), apple flesh and apple seed were the two most prominent foods based on volumetric proportions (Figure 3.19). Mean volume of seed consumed per bird was not significantly different between sexes (male 1.50 ± 0.50 mL; female 1.19 ± 0.42 mL; $t = -0.397$, 20 d.f., $p = 0.348$). However females consumed significantly more apple flesh than males (male 0.70 ± 0.19 mL; female 1.49 ± 0.37 mL; $t = 1.817$, 34 d.f., $p = 0.039$). Cherry primordia represented 3.3% of all foods for males and 1.2% for females within this sample of birds. For female rosellas that fed on cherry buds a total of 70.1% by volume of all foods eaten was represented by just four foods: apple flesh (39.1%), apple seed (14.4%), fat hen *Chenopodium album* seed (11.2%) and wild radish *Raphanus raphanistrum* seed (6.1%). A similar percentage by volume of all foods (70.2%) eaten by males that contained cherry primordia was represented by six foods: apple seed (24.8%), apple flesh (15.4%), sub-clover seed (8.1%), wild radish seed (7.8%), soursob stem (7.7%) and barley seed (6.4%). For the sample of birds of either sex that contained cherry primordia (n=54), 24.6% of the crop contents contained apple flesh and 20.8% contained apple seed by volume. By comparison, for all birds examined during the same period (March to August; n=162), 23.4% of crop contents contained apple flesh and 13.4% apple seed by volume.

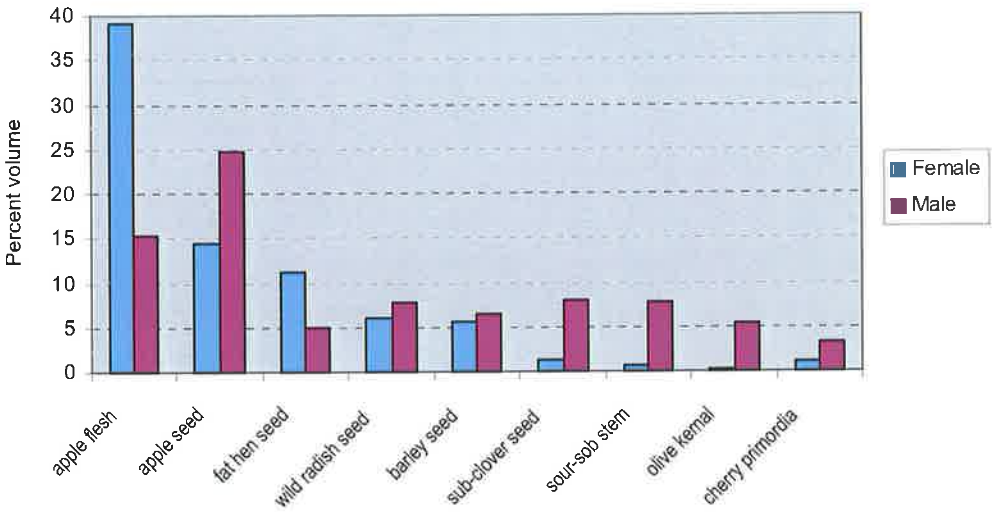

Figure 3.19. Prominent foods used by Adelaide Rosellas that consumed cherry primordia.

Volumetric proportions of individual foods that represented at least 5% by volume of all foods in at least one sex for the sample of 54 birds that fed on cherry primordia. These data are based on volumetric measurements of foods from the crops of 29 male and 25 female birds taken in and around cherry orchards between 1985 and 1992.

Insects

Insects occurred in the diet in all seasons, being recorded in 40.9% of the sample of 323 sexed birds. The volumetric percentage of insects in the diet for all seasons however was only 1.4% (female birds 0.8%; male 0.6%). Seasonally, the largest volumetric percentage of insects was recorded in summer (2.3%) and the lowest percentage in autumn (0.6%). The mean volume of insects consumed per bird was 0.03 ± 0.01 mL (n=323) and was highest in spring (Table 3.18).

Table 3.18. Mean volume of insects in crops of Adelaide Rosellas in each season and for each sex.
These data are based on the crop contents of 323 rosellas taken in and around commercial cherry orchards between 1985 and 1992. Analysis of variance (ANOVA) revealed there was no significant difference in mean volume of insects per bird between sexes (F=2.368; df = 1, 315; p=0.125) or between seasons (F=0.4105; df = 3, 315; p=0.746). There was no significant interaction between sex and season (F=1.371; df = 3, 315; p=0.252).

	Volume (mL) of insects per crop		
Bird sample	mean	s.e.	No. of birds
summer	0.03	± 0.01	83
autumn	0.02	± 0.01	79
winter	0.03	± 0.01	77
spring	0.04	± 0.01	84
female	0.04	± 0.02	132
male	0.02	± 0.005	191
all birds	0.03	± 0.01	323

As a proportion of foods consumed by female birds only (n=132), insects represented 1.8% of the diet. Similarly, for male birds (n=191), insects represented 1.0% by volume of the male diet.

Immature stages of Psylloidea were prominent in the diet in all seasons based on percent occurrence in crops (Figure 3.20). The Psylloidea (jumping plant lice and lerp insects), were represented by two families, Psyllidae (including sub-family Spondyliaspidinae) and Triozidae. Psylloidea were recorded in 91 crops (28% of all crops) compared to all other insect groups which were recorded in 94 crops (29%) of birds. Insects were recorded in 132 crops (41% of the total sample; n=323). Nymphs of *Schedotrioza* spp. (Triozidae) were dominant in the insect component of the diet in winter and spring. Lepidopteran larvae, possibly codling moth, were important in autumn (24% of crops) and to a lesser extent in winter.

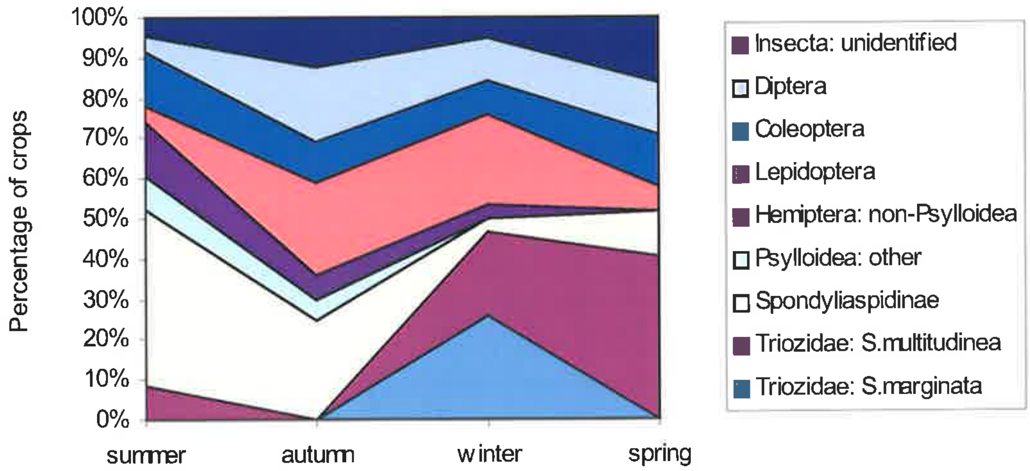

Figure 3.20. Seasonal distribution of immature stages of major insect groups in the diet of Adelaide Rosellas taken in and around cherry orchards between 1985 and 1992.

The area curve for each food is based on four values representing pooled data for each season. For each season the number of crops in which each major insect group was found was expressed as a percentage of all crops in which insects were found for the particular season. The total numbers of crops examined for each season were 87 crops in summer, 80 in autumn, 82 in winter and 84 in spring. The percent occurrence of adult insects in crops in each season was as follows: 3.4% in summer, 11.3% in autumn, 2.4% in winter and 7.1% in spring.

Based on volumetric proportion the order Hemiptera, including the super-family Psylloidea, was the major insect order represented in the diet of rosellas in each season (Figure 3.21). Hemipteran insects were most highly represented in the diet in summer (93% by volume of all insects found) and the least represented in winter (58%). Other insect groupings of seasonal importance in the insect component of the diet, based on percent volume, were Lepidoptera (winter 24%), Diptera (autumn 21%) and Coleoptera (autumn 10%, winter 11%).

The super-family Psylloidea was the main hemipteran group in the diet in all seasons except summer when immature stages of Coccoidea (Hemiptera) were dominant (Figure 3.22). On a seasonal basis Psylloidea comprised a maximum of 89% by volume of all insects in spring. In autumn, triozid insects were not present in the diet however the sub-family Spondyliaspidinae was the dominant insect group, contributing 53% of all insects by volume. Triozid nymphs were the dominant insect group in winter and spring and were represented by two species *Schedotrioza marginata* and *S. multitudinea* (Figure 3.22; Plate 6). The latter represented 86% of the insect component of the diet by volume in spring.

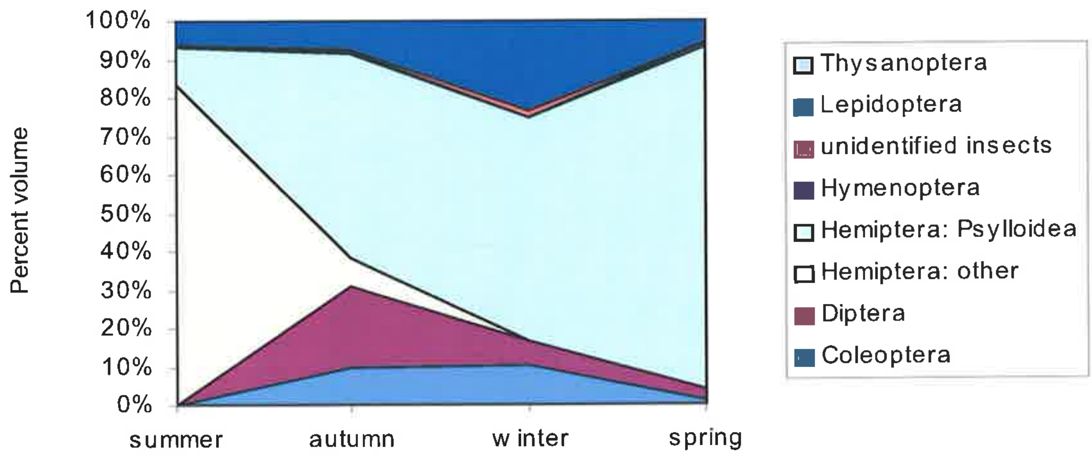

Figure 3.21. Relative proportions of insect orders in the diet of Adelaide Rosellas based on volumetric measurements of the insect component in the crops of birds taken in and around cherry orchards between 1985 and 1992.

The area curve for each food is based on four values representing pooled data for each season. The crop contents of a total of 333 birds were examined and insect material was found in 158 crops (19 in summer, 41 in winter, 57 in winter and 41 in spring).

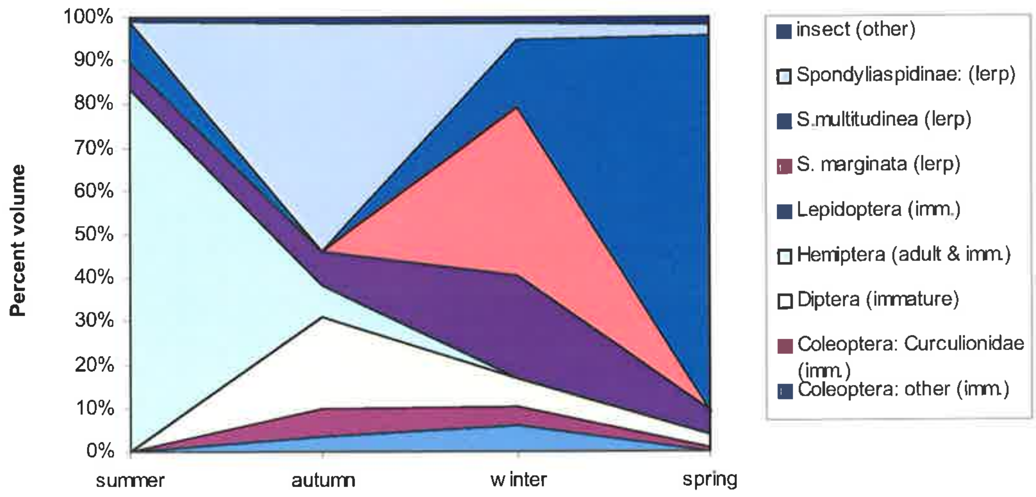

Figure 3.22. Relative proportions of major invertebrate groups in the diet of Adelaide Rosellas based on volumetric measurements of the insect component in the crops of birds taken in and around cherry orchards between 1985 and 1992.

The area curve for each food is based on four values representing pooled data for each season. The crop contents of a total of 333 birds were examined and insect material was found in 158 crops (19 in summer, 41 in winter, 57 in winter and 41 in spring). *S. multitudinea* = Triozidae: *Schedotrioza multitudinea*; *S. marginata* = Triozidae: *Schedotrioza marginata.*

Plate 6. Some psylloid insects recorded in crops of Adelaide Rosellas from the Adelaide Hills.

The order of descriptions given for each row is from left to right. A scale with 1mm graduations is shown in the photographs in the middle and bottom rows.

Top row: Galls formed on the leaves of *Eucalyptus obliqua* by nymphs of *Schedotrioza multitudinea* (Triozidae). Note nymph from broken *Eucalyptus obliqua* leaf gall on match-stick (left photograph).

Middle row: Nymphal instars of *Schedotrioza multitudinea* (dorsal side). The nymphs were taken from the crop of a male bird (age 21 months) in August 1985.

Bottom row: Nymphal instars of *Schedotriza marginata* (ventral side on left; dorsal side on right). The *S. marginata* nymphs were taken from the crop of a male bird (estimated age 33 months) in August 1985.

3.3.4 Observations of rosella foraging behaviour

General observations of feeding by rosellas within the study area were recorded for six broad habitat types: orchard, orchard pasture, other areas (adjacent orchard), roadside, native vegetation, and ornamental garden (Table 3.19). A total of 31 different foods were recorded by opportunistic field observations. Insect items were unable to be determined from direct field observation of foraging birds.

Six food items not identified in crop samples were recorded from field observations of foraging birds (Table 3.20). Apparent feeding behaviour involving the handling of flowers of South Australian blue gum *Eucalyptus leucoxylon* was recorded on a number of occasions (also *E. maculata*, a non-indigenous eucalypt, on one occasion). This activity involved biting the flower off at the pedicel and then dropping it to the ground. Although it was difficult to determine precisely how the birds were using the flowers I assumed they were extracting nectar, a food item that I was not able to detect in the crop analysis. Elsewhere rosellas have been observed consuming nectar from flowers of this species (D. Paton, pers. comm.[7]).

The seed of drooping sheoak *Allocasuarina verticillata*, an uncommon species within the study area, was observed being eaten on two occasions but was not recorded in crops. All reproductive stages of the cherry (flower bud, flower, fruit and kernel) were recorded as foods from field observations, however flower and kernels were not found in crops. Rosellas were frequently seen feeding on apples in trees, but more commonly on the ground. In several commercial orchards apples from pre-harvest thinning, windfalls and harvesting activity (late summer/ early autumn) were often left on the ground, providing a potential food source until the following spring for birds that also had access to cherry trees.

As the observations were opportunistic there was a bias of records towards specific habitat types, in particular orchards (59% of observations) and roadsides (24% of observations). Less than 8% of feeding observations were recorded for non-roadside native vegetation areas.

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[7] Dr DC Paton, Department of Environmental Biology, University of Adelaide.

Table 3.19. Summary of opportunistic observations of feeding by Adelaide Rosellas within cherry growing districts of the Adelaide Hills between 1985 and 1992 according to habitat type.

	Feeding observations	
Land use	No. of observations	Percent
Native vegetation	6	7.2
Roadside	20	24.1
Orchard pasture	38	45.8
Orchard	11	13.3
Other areas (adjacent orchard)	6	7.2
Garden (ornamental)	2	2.4

Table 3.20. Field observations within the study area of Adelaide Rosellas feeding on foods not recorded from crop samples of birds taken from cherry orchards between 1985 and 1992.

Observations were recorded from the following habitat types: native vegetation (A), roadside (B), orchard pasture (C), orchard (D), other areas - adjacent orchard (E), garden/ ornamental (F).

Food source	Food type	No. of records	Months	Habitat type
Allocasuarina verticillata	seed	2	April, May	A,B
Eucalyptus leucoxylon	flower	7	May, July, October	A,B,C
Eucalyptus maculata	flower	1	June	F
Ixodia achilleoides	leaf	1	December	A
Populus sp.	bud	1	September	E
Prunus avium	kernel	2	March, June	D
Prunus avium	flower	many	September, October	D
Romulea sp.	bulb	1	November	C

When in or around cherry orchards, rosellas generally foraged on the ground, usually in pairs or in small groups. Time spent feeding on cherry buds was often a relatively small proportion of the total time spent in the orchard (including foraging for other foods and other activities) and thus appeared to be an incidental activity of rosellas. Cherry trees were often used by birds to briefly perch above desired foraging sites in the orchard pasture before descending to the ground. On many occasions "incidental", intermittent browsing on buds in trees was observed to occur before the birds flew down to the ground to forage. However a number of observations suggested that when birds fly from a ground feeding position into a nearby cherry tree in response to an alarm call or perceived threat they are less likely to engage in "incidental" bud feeding than at other times.

3.4 DISCUSSION

3.4.1 Sampling techniques

Diet analysis generally consists of sorting and identifying food items, and presenting the results in terms of occurrence, frequency, volumetric, or gravimetric measures (eg Hyslop 1980; Rosenberg and Cooper 1990). Presenting dietary data in more than one form also helps to minimise or counter biased interpretations. Opportunistic field observations were made in order to complement dietary information obtained from the crop analysis. Direct observation for the purpose of identifying foods or their proportions in the diet however is difficult for birds that use a wide diversity of food items and which are often obscured from the observer. Ford *et al.* (1982) advised of the importance of not presupposing what the bird is doing or eating when making direct observations. A food that requires field observation to detect in the diet is nectar (e.g. nectar from flowers of cherry or *Eucalyptus leucoxylon*), which may have become lost in the alcohol treatment of the crop contents as no method was found to extract it. Ford *et al.* (1982) advised that nectar is difficult to find in the alimentary canal of birds as it is rapidly absorbed.

Direct observation may be an adequate means of assessing diet in more specialised foragers such as nectarivores or frugivores for which the species of food plant can be readily identified. Although this technique may be biased towards large, conspicuous items or food sources, it can provide information on consumption rates, food handling and diet selectivity not detectable from gut contents alone (e.g. Rosenberg and Cooper 1990). Observations of the birds' feeding behaviour and knowledge of what they are eating can also contribute to a greater understanding of food availability.

Occurrence measures are based on the number of samples in which a particular food type occurs. Percent occurrence is the simplest measure of diet and its primary advantage is that virtually all food types can be counted, even if individual items ingested cannot be quantified (Rosenberg and Cooper 1990). This method of food analysis gives little indication of the relative amount or bulk of each food present in the crop (Hyslop 1980), though it provides a qualitative picture of the food spectrum.

Direct examination of collected birds enables the gut contents to be accurately quantified. A disadvantage is that multiple samples from one bird are not possible, except when forced regurgitation or flushing methods are employed. Differential digestion rates of dietary items impose the largest potential bias in any study of gut contents and may influence every phase of the study (Rosenberg and Cooper 1990). In this study, dietary assessment was based principally on the contents of crops as this structure is the only part of the alimentary canal in which foods remain in the same proportionate amounts as eaten (e.g. Davison 1940). Volumetric techniques probably give the most representative measure of bulk and may be applied to all food items (Hyslop 1980). The Aggregate Volume measure, which gives equal weight to each unit of food consumed by any bird, was used instead of the Aggregate Percentage measure (average of volumetric percentages for a given food), which gives equal weight in the analysis to each bird. A disadvantage of the latter measure is over-rating the importance of dominant foods in individuals with small crop samples.

In order to measure food selection a comparison of the relative availability of food items compared with the relative quantity of food items used by an animal is required. Under field conditions selection or 'preference' has most often been recorded as a simple ratio of the proportion of a food type in the diet to the proportion of that food in the environment. However when resources have been measured the distinction should be made between abundance (the total amount of the resource) and availability (the amount of the resource that birds can use). In order to measure food selection a comparison of the relative availability of food items compared with the relative quantity of food items used by an animal is required. The degree to which a population is selective in its feeding (i.e. consumes foods in proportions which deviate from the proportional availability of the foods in the environment) may determine its preferences for agriculturally valuable crops when they become available to the birds (Wiens and Dyer 1977). Low availability and high utilisation of food types indicates relatively high selection (e.g. Norbury and Sanson 1992). The dietary data presented here have not been related to actual damage levels in individual cherry orchards for a particular season as the bird sample was obtained from a number of sites over a period of several years (1985 to 1992). However, all birds were collected from sites where significant bud damage levels are generally experienced in most years. As shooting is a destructive sampling method, damage levels in the orchard could be affected by the sampling process if the required sample size were obtained. A more desirable method would be to record consumption of buds by field observation based on estimated feeding rates and then compare this with subsequently observed damage levels.

Gravimetric methods of food analysis give a reasonable estimate of bulk but are relatively difficult to apply when there are many small food items; hence the method was not used in this dietary study. Dry weight estimation is relatively time consuming and is usually employed where accurate determinations of calorific intake are required.

3.4.2 Broad seasonal differences in diet

Rosellas within the study area had a diverse diet based on the whole sample (172 foods from 333 birds), and in relation to individual bird samples. The quantity (volume) of food in a crop also appeared to influence the number of foods in a crop, irrespective of season, suggesting a positive correlation between crop volume and number of foods present. Differences in the diet between seasons based on volume and number of foods in crops were also demonstrated. The fewest number of foods per crop and smallest volume per crop were recorded for summer, and the highest of each for autumn. Winter and spring diets were similar. The difference in number of foods per crop between summer (mean 4.5 ± 0.3; minimum 4.2 in January) and autumn (mean 7.4 ± 0.4; maximum 7.7 in May) reflected seasonal differences in mean food volume per crop. The mean volume of food per crop was lowest in summer (1.35 ± 0.12 mL) when the energy requirement of birds is expected to be lowest. However, the highest seasonal mean volume occurred in autumn (3.15 ± 0.27 mL) rather than winter when energy demands are expected to be greatest. This may be partly attributable to the incidence of apple, in particular apple flesh, in the diet and variation in seasonal abundance of apples.

3.4.3 The use of particular foods by rosellas

For the purpose of describing the diet here 'importance' of a food is taken to mean the bulk (volume) or percent occurrence in the diet. Nutritional importance in energetics terms will be considered later.

Apple

Apple flesh contributed the most by volume to the diet of any food. Seasonally, apple flesh was of least importance in the diet in summer (11% by volume of all foods) and of greatest importance in autumn (27% by volume). Apple flesh was the most frequently recorded food item in autumn and winter (58% and 55% of birds). The prominence of apple flesh in the diet in autumn coincides with the harvesting of apples. Apple seed was second in importance to apple flesh in terms of accounting for volumetric differences between summer and autumn diets. Apple seed was present in the diet through all seasons and was most frequently recorded in autumn and winter (26% and 38% of birds respectively), representing 18% by volume of the diet in winter but only 1.7% of the summer diet by volume. Similar volumes of apple seed were consumed in autumn and winter (0.32 mL and 0.38 mL per bird respectively) however the difference in volumetric proportions between these seasons was greater (10% and 18% respectively) due to the much greater bulk of apple flesh in the autumn diet (0.78 mL per bird compared to 0.36 mL per bird). This suggests that apple flesh is exploited to a greater extent nearer harvest and when availability is higher.

For birds that fed on apple seed, the mean volume consumed per bird was higher in autumn than in winter, reflecting greater availability of apples in autumn (the principal source being hand-thinned and wind-fallen apples). Although the consumption of apple seed per bird was lower in winter, the proportion of seed to pulp in the diet (mean volume per bird) was higher in winter than in autumn. There may be several reasons for this including a need for food of higher energy content in winter, greater accessibility of seed in winter (i.e. decomposing apples may allow a greater harvesting rate of seeds) and declining availability of apple flesh.

Three other foods largely contributed to the difference in the total volume of food consumed by rosellas between autumn and winter. St John's wort seed (0.29 mL per bird in autumn; 0.02 mL per bird in winter), olive flesh (0.18 mL; 0.02 mL) and wild radish seed (0.28 mL; 0.14 mL) were also recorded in markedly greater amounts in autumn compared to the winter diet.

The energy content of the diet is likely to reflect food quality, in particular energy density, as well as food quantity (e.g. volume). The calorific value of each seasonal diet therefore is determined by the physiological requirements of birds in response to environmental factors (e.g. climate) and biological factors (e.g. reproduction).

This variation in these aspects of the diet between seasons could also be a function of the time of day that birds were shot (in relation to feeding sessions) in each season. The majority of specimens used in this study were contributed by landholders, often without information of when birds were shot during the day. Birds shot around the middle of the day are likely to have crops that are less full than birds shot mid-morning or just prior to dusk based on the observation that the greatest feeding activity occurs in early morning and late afternoon. For this reason relative proportions of foods are more meaningful than absolute quantities.

Given the extensive use of apples as a food resource by rosellas the availability of apples to rosellas may have potential to be manipulated in order to modify foraging behaviour in cherry orchards and reduce damage to cherry trees.

Cherry

Rosellas foraged on the floral buds of cherry trees from March to September in order to extract the small flower primordia enclosed within the outer bud scales. Each bud of sweet cherry possesses two to four flowers, and the buds are borne laterally in groups on short spurs or near the base of longer shoots (Westwood 1978). Within the study area, bud initiation takes place soon after fruit maturation in December or January and bud development continues until bud burst in August or September, depending on variety and location. In the study area cherry buds of all varieties were a super-abundant food source given that in any year many buds remained undamaged by rosellas.

Cherry primordia were readily identified in crop samples, but it was not possible to distinguish between varieties. I assumed that the majority of primordia recorded in crop samples were from varieties that consistently received high levels of damage (i.e. William's Favourite or related cherry varieties). Feeding on cherry flowers for nectar was frequently observed in the field however this food was not recorded from crop examinations, as a method for extraction or identification was not available.

Almost 17% of the bird sample collected over all months fed on cherry buds, and for the months of March to September when cherry buds were available, almost a third of birds (29%) fed on this food. During the winter period 43% of birds fed on cherry buds but primordia comprised only 1.9% of all foods by volume in this season (compared with 18% for apple fruit). The relatively low importance of primordia in the diet therefore may not reflect levels of damage to buds in orchards, unless primordia are of particularly high nutritional value. Birds eat primarily to obtain energy (e.g. Kendeigh *et al.* 1977), and it is unlikely that cherry primordia contribute significantly to the energy needs of rosellas in winter simply based on the quantity represented in the diet.

Similar proportions of female and male birds fed on cherry primordia (32% of all females and 27% of all males). However male birds consumed more primordia than female birds (0.10 ± 0.04 mL compared to 0.03 ± 0.01 mL mean volume per crop), presumably spending more time undertaking this activity.

Only six of the 54 birds that fed on cherry primordia were recorded prior to April with this food item; all six were recorded in late March during the study period, three of which were juvenile or first year birds (each aged 5 months) and three adult birds. Cherry buds reach the stage of development where they first become available as a food source to rosellas during March and these data indicate that rosellas are capable of developing this apparently complex foraging task as juvenile birds within only a few months of fledging.

Amongst birds that had eaten cherry primordia (n=54), female and male birds consumed a similar range of foods. Within this sample, the two most prominent foods based on volumetric proportions were apple flesh and apple seed. Birds that fed on cherry buds (n=54) had a higher proportion of apple seed in their diet (21% by volume) compared to all birds (n=162; 13% by volume) examined during the bud-feeding period of the year, i.e. March to August. The quantity of apple seed or flesh consumed (mL per bird) was greater amongst birds that fed on primordia compared to all birds considered in the crop analysis (n=323) (Table 3.21). These differences suggest that feeding on cherry buds is often closely associated with feeding on apples.

Table 3.21. Mean volume of apple seed and apple flesh recorded in the crops of Adelaide Rosellas of known sex.

These data are based on examination of the crop contents of all birds of known sex collected in and around cherry orchards between 1985 and 1992 (191 male and 132 female). Within this sample, 54 birds consumed cherry primordia, and of these, 39 birds consumed apple seed or apple flesh (21 male and 18 female). Of the latter 39 birds, 4 female and 13 male birds each consumed apple seed and apple flesh. The mean volume of apple seed and apple flesh for birds of each sex that consumed cherry primordia is also presented in this table. Values given in parentheses are the numbers of birds from which the volumetric means were calculated.

Bird sample	Volume of apple seed (mL) mean ± s.e. (n)	Volume of apple flesh (mL) mean ± s.e. (n)	ratio of seed : flesh
male (all)	0.22 ± 0.05 (191)	0.29 ± 0.07 (191)	0.76
female (all)	0.14 ± 0.06 (132)	0.57 ± 0.08 (132)	0.25
male + female (all)	0.19 ± 0.04 (323)	0.40 ± 0.06 (323)	0.48
male (primordia*)	1.50 ± 0.50 (15)	0.70 ± 0.19 (20)	2.14
female (primordia*)	1.19 ± 0.42 (7)	1.41 ± 0.37 (16)	0.84
male + female (primordia*)	1.40 ± 0.38 (22)	1.01 ± 0.49 (36)	1.39

*Crops containing cherry primordia

Consumption of apple flesh (mL per bird) was significantly higher for females compared to males amongst the group that fed on cherry buds (n=54), and amongst all birds examined (n=323), but there is no obvious explanation for this difference. I frequently observed single birds - often with brightly coloured, adult plumage - perched on a high branch of a tree in close vicinity to a group of rosellas feeding on the ground (e.g. on wind-fallen apples). It appears that these birds were acting as sentinels against possible predators. Such birds were likely to be male (R. Sinclair, pers. comm.[8]), which may partly account for the difference in apple flesh consumption between sexes. There was no difference though between sexes in the mean volume of apple seed consumed per bird (Figure 3.14).

The seed of apple is likely to be of higher food quality than apple flesh in terms of energy density based on wet mass and the difference in water content (Westwood 1978). Based on the quantity of food in crops (percent volume of food items), males also appeared to spend more time than females on the ground foraging for sub-clover seed (8.1% and 1.4% respectively) and soursob stem (7.7% and 0.7%).

[8] Dr RG Sinclair, Animal and Plant Control Commission, Adelaide.

For birds that consumed cherry primordia (n=54), cherry primordia represented 3.3% of all foods by volume for males and 1.2% for females. Even though cherry primordia comprised a small proportion by quantity of the overall diet, significant levels of damage to buds on cherry trees occurred over the study period.

Invertebrates

At certain times animal food is included in the diet of granivorous birds and, although it may be in relatively small quantities and of relatively low calorific value its importance lies in the amino acid content (Dyer and Ward 1977). Since the protein requirements of males and females may differ considerably, particularly during breeding periods, large differences in the need for animal food may exist between the sexes. Dyer and Ward (1977) suggest there is merit in treating the sexes differently in dietary studies, at least until the periods of dietary divergence are known.

A greater quantity of insect items was recorded in the crops of female birds (mean 0.04 ± 0.01 mL per bird; n=132) than in the crops of male birds (mean 0.02 ± 0.01 mL per bird; n=191). A significant difference in the use of insect prey in the diet between sexes could suggest that the nutritional demands of breeding are an important factor in food selection.

The most important insect group in the diet was the hemipteran super-family Psylloidea (plant lice or lerp insects), represented by two families, Psyllidae (sub-family Spondyliaspidinae) and Triozidae. The latter comprised two species of *Schedotrioza* (*S. marginata* and *S. multitudinea*). Insects, however, represented only 1.4% of the diet by volume of all foods though they were recorded in 41% of all birds. Seasonally, the lowest frequency (21%), highest percent volume (2%) and highest mean volume of insects in the diet was recorded for the bird sample collected in summer, although the mean volume of all foods consumed was the lowest in summer. Based on percent occurrence in crops, Hemiptera was the dominant insect group in all seasons. In autumn, winter and spring Psylloidea was the main hemipteran group but in summer non-psylloid hemipterans dominated the diet.

On a seasonal basis, the order Hemiptera was the major insect group represented in the diet of rosellas. The percent contribution of all hemipteran insects to the volume of insect material in the diets was highest in summer (93% of all insects) and lowest in winter (58%). The Psylloidea (jumping plant lice and lerp insects) were the main component of hemipteran insects in the diet in each season except summer. In spring Psylloidea comprised a maximum of 89% by volume of all insect material. Psylloid insects in the diet were represented mainly by immature stages of two families, Psyllidae (principally the sub-family Spondyliaspidinae) and Triozidae. This indicates that rosellas probably obtain most of the insects in their diet from leaf gleaning, particularly in the canopies of eucalypts such as *Eucalyptus obliqua*, *E. baxteri*, *E. viminalis* and *E. leucoxylon*. Lepidopteran larvae, possibly codling moth, were important in winter (24% of insect material by volume).

Adults and nymphs of Psylloidea feed on phloem through the leaf stomata (Clark 1962; Woodburn and Lewis 1973). There are five nymphal instars, the fifth moulting to the winged adult. Adults often occur away from the plants on which they breed but nymphs are very closely restricted to their food plants. Many species are notable for their tendency to remain for successive generations on the same plant, tree or copse of trees with few individuals, usually adults, dispersing to other areas (Morgan 1984). The distribution of psylloid insects is noticeably contagious, a feature that is probably attractive to birds that forage for insects. Aggregations of different psylloid species may also occupy the same leaf, twig or tree.

The Spondyliaspidinae are predominantly Australian lerp-building species and are largely associated with *Eucalyptus*. The nymphs of lerp-building species retain drops of honeydew at the abdominal apex until most of the water content has evaporated, sticking the resulting sugary pellets together into tent-like coverings called lerps. Because of their high sugar content, lerps are important in the diet of some Australian birds (Dolling 1991). *Schedotrioza multitudinea*, *S. marginata* (Triozidae) and *Glycaspis cameloides* (Spondyliaspididae) are native species of gall forming Psylloidea occurring on the foliage of *Eucalyptus obliqua* in the Mt Lofty Ranges (Taylor 1987). *Schedotrioza* initiates formation of closed, globular, woody galls on *Eucalyptus* leaves.

According to Morgan (1984), perhaps the major predators of psylloid species are birds, which vary somewhat in the stages of insects taken and in their behaviour during predation. The method described for the Ring-necked Parrot, *Barnardius barnardi*, in the lower Flinders Ranges for removing the leaf dwelling nymphs of *Cardiaspina albitextura* (Morgan 1984) may be similar to the method used by Adelaide Rosellas for lerp-building species found in their diet, such as *Lasiopsylla striatus* and *Creiis* sp.: "The birds sit in infested trees and pluck off infested leaves and pass them, individually, through their beaks like a horizontal revolving disc. The nymphs are removed and swallowed while the lerps and leaves are discarded on to the ground." Loyn *et al.* (1983) observed that when feeding on psyllids, Crimson Rosellas often held the leaf or small branch with the foot, and removed all psyllids and covering lerps from the leaf by drawing it through the bill. Near Olinda, Victoria, birds took 48 psyllids and lerp per minute. The method of removing psyllids from leaves has not been observed or reported for Adelaide Rosellas.

Sour-sob

Rosellas foraged on three parts of the soursob plant (*Oxalis pes-caprae*): the flower bud, the lower stem tissue or stem bases, and the bulbs (including aerial bulbils). On a seasonal basis soursob bud, stem and bulb foods were each of greatest importance in the diet in spring and of least importance in summer and autumn (when the aerial parts have died back or are much reduced). Based on volumetric percentages bulbs were the most highly represented part of the soursob plant in the diet and the most important food in the diet in spring. In all other seasons bulb material was recorded in very low or trace amounts.

Soursob was introduced from South Africa (Salter 1939) and is now a common and widespread winter-growing weed in south-eastern Australia. Soursob plants rarely set seed, the plants emerging in autumn from underground bulbs that are dormant over summer. Emergence may commence in relatively dry conditions, prior to the opening autumn rains but subsequent growth and development of plants is markedly influenced by seasonal rainfall. The early top and root growth is supported by food reserves provided by the parent bulb until exhausted when new bulbs are produced. Under favourable conditions soursob has a high capacity for reproduction, producing an average of 20 bulbils per plant, the majority of which are found near the surface of the soil (Mahoney 1982).

The exhaustion of bulbs produced in the previous year commences from the time of emergence of plants in early autumn. Maximum bulb development is attained prior to senescence of plants in spring. Thus, the potential bulb resource is relatively low when damage to cherry buds usually commences in autumn but increases during the period of bud development that finishes in late winter to early spring.

The relatively high incidence of bulbs in the diet in spring reflects seasonal bulb development and the influence of orchard management activity on the availability of this food. Over 60% of birds that fed on soursob bulb were recorded with this food in September and October. Only two birds (4%) fed on bulbs in November when soil conditions are usually drier. The peak in the bulb resource in spring coincides with an increase in machinery activity including spraying and mowing, which creates soil disturbance providing much greater bulb harvesting opportunities for rosellas. Based on observations of foraging behaviour of rosellas in the field there is no clear evidence that birds excavate soursob bulbs. Instead, they appear to rely on prior soil disturbance in order to gain access to this food source.

The very low quantity of bulbs recorded in the summer diet may not reflect the abundance of this food resource. Given that rosellas do not dig for bulbs, but principally rely on bulbs being brought to the surface by human activity, dry soil conditions in summer possibly limit the availability of bulbs to rosellas as the ground surface at this time of year may be too hard for machinery activity in orchards to readily expose bulbs. Orchard operations involving tractors are usually not possible, necessary or at least seldom undertaken any earlier than late August. Cherry trees require good drainage for optimum growth so many orchards in the Adelaide Hills have been established on steep, well-drained hill slopes. Commercial orchards on steep terrain however are generally inaccessible to tractors during the wet winters that are typically experienced in this region (annual mean rainfall 1028 mm at Lenswood Research Centre). In a commercial orchard at Basket Range the first aerial blossom spray is applied by a tractor-mounted blower at bud burst in September and when the ground is dry enough for machinery access (Bishop, pers. comm.[9]). In another orchard at Uraidla in 1992 the first spray was applied in the last week of August but in most years tractor access was usually not possible before the first week of September. A series of fungicide applications to cherry trees are carried out in September after which occasional tractor access may be necessary for mowing of the orchard pasture. In winter, low incidence of bulbs in the diet probably reflects the lower availability of bulbs which are underground at this time of year, and less disturbance to the soil surface by machinery when the ground surface is generally too wet to allow access of the machinery, particularly on steep slopes.

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[9] D. Bishop, Basket Range, South Australia.

In addition to producing underground bulbs, soursob plants sometimes produce small aerial bulbils, mainly during winter. However, as these are smaller than underground bulbs and are produced in relatively low numbers, they probably were only a minor proportion of the total amount of bulbs consumed. Flower buds and stem bases of sour-sob were also sought by rosellas, mainly in winter and spring, with volumetric proportions highest in spring (5% and 6% respectively). The other flower bud of importance in the diet was cherry primordia, which represented 1.9% of aggregate volume in winter but was absent or only present in trace amounts in other seasons.

The presence and relative abundance of food resources is a principal reason for birds visiting orchards. Horticultural practices, such as supplementary watering and fertilising of trees, and mowing of pasture, also encourages the growth of a suite of food plants including broad leaf weeds and grasses in orchard pastures. There may be some potential for utilisation of soursob bulbs as an alternative food source for rosellas at a time when cherry trees are vulnerable to bud predation in order to influence foraging behaviour in orchards or divert their attention away from orchards.

There are several features of soursob that indicate this potential:

- soursob is an important food source for rosellas;
- soursob is a common, widespread and abundant weed in the study area;
- the period of availability may overlap with cherry buds (i.e. winter); and
- soursob crops have the potential to be manipulated to increase their availability to rosellas.

3.4.4 Influence of land-use changes on the diet of rosellas

Since European settlement in South Australia (i.e. since the 1830s), extensive loss of natural habitat within agricultural districts has occurred. In 1945 large continuous tracts of native vegetation still remained in the Mount Lofty Ranges. However, during the period from 1945 to 1988, the area of native vegetation in the central and southern Mount Lofty Ranges decreased from 140,000 hectares to 56,000 hectares, an overall reduction of 74%, with as little as 5% of the original vegetation remaining in some districts (Mount Lofty Ranges Steering Committee, 1989). Within the Hundred of Onkaparinga, representing the greater part of the study area, the destruction of native forest and woodland has been in excess of 84% of the total land area of 29,655 hectares (Department for Environment and Natural Resources, 1987). Despite this scale of habitat change, Adelaide Rosellas are a relatively common species and have been able to exploit a wide range of foods from plants that have become naturalised within the region. A study of foods eaten by Long-billed Corellas in western Victoria indicated that more than 90% of their diet was introduced plant food, mainly cereal grains, sunflower and thistle seeds and corms of onion grass *Romulea* spp. (Temby and Emison 1986). This diet is likely to be an adaptation to extensive loss of its natural food plants as a result of land use changes introduced by Europeans in much of its range. It is difficult to infer the composition of the pre-European diet of Adelaide Rosellas from the present-day diet because the original vegetation in the Adelaide Hills region has been so much reduced in area,fragmented and modified that it is unlikely a population of rosellas would be entirely confined to any of these areas or would not have access to naturalised food plants within those areas. Many of the largest tracts of remnant vegetation occur in conservation reserves (e.g., Morialta, Black Hill, Montacute, Horsnell Gully, Cleland, Kenneth-Stirling and Mt George Conservation Parks). These areas support vegetation on soils of relatively low fertility and are not fully representative of the original vegetation of the study area. Each is adjacent to areas of horticulture and other highly altered habitats so non-native foods are readily available to rosellas.

There is little indication of the original (pre-European) diet of rosellas within the study area given the dominance in the present diet of introduced species which have replaced many native plants and now provide a year round supply of food. These introduced plants, including an extensive weed flora, may now support higher local populations of rosellas than the original native vegetation, despite the reduction of nesting resources.

Differential rates of clearing of native plant communities in the Mount Lofty Ranges for agricultural development may also have been a significant factor in the decline of indigenous food sources of rosellas. Plant communities that supported greater densities of prolific seed-bearing plants such as grasses were likely to be the more favoured foraging habitat of rosellas but were also the more intensively exploited for agricultural development. Based on their probable extent prior to European settlement, plant communities of the “savannah” land systems have been disproportionately cleared for agricultural development compared to plant communities of the “sclerophyll” land systems. The former generally occurred on soils of higher fertility, provided better pasturage and were more easily converted into farmland (Specht 1972). Paton *et al.* (1999) reported that within the central spine of the Mount Lofty Ranges woodlands have been disproportionately cleared relative to other vegetation types indicated by the greater extent that lower elevations (woodlands) have been cleared relative to higher elevations (open forests). For example, within the elevation range 150 - 300 metres, native vegetation remains over 9.7% of the land area compared to 16.6% of land area for elevations over 450 metres.

Plant communities of the "savannah" and "sclerophyll" land systems are clearly defined by the nature of their understoreys. Two plant communities in the study area that represent the "savannah" land system, *Eucalyptus obliqua* ± *E. dalrympleana* (syn. *E. rubida*) ± *E. viminalis* woodland and *E. leucoxylon* - *E. viminalis* woodland (Figure 3.4) are typified by an herbaceous understorey differing structurally from communities within the "sclerophyll" land systems which contain predominantly sclerophyllous (heathy) understoreys. The understorey of the "savannah" communities typically contains a greater abundance of hemicryptophytes (perennial grass-like plants, within Graminae, Cyperaceae, Juncaceae and Liliaceae), geophytes (pseudo-annual plants reproducing from bulbs, corms and rhizomes, predominantly in Liliaceae, Orchidaceae, Droseraceae, and Compositae) and therophytes (annual plants reproducing from seeds, including many Compositae) than the "sclerophyll" communities. These plants may have provided a substantial component of the pre-European diet of rosellas. According to Paton *et al.* (1999), the pre-European vegetation of the central spine of the Mount Lofty Ranges comprised various open forests (i.e. >30% projected canopy cover) dominated by *E. baxteri*, *E. obliqua*, *E. goniocalyx*, and/or *E. dalrympleana* with a shrubby understorey, but at lower elevations and on heavy (mesic) soils these open forest formations gave way to grassy woodlands of *E. leucoxylon* and/or *E. viminalis*. Prominent understorey plants in some of these woodland formations were *Acacia pycnantha*, *Bursaria spinosa*, *Hibbertia riparia*, and grasses such as *Danthonia* spp., *Stipa* spp., and *Themeda triandra*.

Despite the introduction of broad-acre clearance controls the integrity of many native vegetation remnants in the Mount Lofty Ranges continues to be threatened by weed invasion, stock grazing, altered fire regimes, water harvesting and various forms of dieback associated with human activity. The indigenous herbaceous understoreys of woodland communities have been particularly vulnerable to alien plant invasion. The chief alien invaders in the "savannah" land systems have been grasses, rosette annuals, and geophytes. The invasion has tended to displace the period of maximum growth and flowering from late spring-summer to spring resulting in less summer growth (Specht 1972). Earlier seed production provided by the exotic flora may advantage the breeding pattern of rosellas including the chick rearing and post-fledging periods when food resources are particularly important for offspring survival.

Extensive habitat modification within the study area has almost certainly influenced the seasonal patterns of behaviour of rosellas and the population size. Eucalypt forests generally do not suffer from the extremes of heat or cold or frequent high winds that more open, human-modified habitats provide (Ford 1985), and therefore may provide an important refuge for birds during adverse weather conditions. Lerps and honeydew are a food resource that is almost uniquely important to birds in eucalypt forests (Ford 1985) and appear to be a favoured food of rosellas at certain times of the year. In an open eucalypt woodland psyllids and scale insects attached to leaves of eucalypts were eaten by Eastern Rosellas *Platycercus eximius* in most months of the year and constituted nearly 50% of the diet (based on proportion of feeding observations) during July (Cannon 1977). The tree orchards and pastures that now predominate the Adelaide Hills may therefore provide a greater range of foraging sites and a greater abundance of foods, in particular seeds and fruits, compared to the more extensively forested environment that existed when Europeans first arrived.

The loss and modification of natural habitat in the Mount Lofty Ranges has shifted the reliance of rosellas on native foods towards introduced food sources, the former having declined in abundance in the region. For example, since European settlement, extensive clearing of land on the more arable soils within this region has resulted in a disproportionately high reduction of habitats supporting tree species such as South Australian blue gum *Eucalyptus leucoxylon*, pink gum *E. fasciculosa,* candlebark gum *E. dalrympleana*, manna gum *E. viminalis*, drooping sheoak *Allocasuarina verticillata*, blackwood *Acacia melanoxylon* and wirilda *A. retinodes*.

Riparian habitats in particular have been extensively modified. Only one percent of the stream network of the Adelaide Hills has riparian vegetation that is described as being in healthy condition (Environment Protection Authority, 2000). Within the study area *A. melanoxylon, A. retinodes* and *E. viminalis* are usually associated with riparian habitats. *A. melanoxylon* grows chiefly on soils of fair to high fertility and is very rare on sandy podzols (Farrell and Ashton, 1978). Some riparian species may have been important food sources in autumn and winter. (N.B. in the Adelaide Hills the seed of *A. melanoxylon* ripens in December and January and seed is usually retained on the tree at least until late winter (e.g. August at Stirling), unlike other acacias such as *A. pycnantha* and *A. retinodes* which tend to shed their seed soon after ripening). Silver banksia *Banksia marginata* is a small tree species usually associated with riparian habitats and eucalypt woodlands in the Mount Lofty Ranges and has also declined in abundance. The seed is readily accessible to larger parrots such as Yellow-tailed Black Cockatoos though Paton (pers. comm.)[10] has observed Adelaide Rosellas feeding on opened *Banksia marginata* cones on the ground. At Scott Creek, just south of the study area, Adelaide Rosellas have been noted feeding on the fruits or seeds of the riparian species *Leptospermum lanigerum*, *Eucalyptus viminalis*, and *E. camaldulensis* (Hands, pers. comm.[11]).

Based on feeding observations of Crimson Rosellas in native forest in Victoria, Magrath and Lill (1983) found that the diet in autumn and winter was largely derived from native tree crops. At least half of the feeding records in each season (55% in autumn and 77% in winter) were represented by three foods, sori of the soft tree fern *Dicksonia antarctica*, flower buds of mountain ash *Eucalyptus regnans* and seed of blackwood *Acacia melanoxylon*. All were energy rich food sources (25.7 kJ g^{-1}, 24.1 kJ g^{-1} and 18.3 kJ g^{-1} dry wt. respectively) and therefore important to the seasonal energy requirements of rosellas. Tree fern sori possess several similar characteristics to cherry buds. The reproductive structures are small (i.e. sori, about 1mm diameter), numerous and easily locatable (borne on the margins of fronds), energy rich and are enclosed structures, i.e. protected by a two-valved cap (Jones and Clemesha 1976; Magrath and Lill 1983). As a consequence of the loss of native vegetation in the Mount Lofty Ranges there is clearly now greater dependence by Adelaide Rosellas on introduced food plants that now occupy much of the original range of the subspecies. Native tree crops may have been important food sources in autumn and winter for which cherry and apple trees have possibly become replacement sources of food.

The adaptive foraging ability of Adelaide Rosellas is indicated by the wide range of foods from non-indigenous food sources identified in the diet. Of a total of 172 foods recorded in the diet, representing 149 species, at least 69% in any one season were of non-indigenous origin. The percentage of birds that had eaten non-indigenous foods was 91% in summer and 100% in each of the other seasons. On a seasonal

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[10] Dr DC Paton, Department of Environmental Biology, University of Adelaide.

[11] T. Hands, Cherry Gardens, South Australia

basis 82% - 95% of the volume of food consumed was from non-indigenous food sources.

Joseph (1986) recognised that agricultural practices and the ecology of many bird species are now closely tied; and noted that clearing operations for agricultural development, which have created open woodland with a seed-bearing, grassy understorey for stock, have provided ideal habitat for some seed-eating birds in wetter parts of southern Australia. He suggested that a factor limiting the successful conservation of southern Australian parrots was ever declining nest-hollow availability. Despite the evidence that rosellas are highly adaptable in their feeding habits, their obligate nesting requirement for tree hollows (mainly provided by large eucalypts) underlines the need to maintain the remaining natural habitat for successful long-term conservation of the species.

In addition to land clearing, agricultural activities such as stock grazing, and the cultivation of crops (including irrigation, and chemical fertiliser and herbicide use) have contributed to further changes in the vegetation and availability of foods to rosellas. In the study area, rosellas appear to have benefited from the complex weed flora that typically results from agricultural development.

3.4.5 Adaptations for feeding specialisation

Two categories of granivorous or seed-eating birds in southern Australia, primary and secondary, are recognised by Joseph (1986). Primary species are defined as those for which 'seeds comprise at least 80% of the diet throughout the year'. Birds in this category usually supplement their seed diet with small quantities of other items such as flowers, fruit, insects and green vegetable matter which may be taken more frequently when seeds are scarce or when the birds are nesting. Secondary seed-eaters are 'species taking roughly equal proportions of seeds and other items'. Joseph (1986) also recognised that there is a gradation rather than a clear distinction between these categories; "...some species are primary seed-eaters in some areas or at some times of the year and secondary at other places and times...".

Primary seed eaters are further categorised based on the degree of diet specialisation; specialists, which eat only one or a few seed types, and generalists, which feed on a wide variety of seeds. The designation of a generalist as a species that uses a wide range of resources may however depend on whether the resources are diverse or restricted in their abundance (Recher 1990).

Rosellas possess several anatomical adaptations to granivory. The structure of the bill allows birds to efficiently extract and de-husk seeds. The strongly hooked upper mandible (maxilla) facilitates the extraction of seeds or other small items and the lower mandible assists the de-husking of seeds in conjunction with the inner surface of the upper mandible. The tip of the upper mandible has a sharp cutting edge, inside of which is flattened with shallow transverse grooves, and the lower mandible is broad and shovel-like with a slightly raised cutting edge at the tip (Higgins 1999). The method used by rosellas to de-husk seeds is possibly similar to the method described for Red-browed Firetails by Read (1987), viz: " the blade-like lower mandible peels the husk from the kernel while the seed is held in grooves in the upper mandible and rotated with the tongue".

The crop, a structural modification of the oesophagus, allows seeds to be stored and carried from a feeding site. "Possession of a crop allows individuals to eat rapidly, minimising feeding time when they are more vulnerable to predators and maximising the time available to search for seeds once a patch has been exhausted" (Wiens and Johnston 1977). The muscular gizzard, often assisted by the ingestion of grit, augments the breakage of the seed coat if not completed with the bill, and crushes seeds to assist enzymatic digestion.

Within the study area Adelaide Rosellas were shown to be primarily seed and fruit feeders, supplementing their diet with insects, and at times, flower buds and bulbs. Seeds were the main component of the diet (in each season seeds occurred in at least 90% of birds and comprised between 44% and 70% of all foods by volume). However fruit flesh, mainly apple or cherry, was seasonally important (in each season at least 62% of birds consumed fruit, representing between 21 and 34% by volume of all foods).

3.4.6 Other food studies

A summary of other food studies of the Crimson Rosella is given in Chapter 1. Some aspects of these studies that are relevant to the present investigation of the Adelaide Rosella are discussed below.

The following foods recorded by Bridgewater (1934) for Crimson Rosellas in north-eastern Victoria were also found in crops of Adelaide Rosellas in the current study: *Trifolium subterraneum* seed, apple flesh, apple seed, chickweed *Stellaria media* seed, mouse-eared chickweed *Cerastium glomeratum* seed, hawthorn kernel, cherry pulp, *Trifolium* sp. seed, *Acetosella vulgaris* seed, *Hypochaeris radicata* seed, and seeds of wheat and oats. The similarity in diet to the Adelaide Rosella suggests a similar pattern of land-use and a similar suite of food plants for the two study areas. A few seeds of the broad-leaf weed, plantain *Plantago lanceolata*, were recorded in one crop by Bridgewater (1934), but despite being a common plant in the current study area, it was not recorded in any crops of Adelaide Rosellas. Bridgewater (1934) observed that the Crimson Rosella showed a "decided preference for weed seeds – weeds of the cultivation paddock" and was "very partial to thistle seeds". It was noted that birds were "very fond of clover seeds" (presumably *T. subterraneum*) and "a constant feeder on eucalyptus seeds".

Adelaide Rosellas generally de-husk most seeds (i.e. removal of the testa or seed coat) with the exception of the smallest seeds such as mouse-eared chickweed *Cerastium glomeratum* and St John's wort *Hypericum perforatum*. This was also noted in the study of Bridgewater (1934) who concluded that Crimson Rosellas were not distributors of plants by seed as all ingested matter was ground very finely in the gizzard. Bridgewater (1934) also noted that "numerically the weed seeds eaten are far in excess of seeds that are of value, i.e. *Trifolium*, *Medicago*, and certain grass seeds, and fruit", but recognised that the birds "if left to their own devices, would soon ruin a fruit crop, and it is evident that they must be kept away from the orchards".

A number of important foods from weed species in the current study (Adelaide Hills) were recorded by Lepschi (1993) as foods of Crimson Rosellas in eastern New South Wales. These foods included *Avena* sp. (seed), *Arctotheca calendula* (seed), *Poa annua* (seed), *Chenopodium album* (seed), *Hypericum perforatum* (seed) and *Polygonum aviculare* (seed).

The feeding on flower buds has also been reported for Crimson Rosellas by Lepschi (1993) (9 species) and Magrath and Lill (1983) (*Eucalyptus regnans*), and for the Green Rosella in Tasmania by Brown (1984).

Brown (1984) observed that large feeding flocks of the Green Rosella in Tasmania were usually encountered during winter including an observation of 60 - 70 birds, mostly juveniles, feeding on post-ripened blackberries. In the current study many crops of Adelaide Rosellas contained blackberry seeds but not the flesh, suggesting that the birds usually fed on blackberry plants at a similar stage.

The only native food that has been reported in the literature for the Crimson Rosella in South Australia since the study of Lea and Gray (1935) is the "pulpy epicarp of *Persoonia* spp., geebung" (Forde 1986). Recent observations of native foods eaten by Adelaide Rosellas close to the study area, include seed of *Daviesia leptophylla* (Pedler, pers. comm.)[12], *D. ulicifolia* (Hands, pers. comm.[13]) and *Schoenus apogon* (pers. obs.); nectar from flowers of *Astroloma conostephioides* (Paton, pers. comm.[14]); flowers (possibly nectar) of *Pultenaea daphnoides* and *Banksia marginata* (Robinson, pers. comm.[15]); seed or ripened fruit of *Exocarpos cuppressiformis, Leptospermum lanigerum*, and *Eucalyptus camaldulensis* (Hands, pers. comm.[15]).

3.4.7 Conclusions

Adelaide Rosellas in the Adelaide Hills are predominantly seed-eaters but supplement their diet at times with other foods such as fruit, bulbs, buds and insects when seasonally abundant. The birds are generalists, feeding on a wide range of foods. The high proportion and variety of non-indigenous foods in the diet of rosellas indicate that they are highly adaptable in their foraging behaviour and that they forage opportunistically according to the seasonal availability of foods.

Adelaide Rosellas consumed a greater volume and number of food items in autumn than in other seasons. The higher consumption of food in autumn was to a large extent attributable to the availability of apples at this time of year. The wide variety of foods in the diet in autumn may be a response to the generally low abundance of other foods that are available to rosellas in this season. Less food items and less volume of food was consumed by rosellas in summer when seeds and insects are possibly more abundant compared to autumn. Non-indigenous foods comprised the

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[12] R. Pedler, Bridgewater , South Australia.
[13] T. Hands, Cherry Gardens, South Australia.
[14] Dr DC Paton, Department of Environmental Biology, University of Adelaide.
[15] P. Robinson, Summertown, South Australia.

bulk of the diet throughout the year but were of least importance in summer possibly due to lesser availability of these foods and greater availability of indigenous foods. The presence in the diet of foods from indigenous and non-indigenous food sources indicates that rosellas probably forage in two broad habitat types, agricultural land and native vegetation, including the interface between each. Weeds were an important food source in all seasons, providing seeds, buds and bulbs, but are of greatest importance in spring. Fruit pulp represented a large component of the diet based on the volume consumed although it is likely to be of lesser relative importance than seeds in terms of energy content.

Although significant levels of cherry bud damage occurred in the study area, flower primordia were a food of minor importance in the diet based on the quantity consumed relative to other foods. Cherry primordia were absent in the diet in summer (when they are not available) and occurred in negligible amounts in autumn and spring (0.1% and 0.2% by volume). Primordia, though, comprised 1.9% by volume of all foods in winter. Several factors appeared to make buds a relatively attractive food source. Rosellas foraged for most foods on the ground (including apples) as indicated by the predominance of seeds and other foods in the diet obtained from weed species. As a tree crop, cherry buds may enable rosellas to continue feeding when weather conditions are adverse for ground feeding. When cherry buds are available in commercial orchards they usually represent a superabundant, relatively predictable and easily harvested food resource.

Rosellas do not appear to specialise on cherry flower primordia, given that a wide range of other foods were present in the crops of birds that had fed on primordia. Selection for cherry buds in general is not considered to be high relative to other foods given their overall abundance and apparent availability, however selection clearly differs between particular varieties. For example, damage levels for William's Favourite trees are markedly higher than for the majority of other cherry varieties, despite the presence of a large bud resource represented by a wide range of other varieties in most commercial orchards. Possible factors involved in differential selection observed between certain varieties require further investigation. Fisher (1991; 1993) considered certain aspects of bud density that may influence varietal preference but did not identify causal factors. Further investigation of the reasons for varietal preference should consider the importance of energetic factors in food selection. In the next chapter various energetic aspects of food use by rosellas will be considered prior to investigating potential strategies for managing rosella damage to cherry trees.

The presence of cherry primordia may be largely incidental to foraging for more prominent foods recorded in the diet, despite the amount of damage they cause to cherry trees. Male rosellas consumed a greater quantity of primordia than female birds however the difference was not significant. The main foods on which these birds fed were apple flesh and apple seed, supporting field observations that rosellas fed on cherry buds close to apple orchards, and that apple orchards were a principal source of food. Amongst birds that fed on cherry primordia, females consumed more apple flesh than males. This reflects the casual observation that some birds, possibly males, devote a greater proportion of their time perching in the high branches of trees acting as sentinels over ground-feeding flocks.

The dietary results presented in this chapter indicate potential for the use of alternative food sources of high dietary importance for diverting the attention of rosellas from cherry buds. Aspects of the diet (such as the diversity of foods) and foraging behaviour (such as the tendency to feed in flocks when certain foods are abundant) further indicate the potential effectiveness of this strategy.

4 ENERGETICS OF FORAGING BEHAVIOUR AND FOOD USE

4.1 INTRODUCTION

Birds consume food primarily to obtain energy though there is evidence that under special circumstances birds may also eat for nutrients, not just energy (Kendeigh *et al.* 1977). The largest amounts of food required by animals are therefore those providing the energy yielding compounds in the form of carbohydrates, lipids, and to a lesser extent proteins. Essential amino acids and fats are needed in much smaller quantities, while specific growth factors like vitamins are required in minute quantities in the daily diet (Wood 1968). Knowledge of bioenergetics is necessary for an understanding of behaviour as well as for evaluation of the impact of a species in the ecosystem where it lives (Kendeigh *et al.* 1977).

This dietary study shows differences in the quantity and composition of foods consumed by rosellas between seasons. Rosellas consumed a significantly greater volume of food in autumn than in other seasons and the volume of foods consumed in summer was significantly less than in spring (Chapter 3). The principal food groups in the diet were seeds (including kernels) and fruit flesh. Seeds contributed at least 62% of all foods by volume in all seasons except spring when bulbs (soursob) and seeds combined represented 60% by volume of all foods. In other seasons the contribution of bulbs to the diet was negligible. Fruit flesh represented at least 20% of the diet by volume in each season, and in summer and autumn, approximately one third of all foods by volume.

Cherry primordia were a relatively unimportant food based on the quantity recorded in crops. This food was absent in the diet in summer and was only a minor food in autumn and spring. Primordia were most prominent in the diet in winter when 43% of birds fed on buds but the volume consumed relative to all other foods was approximately 2%. For all months, the majority of individual foods (72%) represented less than 1% of the total volume of food, including cherry primordia.

As the Adelaide Rosella was the only bird known to feed on cherry buds, food use and resource depletion could be readily determined for this species by assessing bud damage levels in trees just prior to flowering. I was able to confirm varietal preferences reported in previous studies (e.g. Sinclair and Bird 1987) by demonstrating a clear preference amongst three varieties, Lustre, Makings and William's Favourite at Basket Range, where birds took a higher proportion of buds of William's Favourite compared to the other varieties (Chapter 2). In the current study the pattern of damage was shown to be reasonably consistent between years over a five-year period. Damage also appeared to shift to other varieties as the food resource on the preferred variety diminished. The purpose of these assessments was to determine patterns of bud damage and therefore food use amongst several different varieties of cherry trees as a basis for investigating underlying factors in varietal preference.

To understand the connection between foraging behaviour and resource use, there is a need to know what foods birds use and what factors influence their selection (Grubb 1979). Thus in order to control the impact of rosellas on cherry crops it is first necessary to understand the factors that attract rosellas to cherry buds. A diverse range of variables may affect the foraging patterns of birds. Optimal foraging theory has shown that birds often select food based on energy, time, and effort (Pyke *et al.* 1977; Krebs 1978). The overall level of energy expenditure by birds must be balanced by the reward (including energy) gained by foraging. A foraging bird is required to choose among behaviours with different energy costs, and must therefore acquire sufficient energy to meet the cost of this activity as well as the costs of other activities, thermo-regulation, maintenance, storage and reproduction.

Optimal foraging theory is therefore based on the proposition that animals forage in a way that optimises their success or energy gain per unit time. Models of foraging theory generally predict that foragers are likely to choose food sources that yield more food in less time. In this chapter I consider some ways in which rosellas might increase the profitability of diet selection or food use, recognising however that clear demonstrations of optimal foraging theory predictions in the field are rarely possible and often problematic (Krebs *et al.* 1983).

4.2 METHODS

4.2.1 Bud primordia density

The buds of three varieties of sweet cherry collected from a commercial orchard at Basket Range between 26/7/98 and 1/8/98 were examined to determine whether there were differences in the number or quantity of primordia per bud between varieties that may influence predation by rosellas. Buds of Williams Favourite, Lustre and Makings were selected for examination as examples of varieties that differed in the level of feeding damage from rosellas within this orchard. The bud sample was collected at several levels within a tree (i.e. high, middle and low level branches) and from several trees of each variety. A total of 384 buds of William's Favourite, 463 buds of Makings and 506 buds of Lustre varieties were thus collected and examined. In the same orchard, buds of William's Favourite and Makings were collected on 26/7/98 and 1/8/98, and buds of Lustre were collected on 1/8/98.

4.2.2 Energy yields of various foods in the diet

The energy yields based on the heat of combustion using a bomb calorimeter were determined for several foods known from the diet of Adelaide Rosellas. Energy yields for flower primordia were determined for the three cherry varieties (above) in order to ascertain any correlation with recorded bud damage levels. Energy yields were determined or obtained for a number of other foods in the diet including apple seed, soursob bulbs and soursob flower buds. This was to allow comparisons of food use and food quality (calorific value) to be made from which an explanation of why rosellas choose certain foods might be developed.

Flower primordia at the same developmental stage were dissected from buds of the three cherry varieties collected between 26/7/98 and 1/8/98. Test samples of flower primordia were weighed fresh then frozen in small vials. The primordia were later freeze-dried to ensure that the manner of drying did not volatilise or destroy any of the combustible material. Each primordia sample was reweighed during the drying process until there was no further weight loss to ensure that complete drying had been achieved. The dried primordia were ground, formed into pellets and weighed in order to obtain test samples of at least 25 mg in weight. A ballistic bomb calorimeter was used to measure the calorific value of the sample material. For each variety either eight or nine samples were prepared and tested. The heat release from the burnt samples was recorded in kJ kg^{-1} units from which mean values were calculated.

Test samples of apple seed, soursob bulbs and soursob buds were prepared and measured in the same manner. To allow a wider comparison with other foods in the diet, calculated energetic values were referenced from other sources (Bryant 1973;

Golley 1961; Kale 1965; Kendeigh and West 1965; Thomas and Corden 1977; Watt and Merrill 1963).

4.2.3 Harvesting rate of cherry flower buds

I undertook a series of observations of bud feeding activity by Adelaide Rosellas in a cherry orchard at Basket Range during the period 10/8/98 to 16/8/98 in order to obtain an estimate of the bud harvesting rate. Observations were made from a hide (vehicle) during the late afternoon period between 4.00 p.m. and dusk at 5.45 p.m. As soon as I recognised a rosella feeding I commenced counting the number of buds consumed and recorded the time elapsed in seconds with a stopwatch. Observations of individual birds continued until feeding was interrupted by another activity (e.g. resting or flight), or the bird became obscured from view.

4.3 RESULTS

4.3.1 Energy yield of cherry flower buds

Energy determinations were made for primordia from three cherry varieties varying in extent of use by rosellas. The heat of combustion (kJ g^{-1}) of cherry flower primordia did not differ significantly between the heavily damaged variety, William's Favourite, and two less damaged varieties (Table 4.1).

Table 4.1. Energy yields for cherry flower primordia collected at Basket Range between 26 July and 1 August 1998.

Heat of combustion values were determined using a bomb calorimeter. A two way Analysis of Variance revealed there was no significant difference in mean energy density based on dry weights between cherry varieties ($F = 2.815$; $df = 2, 22$; $p = 0.0816$).

	Energy density of primordia (kJ g^{-1})		
	mean	s.e.	No. of test samples
William's Favourite	18.88	0.22	8
Lustre	19.17	0.21	9
Makings	19.62	0.22	8

4.3.2 Density of flower bud primordia

The distribution of bud primordia-group sizes (number of primordia per bud) differed between buds examined from each of three cherry varieties, Williams Favourite, Lustre and Makings. There were six primordia group sizes recorded amongst the three varieties. No buds of any variety were recorded with less than two or more than seven primordia. No buds of Lustre or Makings were recorded with five or more primordia per bud but 15% of William's Favourite buds contained more than five primordia. The most frequently recorded primordia group sizes for each variety were as follows: 4 primordia bud^{-1} for William's Favourite (52% of buds), 3 primordia bud^{-1} for Lustre (68%) and 3 primordia bud^{-1} for Makings (51%). The percentage of buds containing four or more primordia was 67.5% for William's Favourite, 21.2% for Lustre and 2.2% for Makings. Two primordia per bud were recorded for 47% of Makings buds but were recorded for only 11% and 0.5 % of Lustre and William's Favourite buds respectively.

There were significantly more primordia per bud for William's Favourite than Lustre or Makings (Figure 4.1), and buds of Lustre contained significantly more primordia than Makings.

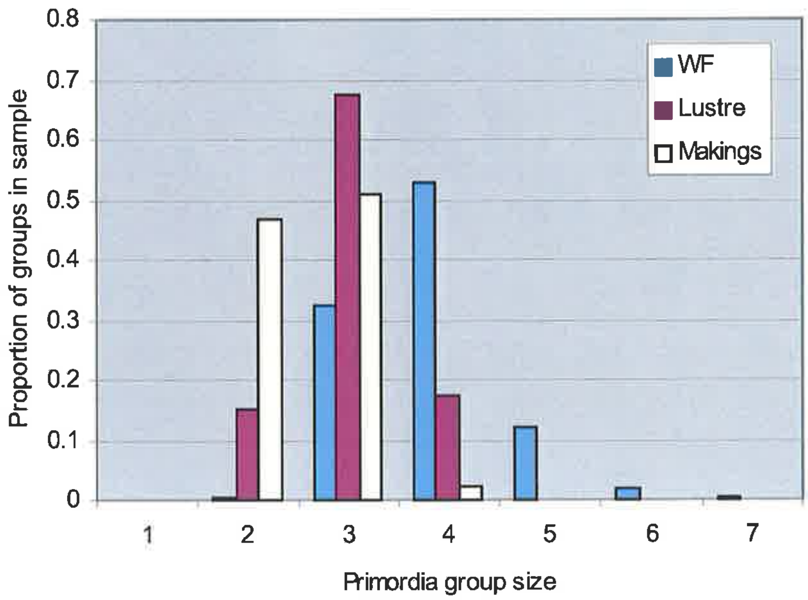

Figure 4.1. Relative frequency of buds for three commercial varieties of sweet cherry from Basket Range (26/7/98-1/8/98) based on number of primordia per bud.

No buds were recorded with less than 2 or more than 7 primordia. The proportion of buds in each primordia group size (i.e. ranging from 2 buds per group to 7 buds per group) was based on counts from a total of 384, 506 and 463 buds for William's Favourite, Lustre and Makings respectively. A two way Analysis of Variance revealed a significant difference in mean number of primordia per bud between varieties ($F=151.88$, d.f. $=2, 19$; $p<0.0001$). A Tukey-Kramer HSD test revealed that the mean number of primordia per bud differed significantly between each of the varieties.

4.3.3 Energy content of flower buds

Although the energy yields (heat of combustion) for primordia did not differ significantly between preferred and non-preferred varieties based on unit dry mass, the difference in mean energy content per bud was significant due to the difference between varieties in the number and dry weight of primordia per bud (Table 4.2). A comparison of the three varieties shows that the primordia energy content per bud for William's Favourite was 27% higher than Lustre and 18% higher than Makings.

Table 4.2. Energy content of flower primordia from three commercial varieties of sweet cherry collected at Basket Range, 26/7/98 to 1/8/98.

An analysis of variance revealed a significant difference in mean energy content per bud (dry weight) between cherry varieties (F=19.86, df = 2,19; p<0.0001). A Tukey-Kramer HSD test revealed that the mean energy content per bud differed significantly between William's Favourite (WF) and each of the other varieties. There was no significant difference between Lustre and Makings.

Cherry variety	total no. of buds	no. primordia bud^{-1} mean ± s.e.^{A}	primordia wet wt. bud^{-1} (mg) mean ± s.e.^{B}	primordia dry wt. bud^{-1} (mg) mean ± s.e.^{B}	energy density (J mg^{-1} dry wt.) mean ± s.e.^{B}	energy content (J mg^{-1} of bud dry wt.) mean ± s.e.^{B}
WF	384	3.83 ± 0.06	3.37 ± 0.09	1.18 ± 0.04	18.88 ± 0.24	22.20 ± 0.66
Lustre	506	3.00 ± 0.05	2.26 ± 0.05	0.91 ± 0.02	19.17 ± 0.22	17.54 ± 0.45
Makings	463	2.54 ± 0.04	2.46 ± 0.07	0.96 ± 0.03	19.62 ± 0.18	18.82 ± 0.51

^{A}n = 14 (WF), 8 (Lustre), 7 (Makings)
^{B}n = 7 (WF), 8 (Lustre), 7 (Makings)

4.3.4 Harvesting rate of cherry flower buds by rosellas

A total of 37 observations of feeding were recorded, ranging from 8 seconds to 201 seconds in duration. All foraging activity usually ceased at dusk (approximately 5.45 p.m.). The late afternoon period until dusk was the period of greatest foraging activity in cherry trees.

The harvesting rate for individual feeding observations ranged from 0.14 buds per second to 0.83 buds per second. Based on all observations the mean feeding rate was 0.50 ± 0.03 buds s^{-1} (n=37). Feeding activity was observed principally in William's Favourite trees. The actual rate of harvesting of buds within individual bud groups was greater than this value, possibly exceeding one bud per second, given the time required to move between bud groups on the same branch or between branches.

The rate of energy intake by rosellas for William's Favourite primordia was estimated to be 11.08 J sec^{-1} (Table 4.3), which was 27% higher than for Lustre primordia and 18% higher than for Makings primordia, assuming the same consumption rate of 0.50 buds s^{-1} between varieties.

Table 4.3. Estimated rate of energy intake by rosellas consuming flower primordia of three cherry varieties, William's Favourite, Lustre and Makings.

The values shown here are based on the estimated energy content of buds (also shown in Table 4.2) and an assumed consumption rate of 0.50 buds sec^{-1} for all varieties.

Cherry variety	Energy density (J mg^{-1} dry mass)	Energy content per bud (J)	Estimated rate of energy intake (J s^{-1})
William's Favourite	18.88	22.20	11.08
Lustre	19.17	17.54	8.75
Makings	19.62	18.82	9.39

4.3.5 Energy values of other foods in the diet

In addition to cherry flower bud primordia, energy values were determined for several prominent foods in the diet, i.e. apple seed, soursob bulbs and soursob flower buds (Table 4.4). Values for some other foods in the diet are cited from various other sources.

Table 4.4. Energy values of some foods in the diet of the Adelaide Rosella.

Wet weight equivalent values were calculated based on the proportion of water in the material. Dry weight to wet weight energy conversion factors were as follows: Soursob, bulb coll. 31/7/98 (0.414), coll. 19/9/92 (0.417); soursob, flower bud (0.222); cherry flower primordia, "Lustre" (0.4057), "Williams Favourite" (0.3529), "Makings" (0.3896); apple, flesh (0.152); cherry (sweet) flesh (0.196); blackberry flesh (0.155); apple, seed (0.742); insects, Psylloidea (Triozidae) nymphs (0.337). Data are means ± s.e. when given.

	Energy concentration kJ g^{-1}	
Food	Dry mass equivalent	Wet mass equivalent
soursob, bulb [1]		
collected July	15.78 ± 0.16	6.54
colected September	17.81 ± 0.64	7.43
soursob, flower bud [2]	21.24 ± 0.20	4.73
cherry, flower primordia [3]		
Lustre	19.17 ± 0.22	7.77
Williams Favourite	18.88 ± 0.24	6.66
Makings	19.62 ± 0.18	7.64
apple, seed [4]	25.71 ± 0.31	19.07
apple, flesh	15.43	2.35 [5]
cherry (sweet), flesh	14.95	2.93 [5]
blackberry, flesh	15.67	2.43 [5]
insects (Psylloidea nymphs)	23.03 [6]	7.75 [7]

1 2.756 g wet mass collected 31/7/98, 15.17g wet mass, coll. 19/9/92
2 470 buds (2.01g wet mass), coll. 29/7/98-31/7/98
3 506 Lustre buds, 384 Williams Favourite buds, 463 Makings buds, coll. 27/7/98-3/8/98, Basket Range
4 27 seeds "Golden Delicious" variety
5 wet mass values from Watt and Merrill (1963)
6 general insect material (Kale 1965)
7 based on 220 psyllid nymphs, 0.3ml (Triozidae: *Schedotrioza marginata*)

The energy value for apple seed was 6-7 kJ g^{-1} dry mass higher than each of the three varieties of cherry primordia, and about 8-10 kJ g^{-1} dry mass higher than for soursob bulbs. The value determined for apple seed (25.7 kJ g^{-1}) however is relatively high for seed material (Golley 1961, Ricklefs 1974). Kendeigh and West (1965) determined a value of 20.57 kJ g^{-1} dry mass for *Chenopodium album* seed (a prominent food in the diet in autumn and winter), and 21.37 kJ g^{-1} dry mass for *Taraxacum officinale* seed (prominent in the spring diet).

Dry mass energy values for fruit flesh are similar to several other foods such as soursob bulbs and cherry primordia. However, on a wet weight basis energy values for fruit flesh are low due to their high water content. Based on wet mass, the energy density for apple seed is approximately eight times the value determined for apple flesh. Insects have energy values of about 23 kJ g^{-1} dry mass, around 4 kJ g^{-1} higher than average plant materials (Golley 1961; Maxson and Oring 1980).

On a dry weight basis the energy values for flower primordia are intermediate between bulbs or fruit flesh and seeds. A higher energy value was determined for soursob bulbs collected in spring than for bulbs collected in winter.

More than half of the birds examined fed on apple flesh in autumn and winter (58% and 55% respectively). The mean volume of apple flesh per crop was greater than for apple seed in all seasons, particularly in autumn when the mean consumption of flesh was 0.86 ± 0.17 mL compared to 0.33 ± 0.10 mL of seed (Table 4.5). However, based on estimated energy-volume equivalents, birds obtained more energy from seeds than flesh in each season (Table 4.5). Apple seed was of greatest importance to birds in winter when the volume of seed and flesh consumed was similar but the mean energy content of apple seed per crop was markedly higher than for apple flesh (i.e. 7.01 kJ $bird^{-1}$ compared to 0.83 kJ $bird^{-1}$).

Table 4.5. Mean volume and estimated energy content (kJ) of apple seed and flesh per crop sample for Adelaide Rosellas collected in cherry orchards in the Adelaide Hills between 1985 and 1992.
Calculations of energy values (kJ) are based on 18.69 kJ ml^{-1} for apple seed and 2.08 kJ mL^{-1} for apple flesh.

		Volume (mL) and energy content (kJ) per crop			
		SEED		FLESH	
Sample	No. of birds	mL (mean ± s.e.)	kJ	mL (mean ± s.e.)	kJ
summer	83	0.02 ± 0.02	0.45	0.14 ± 0.04	0.29
autumn	78	0.33 ± 0.10	6.17	0.86 ± 0.17	1.80
winter	78	0.38 ± 0.11	7.01	0.40 ± 0.09	0.83
spring	84	0.04 ± 0.02	0.70	0.24 ± 0.09	0.50
all	323	0.27 ± 0.06	4.96	0.48 ± 0.07	1.00

The seed in apples was estimated to be only a small proportion of the total quantity of flesh. Apple seed from the Golden Delicious variety represented approximately 0.1% of the flesh by wet weight per apple (mean 165.6 ± 4.0 g; n=5) and 0.08% of the flesh by wet volume per apple (mean 200.9 ± 5.0 mL; n=5). Rosellas thus consumed a disproportionately higher quantity of apple seed compared to apple flesh based on the relative abundance of these foods. A comparison of apple seed, soursob bulb and cherry primordia shows the greater influence of the relative mass of food items than energy density on the energy content of food items (Table 4.6). The energy content of individual bulbs was markedly greater than the other food items due to the relatively high mass of bulbs.

Table 4.6. Energy content per food item for apple seeds, soursob bulbs and cherry buds based on wet weights.

	Weight (g) and kJ			
Food	Average weight unhusked (g)	Average weight husked (g)	kJ g^{-1} (wet)	kJ $item^{-1}$ (wet)
apple seed[1]	0.036	0.024	25.87	0.61
soursob bulb[2]	0.296	0.249	15.78	3.93
cherry primordia [3]	n/a	0.003	6.66	0.002

[1] 100 seeds

[2] 200 bulbs collected in study area, January 1992

[3] William's Favourite variety (3.37 mg; mean 3.83 primordia bud^{-1})

4.3.6 Contribution of major food groups to the diet

A high proportion of the diet comprised energy rich food sources such as seeds, flower buds and insects, i.e. foods ranging in energy density from 20 to 23 kJ g^{-1} dry mass (Table 4.7). Fruit flesh is a low quality food source in terms of energy density but was abundant and readily available at certain times of the year, notably cherries in summer and apples in autumn and winter. This seasonal abundance thus appeared to be an important factor in food selection by rosellas. The presence of flower parts in the diet generally corresponded with their seasonal abundance (i.e. cherry buds in winter; soursob buds in winter and spring).

Table 4.7. Approximate energy values (kJ g^{-1} dry mass) for foods in major food groups being considered in this study.

Food group	Approximate energy value (dry mass)
seeds [1]	21 kJ g^{-1}
bulbs [2]	17 kJ g^{-1}
flower buds [3]	20 kJ g^{-1}
fruit flesh[1a]	15 kJ g^{-1}
insects; arthropod material [2a]	23 kJ g^{-1}
vegetative [1]	17 kJ g^{-1}

[1] after Golley 1961; [2] this study (based on *Oxalis pes-caprae*); [3] this study (based on cherry & soursob); [1a] after Watt & Merrill 1963; Thomas & Corden 1977; [2a] Kale 1965; Golly 1961; Bryant 1973.

The contribution of foods within each Food Group in the diet of rosellas according to energy value was 87% for seeds and kernels, which represented 60% by volume of all foods (Table 4.8). The second highest energy contribution to the diet was from fruit flesh (6.4%), which represented 29% by volume of all foods.

Table 4.8. Percent volume (wet mass) and estimated percent energy contributed by major food groups to the diet of Adelaide Rosellas in the Adelaide Hills.

These data are based on the crop contents of 333 birds taken in cherry orchards in the Adelaide Hills between 1985 and 1992. For each food group a conversion factor for wet volume to dry mass equivalent was determined which was then applied to the total volume of each food group in the diet and the dry mass energy value estimates shown in Table 4.7.

Food group	Percent volume	Estimated percent energy content
seeds & kernels	60.4	87.3
bulbs	4.4	2.6
flower parts	2.3	1.3
fruit flesh	29.0	6.4
vegetative	2.5	1.5
insect	1.4	0.9

The dietary contribution of foods within each Food Group based on energy value was highest for seeds and kernels in each season (Table 4.9).

Table 4.9. Percent volume and estimated percent energy content of foods eaten by Adelaide Rosellas in each season according to major food groups.

These data are based on the crop contents of 333 Adelaide Rosellas collected in and around cherry orchards in the Adelaide Hills between 1985 and 1992. For each food group a conversion factor for wet volume to dry mass equivalent was determined which was then applied to the total volume of each food group in the diet and the dry mass energy value estimates shown in Table 4.7. Total volumetric and energy values for each season were: summer (116.8mL, 1231kJ; n=87); autumn (249.6mL, 2662 kJ; n=80); winter (172.6mL, 2007kJ; n=82); spring (181.1mL, 1652kJ; n=84).

	SUMMER		AUTUMN		WINTER		SPRING	
Food Group	percent volume	percent kJ	percent volume	percent kJ	percent volume	percent kJ	percent volume	percent kJ
seed/kernel	62.8	90.5	64.3	91.5	69.9	91.2	44.3	73.8
Bulb	0.2	0.1	1.1	0.7	0.1	0.1	15.7	10.9
flower parts	0.02	0.0	0.2	0.1	4.1	2.0	5.1	3.2
fruit flesh	33.6	7.4	33.7	7.3	21.2	4.2	26.9	6.8
Vegetative	1.2	0.7	0.2	0.1	3.1	1.6	6.3	4.1
Insect	2.2	1.4	0.6	0.4	1.5	0.9	1.7	1.2

4.4 DISCUSSION

4.4.1 Energy content of foods

The process of food selection is affected by a wide array of variables, including the energy content of individual foods (Ellis *et al.* 1976). Energy values of foods examined in the present study varied considerably based on wet mass equivalents. Energy density values recorded for cherry primordia were about two to three times higher than for fruit flesh. On a dry mass basis the values for cherry primordia were intermediate between bulbs or fruit flesh and seeds. Food selection by birds is likely to be more strongly influenced by the energy concentration of foods on a wet mass rather than dry mass basis. It is thus more energy efficient for birds to consume foods that are relatively low in water content such as seeds compared to bulkier, less energy dense foods such as fruit flesh.

Cherry bud primordia comprised a relatively small proportion of the seasonal diet based on volume or wet mass. This food source did not contribute significantly to gross energy intake or the total energy content of the diet. Primordia were absent in the diet in summer and were only a minor food in autumn and spring. Based on percentage volume the relative importance of cherry primordia in the diet was greatest in winter when this food represented only 2% of all foods.

Apples were an important food resource for rosellas in respect of the proportion of birds that fed on apple seed or apple flesh as well as the volumetric proportions consumed. The quantity of apple flesh consumed by birds was greater than for apple seed in all seasons. However, birds obtained more energy by consuming apple seed. Although apple flesh is a low quality food its attraction to rosellas may be its relative abundance and accessibility. The consumption of apple seed in the diet was disproportionately high based on the relative abundance and availability of apple seed and apple flesh in the study area. In apple orchards during winter, small heaps of chewed apple pulp pieces, attributed to rosellas, were often seen next to fallen apples. This suggests that birds fed selectively on apple seed by removing and discarding the surrounding apple flesh due to its lower nutritional value. Food availability was not assessed quantitatively but apples were noted to be generally abundant, particularly in the Basket Range, Uraidla and Lenswood districts. The seed in individual apples comprised only a very small proportion of the quantity of flesh (e.g. 0.1% by wet weight and 0.08% wet volume), further suggesting that rosellas selectively foraged for apple seed. The consumption of apple flesh by rosellas thus may frequently be only incidental to foraging for seed. Long (1985) observed that Red-capped Parrots in the south-west of Western Australia burrowed into apples mainly for the seeds, but also squeezed the juice from pieces of ripe fruit. This behaviour supports the hypothesis of preferential feeding for the seeds.

Apple seed as a food resource is relatively easy for birds to locate or detect, but it is a food that requires a greater investment of time and effort to obtain than apple flesh. The markedly higher energy density of apple seed compared to apple flesh may however offset the greater effort required to harvest the seed. A time-activity-energy budget may reveal the foraging profitability for each food. However, differentiating and quantifying the foods being consumed is a practical difficulty in determining intake rates by birds in the field.

Food quality is an important factor in choice and involves several attributes including energy content. It has become conventional to measure the value of food items for a feeding animal as the net rate of energy gain achieved (e.g. Krebs 1978). In the next chapter the feeding response of captive rosellas given a free choice of two prominent foods in their diet, apple seed and soursob bulbs, will be investigated. Any difference in selection between two foods is most likely to be attributed to characteristics of each food that may influence the rate of net energy intake, such as relative de-husking rates, food item size, weight of individual food items, and energy values of each material. The average energy content per food item was estimated as 0.61 kJ for apple seed and 3.93 kJ for soursob bulbs (Table 4.6). Rosellas de-husk apple seeds and sour-sob bulbs before ingesting them. Although apple seed has a thicker husk than sour-sob, the rate of de-husking may not differ significantly. Apple seeds are relatively consistent and usually smaller in size and weight compared to fully developed soursob bulbs. The average wet weight of a sample of de-husked soursob bulbs (249 mg; n = 200) was more than 10 times the wet weight of de-husked apple seeds (24 mg; n = 100).

Given a similar handling time and foraging effort for items of each food, birds would be able to achieve an energy intake rate approximately six times greater when feeding on soursob bulb compared to apple seed. Based on an energy intake rate of 11.1 J s^{-1} for flower bud primordia from William's Favourite cherry trees, birds would need to feed for almost six minutes (355 seconds) to achieve the energy gain equivalent to consuming one soursob bulb, not taking into account energy expended whilst foraging. A dense patch of soursob cultivated to expose numerous bulbs at the surface would provide rosellas with a considerably more attractive foraging resource than cherry buds in terms of potential net energy gain per unit time. Similarly, birds would need to feed on buds for 55 seconds to achieve the energy gain equivalent to consuming one apple seed. The de-husking rate for individual apple seeds or soursob bulbs was not determined in this study. However, given the expected time required by a bird to remove the pulp from an intact apple in order to gain access to the seeds in the core of the fruit, the net energy gain may not be markedly different from feeding on cherry buds over the same time period. Circumstances might be altered to make apple seed or soursob bulbs more accessible to rosellas and thus foraging for these foods more profitable. There may be potential to use soursob bulbs as a diversionary food source (decoy food) for mitigating damage to cherry fruit in summer or cherry buds in winter, on the basis of differences in food quality (e.g. energy reward). Differences in energy values were obtained for soursob bulbs collected in spring (September) compared to winter (July), reflecting the phenology of bulb development over this period. The potential use of soursob bulbs to modify foraging behaviour will be investigated in Chapters 5 and 6.

4.4.2 Energy requirements of rosellas

Based on crop volumes the quantity of food in the diet was significantly greater in autumn than in each other season and the quantity in summer significantly less than in spring. The calorific value of the diet is likely to be strongly influenced by the seasonal thermo-regulatory needs of birds. Daily energy requirements are likely to be less during late spring and summer than during the winter months when energy required for thermo-regulation would be higher. In a study of the feeding ecology of the Crimson Rosella in a temperate wet forest in autumn and winter (Sherbrooke Forest, Victoria) birds in general had a diet with a high energy content, including reproductive parts of plants and insect larvae (Magrath and Lill 1983).

Basal metabolism may be used as a reference base for use of coefficients to estimate the energy costs of other activities. The basal metabolic rate (BMR) is defined here as the rate of energy expenditure in a resting, post absorptive state in a thermo-neutral environment (Kendeigh *et al.* 1977). It was estimated from the allometric formula $BMR = 1.938m^{0.734}$ kJ day^{-1} where *m* is body weight in grams (Aschoff and Pohl 1970).

The *BMR* estimated by Magrath and Lill (1983) for Crimson Rosellas in a temperate wet forest was a similar proportion of the Daily Expenditure of Energy (DEE) in autumn and winter (49.6% and 47.1%), and the thermo-regulatory cost in winter (27.1% of *DEE* or 42.07 kJ day^{-1}) was shown to be higher than in autumn (16.1% of DEE or 25.30 kJ day^{-1}). The estimated cost of thermo-regulation in winter for Adelaide Rosellas in the study area was approximately twice the estimate for autumn based on a seasonal difference in mean daily ambient temperature of 5.4°C (Table 4.10). However, the estimated energy content of food per crop was greater in autumn (33.3 kJ; n=80) compared to winter (24.5 kJ; n=82) for Adelaide Rosellas in the study area, despite the higher cost of thermo-regulation in winter.

Table 4.10. Cost of thermo-regulation for Adelaide Rosellas in autumn and winter (kJ day^{-1}) in the Mount Lofty Ranges.

Data are presented for both sexes as differences in basal metabolism usually occur between males and females when there are pronounced differences in weight (Kendeigh *et al.* 1977).

			AUTUMN		WINTER	
Sex	Mean body weight, g (no. of birds)	*BMR* [A]	*M* [B]	Cost of thermo-regulation [C]	*M* [B]	Cost of thermo-regulation [C]
females	115.2 ± 0.7 (188)	63.16	81.61	18.44	98.48	35.32
males	130.2 ± 0.5 (278)	69.10	87.80	18.70	105.94	36.84
both sexes	124.3 ± 0.6 (466)	66.79	85.40	18.61	103.05	36.26

[A] basal metabolic rate: *BMR* = 1.938 $m^{0.734}$ kJ day^{-1} where *m* is body weight in grams (Aschoff and Pohl 1970).

[B] metabolic rate at T_a = 14.6°C (autumn) and T_a = 9.2°C (winter): mean daily temperatures for Lenswood Research Centre. $M = a - b\,T_a$ (Kendeigh *et al.* 1977) , where *a* is the metabolic rate at 0°C (= 7.573 $m^{0.5944}$), *b* is the temperature coefficient (=0.1912 $m^{0.5886}$ kJ day^{-1} $°C^{-1}$), and *m* is body weight in grams.

[C] The cost of thermo-regulation is *M* – *BMR*

This seasonal comparison of energy intake suggests that rosellas in winter may need to reduce their daily expenditure of energy for activity in order to meet the higher thermo-regulatory costs. Rosellas may reduce energy expenditure by one or several means, including resting more and by expending less energy on foraging (i.e. foraging more efficiently). Magrath and Lill (1983) suggested that lower food consumption in winter by Crimson Rosellas, when the climate is more energetically stressful compared to autumn, could be a means for conserving energy by increasing time spent resting.

The mean body weight of adult Adelaide Rosellas did not differ significantly between birds collected in each season (Table 4.11), suggesting that loss of body weight or stored energy reserves (fat) is not used as a strategy to meet higher thermo-regulation needs in winter. The similarity in seasonal mean body weights also suggests that food resources are sufficient to meet increased energy demands.

Table 4.11. Mean body weight of adult Adelaide Rosellas of minimum age of 12 months taken from cherry orchards in the Adelaide Hills between 1985 and 1992.
A one way analysis of variance revealed that there was no significant difference in mean body weight per bird between seasons (F=1.3950; df = 3, 136; p=0.2471). Values given are mean body weight (g) ± standard error.

Bird sample	Number of birds	Body weight (g) mean ± s.e.
summer	29	125.7 ± 1.8
autumn	39	130.5 ± 1.6
winter	29	128.2 ± 1.8
spring	43	127.7 ± 1.5

Magrath and Lill (1983) suggested that Crimson Rosellas in winter could, in principle, increase their foraging efficiency to meet the additional cost of winter existence in one or more of four main ways: (i) by switching to a diet with a higher energy content; (ii) by increasing food intake rate; (iii) by exploiting food not used by cohabiting species; and (iv) by switching to a diet with a higher average metabolizable energy coefficient (the energy obtained from food after the gastrointestinal and urinary wastes are subtracted).

A time-activity budget may determine how rosellas in the Mount Lofty Ranges modify their behaviour in winter in order to meet their overall energy needs. Estimates of energy expenditure of free-living birds can demonstrate how daily and seasonal totals are apportioned among the requirements of foraging, thermo-regulation, digestion, reproduction, moult and other activities. Goldstein (1990) contends that such studies may provide a greater understanding of the link between foraging ecology (patterns of behaviour) and measures of fitness (the ability to survive and reproduce). Behavioural flexibility may be critical to the maintenance of energy balance in the face of changing physical environments and resource availability (Goldstein 1990). For example, changing weather may alter food availability, thereby necessitating a change in foraging strategies (e.g. Murphy 1987). The measurement of daily energy expenditure (DEE, the sum of all energy costs incurred in a 24-hour period) for birds most commonly involves the construction of time-energy budgets (e.g. Goldstein 1990). A time-energy budget analysis requires activities to be categorised and accurately timed, and that thermo-regulatory costs be accurately assessed.

Behavioural thermo-regulation is an important supplement to physiological modes of thermo-regulation, and includes the forms of sheltering from environmental stresses, postural adjustments and sunbathing (King 1974). Adelaide Rosellas were often observed loafing or resting in the leafless canopy of deciduous trees (e.g. cherry trees) in winter, possibly for the purpose of conserving energy. This activity may also be a form of basking, enabling birds to absorb thermal radiation thereby reducing the cost of thermo-regulation.

A bird's crop allows the storage of food and may be an adaptation to improve overnight survival in cold weather. Rosellas have a distinct diurnal cycle of feeding and food storage in the crop. The afternoon feeding period generally continues until just prior to dusk when birds depart to their over-night roost. The need to arrive at their roost with a full crop may be particularly important in the cold climate of the Adelaide Hills during winter. Fluffing of the plumage allows birds to increase the volume of the plumage to control the rate of heat loss from the body, and occurs most commonly as birds are roosting at night (Kendeigh *et al.* 1977). With a drop in ambient temperature there comes a point where insulation approaches its maximum capacity, below which body temperature cannot be maintained without an increase in heat production (Kendeigh *et al.* 1977). At this point there is a change from insulation to metabolic heat regulation requiring utilisation of food stored in the crop.

4.4.3 Some foraging theory considerations

Foraging animals act economically given that they tend to choose alternatives that yield more food in less time. According to the prey foraging model, foragers select prey items that are most profitable. That is, selected prey items have the highest ratio of energy available to time required for handling and consumption (e.g. Stephens 1990).

Varietal selection and the selection of individual trees on the basis of the density of undamaged buds may be a deliberate strategy of rosellas to maximise the rate of energy intake (i.e. more food in less time) when foraging on cherry buds. The time spent exploiting a depleting patch of food plants (e.g. cherry trees of a preferred variety) may be dependent on the rate of finding undamaged buds. Birds may depart to a more profitable patch (i.e. trees of another variety with more undamaged buds) when the rate of gain drops to a critical value. Theories of optimum diet predict that animals feed more selectively at higher prey densities when food is more abundant, and when prey are scarce there is no selectivity, with prey being taken in proportion to their relative abundance in the environment (e.g. Schoener 1969, 1971; Estabrook and Dunham, 1976). Dead-leaf foraging birds in tropical forests, for example, selected foraging sites for arthropod prey non-randomly, at least partly on the basis of the differential prey availability in each type, avoiding the least productive substrates (Rosenberg 1990). Within the study area, an increase in bud damage to less preferred varieties by rosellas has been observed to occur near the end of the bud development period when damage levels to preferred varieties had reached high levels (e.g. Fisher 1993). The variability in food gain (or risk in locating food) may also increase in a depleting food patch, thereby prompting departure to a less depleted patch where the variability and risk is less. Patches usually decline in quality as the forager exploits them (Charnov 1976). An animal's experience often changes its behaviour and learning permits adaptation to ecological factors that vary over time. Experience gained while exploiting a patch may tell the forager that the patch is an inferior one and hence not worth further effort (Oaten 1977).

The diverse diet of Adelaide Rosellas suggests that birds are readily able to vary food choice to include more abundant foods in response to seasonal availability or shortages of particular foods, which may minimise foraging time. Magrath and Lill (1983) noted that the "catholic" diet of the Crimson Rosella in a temperate wet forest in Victoria may facilitate a relatively smaller investment of time in foraging than that of dietary specialists of similar size when food is scarce. In autumn, when food is likely to be relatively scarce due to less favourable growth conditions for many food plants (particularly just prior to the break of season), Adelaide Rosellas consumed a wider variety of foods than in other seasons. Apples were probably the most abundant food source in autumn and this was reflected in the diet.

Adults and immature birds may differ in foraging efficiency, particularly for difficult foraging repertoires, a likely consequence of the difficulty of learning how to forage (Morse 1990). The relative numbers of adult and juvenile rosellas that consumed cherry flower primordia suggested there were no age-related differences in foraging success. The youngest birds from which primordia were recorded were estimated to be five months of age, suggesting that bud feeding is quickly learned or there is a strong innate component of the behaviour. A better measure of cherry bud foraging success is perhaps foraging time (i.e. number primordia consumed per unit time) but insufficient data were collected for birds of different ages to further investigate this in the current study.

When attempting to make broad correlations between food selection and energy values all components of the profitability of feeding should be taken into account. Food use and preference reflects a balance between the energy content of the diet, dietary nutrients, the digestibility of individual foods and behavioural costs of foraging. According to Karasov (1990), digestion is important in avian ecology at the level of individuals, populations and community structure by affecting resource removal rate. Karasov (1990) has reviewed the utilization efficiencies (a general term used for various expressions of digestibility and metabolizability) of wild birds on various foods. The largest source of variation in observed utilization efficiencies was due to the type of food consumed. Average apparent metabolizable energy coefficients, MEC, ([food energy – excreta energy] / food energy) according to type of food consumed included: nectar, 0.98; arthropods, 0.77; cultivated seeds, 0.80; wild seeds, 0.62; fruit pulp and skin, 0.64; herbage, 0.35. Utilization efficiency may also vary with physiological condition, for example young, developing birds may be less efficient than adults at extracting energy and nutrients from particular foods.

A common seed-producing pasture weed, plantain *Plantago lanceolata*, was not recorded in the diet despite being a common plant within the study area. The absence of seed from this species from the diet could be due either to the presence of a toxin (tannins, phenolics, etc.) or low metabolizability causing an aversion to the seed by birds. The energy value of 21.79 kJ g^{-1} obtained for *Plantago* sp. seed (Kendeigh and West 1965), however, is similar to average values recorded for seed material (e.g. Golley 1961).

4.4.4 Factors influencing foraging on cherry buds

Evidence has been presented that feeding occurs preferentially on cherry varieties in a broadly consistent pattern between years and between orchards (Chapter 2). However, why do rosellas feed on cherry buds of any variety given that cherry primordia appear to be a relatively unimportant food? The first consideration is that rosellas are generalists and cherry primordia are one food in a wide and diverse diet. Nonetheless there appears to be specific characteristics of cherry trees and cherry orchards that may encourage their use by rosellas as a food resource patch. The use or attractiveness of cherry trees for non-foraging activities may also lead to bud foraging as a secondary or incidental activity. Cherry trees may also provide rosellas the opportunity to feed when foods of higher quality are temporarily unavailable or are in short supply. A number of possible factors are considered below.

Energy content of buds

The relative attractiveness to rosellas of cherry buds from William's Favourite trees may be related to its specific physical attributes, such as the number of buds per whorl or number of flower primordia per bud. The data presented in this study indicate that the opportunity to maximise energy intake (or net energy gain) during bud feeding may be a key factor influencing varietal preference by rosellas. The energy density (J mg^{-1} dry mass) of cherry flower primordia did not differ significantly between the heavily damaged variety, William's Favourite, and two less damaged varieties, however the energy content per bud differed significantly, reflecting differences in the mean number of primordia per flower bud. Assuming similar bud densities between varieties, this difference offers rosellas the ability to increase the rate of energy intake and therefore influence choice between varieties. The differences in the estimated rate of energy intake between the three varieties broadly corresponds with bud damage levels observed for each of these varieties within the same orchard at Basket Range over a five year period (1988 to 1992). The estimated rate of energy intake (assuming the same feeding rate of 0.5 buds s^{-1} for each variety) for William's Favourite was 11 J s^{-1} compared to 8 J s^{-1} for Lustre or Makings which correlated with high damage levels to William's Favourite trees (80% of trees with 75% or more bud loss) and low damage levels for Lustre and Makings trees (over 90% of trees with 5% or less bud loss). An examination of bud density observations (e.g. Fisher 1993) indicates that feeding on buds of William's Favourite is energetically more profitable than a comparison between the three varieties based on bud energy content alone would suggest.

Rosellas thus appear to be able to differentiate between food alternatives differing in energy reward, reflecting observed patterns of bud damage in orchards. For each bud primordia group taken, a bird faces a period of search that would be negligible in duration due to the closely packed clusters of buds. The more time-consuming actions therefore would involve movements between bud groups, along and between branches. Therefore, in order to maximise their rate of energy intake, it is advantageous for birds to feed on the buds of a variety in which the density of primordia is greater, based either on the average number of primordia within buds, the size of bud groups or the spacing of bud groups. Thus, as demonstrated here, if the potential reward from each bud is approximately 4 primordia (i.e. William's Favourite) compared to 2-3 primordia (i.e. Lustre or Makings), it could reasonably be expected that birds will exercise preference for buds of William's Favourite trees. This reflects observations from the current study that varieties with fewer primordia per bud (i.e. Lustre and Makings) received less damage than varieties with more primordia per bud (i.e. Williams Favourite). This pattern of food utilisation probably involves a learned recognition by birds that there is a higher probability of obtaining more primordia per bud (and therefore greater net energy gain) from William's Favourite trees than from trees of the other two varieties.

The rate of development of buds in terms of energy content between varieties may require further investigation. In a study of fruit damage by parrots in Western Australia, Long (1985) observed that the red or sweeter apple varieties contained larger and more mature seeds earlier than the green varieties and suggested this as a possible reason for the greater damage to those varieties. The relative energy content between cherry varieties earlier in the period of bud development (e.g. April and May) may differ from the levels recorded in late July and early August in this study. Further investigation may therefore show whether absolute energy values change and if the energy content of William's Favourite buds relative to other varieties changes significantly and damage levels correspond to these changes. There may also be differences in bud energy content at different levels within a tree that correlate with the observed general pattern of feeding (i.e. commencing on higher branches and progressing to lower branches during the course of the season). Another possible explanation for this pattern is that feeding commences at the level within a tree where birds are more frequently expected to first alight, i.e. the higher branches.

Spatial density of buds

The spatial density of buds based on the structure or branching pattern of cherry trees may also influence the rate of harvesting of flower primordia by rosellas and therefore influence choice where differences in bud density exist between varieties. The differences in bud density recorded by Fisher (1991; 1993) for three cherry varieties may contribute to differing bud feeding rates between varieties, reflecting the varietal differences in mean number of primordia and mean energy content per bud identified in the current study. Comparison of several cherry varieties showed differences of at least two buds per whorl between heavily damaged varieties

(William's Favourite and Black Douglas) and less damaged varieties (Lustre and Makings). The number of buds per whorl (mean ± s.e.) based on a count of 200 whorls from five trees of each of three varieties were 9.8 ± 0.3, 6.7 ± 0.2 and 7.0 ± 0.02 for Williams Favourite, Lustre and Makings respectively (Fisher 1993).

Fisher (1991) noted that the mean length of spurs (small lateral branches bearing floral and leaf buds) on a William's Favourite branch was twice that of Lustre, providing a closer branch pattern and a greater density of buds. The density of buds based on the number of buds within 200 mm of a bud group, at each of three positions along a branch, appeared to differ between William's Favourite and Lustre (no data presented for Makings). He recorded 66.6 ± 12.0 and 31.6 ± 3.2 buds "at the tip", 72.4 ± 12.7 and 55.8 ± 6.1 buds "a third in", and 54.9 ± 6.1 and 41.2 ± 4.8 buds "two thirds in", for William's Favourite and Lustre respectively (mean number of buds ± s.e.). He suggested that a closer branch pattern would facilitate greater efficiency of movement by birds when foraging. The spur length was not measured for Makings, however from my observations there appears to be a greater similarity to William's Favourite than to Lustre, with the result being an inter-locking branch pattern in the former. These observations suggest that feeding on the buds of William's Favourite may be more energetically profitable than Lustre or Makings.

Rosellas have the ability to harvest primordia from individual bud groups at a rate approximating or greater than one bud per second (pers. obs.). However, the mean harvesting rate of 0.50 buds sec^{-1} observed near the end of the bud development period (August 1998) was lower presumably due to the time that birds spent moving between undamaged bud groups, along branches and between branches. The lower density of undamaged bud groups (resulting from earlier heavy predation by birds) is thus likely to affect the rate of harvesting. Foraging for cherry buds by rosellas involves walking along branches and hopping between branches in order to reach new bud groups thereby influencing the potential harvesting rate. The harvesting rate would therefore be expected to be higher earlier in the season (i.e. June and July) when bud densities were higher.

The selection of particular cherry varieties with a higher density of buds, or higher density of primordia within buds and bud groups, may therefore provide Adelaide Rosellas with the opportunity to achieve a higher rate of energy intake. A strategy used by Crimson Rosellas in a native forest in Victoria in autumn and winter for increasing foraging efficiency was increasing the rate of food intake (Magrath and Lill 1983). The Adelaide Rosella is probably the only species occurring within the cherry growing area of the Adelaide Hills possessing a bill structure adapted for granivory that is suitable for the efficient and rapid extraction of the small flower primordia from cherry buds. Another advantage of cherry primordia as a food source is that compared to cryptic foods (e.g. sub-clover seed) there is relatively little search time required to locate food items.

Comparative accessibility

A comparison of the profitability of feeding on each food should take into account factors such as accessibility, harvesting rate (involving searching and dehusking), and digestibility. A measure of food quality is the potential energy gain per unit time based on the speed of harvesting, calorific value and digestibility (i.e. speed of harvesting [energy gain per unit time] x calorific value / digestibility). A comparison of cherry buds with two prominent foods in the diet, soursob bulbs and apple seed, indicates a marked difference in the mean energy content per food item. The energy content of individual apple seeds and soursob bulbs are respectively 305 and 1965 times greater than individual cherry buds (Table 4.6). The digestibility or metabolisable energy coefficient is unlikely to differ by more than a factor of two between the three foods so there are clear differences in food value between these foods.

Cherry buds are generally more accessible than these other foods. However, the availability and accessibility of soursob bulbs is unpredictable, being dependent on soil disturbance. The search time for cherry buds is negligible, but high for apple seed, particularly in undamaged apples. As a thick layer of pulp surrounds the seeds of apples they are not immediately accessible to birds. In gaining access to apple seeds the ingestion of the pulp, although of lower calorific value, reduces the cost of foraging for seed. The task of gaining access to the core containing the seeds may require more than one feeding event and repeated attempts by more than one bird. Once reached, the energy reward is variable, yielding from 2 to 10 seeds. However, given similar accessibility to each food, cherry buds are clearly a food of lower quality and energy reward than apple seed or soursob bulbs, even given a de-husking rate per food item that may differ by a factor of two or three.

Other foods that allow high de-husking rates may be regarded as high quality foods, particularly seeds that also have a relatively high calorific value. Food plants which produce seeds in dense arrangements, such as in spikes, panicles, pods or clusters (e.g. *Chenopodium album*, *Raphanus raphanistrum* and many grass species) are therefore likely to be highly attractive to rosellas compared to other foods. Small seeds (e.g. *Cerastium semidecandrum*, *Chenopodium album* and *Hypericum perforatum*) are usually not de-husked by rosellas, which may reduce their digestibility compared to larger seeds that are usually de-husked such as apple and sub-clover seed. However, rosellas often feed on seeds before they have fully ripened, such as seed of *Taraxacum officinale*, *Poa annua* and *Cerastium semidecandrum*, possibly when the seed coat (testa) is relatively soft and in a more digestible state, thus obviating the need to de-husk the seed when ripened.

Foraging effort may be lower for cherry buds than for a number of foods that occur on the ground, particularly where the latter are present amongst low growing herbage where birds must devote more time searching for more dispersed items. The seed of sub-clover is an important food in the diet, particularly in autumn and winter. In winter, sub-clover seed is harvested involving foraging on the ground for pods that may be partially buried[16]. Although the seed of sub-clover is relatively energy dense (c.f. *Trifolium pratense* 20.67 kJ g^{-1}, Kendeigh & West 1965), foraging during autumn and winter involves searching for ripened pods anchored in the soil often amongst a diverse array of other plant species, which would involve greater search time than for a food such as cherry buds. The energy gain per unit time whilst foraging for cherry primordia may be high relative to gross energy intake albeit small (i.e. calorific value and digestibility) compared to many other foods in the diet, thus making cherry buds a relatively attractive food source.

Competition and niche exploitation

Cherry flower buds represent a foraging niche that is not exploited by cohabiting bird species or other animals, thus foraging efficiency is not influenced by inter-specific competition.

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[16] The pod, enclosing 3 or 4 seeds, becomes anchored or buried in the soil as it ripens following fertilisation of the flower cluster. Pods are produced from flowers in the previous year (August to November).

The possession of a specialised bill with which they are able to efficiently manipulate the bud and excise the small flower primordia therefore appears to be of importance for foraging efficiency rather than providing a competitive advantage over other species. As cherry trees are widely grown in the Adelaide Hills and individual commercial orchards usually contain many trees, cherry buds are generally a super-abundant food resource. Intra-specific competition for this resource is therefore unlikely to be a significant factor in foraging efficiency.

Resource predictability

A commercial cherry orchard represents a relatively predictable food resource in terms of availability and accessibility. Cherry buds are readily locatable and there is no competition for this food resource from other species. As birds must satisfy a high minimum energy input, a risk-averse strategy for rosellas when the probability of finding other foods is variable is to utilise a predictable food resource such as cherry buds in a commercial orchard. At other times foraging birds may adopt a risk-prone strategy choosing variable rewards over constant ones of similar abundance to attain maximum body mass, e.g. for reproduction. Moore and Simm (1986) reported that migrating Yellow-rumped Warblers adopted a risk-prone foraging strategy but upon attaining maximum body mass, they shifted to a risk-averse strategy, selecting predictable rewards rather than unpredictable ones of the same average abundance.

Risk of predation

Foraging in trees (e.g. cherry trees) may be a strategy used at certain times to reduce the risk of predation, for example from cats or goshawks, particularly in wet conditions. Compared to the ground, trees provide a better vantage position for detecting the approach of predators and therefore allow birds to respond earlier to a threat. Wet ground foliage may also hinder escape from a predator approaching from either the air or the ground. Under dry weather conditions, birds may choose foraging on the ground for more energetically rewarding foods such as seeds despite the higher risk of predation.

Immediacy in food gain

Rosellas may have a preference for immediacy in food acquisition, an opportunity that is readily provided by cherry trees. Birds may favour a small immediate reward (e.g. cherry buds) rather than a larger delayed reward, despite the opportunity for maximising the long-term average rate of energy intake offered by the latter choice (e.g. Green *et al.* 1981). One explanation of this phenomenon could be an expectation by foragers of being interrupted, thereby encouraging the immediate gain option (e.g. Kagel *et al.* 1986).

Non-foraging activities

Feeding bouts in trees may be interspersed more readily with non-foraging activities such as perching (e.g. time spent vocalising), resting, body maintenance (e.g. preening) or reproductive activity (courtship behaviour) compared to foraging on the ground. Foraging in cherry trees for buds may be a useful strategy for energy conservation because resting is the least energetically expensive daytime activity and can readily complement bud foraging activity without the additional expenditure of energy required to fly to a safe perching position when feeding on the ground. Energy conservation through reducing foraging time and increased resting time may be an important energy budget strategy particularly in winter. Because birds are more vulnerable to predation on the ground the devotion of time to resting or browsing in the leafless canopy of cherry trees in winter by rosellas may also be an effective anti-predation strategy against cats, foxes, goshawks and other predators that hunt by stealth.

Thermo-regulation

Weather can affect foraging patterns. Morse (1990) has suggested that birds may forage most efficiently when the foliage is dry and may even lack strong adaptations for foraging in wet conditions. Wet foliage may be one of the most serious factors for foliage gleaners. Without a substantial change in the ambient temperature, Carolina Chickadees *Parus carolinensis* shifted from foliage gleaning to large-limb hunting during rainy periods in the winter, thereby sparing their plumage from the wet foliage (Morse 1970).

Rosellas are primarily a ground foraging bird as they obtain a high proportion of their food on the ground (i.e. almost 80% by volume). A disadvantage of foraging on the ground in winter is that their plumage may become wet from contact with vegetation, and thereby increase the cost of thermo-regulation. As a tree crop, cherry buds may be a relatively important food source during winter when wet ground conditions make ground feeding more difficult and when other food resources are low. Cherry buds are therefore a food resource that allows rosellas to feed when conditions are adverse for ground feeding.

An activity of birds that is of potential energy-conserving importance is the movement into and out of the sunlight for periods of time (basking). Conservation of energy by basking may be important for species occurring in open country where there is almost continuous exposure, but becomes less important in biotypes such as forests where birds are only occasionally exposed (Kendeigh *et al.* 1977). Torcello (1990) observed that Adelaide Rosellas bask on exposed perches in morning and evening. Magrath and Lill (1983) showed that there was a significant increase in the percentage time spent resting in winter compared with autumn for Crimson Rosellas in Victoria. They suggested that resting was not merely a consequence of reduced foraging time but an important energy conserving strategy in meeting the additional thermo-regulatory cost of winter existence. They noted that in temperate latitudes the environment seems to be more energetically stressful for a resident bird in winter than in other seasons.

The original vegetation of the study area (i.e. pre-European settlement) comprised mostly eucalypt forest with relatively smaller areas of more open woodland, shrubland (heath) or sedgeland. The present day vegetation is generally much more open in character due to the removal of over 84% of the original vegetation and its replacement with pastures, annual crops and deciduous tree orchards. With this substantial change in vegetation structure, and given the cold winter climate of the Adelaide Hills, the leafless canopy of cherry trees in autumn and winter may provide rosellas with the opportunity to conserve energy by basking. The use of exposed perches for basking at this time of year would bring the birds in closer proximity to cherry buds and consequently more opportunity to browse on buds.

4.4.5 Conclusions

The most profitable or energy rich foods may not be in sufficient abundance at all times to satisfy the energy needs of rosellas. As a consequence rosellas may need to obtain their energy requirements from a wider range of food sources. Preferred foods may be temporarily unavailable or not in sufficient abundance to meet the total energy needs, in which case birds must supplement their diet with lower quality foods. By being generalists, rosellas are able to readily adapt to shortages of a preferred food by switching to another food within their wide dietary range to obtain energy required for existence. Recognition of the shortage of a preferred food by rosellas is likely to be based on relative foraging profitability rather than absolute abundance of the food.

The most energetically profitable foods may not contain the highest energy value per food item. Although food use is influenced by the energy value of foods, other factors should be taken into account, such as behavioural costs of foraging and the digestibility of individual foods. For example, apple seeds have a higher energy concentration than apple flesh but the seeds require more time and effort to obtain so a simple comparison of raw energy values is unlikely to reflect the true foraging profitability of each food. The digestibility of apple flesh and apple seed may be similar based on the average apparent metabolizable energy coefficients calculated for wild birds for fruit pulp and skin (0.64) and wild seeds (0.62) (Karasov 1990). Despite the low calorific value of apple flesh, rosellas consume a relatively large quantity in their diet possibly due to its relative abundance and accessibility. The consumption of flesh may at times though be incidental to consumption of the more nutritionally attractive seed.

In some respects cherry buds are a relatively low quality food compared to prominent foods in the diet such as apple seed and soursob bulb. However, the energy rewards from apple seed or soursob bulbs are variable and unpredictable though of higher nutritional quality. Other factors that may influence the use of cherry buds by rosellas include the following:

- cherry buds are an abundant food resource;
- cherry buds are a relatively constant and predictable food resource;
- some varieties, e.g. William's Favourite, provide the opportunity for increasing foraging profitability;
- the energy content of individual food units (buds) is low due to their small size but high harvesting rates are possible (due to several factors including density of buds and primordia and the bill structure of rosellas), allowing a higher rate of energy intake compared to some other foods (possibly seed of salvation jane *Echium plantagineum* or wireweed *Polygonum aviculare*, for example);
- the digestibility of flower primordia may be relatively high, although there is no evidence yet to suggest this;

- as a tree crop, cherry buds provide some advantages over foraging on the ground for other foods, e.g. the opportunity to reduce thermo-regulation costs in wet weather and reducing the risk of predation;
- there is no competition for this food resource by cohabiting species; and
- cherry buds may provide minor nutrients that occur in very low amounts, or are not present, in other foods.

Although cherry buds are not a dietary staple of rosellas this food is possibly sought when birds have been able to meet their minimum daily energy requirement from more energetically profitable foods. Rosellas are more likely to feed on cherry buds to meet their minimum daily energy requirements when weather conditions are unfavourable for ground foraging for other foods. At such times rosellas may also rely on other tree crops such as eucalypt and apple trees (there are usually a small number of unpicked apples that remain on trees in winter).

The abundance and accessibility of cherry buds appears to be an important factor in the relatively high representation of primordia in the diet of birds in autumn and winter. However, when faced with a choice of several varieties of cherry trees, birds exercise preference for particular varieties such as William's Favourite. The principal factor influencing varietal preference is most probably the total energy content per "food unit" (i.e. bud), which is related to the number of primordia per bud, rather than energy density (energy per unit weight).

The lower energy content of the diet in winter compared to autumn is consistent with the observation by Magrath and Lill (1983) that rosellas spent less time foraging in winter and rested more in order to conserve energy. Feeding on cherry buds therefore may be an activity that is usually complementary or secondary to the principal activity of resting or basking in the leafless canopy of cherry trees in winter. As a secondary activity, bud foraging (e.g. browsing) provides birds the opportunity of obtaining energy from a food source that is relatively risk free (i.e. lower predation risk and relatively productive foraging time) and enables them to avoid foraging on the ground in wet conditions. If the typical behavioural pattern of rosellas in winter is to reduce foraging time and to spend more time resting (e.g. in cherry trees) this behaviour could be disrupted by providing a food source that makes foraging more energetically profitable than resting. I suggest therefore that rosellas do not have a strong feeding preference for cherry buds, except when adverse weather conditions may preclude ground foraging or when there is perceived to be a higher risk of predation whilst foraging on the ground.

Earlier in this chapter the importance of food quality as a factor in choice was discussed with respect to apple seed and soursob bulbs, each a prominent food in the diet of rosellas. It was suggested that characteristics of each food that may influence the rate of net energy intake, such as relative de-husking rates, food item size, weight of individual food items, and energy values of each material are likely to result in differences in selection between foods. The feeding response of captive rosellas to equally available quantities of apple seeds and soursob bulbs will be investigated in the next chapter.

5 FOOD SELECTION TRIAL

5.1 INTRODUCTION

Food selection by birds is influenced by a range of factors, including nutritional quality, food availability and ease of harvesting (e.g. Pyke *et al.* 1977; Krebs 1978). The presence and relative abundance of food resources as a key factor influencing birds visiting cherry orchards was discussed in the previous chapter. Manipulating the availability of alternative food resources (e.g. soursob bulbs) when cherry trees are vulnerable to bud predation by rosellas was also considered as a way of influencing foraging behaviour in orchards by diverting the attention of birds away from cherry buds.

In a review of parrot damage in apple orchards in south-western Australia, Halse (1986) suggested the use of food-choice experiments for establishing a preference hierarchy amongst alternative crops that could be grown to reduce bird damage in orchards. In the current study, apple seed and soursob bulbs were considered for a comparison of food selection by rosellas on the basis that they are examples of prominent foods in the diet that may have potential as a diversionary food source. To investigate the order of preference for these foods I conducted feeding experiments. In particular, I sought to compare the consumption by weight of two foods by captive wild rosellas when offered a free choice.

Apples were an abundant food source within the study area and were readily available to rosellas. Apple seed was present in the diet in all months except November and was an important food item particularly in autumn and winter. Within the study area soursob was a relatively common weed, producing edible underground bulbs that were generally unavailable to rosellas unless the soil was disturbed to bring bulbs to the surface. Rosellas therefore could only exploit this food opportunistically, i.e. when the soil had been disturbed by human activity.

Soursob bulbs were recorded in crop samples in all months except December and January. The incidence of bulbs in the diet, however, generally corresponded with the peak in bulb production in spring and the period of bulb exhaustion and new bulb formation during the autumn - winter period. In summer and mid winter soursob bulbs were either absent or in very low quantity in the diet possibly due to a lack of accessibility to bulbs rather than a lack of abundance of this food. Ground disturbance where soursob plants are growing was observed to initiate a strong foraging response from rosellas.

5.2 METHODS

Two feeding trials were conducted with eleven wild caught Adelaide Rosellas housed in five cages. The birds were caught from a commercial apple orchard at Basket Range within the study area on 29 June 1991, under National Parks and Wildlife SA Permit No. Y03744. The birds were trapped using a spring net device following a ten day period of free-feeding with oats and were then taken to the National Parks and Wildlife Service fauna complex at Monarto. Two birds were housed in each of four aviaries, and three birds in the fifth aviary. Birds were not housed singly as rosellas frequently forage on the ground in groups (e.g. Higgins (1999). The five vermin proof aviaries were contiguous, each 2 m high, 4.5 m long and 1.2 m wide and contained a rear semi-enclosed section. A period of several months (from the time of capture and housing in the aviaries until the commencement of trials) was allowed for the birds to acclimatise to captivity. At the conclusion of the trials the birds were returned to the original capture locality and released.

The birds in each cage were offered similar quantities (by weight) of two foods in their natural diet, apple seed and soursob bulbs. The first trial was conducted over a two-day period (47 h) between 18/2/92 and 20/2/92. A further trial was conducted six weeks later (27/3/92 to 28/3/92) over a 24-hour period corresponding to the time when rosellas normally commenced feeding on the flower buds of cherry trees.

The normal aviary seed mix was withdrawn from the birds in each cage 24 hours prior to the commencement of each trial. In each trial an amount of food exceeding the estimated daily energy needs, was provided in equal proportions to each group of birds. At least 5g of consumable food (husked) remained of each food in any aviary at the end of each trial.

The food was offered to the birds in each aviary on a single tray measuring 400 mm by 300 mm by 30 mm, with a central partition to prevent mixing of the two foods. Each section of the tray was sufficiently large to allow two or three birds to feed at the same time in any one section. As rosellas commonly feed on the ground in the wild (pers. obs.) the trays were placed on the floor in the middle of each aviary. The quantities of each food offered to the caged birds and remaining at the end of each trial were weighed and recorded for each of the five aviaries. No weight correction was made at the end of each trial for possible evaporative losses as any weight loss by this means was assumed to be insignificant given the short duration of the trials and the relatively impervious husk material enclosing the edible portions of each food which serve to minimise such loss.

The difference in mean consumption of the two foods was analysed using paired Student's t-tests, testing the hypothesis that the mean weight of soursob bulb consumed by the caged rosellas would be greater than the mean weight of apple seed consumed.

5.3 RESULTS

In the first trial, captive Adelaide rosellas consumed significantly more soursob bulb (14.06 ± 0.71 g) than apple seed (4.44 ± 0.75 g) (Table 5.1).

Table 5.1. Consumption of soursob bulbs and apple seeds in a choice trial (Trial 1) involving 5 replicates with 2 or 3 rosellas housed in each aviary.
A t-test (paired two sample for means) revealed that birds consumed significantly more soursob bulb by weight per bird than apple seed (t=6.88, 4 d.f., p=0.0011, one-tailed test). The trial was conducted over a 47-hour period between 18/2/92 and 20/2/92.

	Weight (g) consumed per bird per 24 hour period	
Cage No. (no. of birds)	Soursob bulb (A)	Apple seed (B)
1 (2)	15.07	3.04
2 (2)	14.23	4.43
3 (2)	14.41	5.63
4 (2)	15.27	2.57
5 (3)	11.31	6.51
mean ± s.e.	14.06 ± 0.71	4.44 ± 0.75

In the second trial the rosellas also consumed significantly more soursob bulb (17.93 ± 1.48 g) than apple seed (2.51 ± 0.69 g) (Table 5.2).

Table 5.2. Consumption of soursob bulbs and apple seeds in a choice trial (Trial 2) involving 5 replicates with 2 or 3 rosellas housed in each aviary.
A t-test (paired two sample for means) revealed that birds consumed significantly more soursob bulb by weight per bird than apple seed (t=7.854, 4 d.f., p=0.0007, one-tailed test). The trial was conducted over 24 hour period between 27/3/92 & 28/3/92.

	Weight (g) consumed per bird per 24 hour period	
Cage No. (no. of birds)	Soursob bulb (A)	Apple seed (B)
1 (2)	14.84	1.71
2 (2)	16.92	3.81
3 (2)	18.63	3.55
4 (2)	23.30	0.20
5 (3)	15.98	3.30
mean ± s.e.	17.93 ± 1.48	2.51 ± 0.69

The birds were adequately fed given that at least 5g of soursob bulb and 11g of apple seed remained uneaten in each cage at the end of each trial.

5.4 DISCUSSION

Captive rosellas were offered a choice of apple seed and soursob bulb in similar proportions, each freely available, and each in amounts exceeding their daily energy requirements. The observed differences in consumption of the two foods were substantial and consistent between trials. This demonstrates that rosellas prefer, at least under the conditions offered by the caged trial (with respect to food accessibility, seasonal timing, etc.), soursob bulbs to apple seed and suggests that the greater incidence of apple seed than soursob bulb in the diet of wild birds is influenced by the greater availability of apple seed in their environment.

Choice tests in the laboratory can complement other dietary studies such as stomach analyses and direct field observations. Studies of food use under controlled conditions, when all foods are abundant and equally available, allow the measurement of preference and an assessment of the components underlying food selection. In this experiment the order and rate of consumption of the foods offered to captive rosellas were not determined. These are important parameters in evaluating preference in laboratory tests of food choice in addition to the total amount of each food eaten (e.g. Rodgers 1990).

Apple seeds and soursob bulbs each comprise a significant proportion of the diet of wild birds at certain times of the year. In the wild, it might be expected that rosellas would choose to feed on soursob bulbs in preference to apple seed when equally available based on the relative ease of harvesting. Apple seed is often harvested by rosellas from apples on the ground (wind-fallen or hand-thinned), but may also feed from the few apples that remain on trees after harvest. In either case the harvesting of seed by rosellas requires the removal of a relatively large quantity of fruit pulp in order to gain access to the more energy dense seed in the core of the fruit. The incidence in the diet of apple seed however is broadly correlated with seasonal availability (i.e. high in autumn and winter, low in spring and summer). The proportion of apple seed in the diet was higher in winter (18% by volume) than in autumn (10%), which may reflect greater ease of harvesting in winter due to the process of natural decomposition of the pulp of apples from the previous autumn crop. The main limit to consumption of apple seed when abundant is probably accessibility or ease of harvesting by birds.

Apple seed and sour-sob bulbs are de-husked by birds before being eaten. Although apple seed has a thicker husk than sour-sob, the rate of de-husking is probably similar. Apple seeds are relatively consistent in size and weight, but although soursob bulbs are highly variable in size, each usually exceeds apple seed in size and weight. The average weight (fresh mass) of unhusked soursob bulbs (296 mg, n=200) was approximately eight times greater than for unhusked apple seeds (36 mg, n=100). The proportion of husk weight to total item weight was 16% for bulbs compared to 34% for seeds.

Observations drawn from the cafeteria type experiment though may bear little relation to food choice in a more realistic situation where many other factors such as accessibility, detectability and handling time intrude (Norbury and Sanson 1992). A dietary analysis is more easily interpreted if accompanied by knowledge of the availability of foods. Assuming equal abundance and accessibility of soursob bulb and apple seed in the field, it could be expected that rosellas would exercise a preference for soursob bulb based on greater ease of harvesting and potential for a greater rate of consumption of food material. Food use during these trials was obviously affected by the presentation of each food without the surrounding matrix of material normally encountered in their natural environment, i.e. the fruit pulp (apple seed) or soil (soursob bulbs). The practical application of apple seed and soursob bulbs as decoy crops in commercial orchards would depend not only on the quantity provided of either food but also on presenting them in a sufficiently accessible form to encourage a shift in foraging response from other foods. The development of decoy crops as an option for reducing bird damage to horticultural crops will be discussed in the following chapters.

6 HABITAT MANIPULATION TRIAL

6.1 INTRODUCTION

Direct manipulation of bird numbers is often ineffective in mitigating damage to agricultural crops in the long term. Shooting for example has been recognised as the most widely practised and most ineffective bird control technique used in Australia (Emison 1990; Ford 1990; Bomford 1992). Reducing the pest population to an acceptable level (e.g. by shooting, trapping or poisoning) is usually difficult to achieve and the effort difficult to maintain (e.g. Allen 1990). The use of scaring devices has also generally proved ineffective for damage control. Given that the Adelaide Rosella is a sedentary bird (e.g. Forshaw 1981; Ford and Paton 1976) the effectiveness of scaring devices is likely to be limited and population reduction methods unacceptable.

Indirect methods of damage control may involve some form of habitat modification or change in farm cultural practice in order to influence the behaviour of the pest bird. For example, the provision of alternate food sources by planting diversionary crops has variously been suggested or investigated as a potential means of reducing damage to commercial crops. In Australia, Jarman and McKenzie (1983) for example, reported the successful manipulation of the feeding behaviour of galahs to mitigate damage to a small wheat trial.

Sour-sob *Oxalis pes-caprae*, a common weed within the study area, was identified as a food source that could be manipulated in the field and for which observations of any foraging response by rosellas could be readily made. Two reproductive parts of this plant, flower buds and the under-ground corms, were identified in the diet analysis as seasonally important foods used by rosellas. Although both foods are abundant in the study area, only flower buds are a readily accessible food source to rosellas (i.e. between April and September). The apparent inability or reluctance of rosellas to dig or excavate suggests that soursob corms are only accessible to birds if they have been brought to the surface by some form of soil disturbance, usually associated with orchard machinery operations.

The potential of soursobs as a decoy crop for mitigating damage to cherry orchards was therefore investigated on the basis of several factors: soursob corms are a potentially highly attractive food source (permitting a high energy intake rate when made accessible to birds), soursobs are relatively abundant within the study area, and bulbs can readily be made accessible to foraging birds by lightly cultivating the soil surface. It is likely that the use of a common pasture weed in orchards such as this plant for pest animal control would have greater appeal to orchard managers than a planted diversionary or sacrificial crop requiring more intensive management.

6.2 METHODS

Four sites within the dietary study area (Chapter 3) were chosen for the trial. Two sites were established in a plum orchard and a cherry orchard at Montacute; the other two sites were established in a pasture and an adjacent cherry orchard at Basket Range. At each site two plots were selected, one to be hand-tilled (treatment) and the other to remain untilled (control). Each plot was 75 m^2 in area and at each site the two plots were contiguous. Treatment plots comprised a cover of sour-sob of varying density between sites (Table 6.1) and were hand-tilled at the beginning of the experiment to expose soursob bulbs at the surface. Control plots were not tilled in order that the underground bulbs of any soursob plants that may have been present were not accessible to rosellas.

The plots were selected based on an initial visual assessment of the site and estimation of percent cover of soursob plants on each plot. The density of soursob bulbs exposed at the surface in treatment plots was estimated at the conclusion of the experiment by counting eaten (full husks) and uneaten bulbs on the surface based on counts from 60 random throws of a 0.5m x 0.5m quadrat in each plot. Although the density of bulbs of *Romulea* sp. was found to be greater than the density of soursob bulbs at Site 3 (Table 6), a similar response by rosellas was expected for the bulbs of each. Observations of feeding on *Romulea* bulbs by birds of another parrot species (Sulphur-crested Cockatoo *Cacatua galerita*) at this site on other occasions indicated that it was also likely to be an attractive food to rosellas. Although percent cover of soursob within control plots varied between sites, experimental sites were chosen prior to the commencement of the trial where percent cover was similar between treatment and control at the same site. Although soursob plants are able to produce aerial corms the density of bulbs on the surface of control plots was assumed to be negligible.

Observations of rosella feeding activity were made from a hide at Sites 2, 3 and 4 while bird visits were monitored by video camera at Site 1 and scored from video playback. Hides were erected on a site 10 to 12 days prior to commencement of the experiment to allow birds to become accustomed to the structures.

Observations were recorded as visits to a plot by rosellas; a bird alighting on the ground within the plot was recorded as a single visit. Individual birds rather than individual foraging records were used as the recording event (for statistical tests) due to the potential bias created by multiple records from a single bird. As rosellas tend to readily take flight in response to minor disturbances, the return to a plot by the same individual within 2 minutes of alighting was not recorded as a new visit. As they generally flew a short distance to a nearby perch before returning to the plot these birds could be easily recognised from the hide. Feeding on bulbs within the plots was determined by direct observation, and consumption of bulbs was determined at the conclusion of the experiment by scoring uneaten bulbs and husks of eaten bulbs at the surface from a sample of randomly placed quadrats.

The experiment was conducted between 19 October and 4 November 1992. During this period cherry buds or fruit were unavailable to birds. Observations were undertaken in two 3-hour periods each day over three or four consecutive days. Daily observations were made between 5.30 am and 9.30 am and then between 4.30 pm and 8.30 pm to coincide with periods of greatest feeding activity. The twice-daily observations to score rosella behaviour within plots were conducted over three or four days (total of 18 – 21 hours per plot) prior to treatment and then over a further three or four days (total of 18 – 20 hours per plot) after treatment.

The treatment of plots involved hand-tilling a 75 m^2 area (15 m x 5 m) to a depth of approximately 10 cm at each of the four sites to ensure the exposure of as many bulbs at the surface as possible. Following the hand-tilling of treatment plots, observations were commenced within one daylight hour of the treatment.

The data were analysed by a randomised block analysis of variance (ANOVA) based on number of rosella visits per hour to experimental plots (two treatments, untilled and tilled) at each of four sites. It was necessary to calculate the natural logarithms for the number of visits h^{-1} and to use ln (visits h^{-1}) as the dependent variable, in order that all ANOVA assumptions were valid.

6.3 RESULTS

At each site there was a marked increase in rosella visits to treated plots following the exposure of soursob bulbs to the surface by hand-tilling (Table 6.1). The ratio of post-treatment to pre-treatment visits h^{-1} by rosellas for hand-tilled plots ranged from 3.1 : 1 for Site 2 to 19.1 : 1 for Site 4. In untilled (control) plots there was no consistent increase in visits recorded in post-treatment observations but for two plots (Sites 2 and 4) there was a decrease in the number of visits after treatment.

There was no significant difference between sites in visits h^{-1} to plots, but the difference between treatments (tilled and un-tilled) was significant (Table 6.1).

Table 6.1. Habitat manipulation trial: Visitation by Adelaide Rosellas to tilled and untilled plots differing in cover of soursob plants at four sites in the Adelaide Hills during October and November 1992.

The behavioural response of Adelaide Rosellas to the treatment (hand-tilling) was measured by the visitation of birds to experimental plots (control and hand-tilled) before and after treatment. Sites 1 & 2 were at Montacute, Sites 3 & 4 at Basket Range. There was no significant difference in ln (visits h^{-1}) between sites ($p = 0.2059$), however the difference between treatments for ln (visits h^{-1}) was significant ($p = 0.0337$). On the natural logarithm scale the mean number of visits h^{-1} to tilled plots (1.632) was significantly greater ($p = 0.0337$) than the mean number of visits h^{-1} to the untilled plots (0.09401). Based on the relative difference of ln (1.538) between treatments there were 4.7 times more visits h^{-1} by rosellas to tilled plots than to untilled (control) plots.

Site No.	Experimental plot	visits h^{-1} (pre-treatment)	hours of observation (pre-treatment)	visits h^{-1} (post-treatment)	hours of observation (post-treatment)	Ratio of pre : post treatment visits	soursob cover %	No. of bulbs per m^2 mean ± s.e.[1]
1	control	0.28	19.0	0.39	18.0	1.39	0	nr
1	hand-tilled	0.61	19.0	2.94	18.0	4.82	4.9	9.08 ± 1.12
2	control	2.17	20.8	1.28	18.0	0.59	73.4	nr
2	hand-tilled	1.44	20.8	4.44	18.0	3.08	69.2	47.0 ± 1.86
3	control	0.67	18.0	1.63	18.0	2.43	0	nr
3	hand-tilled	0.39	18.0	2.74	18.0	7.02	1.0	1.73 ± 0.40[2]
4	control	2.56	18.0	1.79	19.5	0.70	nr	nr
4	hand-tilled	1.33	18.0	19.11	19.5	14.37	nr	76.67 ± 0.89

[1] soursob bulb density at the surface after treatment (calculated from 60 x 0.25 m^2 quadrats) ± standard error (s.e.)
[2] soursob (0.13) + Romulea (1.6)
nr = not recorded

6.4 DISCUSSION

The diet analysis showed that soursob bulbs were an important food in spring (16% of the diet by volume) but in other seasons it was a minor food, representing 1% of the diet or less by volume. Consumption of soursob bulbs in summer and winter was negligible in terms of percentage volume, and it is suggested that if this food is made more accessible to birds, bulbs are likely to become more prominent in the diet, thereby diverting their attention from other foods. This has implications for mitigation of bird damage to cherry crops as discussed in the previous chapter.

Bulb exhaustion occurs during autumn and early winter following emergence of soursob plants. This is reflected in the lower incidence of soursob bulbs in the diet at this time of year, however the absence of bulbs in the diet in summer is probably more an indication of the accessibility rather than the true abundance of this food in the environment. Despite frequent observations of foraging activity by rosellas I have not observed birds excavating bulbs from below the soil surface, suggesting that birds are unable to dig to the depth at which bulbs usually occur. However, as rosellas feed on seed of sub-clover, a plant that anchors seed-bearing pods at or just below the ground surface, they appear to have a limited capability of digging for food items. Freshly cultivated soil often seems to attract the initial interest of rosellas, irrespective of the presence of soursob bulbs (pers. obs.). The drier ground in summer may be too hard for bulbs to be exposed at the surface by normal machinery activity (e.g. vehicles), and in late winter the ground may be too wet to allow access of machinery to steep slopes that would expose bulbs at the surface. Therefore, as it appears that rosellas do not dig for bulbs, but rely on bulbs being brought to the surface, conditions in summer and early autumn are likely to restrict the accessibility of bulbs to rosellas. Soursobs also produce small aerial corms around the base of the stem in winter. However these are few in number compared to the underground corms that are usually produced in large numbers by the plant.

Maximum development of soursob bulbs is usually attained in spring however there may be a sufficient resource of bulbs in late winter and early spring (i.e. July and August) for use as a diversionary crop to provide some degree of crop protection to cherry trees. Tillage of soursob patches may expose sufficient numbers of bulbs at the surface to provide an alternative food source to cherry buds. In spring, the tillage of soil that supported soursob plants in winter may, by exposing new bulbs, divert the attention of rosellas away from feeding on cherry flowers and similarly, in summer, this would provide a diversionary food source to reduce damage to cherry fruit. The opportunity for using soursob bulbs *in situ* as a diversionary crop in autumn when feeding on cherry buds by rosellas commences may however be limited. Bulb exhaustion occurs during autumn when the emergence and growth of soursob plants depletes the food reserves in the bulbs developed in the previous year.

Based on the analysis of crop contents, cherry primordia do not appear to contribute significantly to the nutritional needs of rosellas, indicating the potential of alternate (more nutritionally rewarding) food sources to change foraging behaviour. The provision of a regular supply of soursob bulbs may draw birds from neighbouring properties and bring them in closer proximity to cherry trees resulting in higher damage levels. This may be avoided by manipulating the quantity and period of availability of bulbs, and feeding site, based on the number of resident birds and their existing foraging patterns. Other behavioural factors may influence the choice of feeding sites and therefore may need to be considered in conjunction with the use of diversionary crops. Rosellas also appear to "browse" on buds as they pass cherry trees whilst seeking safe perches or seeking more nutritionally rewarding food sources. The extent to which rosellas feed on cherry buds may be influenced by factors such as the proximity to more nutritionally attractive food sources, the relative safety from predators (e.g. cats and foxes), and the proximity or accessibility of feeding sites to preferred perching or roosting sites.

These results show that the manipulation of a key food source that is not readily accessible to rosellas (soursob bulbs) has the potential to elicit a significant foraging response. Further investigation is required in order to determine the implications of this behavioural response in regard to mitigation of damage to cherry trees. This experiment was conducted in the early period of fruit development and would thus need to be repeated at other times in order to determine whether a similar foraging response can be achieved that would result in a reduction in damage to cherry buds and flowers to economically acceptable levels.

Management strategies therefore need to be developed that optimise the benefit of a diversionary crop. Such strategies should be based on an understanding of the aspects of the commercial cherry crop and other foraging areas that could influence feeding behaviour. This will enable suitable alternative food sources to be identified and manipulated.

7 MANAGEMENT OF PEST ROSELLA POPULATIONS

7.1 IMPACT OF ROSELLAS ON CHERRY PRODUCTION

The impact of rosellas feeding on cherry buds and flowers on commercial fruit production was first demonstrated by Sinclair and Bird (1987). Although many cherry varieties were commonly grown in the Adelaide Hills, severe damage to buds and flowers by rosellas was usually restricted to one variety (William's Favourite). They recognised that bird damage of this type to cherries or any other fruit was unknown elsewhere in Australia.

Bud feeding usually commences in late autumn and continues until late winter, just prior to flowering. Based on a survey of William's Favourite trees in 20 orchards in the Adelaide Hills over the 1986-1987 season, Sinclair and Bird (1987) reported that levels of bud damage varied widely between orchards and between trees in orchards. In a quarter of the orchards more than 60% of the buds were damaged. In the most severely affected orchard more than 90% bud loss occurred. In the latter orchard, individual William's Favourite trees were estimated to produce up to 140,000 buds.

According to Westwood (1978) the floral buds of sweet cherry trees produce two to four flowers. The heavily damaged variety, William's Favourite, produces approximately four flower primordia per bud (mean 3.8; range 1-7; n = 384). Each bud can thus potentially produce four fruit given a 100 per cent pollination rate, though this rarely occurs. Sinclair and Bird (1987) estimated that 44 William's Favourite trees in a commercial orchard in 1986 produced, in the absence of bird damage, 3 x 10^6 buds (i.e. 68,200 per tree) equivalent to 1.7 x 10^6 fruits (i.e. 38,600 per tree), representing 15 per cent of the theoretical maximum fruit yield. The average fruit yield per tree of 70 kg (9000 fruits) in the previous year suggested significant bird damage. In 1986-1987 the fruit yield was expected to be less than 30 kg per tree (i.e. less than 3900 fruits).

A certain level of bud loss may increase the net return per tree through improved fruit size and reduced harvesting costs (P. Bird pers. comm.[17]). Cherry trees are therefore able to compensate for quite high levels of bud damage by increasing fruit size with little net loss in yield. The loss of a proportion of the buds may also be

[17] PL Bird, Animal and Plant Control Commission, Adelaide.

offset by increased pollination rates given the substantially fewer flowers and particularly if the number of bees is sub-optimal. Larger fruit generally have a higher market value than small fruit, and are cheaper to pick. Furthermore, buds are typically lost from higher branches obviating the need to harvest fruit where the cost of picking is substantially greater. The risk in allowing birds to feed on buds only up to the point when further losses would no longer increase the fruit yield is that changing feeding behaviour after a regular pattern has become well established can be difficult.

Rosellas may also cause severe flower damage to William's Favourite trees. Sinclair and Bird (1987) noted that the average loss per tree in one orchard was around 10,000 flowers, including one tree with an estimated 105,000 buds prior to bud burst losing 31,000 flowers over a period of three days. Rosellas also feed on ripening and ripe fruit until the end of the season in January. Varieties that ripen early have been the most severely affected (Sinclair and Bird 1987).

Sinclair and Bird (1987) reported that birds are capable of damaging one bud per second and may feed continuously for several minutes without a break. My observations of bud feeding on heavily damaged trees in August (near the end of the bud development period) indicated a feeding rate of 0.5 buds per second.

The following hypothetical example is given to demonstrate the ability of a group of resident rosellas to deplete the bud resource in a cherry orchard containing a preferred variety over an autumn - winter period. Depletion of the buds on 25 trees by 20 resident birds over this period would require each bird to feed for an average of 26 minutes daily based on the assumption derived from field observations given in Table 7.1. At a higher harvesting rate of 0.75 buds sec^{-1} (more readily achievable earlier in the year when overall bud damage levels are relatively low), the same number of birds would consume all available buds in only 101 days based on the same daily foraging time. At the higher harvesting rate all buds would be consumed over the length of the season (153 days) with each bird feeding for an average of 17 minutes per day.

Table 7.1. Potential depletion of the bud resource in a small cherry orchard by Adelaide Rosellas.

Estimated percentage of the bud resource of 25 trees consumed by 20 rosellas at the end of a 5 month autumn-winter period* based on two harvesting rates and total daily feeding periods of different duration per bird.

	Percentage of buds from 25 trees consumed by 20 rosellas					
	Total daily feeding time per bird (minutes)					
Feeding rate	**5'**	**10'**	**15'**	**20'**	**25'**	**30'**
0.5 buds sec $^{-1}$	19	39	58	77	97	100
0.75 buds sec $^{-1}$	29	58	87	100	100	100

*Assumptions used for calculations: Period of availability of buds is 1st April – 1st September (153 days). A total of 2,375,000 buds are accessible to birds on 1st April (based on average 100,000 buds per tree & 95% of buds accessible).

William's Favourite was one of the most widely grown varieties in the Adelaide Hills (Sinclair and Bird 1987), though the most susceptible to bird damage, during the period when information on the diets of Adelaide Rosellas was being collected for the current study (i.e. 1985 to 1992). This variety produced almost 40% of the gross returns to the local industry before damage became so severe (Sinclair 1989b). Sinclair and Bird (1987) noted there was a general acceptance within the local cherry industry that damage caused by rosellas to buds and flowers was one of the major problems of production and perhaps the most difficult to manage. Most growers believed that the problem did not exist 8-10 years prior to that time. A more recent survey of grower perceptions of damage to cherries in the Adelaide Hills (Graham *et al.* 1999) indicated that the situation had possibly changed by the mid 1990s. Fruit damage was considered to be worse than bud and flower damage and at least 70% of respondents considered that damage levels to fruit increased between 1992 and 1996 to an estimated loss of $380,000 in 1996. The Adelaide Rosella, Red Wattlebird, Silvereye, Rainbow Lorikeet and the Musk Lorikeet were nominated by growers as the main species causing damage.

Since the late 1980s cherry varieties that were highly susceptible to bud damage, particularly William's Favourite, have been progressively replaced in the Adelaide Hills by varieties such as Stella, Lapin and Sweetheart all of which typically receive less damage (A. Granger, pers. comm.[18]).

[18] A. Granger, Primary Industries and Resources SA, Lenswood, 2001.

Nowadays, a greater number of tree varieties appear to experience some bud damage but severe damage is less common compared to the late 1980s (R. Sinclair, pers. comm.[19]). The overall amount of bud damage within the cherry industry in the Adelaide Hills may be similar to approximately 10 years ago (early 1990s) but more recently there appears to be greater variability in damage levels between years compared to the earlier, more consistently high damage levels (A. Granger, pers. comm. [20]).

7.2 DEVELOPING CONTROL STRATEGIES

In a review of Australian research on bird pests Bomford and Sinclair (2002) emphasised the need to evaluate the extent of any perceived bird pest problem before investing in damage control. A method for assessing damage to cherry buds by rosellas was developed by Sinclair and Bird (1987) to determine whether control measures are warranted from an economic point of view and to provide a baseline against which the effectiveness of control could be measured. However, a lack of knowledge of the ecology of rosellas has limited the development of effective methods (other than exclusion netting) to control damage. Bomford and Sinclair (2002) recognised that obtaining reliable estimates of bird damage in order to develop, implement and evaluate the success of control techniques is difficult for several reasons. One reason, of relevance to this study, is that harm caused by birds is often unpredictable, varying greatly in time and place, and the factors causing this variability are often poorly understood. They also recognised that damage mitigation strategies that work in one place or time or for one particular species may not work in other circumstances.

Dyer and Ward (1977) warned against overemphasis of the pest bird species and ignoring the wider view. They suggested that any problems posed by granivorous birds are due to some change in the agro-ecology of an area, not necessarily to a change in the birds' behaviour. If all attention is fixed on the pest, only those strategies that involve doing something to the pest (e.g. killing or scaring) tend to be considered.

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[19] Dr RG Sinclair, Animal and Plant Control Commission, Adelaide.
[20] A. Granger, Primary Industries and Resources SA, Lenswood, 2001.

Contrary to the view that pests have been attracted into an area by the crops, it is more generally the case that the crops have been introduced into an area already carrying a large population of granivorous birds for which, at times, the crops may provide a substitute for the wild seeds eaten exclusively before (Dyer and Ward 1977). They also warned that the replacement of the target pest by another pest species (e.g. with dietary overlap) cannot be anticipated in the absence of a wider view.

The extent, nature and economic impact of any claimed pest problem should be evaluated before developing government policy or implementing control programmes. When wildlife species are implicated in crop damage some caution should be exercised if considering the use of destructive control strategies. Long-term studies on the ecology of pest species should therefore be undertaken as the basis for developing control programs. Without an adequate understanding of behaviour and ecological requirements, control measures may be ineffective or detrimental to wildlife populations. Dyer and Ward (1977) suggested the need to consider damage avoidance by crop substitution or changes in crop phenology, which requires a wider view than solely the pest species.

The time and energy required to find, defend, and exploit environmental resources depends on their spatial and temporal distribution and on the intensity of competition for the same resources by animals (e.g. King 1974). Energy and time are basically separate resources even though interrelated in complex ways (Orians 1961). The birds' biotic and physical environment can therefore have profound effects on the ways in which they allocate time and resources. Physical variables, such as weather conditions or agricultural activity, may indirectly affect an animal's energy budget by modulating the availability of food. Behavioural responses to changes in weather or resource availability may therefore be required to balance the energy budget. An understanding of the energy costs of activities provides a means for evaluating the costs and benefits of these changing behavioural strategies. Magrath and Lill (1983) showed that there was a significant variation in the activity budget between autumn and winter for Crimson Rosellas in a forest environment. The daily energy expenditure was seasonally constant because the increased thermoregulatory cost in winter was offset by a reduced cost of activity as birds in winter spent a greater proportion of their time resting.

A typical feeding session of Adelaide Rosellas is frequently interrupted by other activities such as agonistic interactions (e.g. space defence), resting, preening, and courtship behaviour, depending on a range of factors including the density of the food resource. Different food resource patches may therefore yield different time-activity budgets for visiting birds, for example orchards that receive little bud damage compared to orchards that receive high levels of damage. Cherry trees may provide Adelaide Rosellas with the opportunity to manage their daily energy expenditure in several possible ways. The leafless canopy of cherry trees in winter may allow rosellas to bask (behavioural thermoregulation), intermittently browse on buds (with no competition for food resources from other species), and reduce energy normally expended in avoiding predation. The availability of another food resource in the orchard pasture, and the close proximity to favoured roosts or day-time resting sites, could increase the attractiveness of cherry orchards to rosellas. Measuring the time-activity budget of rosellas to determine how total energy expenditure is apportioned among the requirements for existence and of carrying out their various activities (e.g foraging, moult, reproduction) may test this type of hypothesis. Time-activity budgets should record in as much detail as possible the micro-climate to which the birds are exposed when undertaking these activities. Time-activity budgets may be converted to time-energy budgets when the energy cost of each activity is known.

The development of a control strategy should therefore take into account all of the major variables (biotic and abiotic) and their interactions, including seasonal variations, affecting the energy requirements of rosellas. For example, what aspects of the existing physical environment encourage the use of cherry orchards by rosellas, or how can the physical environment be modified in order to influence foraging patterns and reduce damage to cherry buds?

7.3 OPTIONS FOR DAMAGE CONTROL

A number of possible approaches for reducing damage by rosellas to cherry trees are considered below.

7.3.1 Deterrence

Scaring measures

Deterrence control measures are based on the use of scaring devices (auditory or visual), chemical repellents or the use of plant varieties with bird resistance properties to deter birds from feeding on a crop. In a review of sonic pest control devices, Bomford and O'Brien (1990) reported that devices producing sounds other than communicative signals (alarm and distress) generally have no persistent effect on animals' use of food or space. They concluded the main problem was that most birds adjust to and ignore a new sound after a period of time, a process called habituation. This appears to occur as quickly as birds can learn to disassociate the scaring stimulus with actual physical danger. The use of distress or alarm calls showed the most promise as a control technique, but was usually species-specific, and birds habituate if calls are played frequently or over a long period. Scaring devices (visual or sonic) have been largely unsuccessful against rosellas, which are sedentary and appear to habituate quickly to a stimulus or activated device. In one orchard in the Adelaide Hills, for example, bud damage levels in cherry trees immediately adjacent to a noise generating scare device were similar to trees in more remote parts of the orchard (pers. obs.).

While scaring devices on their own are usually ineffective, they may help reduce damage if they are used when a crop is at the early stages of ripening before birds have established a habit of visiting the site and if alternative attractive feeding sites are available (e.g. Jarman 1990a). The duration of the deterrence effect may be prolonged if it is associated with shooting, but according to Bomford and Sinclair (2002) shooting is time-consuming and expensive and birds soon learn to avoid shooters. Sinclair (2000) suggested that each time a scare device activates in a vineyard, it may simply disturb birds so that they move to another area in the vineyard. Bomford and Sinclair (2002) suggest that unless birds are successfully scared to another feeding site (alternative crop), they will inevitably return to the crop where scaring is undertaken. If the birds are continually and regularly disturbed, they will expend more energy flying back and forth and consequently need to eat more of the crop to satisfy their energy requirements.

Chemical repellents

Bomford (1992) believed that the use of chemical repellents on ripening fruit may have promise for the control of pest birds in Australia. There are, however, currently no registered chemical repellents that are known to be effective against Adelaide Rosellas (R. Sinclair, pers. comm.[21]). The use of a suitable repellent is likely to be more effective on ripening fruit than buds given that the outer scales of buds are not consumed, whereas the skin may be ingested by rosellas when feeding on the fruit. Sinclair and Campbell (1995) conducted cage trials testing the repellency of methyl anthranilate on four species of pest birds including the Adelaide Rosella. When alternative food was provided they found that methyl anthranilate was highly repellent to all four species. Field trials (Sinclair and Campbell, unpublished data) using the chemical on cherry crops did not demonstrate effective repellency at application rates that were not phytotoxic.

Bomford and Sinclair (2002) suggested that scaring devices and repellent chemicals are only likely to work if attractive alternative food sources are also made available.

7.3.2 Population reduction

Population reduction may involve any of a variety of methods such as shooting, trapping (to destroy or translocate), fertility control, drugging or poisoning. Population reduction by shooting has been described as the most universally practiced and most ineffective bird control technique used in Australia (Emison 1990; Ford 1990). Shooting, as a method to reduce the number of birds, often requires the investment of considerable time and effort to reduce crop damage to an acceptable level. The effort required to reduce numbers by shooting increases as the number of birds remaining in the population decreases. Shooting often achieves little more than shift the bird problem to another site nearby. A destruction program can be of limited effectiveness for reducing crop damage by common, nomadic species such as Rainbow and Musk Lorikeets. Without a complementary control program on other potential feeding sites including neighbouring land, immigration of birds may rapidly

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[21] Dr RG Sinclair, Animal and Plant Control Commission, Adelaide, South Australia.

replace those shot, thereby limiting the effectiveness of this strategy, even for a largely sedentary species such as the Adelaide Rosella. The culling of birds may enhance the survival of the remaining birds in the population including the new recruits. Localised reduction in numbers of rosellas around individual orchards is usually difficult to achieve, as sub-adult birds appear to be highly mobile and more likely to venture beyond their home territory to feed. The effectiveness of a population reduction program may be further limited if, due to the timing, removals are similar to natural juvenile mortality rates. The use of firearms with lead shot to control birds in orchards may also result in contamination of the fruit crop and a potential hazard to human health.

Regulatory controls for native pest birds in South Australia

The South Australian *National Parks and Wildlife Act 1972* contains provisions for the conservation of native animals and restrictions on the taking of protected animals. Prior to revoking certain regulatory requirements for native birds the Minister for Environment expressed the view that "...bird management issues have attracted increased attention over the past decade, parallel with the increase in both horticultural production and the broader community interest in environmental matters. Some species of native birds have increased significantly in population over the last few decades, while other populations of native birds have significantly declined. This is influenced by factors such as access to water and legacies of vegetation clearance." [22]

Prior to May 1999 a permit system operated under the *National Parks and Wildlife Act 1972* (Section 53) for the destruction of protected native birds causing or likely to cause damage to crops. Under this system a permit could be granted to a grower to shoot a limited number of protected birds on their own property for a period of up to 12 months.

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[22] Parliamentary Hansard, 27 March 2001.

A grower was required to demonstrate that protected birds were causing economic damage to commercial crops for the issue of a destruction permit (National Parks and Wildlife Service, 1988). In May 1999 the need for a permit was waived for a period of 12 months as a result of lobbying from commercial growers. This applied to the destruction of three species, including Adelaide Rosellas and Yellow Rosellas, by any commercial orchardist or vigneron within 19 council districts, including the Adelaide Hills. As no limit was placed on the number of birds that could be destroyed, National Parks and Wildlife SA advised that the new provision did "not represent an open season approach". Instead, it would allow "those persons with a valid need to reduce damage to their commercial crops with a legal means of doing so" (National Parks and Wildlife SA, 1999). In May 2000 the legislation was amended (section 51A) to remove the requirement for destruction permits for these species for a period of five years. Based on a poll of 231 fruit-growers the Department for Environment and Heritage estimated that 5000 rosellas had been culled in the Riverland and Adelaide Hills within the 12 month "no permit" period. However this estimate of birds was considered to be a "gross underestimate" by the Animal and Plant Control Commission (Huppatz and Uren 2000). The policy was supported by industry including the South Australian Farmers Federation which recognised that shooting was an interim control measure until a better way of protecting crops could be found (Huppatz and Uren 2000). In March 2001, due to ongoing public debate and opposition from bird interest groups regarding the exemption of protected status for targeted native bird species, the proclamation enabling horticultural managers to destroy such birds without a permit was revoked. It was announced concurrently with this decision that the government would further consider issues relating to "wildlife conservation…following consultation with the appropriate grower organisations, bird interest groups and other stakeholders"[23]

Although the "no permit" exemption applied to specific areas, means and persons there was no requirement by the latter to restrict destruction of birds to their property or to limit the numbers killed. Furthermore, there was no requirement for orchardists to demonstrate whether they had a "valid need" to destroy birds within commercial crops or whether they were able to correctly identify the target species.

Although regulatory controls provide a legal means of destruction for protected pest birds (under specific situations), they may have the effect of encouraging an

[23] Parliamentary Hansard, 27 March 2001.

“overemphasis” on the pest species rather than towards broader management strategies. Landowners however are encouraged by National Parks and Wildlife SA to investigate integrated management programs rather than rely on destruction as the sole management strategy for pest birds in commercial crops. The destruction of birds by shooting is recommended in conjunction with specialist scaring devices (i.e. “scaring, reinforced by shooting”), in addition to control methods such as exclusion netting (National Parks and Wildlife SA, 1999).

7.3.3 Exclusion

Birds can be excluded from commercial crops by the use of various systems of netting. Throw-over nets are used to provide short-term protection during the ripening season. These nets are usually intended for single use and require labour intensive handling when applied to tree crops. The most commonly adopted netting system for excluding birds from stone-fruit crops is a permanent net structure providing full exclusion (Bomford 1992). Exclusion nets manufactured from long-life ultraviolet-stabilised strong plastics are now frequently used over large areas of horticultural and viticultural crops (Bomford and Sinclair 2001). An economic evaluation of permanent exclusion netting to reduce bird damage in orchards and vineyards by Sinclair (1990) showed that it can be fully effective against all species, is ecologically and socially acceptable, is humane, and the expertise for its installation and maintenance is readily available. The economic benefit of netting depends on the balance between the level of damage the crop receives, the annual (net) returns from the crop and the cost of application. He concluded that it is rarely economic for growers to erect permanent netting over conventional (low tree density) cherry orchards, but that with intensive cultivation of high-yielding, high-value cherry varieties, netting is often economical.

7.3.4 Habitat manipulation

Manipulation of the habitat of the pest bird population has been suggested or investigated by researchers in Australia for reducing the risk of crop damage (e.g. Jarman and McKenzie 1983; Allen 1990; Ford 1990). This approach to damage control may involve sowing and harvesting at times when the risk of damage is lowest, providing decoy food which is more attractive than crops, making crops unattractive by ensuring feeding birds do not have a clear view of surrounding habitat and potential predators, or ensuring that crops are not planted near trees or powerlines where birds can perch between bouts of feeding (Ford 1990).

Control measures are more likely to succeed if based on an understanding of the ecology and behaviour of the pest species. In a review of research on control of bird pests in Australia, Bomford (1992) recognised the need for more studies on the biology of pest birds in relation to the potential mitigation of crop damage by habitat modification or changes in crop growing practices. As rosellas are principally sedentary, management strategies that change their behaviour rather than ones that attempt to remove birds may be more effective in reducing damage to fruit or buds in cherry orchards whilst conserving wild populations.

This dietary study indicates that cherry primordia are an incidental and relatively unimportant food in the diet of Adelaide Rosellas as this food does not form a significant contribution to their nutritional needs. The composition and attractiveness of orchard pastures is likely to influence the amount of time that rosellas spend feeding in cherry trees.

Typical management of orchard pastures appears to have changed since the early 1970s, when soil tillage was a common practice, towards the more widely practiced sod culture nowadays. The purpose of tillage within orchards generally has been to control weed growth and to improve water infiltration into the soil. This practice has been largely replaced by sod culture (partly for soil conservation reasons) involving the maintenance of a perennial pasture. Management of orchards by sod culture may involve one or more of several methods including mowing, stock grazing or herbicide spraying under tree rows. One consequence of this change in orchard management is likely to have been a significant change in pasture composition and the relative abundance of food plants of rosellas. Orchards managed by sod culture generally support a more diverse suite of species including broad-leafed weeds and herbaceous pasture species. The disturbance regime of tillage is more likely to favour fewer species, in particular the agricultural weeds such as soursob that rely on regular soil disturbance.

Sinclair and Bird (1987) reported growers' claims that the problem of Adelaide Rosellas damaging cherry buds and flowers was relatively recent, most of who considered that the problem "did not exist 8-10 years ago". This perceived change in rosella foraging behaviour closely followed a change in orchard management practices that would have resulted in substantial modification to the ground flora, in particular its composition and relative abundance of food plants.

An integrated approach to control of crop damage can involve combining methods to reduce the attractiveness of the crop as a feeding site. Its effectiveness is dependent on the availability of an alternate feeding site and may be assisted by the implementation of measures to deter feeding in the susceptible crop. For example, scaring methods that have limited effectiveness on their own (e.g. shooting) could be used in conjunction with other methods to reinforce protection of the susceptible crop.

The mitigation of damage to cherry trees by Adelaide Rosellas through the use of alternative food sources or crops has only had limited investigation prior to this study. A decoy crop may be grown to protect a more valuable crop from damage. This approach involves diverting the attention of birds from a susceptible crop by providing a more attractive alternative food source. As an alternative to growing decoy crops, supplemental food such as trash grain could be provided at well chosen feeding sites (Jarman 1990a).

Several aspects of the diet of Adelaide Rosellas indicate the potential for the use of decoy crops in reducing damage levels to cherry buds. Food selection is influenced by many variables including nutrient content (mainly energy), abundance, accessibility, detectability and harvesting rate. As a diversity of food resources is available to free-ranging birds within the study area, there is the potential for birds to use foods selectively when food is abundant. Adelaide Rosellas in the study area also eat a wide range of foods, indicating that they are not dietary specialists. As their diet is not restricted to a small number of foods it may be relatively easy to shift their attention from one food to another. Rosellas also obtain most of their food on the ground and therefore spend a high proportion of foraging time on the ground where there is usually an abundant weed flora representing a potential food resource. Given that cherry primordia are a relatively unimportant food in the diet (except in some circumstances, e.g. when weather conditions discourage ground foraging for more profitable foods) there is some potential to encourage foraging activity towards alternative food sources. When conditions are favourable for ground foraging, rosellas are more likely to feed on cherry buds when their minimum daily energy requirement has been obtained from more profitable foods. The attractiveness of a decoy food is therefore dependent on relative food quality and other factors such as the time and energy to defend the resource from competitors and avoid predators. The spatial distribution of other important environmental resources such as nest sites and shelter in relation to food sources will also influence how time and energy will be allocated to finding, exploiting and defending those resources.

An attempt was made to reduce bird damage by rosellas in a cherry orchard at Basket Range in 1989 by providing oats as a decoy food nearby, but there was no reduction observed in the rate of cherry bud predation despite rosellas being attracted to the oats. Some problems can arise by providing supplemental food in orchards that may limit the usefulness of this method for reducing bud damage. Additional birds that would not normally forage at the site may be attracted to the orchard from neighbouring properties, and although birds may satisfy their nutritional needs on the food, they may choose also to browse in nearby cherry trees. Another problem is that providing too much food in autumn and winter may sustain a higher population than normal by reducing juvenile mortality. Knowledge of the optimal distance to locate a decoy crop from an orchard, based on information on home ranges, seasonal shifts in foraging areas and the timing of use of agricultural areas, is important. Providing supplemental food at irregular and therefore unpredictable intervals may overcome the problem of birds from neighbouring areas becoming regular visitors. The tolerance of non-resident birds by resident birds is likely to be lower when food availability is limited. Brereton (1971) has suggested that rosellas have loosely defined, permanent, all-purpose home-ranges that overlap with others and that agonistic behaviour only occurs if birds meet at preferred sites. The amount of supplemental food provided for birds should be based on knowledge of the population size, daily energy requirements and temporal and spatial patterns of feeding.

In this study area, an alternative food source for rosellas should be sufficiently attractive that birds can be readily diverted from feeding on buds, which may be achieved prior to a strong pattern of bud feeding behaviour beoming established. St John (1994) observed that feeding flocks of Little Corellas *Cacatua sanguinea*, in summer, once established at a site, were persistent and regular in their behaviour. A reduction in available food supply before a feeding pattern was established, specifically as a result of improved hygiene around grain storage bunkers, prevented problems with bird depredations at those sites. Rosellas fed on buds from March to September, and of these birds, approximately three quarters (74%) were recorded in the four months of May to August. A decoy crop should thus be available from April or early May through to mid or late August.

Rosellas may regularly "browse" on buds as they pass cherry trees whilst seeking safe perches or seeking other (more nutritionally) rewarding food sources. The extent of feeding on cherry primordia however may be less influenced by the nutritional value of this food than by other factors. The latter may include the proximity to more nutritionally attractive food sources, the proximity or accessibility of feeding sites to favoured / safer perching or roosting sites ("convenience" factors), or the relative safety from predators such as cats, foxes or Goshawks (by feeding in trees rather on the ground).

Given that apples are an important food source there is potential for manipulating their availability in order to influence the general foraging behaviour of rosellas. Apple seeds and flesh were also prominent foods in the crops of birds that fed on cherry buds, suggesting that cherry primordia were only an incidental food. The removal of wind-fallen or hand-thinned fruit from apple orchards in close proximity to cherry orchards could reduce general bird activity and thereby reduce bud damage levels in cherry trees. Use could be made of un-marketable apples to divert foraging activity away from cherry trees susceptible to damage by rosellas. As a food source, apples could be made more attractive to birds by being chopped or cut so that the seeds are more accessible.

Other prominent foods in the diet could similarly be manipulated in order to provide more attractive alternative food sources in autumn and winter when cherry trees are susceptible to damage. Sub-clover *Trifolium subterraneum* seed and wild radish *Raphanus raphanistrum* seed were next in importance to apple seed and flesh in the diet in both autumn and winter, when cherry trees are susceptible to damage. Where wild radish occurs (at a sufficient distance from cherry trees) it could be used as a decoy crop by creating conditions that promote its growth (e.g. cultivation), and by allowing it to set seed (delaying mowing). Sub-clover pasture could be established or re-sown in suitable areas using commercially available seed. As well as bulbs, soursobs provide a resource of flower buds and stem material on which rosellas foraged. Buds and stem of soursob were unimportant in autumn when soursobs are in the early stages of growth, but in winter both represented approximately 5% of foods by volume. Soursob is a common and abundant weed within the study area and is readily encouraged or spread by cultivation.

This dietary study indicates that rosellas spend a high proportion of foraging time on the ground. In a study of Adelaide Rosellas in Belair National Park 71% of all feeding observations (n=108) involved items obtained from the ground (Penck *et al.* 1995). Belair National Park consists of extensive areas of weed-invaded native forest and woodland and grassed recreation areas. An important factor in making ground foraging substrates attractive to rosellas may be the height and density of the vegetation, particularly in winter when wet weather may create unfavourable conditions for feeding on the ground. Food plants may be present at a particular location but they may not be accessible to birds particularly in wet conditions unless there are adjacent open patches or areas with a low sward height (Plate 2). Light grazing by sheep or mowing could be undertaken to reduce the pasture sward height to a level that would allow birds to feed on the ground in wet conditions. The presence of low growing food plants such as winter grass *Poa annua* (Plates 4 and 5) and wireweed *Polygonum aviculare* in areas where the pasture sward is maintained at a low height may be more important to rosellas in wet conditions than at other times.

Reducing the sward height in orchard pastures (e.g. by grazing, mowing, herbicide spraying or cultivation) may however have the undesired effect of encouraging rosellas to spend more time in orchards where they have access to cherry buds. By making orchard pastures more attractive for foraging, intermittent browsing on cherry buds by rosellas may therefore be encouraged. Such intermittent browsing is a reasonably frequent occurrence when birds are foraging on the ground for foods under cherry trees such as sub-clover seed. When birds become alarmed they often fly up into the nearest tree in the orchard where they are exposed to the immediate opportunity of foraging on buds before returning to the ground to feed.

Food quality, with respect to energy content, food item size and ease of handling efficiency (e.g. de-husking rate), are important factors in the attractiveness of an alternative food. The aviary experiments in this study showed that rosellas had a clear preference for soursob bulbs over apple seed. Given a similar handling time and foraging effort for items of each food, it was estimated that birds would be able to achieve an energy intake rate approximately six times greater when feeding on soursob bulb compared to apple seed due to the difference in average size and energy content of each food item. As cherry buds (or primordia) are a much smaller food item than apple seeds or soursob bulbs the energy intake rate is likely to be considerably lower assuming similar accessibility of each food and a similar de-husking rate per food item. However due to the much greater accessibility of cherry buds than apple seeds, the foraging profitability (net energy gain) of cherry buds may be more similar to apple seeds despite differences in size and energy content of food items. Soursob bulbs and apple seeds would therefore be more attractive food sources by making them more accessible to foraging birds. The use of soursob bulbs as a diversionary food source may also have potential in summer for mitigation of damage to cherry fruit, based on the difference in food quality (Table 4.6).

Rosellas usually have several intensive feeding periods during the day, the first soon after day-break and the last in the late afternoon, separated by relatively long periods mainly devoted to resting and activities other than feeding. The close proximity to cherry orchards of favoured resting trees may encourage intermittent foraging on cherry buds between feeding sessions. It may therefore be necessary to consider the removal of such trees, or when establishing an orchard, to select a site that is an appropriate distance from trees regularly used by rosellas.

I have suggested that feeding on cherry buds is an activity that may be complementary or secondary to the principal activity of resting or basking in the leafless canopy of cherry trees in winter. The more time that rosellas spend in cherry trees, the greater the probability of damage levels being higher, whether their initial purpose for being in the trees is for feeding or for non-foraging activities such as resting. The management strategy therefore should focus on reducing the time they spend near cherry trees (reduce their exposure time) by diverting their attention towards other food resources. A possible way of implementing such a strategy is to provide rosellas other deciduous resting trees in winter (in sun-exposed positions) that are not of commercial value, particularly if they produce buds of similar food value to cherry buds during winter or are close to a preferred food source.

A decoy crop could also involve planting sacrificial trees of a preferred variety (e.g. William's Favourite) to ensure that damage is minimised to trees of more commercially important varieties. Certain characteristics of cherry buds (e.g. a tree-borne food resource) may make this an attractive food resource in winter. The use of cherry buds by rosellas in winter may have involved replacement of an indigenous food that was obtained in a similar manner, but it is difficult to infer the diet of rosellas prior to European settlement. The original indigenous food sources may no longer occur in sufficient abundance during winter to alone support current populations due to changes to their natural habitat. The original indigenous food plants of rosellas have probably been largely replaced by an equivalent suite of introduced food plants, in particular the diverse weed flora which provides an almost continuous succession of seeds and other foods throughout the year. It is also difficult to know the extent to which the seasonal abundance of foods has changed since European settlement.

The planting of a sacrificial tree crop of favoured cherry varieties to divert foraging on buds from the main crop may warrant further investigation as a potential control strategy. If it is not possible to provide an alternative food source with a similar range of characteristics provided by cherry trees (as discussed above) it may be of benefit to sacrifice a number of established cherry trees as a winter foraging resource for rosellas. Given that the William's Favourite variety is more attractive to rosellas than many other varieties, and often suffers heavy production losses, this variety may be more valuable for pest management than for commercial fruit production.

As foods from weed species form a significant component of the diet of rosellas, the effect of controlling weeds on foraging behaviour within orchards should be considered prior to commencing a control program. The removal of an important winter food resource such as wireweed, winter grass, or fat hen *Chenopodium album* could have the effect of increasing the reliance of rosellas on other food sources such as cherry trees at this time of year. Replacement of the weeds by an equivalent suite of food plants may therefore need to be considered in conjunction with a weed control program if the loss of this food source is likely to increase feeding activity in cherry trees.

Seasonal changes in the variety, distribution and abundance of foods may cause birds to change their diet, foraging behaviour, and population dynamics (Ford 1985). Winter is the most likely time of the year when food limitation may occur however there may be shorter periods at other times of the year when food limitation may occur. During the period most advantageous for breeding (spring), it is just as important that conditions permit birds to accumulate the additional resources for breeding as it is for birds to survive the winter. To enable survival through autumn and winter, it has been necessary for rosellas to shift their attention to introduced food sources, such as apples, sub-clover, wild radish, and to a lesser extent, cherry buds due to the decline in abundance of indigenous food sources since European settlement. The highest representation in the diet for cherry primordia occurred in winter when all other native foods, including eucalypt seed, were the least represented. Cherry primordia however were still a minor food in the diet based on volumetric proportions.

In summary, the following are suggested as desirable attributes of decoy crops for reducing bud damage by rosellas in cherry orchards. Further research is required to test or fully evaluate these ideas in the field. An outline of possible future research directions for development of control strategies is given in Table 7.2.

1. *Matching the quantity, density and quality of food provided by the decoy crop to the nutritional requirements of the pest bird population.*
   The decoy crop should at least replace the nutritional value provided by the cherry buds normally consumed by a resident rosella population within an orchard during a season.

2. *Making the decoy feeding site more attractive for feeding than the crop.*
   Rosellas have a catholic diet and obtain much of their food as seed from low herbaceous weed and pasture species. The feeding site should incorporate a diversity of foraging opportunities including a variety of food plants. Low or irregular plant density, uneven plant height and "weedy" are suggested as some desirable attributes of decoy crops by Bomford and Sinclair (2002). It is important that birds feel secure (e.g. from predators and danger) at the decoy site, for example by removal of screening plants on the perimeter of the site to improve horizontal visibility. Perches to which the birds can fly before dropping down onto the feeding site, and to which they may return when disturbed, allow birds to watch for predators and thus feel more secure (Jarman 1990a). The leafless canopy of a cherry tree provides convenient perches that offer birds good visual vantage positions. Other deciduous trees (e.g. sacrificial cherry trees) could be established at a site where feeding birds are less likely to be disturbed.

3. *The proximity of the decoy crop in relation to shelter and roosts.*

   The decoy crop should be grown as close as possible to the roost, resting trees and other food sources, avoiding flight paths in the vicinity of the vulnerable crop.

4. *The distance of a decoy crop from the crop to be protected.*

   The distribution and abundance of food resources is usually an important factor in defining home ranges of birds. Brereton (1971) suggested that individuals, pairs and groups of rosellas have loosely defined, permanent, all-purpose home ranges that overlap with others and that agonistic behaviour only occurs if birds meet at preferred sites. A decoy crop too close to the commercial crop may not sufficiently reduce damage levels, in which case the optimum distance should be determined. Due to the small size of land-holdings in relation to the home ranges of birds some coordination between adjoining land-holders would be necessary in order to appropriately situate a decoy crop. Where bird damage is severe in a neighbourhood, Bomford and Sinclair (2002) suggest there may be benefit in growers jointly investing in setting up and maintaining a decoy feeding site. They advise however, to be economically beneficial, decoy feeding would need to be adopted over a large area, requiring a cooperative and concerted effort among growers.

5. *The timing of the availability of the decoy crop.*

   This should coincide with or precede the period when the commercial crop becomes attractive. The decoy crop should be available before rosellas are allowed to develop a strong feeding pattern in the susceptible commercial crop. The soursob manipulation experiment in this study was conducted in October and November when buds were not available to rosellas. Future studies involving the exposure of soursob bulbs in winter should be conducted in order to test the response of rosellas to bulbs when cherry buds are available, and to determine whether there is a corresponding reduction in damage to cherry buds. The effect on bud damage of exposing bulbs under or near cherry trees could be compared to exposing bulbs at sites more distant from cherry trees. The availability of other food sources within the home range of the resident rosella population should also be considered. The attractiveness of a decoy crop is expected to be enhanced during periods of general food shortage.

6. *The decoy crop also should not attract birds of other species.*
   Large numbers of other birds may consume a significant part of the decoy crop, thereby reducing its attractiveness and the benefit sought.

7.3.5 Integrating methods of control

Combining or integrating control methods may achieve better levels of control than one method alone such as shooting for population reduction. For example, shooting may be more effective if used to scare birds away from a crop when associated with a visual stimulus (e.g. silver streamers) and if alternative feeding sites are available. It is therefore usually more time efficient to use the discharge from a shotgun to frighten birds and only occasionally shoot individuals in a flock. As shotguns emit a loud noise on discharge they are preferable to rifles. If too many birds are shot, naive birds that are not conditioned to the danger stimuli may move into the area. Scare guns (i.e. gas guns) are also least likely to work when the birds have little alternative but to use the main crop.

The success of integrated methods is influenced by two important principles: the first not allowing birds to become accustomed to feeding in the main crop, and the second, providing attractive alternate feeding sites. The first principle may be achieved through the use of deterrent devices at locations where the crop is vulnerable or where birds are likely to approach the crop. As habituation to deterrent devices can occur in a short period of time, their effectiveness can be enhanced by using them sparingly and changing their position as frequently as possible. The removal of shelter and other food sources near the susceptible crop may also discourage birds.

In developing an integrated control programme an adaptive management approach ("trial-by-error") is suggested due to the difficulty of accurately predicting the behavioural response of wild birds. The individual techniques and their combined application should be based on knowledge of the behaviour of the pest population in relation to the commercial crop to be protected in order to increase the chance of success.

7.4 CONSERVATION ISSUES

In a review of Australian research on the harmful impacts of bird pests and the development of control measures, Bomford and Sinclair (2002) note that many of Australia's bird pests are protected native species and that it is necessary to both manage the damage they cause and ensure that control measures do not threaten populations. Wyndham and Cannon (1985) believed that none of the rosellas were in immediate danger of extinction. They reported that "all the rosellas have substantial parts of their range in areas that are used for agriculture or rangeland grazing...and generally, suitable food for rosellas has remained plentiful".

The Adelaide Rosella *Platycercus elegans adelaidae* is widely distributed and frequently reported, extending along the Mount Lofty Ranges from just south of Adelaide northwards to about Clare (Higgins 1999). The bird atlas of the Adelaide area for 1984-85 was based on 268 grid squares (10 000 x 10 000 yd grid system) and recorded a small overall increase in the distribution of Adelaide Rosellas compared to 1974-75 (Paton *et al.* 1994). This change in distribution was based on increases (16 grid squares) exceeding losses (8 grid squares). Small expansions were recorded on the southern Adelaide Plains and in the South-east districts, both outside the current study area.

The Southern Mount Lofty Ranges region of the Adelaide atlas area comprises 2630 km^2 land area of which 9.7% native vegetation remains. Landscapes in all of the seven defined regions were dominated by agricultural development and consisted mainly of introduced grasslands, crops and pasture (Paton *et al.* 1994). The decline and loss of native species from an area is usually attributed to the clearance and fragmentation of native vegetation (e.g. Ford and Howe 1980). The increase in distribution of the Adelaide Rosella reported by Paton *et al.* (1994) occurred prior to the introduction of broad-acre clearance controls under the *Native Vegetation Management Act 1985.* It is unlikely therefore that significant changes in the distribution of the Adelaide Rosella would have occurred between 1985 and 1992 compared to the previous 10 years. Paton *et al.* (1994) noted that although the Ash Wednesday fires of February 1983 burnt about 33 000 hectares in four locations in the Mount Lofty Ranges there had generally had no long term impact on remnant bird populations. Graham *et al.* (2001) recognised the Crimson Rosella as a "native increaser species", i.e. one of a range of native species that have increased in abundance due to various factors including changes in the proportions of different habitat types resulting from vegetation clearance and modification.

Due to the paucity of information on abundance of birds that frequent orchards and vineyards in the Mount Lofty Ranges a survey was recently carried out to form a baseline for measuring trends in abundance of these species (Taylor 2001). Data was collected for twelve species of native and exotic birds from twenty sites during March and April 2001. No significant differences in the abundance of these species were detected between horticultural and natural vegetation sites. The most abundant species detected during the survey period in both natural vegetation and horticultural sites (orchards and vineyards, but excluding arable land and grazing land) was the Adelaide Rosella. The mean density recorded for Adelaide Rosellas was 1.9 ± 0.2 (s.e.) birds per hectare on natural vegetation sites and 2.8 ± 0.4 (s.e.) birds per hectare on horticultural sites. The predicted abundance of Adelaide Rosellas throughout the Mount Lofty Ranges during March and April 2001 (80% C.I.) was 26,208 – 40,150 birds on horticultural land (11,978 ha.) and 84,030 – 107,754 birds on natural vegetation land (49,840 ha.).

Wyndham and Cannon (1985) reported that trees, particularly eucalypts, are important to rosellas in eastern and south-eastern Australia as sources of food, for nest sites and for shelter, and that in most places ample trees remain to ensure the continued survival of the rosellas. They suggested, however, "there could be some localised extinctions, possibly even complete loss of a sub-species, in areas that are extensively cleared or where disease causes widespread mortality of eucalypts, e.g. dieback on the New England Tablelands". The Adelaide Rosella is considered to be a relatively secure taxon over its geographic range, however individual populations may be at some risk within extensively cleared districts where tree losses continue, thereby reducing breeding opportunities. The *Native Vegetation Act 1991* prevents removal of native vegetation including scattered trees without formal consent. Although consent for broad-acre clearance is no longer given under this legislation, losses of trees in the Mount Lofty Ranges continue to occur for fence-lines, road-works, new property access, dwelling construction, service installation and maintenance, farm management and various other purposes. There is a continuing high demand to remove scattered trees within already heavily cleared districts for intensive agriculture, notably viticulture, pasture, and orchard developments. The survival of individual vegetation remnants may also be subject to varying pressures over the long term as a result of changing land ownership and land-use. Paton *et al.*

(1999) recognised that some illegal clearance of native vegetation still continued with offenders rarely being successfully prosecuted.

Revegetation, as a condition applying to consent for clearance of trees, does not adequately compensate for the immediate loss of fauna habitat values provided by large trees, particularly those that contain hollows. Native bird populations that are dependent on this habitat may decline and possibly fail to recover during the long maturation period (i.e. decades) during which eucalypts, in particular, need to form hollows from establishment.

In addition to the loss of trees in the landscape, possible competition for limited nest hollow resources by the introduced Common Starling *Sturnus vulgaris* and the European honeybee *Apis mellifera* may further limit breeding opportunities for rosellas. Pell and Tidemann (1997) showed that two introduced hollow-nesting sturnids, the Common Myna *Acridotheres tristis* and the Common Starling, were the dominant users of available nest resources, nest boxes and natural hollows in savannah and woodland areas which supported native parrot populations in Canberra. Other native species such as Rainbow Lorikeets *Trichoglossus haematodus* and Eastern Rosellas may also compete with Adelaide Rosellas for nest hollows.

Green (1983) believed the cause of the decline of the Eastern Rosella in Tasmania over the previous 50 years to be a combination of fewer nest holes (related to the clearing of eucalypts for pasture improvement) and increasing pressure of competition from Common Starlings for such breeding places. Green (1983) argued that as Psittaciformes are long lived, population declines would not be apparent until some considerable time after the commencement of breeding failures.

The fragmentation of remnant vegetation has disrupted a number of ecological processes in the Mount Lofty Ranges. Paton (2000) has recorded reduced seed production in a range of bird-pollinated plants within surviving vegetation remnants in the Mount Lofty Ranges. He suggests that this decline can be attributed to severe disruption of bird-plant pollinator systems by the extent and pattern of vegetation clearance. The better quality arable land probably supported food resources that sustained nectar-feeding birds over summer and autumn. The more extensive clearing of these areas has caused food-limitation during the summer-autumn period and a decline of populations of nectar-feeding birds. This results in a decline in seed production for a range of bird-pollinated plants that flower during winter and spring such as *Astroloma, Epacris, Grevillea* and *Xanthorrhoea* (Paton *et al.* 1999).

The food resources that eucalypts provide to rosellas are principally seed and various phytophagous insects (mainly psylloids). Where pollination is dependent on wind or insects, tree density may be an important factor for normal levels of seed set in individual trees. Eucalypt woodlands where selective clearing of trees has occurred may offer a smaller food resource than is apparent from the number of trees remaining due to possible reduction in out-crossing and consequent reduction in seed production. There was, however, no evidence of this effect in *Eucalyptus camaldulensis* during a year of high flowering in a current study in the Mount Lofty Ranges (Ottewell, pers. comm.[24]).

Despite the operation of broad-acre clearance controls since 1985, habitat fragmentation has continued to occur due to incremental clearing (both illegal and legal) and the combined effect of degradation processes. The quality of vegetation remnants is in general decline due to a range of factors including grazing by introduced herbivores, weed invasion, plant disease (e.g. *Phytophthora cinnamomi*) and changes to natural hydrology. This trend suggests that a fewer number of rosellas will be supported largely or entirely by the food resources within existing remnants. Rosellas that have adapted their diet to the food resources provided in highly modified habitats generally supplement the diet of introduced foods with native foods. Declining seed production within natural remnants will have greatest effect on populations that are largely dependent on such areas for food resources, and to a lesser extent birds that may be required to supplement their diet of introduced foods with native foods at critical times of the year.

The importance of weeds in the diet of wildlife species is an issue that natural resource managers should also carefully consider when planning weed control programs, given that many weeds are now providing significant quantities of food, shelter and nesting sites for native fauna (Zann and Straw 1984; Paton 1989; Read 1994). There are many weed species that are favoured by disturbance and are generally confined to disturbed sites. Such species are typically agricultural weeds that have a limited ability to invade undisturbed bushland, and include many broad-leafed herbaceous species. Weeds in this category such as *Chenopodium album*,

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[24] Kym Ottewell, University of Adelaide.

Polygonum aviculare, *Echium plantagineum*, *Briza maxima, Poa annua*, *Sonchus oleraceus* and *Acetosella vulgaris* have been recorded as food plants of native bird species such as Adelaide Rosellas (this study) and Red-browed Firetails *Emblema temporalis* (Read, 1994) in the Mount Lofty Ranges, and therefore could be tolerated particularly where they are restricted to disturbed sites. Other weeds that have the ability to readily invade intact bushland such as wild olive *Olea europaea* (e.g. Lange and Reynolds 1981), blackberry *Rubus ulmifolius* and hawthorn *Crataegus monogyna*, and are also food plants of wildlife species such as the Adelaide Rosella, should however be controlled where the overall adverse impact to a natural ecosystem (through displacement of native vegetation) would be greater if the weeds were not controlled.

Although Adelaide Rosellas are able to successfully exploit a wide range of naturalised food resources, some small isolated populations may decline and fail to recover due to several factors, the most important of which are further losses of trees and nesting habitat, competition for tree hollows by introduced species, and in some instances destruction programmes associated with commercial horticulture.

Management of populations of wildlife species that are in conflict with agriculture, including common species such as the Adelaide Rosella, should also be based on sound conservation and animal welfare principles. Where the control of a pest species is warranted, primary consideration should therefore be given to strategies that will not threaten the viability of individual populations.

7.5 CONCLUSIONS AND FUTURE DIRECTIONS

Commonly used approaches for reducing damage by rosellas to cherry crops in the Adelaide Hills involve shooting or the use of scaring devices which require relatively little effort or expertise to carry out, but are generally ineffective (as they are currently used). To be more effective, control strategies should be based on an understanding of the ecology of the bird species and the characteristics of the crop requiring protection, particularly where conservation of a native species is a consideration.

Shooting as a means to reinforce scaring tactics may have a role within a broader control programme, though shooting should not be relied upon as the sole method of control. In developing a control strategy it is important to recognise that rosellas are predominantly sedentary (e.g. Forshaw 1981; Higgins 1999) and that the distribution and abundance of food resources strongly influences population dynamics. Exclusion of birds from the commercial crop by construction of netting structures is perhaps the simplest, most ecologically sound and humane method of control, and has been demonstrated to be cost-effective where potential crop losses are high. Netting however may not be economically beneficial in some situations where damage levels are high, particularly for older fruit orchards with wide tree spacings. In these situations habitat modification in order to change existing patterns of foraging behaviour is worth considering.

As foraging generalists, rosellas have the ability to diversify their diet in order to meet their daily energy requirements throughout the year. This ability is particularly important for a sedentary species in terms of maintaining viable population sizes. The advantage therefore of being a generalist is that the diet can be varied to include less preferred foods when more preferred foods become limiting. The presence of a diverse range of food plants within the normal foraging range of a pest population is likely to provide a reliable and continuous supply of food throughout the year. This may be of greatest importance in autumn and early winter when a pattern of feeding on cherry buds could develop in response to a general food shortage.

The use of decoy crops or foods appears to show some promise as a control strategy, particularly where rosellas are causing damage to trees within cherry orchards that are not economic to enclose with netting. A number of food sources of rosellas identified in this study are common weed or pasture species (e.g. soursob, wild radish, and sub-clover) which could be promoted or manipulated through farm cultural practices, possibly involving only a modest investment of time and effort by the commercial grower. The orchard pasture however may represent an important foraging resource for rosellas, and the effect of its composition on bud damage levels is worthy of further investigation. Control measures for specific situations should be developed with consideration for the physiological requirements (e.g. thermo-regulation) of the birds, their physical environment (e.g. weather conditions), and their use of key environmental resources such as food, nest sites and shelter (in particular their distribution in space and time). Individual control measures may be implemented in combination with others to form an integrated control programme. As a broad approach, measures to discourage feeding at the susceptible crop should be counter-balanced by measures to encourage feeding at other sites. A summary is given in Table 7.2 of the type of experiments that could be carried out in order to develop practical control measures for rosellas damaging buds in commercial cherry crops.

Table 7.2. Summary of suggested experimental approaches for developing control measures to reduce cherry bud damage by Adelaide Rosellas.

Control measure	Example	Aspects	Comments
Decoy foods: supplementary feeding	- Apples - Grain (oats or barley)	- Whole apples compared to chopped apples. - Effect of feeding site location (in & away from orchard) on bud damage levels. - Effect of nearby perches on the use of the feeding site/ decoy food.	Implement before strong pattern of bud feeding established. Select feeding site close to shelter, away from human activity, & with good visibility to reduce risk of predation. Decoy food should not significantly exceed the birds' nutritional needs. Alternative food resources should be frequently available to birds at the decoy crop site from March to August. Avoid attracting other (non-pest) species that may compete for the decoy food. Coordinate trial with neighbouring land-holders.
Decoy crop: planted	- Cherry trees of preferred (susceptible) varieties. - Sub-clover crop.	- Effect on damage levels of sacrificial cherry trees in orchard compared to trees planted away from orchard. - Effect of location of sub-clover crop (in & away from orchard) on bud damage levels.	Ditto above.
Decoy crop: pasture culture	Manipulate pasture sward (height, density, composition) to promote feeding.	- Effect of mowing, tillage & herbicides on food availability & feeding response to pasture species - create strips or patches of low sward or bare ground. - Effect on bud damage levels of cultivation of soursob patches to expose bulbs, particularly in autumn & early winter. - Effect of feeding site location (in & away from orchard) on bud damage levels for each of the above. - Effect of nearby perches on the use of a decoy crop.	Ditto above. "Bare strips" may encourage all weather ground foraging & reduce risk of predation. Cultural method at decoy crop site should encourage a wide variety of food plants, especially low growing forbs & herbs, & promote preferred food plants e.g. chick weed, winter grass, sub-clover, wild radish.
Orchard pasture culture	Manipulate pasture sward (height, density, composition) to discourage feeding.	- Effect of different pasture swards on bud damage levels (e.g. tall, dense, uniform sward, & reduced density of food plants promoted by various cultural methods).	Remove or reduce attributes of pasture that attract birds. Does an orchard pasture sward attractive to birds encourage feeding on or divert attention from cherry buds?
Deterrence devices (susceptible crop)	- Taped alarm calls - Shooting to scare	For each of the above control measures, when the decoy site is located away from the production orchard, compare the effect of the deterrence device used within the orchard (as a complementary measure) on bud damage levels.	Commence use before or at the time bud damage starts. Use device infrequently & irregularly, move position often, & limit duration to prevent habituation. Reinforce occasionally with actual danger (e.g. shooting). An attractive alternative feeding site(s) must be available for birds to move to when deterrence device is in operation.

With the exception of exclusion netting, the use of any control technique should be integrated with other measures to ensure that the orchard to be protected is made as unattractive to birds as possible, and that attractive alternative feeding sites are available. This approach may need to be adopted over a large area involving possibly several land-holdings. To be economically beneficial it would require a sustained and cooperative effort amongst neighbouring growers.

As indicated in this study, the reasons for rosella behaviour may be complex, and knowledge of the feeding ecology can contribute to a greater understanding of the reasons for behavioural patterns in a pest population. In particular, this study indicates that there is probably no single causal factor that can be attributed to significant bud damage in a cherry orchard. For each locality, the attributes of the orchard or orchards that attract rosellas need to be evaluated in relation to the key environmental resources that the population requires to survive during the period when trees are vulnerable to feeding damage. From this understanding more effective management strategies can be developed and implemented.

REFERENCES

Allen LR (1990). Habitat manipulation and the control of cockatoos and galahs in sunflower. pp. 125-133. *In:* P. Fleming, I. Temby and J. Thompson (eds.). "Proceedings of the National Bird Pest Worshop", Armidale 8-9 February NSW Agriculture and Fisheries.

Anon (1952). Manual for Testing Agricultural and Vegetable Seeds. Handbook No. 30. United States Department of Agriculture.

Anon. (1974). Weed Seeds. New Zealand Ministry of Agriculture and Fisheries. Bulletin No. 316.

Aschoff J and Pohl H (1970). Rhythmic variations in energy metabolism. *Fed. Proc.* 29: 1541-1552.

Aslin VM (1978). Behaviour and ecology of the crimson rosella (*Platycercus elegans*). Unpubl. B.Sc. (Hons.) thesis, Univ. New England, Armidale, NSW.

Barker RD and Vestjens WJM (1989). The food of Australian birds: 1. Passerines. CSIRO, Melbourne.

Bomford M (1992). Bird Pest impact and Research in Australia: a survey and bibliography. Bureau of Rural Resources, Canberra, Working Paper No. 3.

Bomford M and O'Brien PH (1990). Sonic deterrents in animal damage control: A review of device test and effectiveness. *Wildl. Soc. Bull.* 18: 411-422.

Bomford M and Sinclair R (2002). Australian research on bird pests: impact, management and future directions. *Emu.* 102: 29 – 45.

Brereton J Le G (1971). A self-regulation to density-independent continuum in Australian parrots, and its implication for ecological management. pp.207-221. *In:* E. Duffey and A.S. Watt (eds.) "The Scientific Management of Animal and Plant Communities for Conservation". 11th Symposium of the British Ecological Society, Blackwell, Oxford.

Bridgewater AE (1934). The food of *Platycercus eximius* and *P. elegans*. *Emu* 33: 175-186.

Brown P (1984). Food and feeding of the Green rosella (*Platycercus caledonicus*). *Tasmanian Bird Report.* 13: 17-24.

Bryant (1973). The factors influencing the selection of food by the house martin (*Delichon urbica* (L.)) *J. Animal Ecol.* 42: 539-64.

Cannon CE (1977). The comparative feeding biology of two Australian parrots, *Platycercus eximius* and *P. adscitus*. Ph.D. thesis, Univ. Queensland.

Charnov EL (1976). Optimal foraging: the marginal value theorem. *Theor. Popul. Biol.* 9: 129-136.

Clark LR (1962). The general biology of *Cardiaspina albitextura* (Psyllidae) and its abundance in relation to weather and parasitism. *Aust. J. Zool.* 10: 537-86.

Clarke PA (1988). A Rosella Lovenest: How suburbia can keep its bird life happy. *Geo* 10(4): 44 – 49.

Davison VE (1940). A field method of analysing game bird foods. *J. Wildl. Manage.* 4 (2): 105-116.

Department for Environment and Natural Resources (1987). Remaining Vegetation in the Southern Agricultural Regions of South Australia. Government of South Australia, Adelaide. (unpubl. report).

Dolling WR (1991). The Hemiptera. Oxford University Press, New York.

Dyer MI and Ward P (1977). Management of pest situations. pp 267-300. *In:* Pinowski J and Kendeigh SC (eds.). Granivorous birds in ecosystems: Their evolution, populations, energetics, adaptations, impact and control. Cambridge University Press, London.

Ellis JE, Wiens JA, Rodell CF and Anway JC (1976). A conceptual model of diet selection as an ecosystem process. *J. Theor. Biol.* 60: 93:108.

Emison WB (1990). Review of bird pest research in Victoria. Proceedings National Bird Pest workshop, Armidale 8-9 February. NSW Agriculture and Fisheries. pp. 23-33.

Environment Protection Authority (2000). The State of the Health of the Mount Lofty Ranges Catchments from a Water Quality Perspective. Government of South Australia, Adelaide.

Estabrook GF and Dunham AE (1976). Optimum diet as a function of absolute abundance, relative abundance, and relative value of available prey. *American Naturalist* 110: 401-413.

Farrell TP and Ashton DH (1978). Population studies on *Acacia melanoxylon* R.Br. I. Variation in seed and vegetative characteristics. *Aust. J. Bot.* 26: 365-79.

Fisher AM (1991). Bud damage by Adelaide rosellas (*Platycercus elegans adelaidae*) to different varieties of sweet cherry (*Prunus avium*) grown in the southern Mt Lofty Ranges. B.Sc. Hons. thesis. Univ. of Adelaide.

Fisher AM (1993). Patterns of damage to cherry buds by Adelaide rosellas *Platycercus elegans adelaidae* in the Southern Mt Lofty Ranges. *SA Ornithologist.* 31: 132-140.

Flood RJ (1986). Seed Identification Handbook. National Institute of Agricultural Botany, Cambridge.

Ford HA (1985). A synthesis of the foraging ecology and behaviour of birds in eucalypt forests and woodlands. In: Keast A, Recher HF, Ford H and Saunders D (eds.). Birds of Eucalypt Forests and Woodlands: Ecology, Conservation and Management. Royal Australasian Ornithologists Union and Surrey Beatty & Sons, Chipping Norton.

Ford H (1990). Research on bird pests of crops in northern New South Wales. *In:* P. Fleming, I. Temby, and J. Thompson (eds.). 'National Bird Pest Workshop Proceedings.' Department Conservation, Forests and Lands, Victoria and NSW Agriculture and Fisheries, Orange.

Ford HA, Forde N and Harrington S (1982). Non-destructive methods to determine the diets of birds. *Corella* 6 (1): 6-10.

Ford HA and Howe RW (1980). The future of birds in the Mount Lofty Ranges. *Sth Aust. Ornith.* 28: 85-89.

Forde N (1986). Nectar and fruit feeding birds. p. 175. *In:* Wallace HR (ed.) The Ecology of the Forests and Woodlands of South Australia. S.A. Govt. Printer, Adelaide.

Forshaw JM (1981). Australian parrots. 2nd Edition. Lansdowne Editions, Melbourne.

Frith HJ, Brown BK and Barker RD (1974). Food of the Crested and Common Bronzewing Pigeons in Inland New South Wales. *Aust. Wildl. Res.* 1: 129-44.

Goldstein DL (1990). Energetics of activity and free living in birds. In: Morrison ML, Ralph CJ, Verner J and Jehl JR (eds.). Avian foraging: Theory, methodology, and applications. Studies in Avian Biology No. 13. Cooper Ornithological Society, Lawrence, Kansas.

Golley FB (1961). Energy values of ecological materials. *Ecology.* 42: 581-4.

Graham A, Paton DC and Berry O. (1999). Survey of the incidence of bird damage to apples, pears, cherries and grapes and methods of control in the Mt Lofty Ranges, South Australia. Final report to the Cherry, Apple, Pear and Grape Growers of the Mt Lofty Ranges. (Department of Environmental Biology, University of Adelaide, South Australia).

Graham A, Oppermann A and Inns RW (2001). Biodiversity Plan for the Northern Agricultural Districts of South Australia. Department for Environment and Heritage, South Australia.

Green RH (1983). The decline of the eastern rosella and other Psittaciformes in Tasmania concomitant with the establishment of the introduced European starling. *Rec. Queen Victoria Museum.* 82: 1-5.

Green L, Fisher EB Jr, Perlow S, and Sherman L (1981). Preference reversal and self-control: choice as a function of reward amount and delay. *Behav. Anal. Let.* 1: 244-256.

Grubb TC Jr. (1979). Factors controlling foraging strategies of insectivorous birds, pp. 119-135. *In:* JG Dickson, RN Connor, RR Fleet, JC Kroll, and JA Jackson [Eds.], The role of insectivorous birds in forest ecosystems. Academic Press, New York.

Halse SA (1986). Parrot damage in apple orchards in south-western Australia – a review. Technical Report No. 8. Department of Conservation and Land Management, Western Australia.

Higgins PJ (Ed.) (1999). Handbook of Australian, New Zealand and Antarctic Birds. Volume 4: Parrots to Dollarbird. Oxford University Press, Melbourne.

Huppatz B and Uren K (2000). Fruitgrowers' guns kill 45,000 parrots. The Advertiser. 12 June 2000.

Hyslop EJ (1980). Stomach contents analysis - a review of methods and their application. *J.Fish Biol.* 17: 411-429.

Inglis JM and Bairstow CJ (1960). A device for measuring the volume of seeds. *J. Wildl. Manage.* 24(2): 221-2.

Jarman P (1990a). Preventing damage to sunflower crops by White Cockatoos and Galahs. pp. 27 - 32 *In:* 'Proceedings of public meeting to discuss Long-billed Corella management and crop damage.' Naracoorte, South Australia. (Eds L. W. Best, R. Sinclair, and P. J. Alexander.) National Parks and Wildlife Service, South Australia, Adelaide.

Jarman P (1990b). Bird pest research: the gap between research and application. pp. 7-12 *In:* P. Fleming, I. Temby and J. Thompson (Eds.). "Proceedings of the National Bird Pest Worshop", Armidale 8-9 February NSW Agric. and Fish.

Jarman PJ and McKenzie DC (1983). Behavioural mitigation of damage by galahs to a wheat trial. *Aust. Wildl. Res.* 10: 210-202.

Jones DL and Clemesha SC (1976). Australian Ferns and Fern Allies. Reed Books, Frenchs Forest NSW.

Joseph L (1986). Seed-eating birds of southern Australia. *In*: Ford HA and Paton DC (eds.) The Dynamic Partnership: Birds and plants in southern Australia. S.A. Govt. Printer, Adelaide.

Kagel JH, Green L, and Caraco T (1986). When foragers discount the future: constraint or adaptation? *Anim. Behav.* 34: 271-283.

Kale HW II (1965). Ecology and bioenergetics of the long-billed marsh wren (*Telmatodytesin palustris griseus* (Brewster) in Georgia salt marshes. Publ. of the Nuttall Ornith. Club. 5. Cambridge, Massachusetts.

Kendeigh SC, Dol'nik VR and Gavrilov VM (1977). Avian energetics. pp. 127-204. *In:* Pinowski J and Kendeigh SC (eds.). Granivorous birds in ecosystems. Cambridge Univ. Press, London.

Kendeigh SC and West GC (1965). Caloric values of plant seeds eaten by birds. *Ecology.* 46: 553-5.

King JR (1974). Seasonal allocation of time and energy resources in birds. *In:* Paynter RA (1974). (ed.). Avian Energetics. Pub. Nuttall Orn. Club No. 15. Cambridge, Massachusetts.

Krebs EA (1997). Breeding biology and parental care of the Crimson Rosella. Unpubl. PhD thesis, Aust. Natn. Univ., Canberra.

Krebs JR (1978). Optimal foraging: decision rules for predators, pp. 23-63. *In:* Krebs JR and Davies NB (eds.), Behavioural ecology: an evolutionary approach. Sinauer Associates, Sunderland, Massachusetts.

Krebs JR, Stephens DW and Sutherland WJ (1983). Perspectives in optimal foraging, p.165-216. *In:* AH Brush and GA Clark, Jr. [eds.], Perspectives in ornithology. Cambridge Univ. Press, New York.

Lange RT and Reynolds T (1981). Halo effects in native vegetation. *Trans. R. Soc. of S.A.* 105: 213-214.

Lea AM and Gray JT (1935). The food of Australian birds. *Emu* 35: 63-98.

Lepschi BJ (1993). Food of some birds in eastern New South Wales: Additions to Barker & Vestjens. *Emu* 93: 195-9.

Long JL (1985). Damage to cultivated fruit by parrots in the south of Western Australia. *Aust. Wildl. Res.* 12: 75-80.

Loyn RH, Runnals RG, Forward GY and Tyers J (1983). Territorial Bell Miners and other birds affecting populations of insect prey. *Science* 221: 1411-3.

Magrath R and Lill A (1983). The use of time and energy by the Crimson Rosella in a temperate wet forest in winter. *Aust. J. Zool.* 31: 903-912.

Mahoney JE (1982). The growth and development of soursob (*Oxalis pes-caprae*) in Victoria. *Australian Weeds*, 1(4): 9-11.

Martin AC, Gensch RH and Brown CP (1946). Alternative methods in upland gamebird food analysis. *J. Wildl. Manage.* 10(1): 8-12.

Maxson SJ and Oring LW (1980). Breeding season time and energy budgets of the polyandrous spotted sandpiper. *Behaviour* 74: 200-263.

Moore FR and Simm PA (1986). Risk-sensitive foraging by a migratory bird (*Dendroica coronata*). *Experientia* 42:1054-1056.

Morgan FD (1984). Psylloidea of South Australia. SA Govt, Adelaide.

Morse DH (1970). Ecological aspects of some mixed-species foraging flocks of birds. *Ecol. Monogr.* 40: 119-168.

Morse DH (1990). Food exploitation by birds: some current problems and future goals. pp 134-143 *In:* Morrison ML, Ralph CJ, Verner J and Jehl JR (eds.). Avian Foraging: Theory, Methodology, and Applications. Studies in Avian Biology No. 13. Cooper Ornithological Society, Lawrence, Kansas.

Mount Lofty Ranges Steering Committee (1989). Mount Lofty Ranges Review: Investigations Report. Govt. of South Australia, Adelaide.

Murphy MT (1987). The impact of weather on kingbird foraging behaviour. *Condor* 89: 721-730.

National Parks and Wildlife SA (1999). Native Birds and Commercial Orchards and Vineyards. Govt. of SA, Adelaide.

National Parks and Wildlife Service (1988). Concerning Animals No. 5: Birds causing damage to fruit and crops and suggested methods of control. Department of Environment and Planning, Adelaide.

Newton, I (1964). Bud-eating by bullfinches in relation to the natural food supply. *Journal of Applied Ecology*. 1: 265-279.

Norbury GL and Sanson GD (1992). Problems with measuring diet selection of terrestrial, mammalian herbivores. *Aust. J. Ecol.* 17: 1-7.

Norman FI and Mumford L (1982). Food of the Chestnut Teal, *Anas castanea*, in the Gippsland Lakes Region of Victoria. *Aust. Wildl. Res.* 9: 151-55.

Oaten A (1977). Optimal foraging in patches: a case for stochasticity. *Theor. Popul. Biol.* 12: 263-285.

Orians G (1961). The ecology of blackbird (*Agelaius*) social systems. *Ecol. Monogr.* 31: 285-312.

Paton DC (1989). Planning wildlife management. *Australian Ranger Bulletin.* 5: 33-34.

Paton DC (2000). Disruption of bird-plant pollination systems in southern Australia. *Cons. Biol.* 14(5): 1232-1234.

Paton DC, Carpenter G and Sinclair RG (1994). A second bird atlas of the Adelaide Region. Part 1: Changes in the distribution of birds: 1974-75 vs 1984-85. *SA Ornithologist* 31:151-193.

Paton DC, Prescott AM, Davies RJ and Heard LH (1999). The distribution, status and threats to temperate woodlands in South Australia. *In:* Hobbs RJ and Yates CY (eds.) Temperate eucalypt woodlands in Australia: Biology, conservation, management and restoration. Surrey Beatty & Sons, Chipping Norton.

Paton DC, Tucker JR, Paton JB and Paton PA (1988). Avian vectors of the seeds of the Europaean olive *Olea europaea*. *SA Ornithologist* 30: 158-9.

Pell AS and Tidemann CR (1997). The impact of two exotic hollow-nesting birds on two native parrots in savannah and woodland in eastern Australia. *Biol. Cons.* 79: 145-153.

Penck M, Torcello JC and Sanderson KJ (1995). Observations of coexistence between Adelaide and Eastern Rosellas (*Platycercus* spp.) in Adelaide. *SA Ornithologist* 32: 25-32.

Pinowski J and Drodz A (1975). Estimation of food preferences. pp 333-337. *In:* W. Grodzinski, RZ Klekowski and A Duncan (eds.). Methods for ecological bioenergetics. Blackwell Scientific Publications, London.

Pyke GH, Pulliam HR and Charnov EL (1977). Optimal foraging: a selective review of theory and tests. *Quart. Rev. Biol.* 52:137-154.

Read JL (1987). The ecology of firetail finches in southern South Australia. Unpubl. B.Sc. Honours thesis, University of Adelaide.

Read JL (1994). The diet of three species of firetail finches in temperate South Australia. *Emu* 94: 1-8.

Recher HF (1990). Specialist or generalist: Avian response to spatial and temporal changes in resources. pp. 333-336 *In*: Morrison ML, Ralph CJ, Verner J and Jehl JR (eds.). Avian foraging: Theory, methodology, and applications. Studies in Avian Biology No. 13. Cooper Ornithological Society, Lawrence, Kansas.

Renner M and Davis LS (1999). Sexing Little Penguins *Eudyptula minor* from Cook Strait, New Zealand using discriminant function analysis. *Emu* 99: 74-9.

Reynolds TM (1991). Foods of the Adelaide Rosella *Platycercus elegans adelaidae* – Preliminary Results. pp. 139 - 142 *In:* Australian Vertebrate Pest Control Conference 1991 – Handbook of Working Papers. Animal and Plant Control Commission, Adelaide.

Ricklefs RE (1974). Energetics of reproduction in birds. In: "Avian Energetics". (Ed. RA Paynter.) Nuttal Ornithol. Club Publ. No. 15, Cambridge, Massachusetts.

Rodgers AR (1990). Evaluating preference in laboratory studies of diet selection. *Can. J. Zool.* 68: 188-190.

Rosenberg KV (1990). Dead-leaf foraging specialization in tropical forest birds: Measuring resource availability and use. pp. 360-368. *In:* Morrison ML, Ralph CJ, Verner J and Jehl JR (eds.). Avian foraging: Theory, methodology, and applications. Studies in Avian Biology No. 13. Cooper Ornithological Society, Lawrence, Kansas.

Rosenberg KV and Cooper RJ (1990). Approaches to avian diet analysis. pp. 80-90 *In:* Morrison ML, Ralph CJ, Verner J and Jehl JR (eds.). Avian foraging: Theory, methodology, and applications. Studies in Avian Biology No. 13. Cooper Ornithological Society, Lawrence, Kansas.

St John B (1994). Ecology and management of the Little Corella (*Cacatua sanguinea*) in the Southern Flinders Ranges, South Australia. M.Sc. thesis, Univ. of Adelaide.

Salter TM (1939). Some notes of the correct identity of *Oxalis pes-caprae* Linn. and *Oxalis purpurea* Linn. with some remarks on the limitations of a species in the genus *Oxalis*. *Journal of South African Botany* 5: 47-52.

Schodde R and Mason I (1997). Aves (Columbidae to Coraciidae. *In*: Houston WWK and Wells A (eds). Zoological Catalogue of Australia Vol. 37.2. Melbourne: CSIRO Publishing, Australia xiii 440pp.

Schoener TW (1969). Models of optimum size for solitary predators. *Amer. Nat.* 103: 277-313.

Schoener TW (1971). Theory of feeding strategies. *Ann. Review Ecol. Syst.* 2: 369-404.

Sinclair RG (1989a). Bird Research *In:* "Proclaimed Animal Research in South Australia: Cost-Benefits, Future Directions and Related Issues." Compiled by RP Henzell. Discussion Paper, Animal & Plant Control Commission, Adelaide.

Sinclair RG (1989b). Research preschedule: Biological studies of the Adelaide Rosella. Unpubl. report. Animal & Plant Control Commission, Adelaide.

Sinclair RG (1990). The economics of netting for bird control. pp. 134–142 *In:* P. Fleming, I. Temby, and J. Thompson (eds.). 'National Bird Pest Workshop Proceedings.' Department Conservation, Forests and Lands, Victoria and NSW Agriculture and Fisheries, Orange.

Sinclair RG and Bird PL (1987). An assessment of bird damage in cherry orchards in South Australia. pp 275-278. *In:* 8th Australian Vertebrate Pest Control Conference Handbook of Working Papers.

Sinclair RG and Campbell KN (1995). Cage trials on the repellency of methyl anthranilate to four species of pest birds. Australian Vertebrate Pest Control Conference 10, 346–351.

Specht RL (1972). Vegetation of South Australia (Second Edition). S.A Govt. Printer, Adelaide.

Stephens DW (1990). Foraging Theory: Up, down, and sideways. *In:* Morrison ML, Ralph CJ, Verner J and Jehl JR (eds.). Avian foraging: Theory, methodology, and applications. Studies in Avian Biology No. 13. Cooper Ornithological Society, Lawrence, Kansas.

Summers DDB and Jones FJS (1976). The importance of protein in the selection of fruit buds by bullfinches. *Experimental Horticulture.* 28: 47-50.

Taylor GS (1987). The gall forming Psylloidea of *Eucalyptus obliqua* in the Mount Lofty Ranges of South Australia. *J. Aust. Ent. Soc.* 26: 223-228.

Taylor T (2001). Population trends in rosellas and lorikeets in the Mount Lofty Ranges, South Australia: A baseline survey (March – April 2001). Unpublished report. South Australian Department of Environment and Heritage, Adelaide.

Temby ID and Emison WB (1986). Foods of the Long-billed Corella. *Aust. Wildl. Res.* 13(1): 57-63.

Thomas S and Corden M (1977). Metric tables of composition of Australian foods. Commonweath Dept. Health, Nutrition Section.

Torcello JC (1990). Time-budget, environment and dietary requirements which enable the co-existence of the Adelaide and Eastern Rosella (*Platycercus* spp.). Unpubl. B.Sc. Honours thesis, Flinders Univ. of South Australia, Adelaide.

Watt BK and Merrill AL (1963). Composition of foods. USDA Agr. Handbook 8.

Westwood MN (1978). Temperate zone pomology. Freeman, San Francisco.

Wiens and Dyer (1977). p243 *In:* Pinowski J and Kendeigh SC (eds). Avian energetics: Granivorous birds in ecosystems. Cambridge Univ. Press, London.

Wiens JA and Johnston RF (1977). Adaptive correlates of granivory in birds. *In:* Pinowski J and Kendeigh SC (eds). Granivorous birds in ecosystems. Cambridge Univ. Press, Cambridge.

Wood DW (1968). Principles of Animal Physiology, pp. 29-30. Edward Arnold, London.

Woodburn TL and Lewis EE (1973). A comparative histological study of the effects of feeding by nymphs of four psyllid species on the leaves of eucalypts. *J. Aust. Ent. Soc.* 12: 134-8.

Wyndham E and Cannon CE (1985). pp. 141-50 *In:* Keast A, Recher HF, Ford H and Saunders D (eds.). Birds of Eucalypt Forests and Woodlands: Ecology, Conservation, Management. RAOU and Surrey Beatty & Sons, Chipping Norton.

Zann R and Straw B (1984). Feeding ecology and breeding of Zebra Finches in farmland in northern Victoria. *Aust. Wildl. Res.* 11: 533-552.

APPENDIX 1

Percent occurrence of foods in crops of Adelaide Rosellas.

For each period the percentage of bird crops in which each food was found is given in the first column and the number of crops in the second column. A total of 333 birds were collected in and around commercial cherry orchards in the Adelaide Hills between 1985 and 1992. The number of bird crops examined in each season were 87 in summer, 80 in autumn, 82 in winter and 84 in spring. Introduced species are indicated by * and species of uncertain origin by †.

Taxon	Food type	all		summer		autumn		winter		spring	
AMARANTHACEAE											
**Amaranthus cruentus*	seed	5.1	17	0.0	0	3.8	3	15.9	13	1.2	1
**Amaranthus* sp.	seed	0.6	2	0.0	0	1.3	1	1.2	1	0.0	0
BORAGINACEAE											
**Echium plantagineum*	seed	3.9	13	8.0	7	1.3	1	0.0	0	6.0	5
CARYOPHYLLACEAE											
**Cerastium semidecandrum*	seed	9.6	32	1.1	1	3.8	3	0.0	0	33.3	28
**Silene gallica*	seed	0.9	3	0.0	0	0.0	0	2.4	2	1.2	1
**Stellaria media*	seed	12.3	41	1.1	1	0.0	0	17.1	14	31.0	26
CHENOPODIACEAE											
**Chenopodium album*	seed	21.0	70	0.0	0	40.0	32	43.9	36	2.4	2
COMPOSITAE											
**Arctotheca calendula*	seed	7.2	24	3.4	3	2.5	2	0.0	0	22.6	19
**Carduus tenuifolius*	seed	2.7	9	3.4	3	3.8	3	0.0	0	3.6	3
**Hypochaeris radicata*	seed	9.6	32	10.3	9	25.0	20	2.4	2	1.2	1
**Senecio vulgaris*	seed	9.6	32	13.8	12	8.8	7	9.8	8	6.0	5
**Sonchus oleraceus*	seed	8.4	28	8.0	7	13.8	11	1.2	1	10.7	9
**Taraxacum officinale*	seed	1.8	6	1.1	1	2.5	2	0.0	0	3.6	3
CRUCIFERAE											
**Raphanus raphanistrum*	seed	21.0	70	14.9	13	22.5	18	28.0	23	19.0	16
FAGACEAE											
**Castanea* sp. (kernel)	kernel	0.6	2	0.0	0	1.3	1	1.2	1	0.0	0
**Quercus* sp. (kernel)	kernel	0.6	2	0.0	0	2.5	2	0.0	0	0.0	0
GERANIACEAE											
**Erodium moschatum*	seed	4.2	14	1.1	1	0.0	0	0.0	0	15.5	13
**Geranium molle*	seed	0.9	3	1.1	1	0.0	0	1.2	1	1.2	1
Geranium solanderi	seed	3.6	12	5.7	5	1.3	1	0.0	0	7.1	6

Taxon	Food type	all		summer		autumn		winter		spring	
GRAMINAE											
**Avena* sp.	seed	11.4	38	18.4	16	3.8	3	0.0	0	22.6	19
**Briza* spp.	seed	14.7	49	23.0	20	26.3	21	2.4	2	7.1	6
Danthonia sp.	seed	1.5	5	2.3	2	1.3	1	0.0	0	2.4	2
**Digitaria sanguinalis*	seed	1.2	4	0.0	0	5.0	4	0.0	0	0.0	0
**Echinochloa crus-galli*	seed	0.9	3	0.0	0	3.8	3	0.0	0	0.0	0
**Ehrharta longiflora*	seed	2.4	8	0.0	0	2.5	2	0.0	0	7.1	6
**Hordeum vulgare*	seed	2.4	8	1.1	1	1.3	1	7.3	6	0.0	0
**Lolium* sp.	seed	7.8	26	8.0	7	5.0	4	17.1	14	1.2	1
**Phalaris* spp.	seed	1.8	6	3.4	3	2.5	2	1.2	1	0.0	0
**Poa annua*	seed	14.7	49	10.3	9	1.3	1	19.5	16	27.4	23
**Setaria verticillata*	seed	0.9	3	0.0	0	2.5	2	1.2	1	0.0	0
Stipa sp.	seed	3.3	11	5.7	5	7.5	6	0.0	0	0.0	0
**Triticum aestivum*	seed	0.3	1	0.0	0	0.0	0	1.2	1	0.0	0
HYPERICACEAE											
**Hypericum perforatum*	seed	11.7	39	11.5	10	27.5	22	7.3	6	1.2	1
IRIDACEAE											
**Romulea* sp.	seed	2.1	7	2.3	2	1.3	1	0.0	0	4.8	4
LEGUMINOSAE											
Acacia pycnantha	seed or aril	6.6	22	25.3	22	0.0	0	0.0	0	0.0	0
†?*Acacia* sp.	seed	0.9	3	3.4	3	0.0	0	0.0	0	0.0	0
**Medicago* spp.	seed	6.9	23	12.6	11	0.0	0	4.9	4	9.5	8
**Trifolium repens*	seed	0.9	3	2.3	2	0.0	0	1.2	1	0.0	0
**Trifolium subterraneum*	seed	23.7	79	24.1	21	47.5	38	19.5	16	4.8	4
**Vicia sativa*	seed	1.5	5	3.4	3	0.0	0	0.0	0	2.4	2
LINIACEAE											
**Linum trigynum*	seed	3.6	12	3.4	3	7.5	6	3.7	3	0.0	0
MYRTACEAE											
**Eucalyptus obliqual E.baxteri*	seed	17.7	59	13.8	12	37.5	30	6.1	5	14.3	12
†?*Eucalyptus* sp.	seed	0.9	3	0.0	0	1.3	1	2.4	2	0.0	0
Eucalyptus viminalis	seed	5.4	18	5.7	5	11.3	9	0.0	0	4.8	4
**Melaleuca armillaris*	seed	2.4	8	1.1	1	3.8	3	3.7	3	1.2	1
OLEACEAE											
**Olea europaea*	fruit flesh	6.3	21	3.4	3	10.0	8	2.4	2	9.5	8
**Olea europaea*	kernel	3.6	12	0.0	0	7.5	6	3.7	3	3.6	3

Taxon	Food type	all		summer		autumn		winter		spring	
OXALIDACEAE											
Oxalis perennans	seed	3.9	13	1.1	1	6.3	5	0.0	0	8.3	7
**Oxalis pes-caprae*	flower bud	12.9	43	0.0	0	0.0	0	30.5	25	21.4	18
**Oxalis pes-caprae*	bulb	13.8	46	1.1	1	12.5	10	6.1	5	35.7	30
**Oxalis pes-caprae*	stem tissue	9.6	32	0.0	0	2.5	2	17.1	14	19.0	16
PITTOSPORACEAE											
Bursaria spinosa	seed	0.3	1	0.0	0	1.3	1	0.0	0	0.0	0
POLYGONACEAE											
**Acetosella vulgaris*	seed	1.5	5	0.0	0	2.5	2	2.4	2	1.2	1
**Polygonum aviculare*	seed	17.1	57	8.0	7	33.8	27	23.2	19	4.8	4
**Rumex crispus*	flower bud	0.3	1	1.1	1	0.0	0	0.0	0	0.0	0
**Rumex crispus*	seed	0.3	1	0.0	0	0.0	0	1.2	1	0.0	0
PRIMULACEAE											
**Anagallis arvensis*	seed	7.5	25	4.6	4	11.3	9	11.0	9	3.6	3
ROSACEAE											
**Crataegus monogyna*	fruit flesh	0.3	1	0.0	0	0.0	0	0.0	0	1.2	1
**Crataegus monogyna*	seed	0.9	3	0.0	0	1.3	1	1.2	1	1.2	1
**Malus sylvestris*	fruit flesh	39.0	130	21.8	19	57.5	46	54.9	45	23.8	20
**Malus sylvestris*	seed	21.9	73	9.2	8	26.3	21	37.8	31	15.5	13
**Prunus avium*	flower bud	17.1	57	0.0	0	23.8	19	42.7	35	3.6	3
**Prunus avium*	fruit flesh	13.5	45	36.8	32	0.0	0	0.0	0	15.5	13
**Pyracantha crenato-serrata*	seed	0.9	3	2.3	2	1.3	1	0.0	0	0.0	0
**Rubus fruticosus*	achene	14.7	49	17.2	15	31.3	25	11.0	9	0.0	0
**Rubus fruticosus*	fruit flesh	4.5	15	12.6	11	5.0	4	0.0	0	0.0	0
SCROPHULARIACEAE											
**Kicksia elatine*	seed	0.6	2	0.0	0	2.5	2	0.0	0	0.0	0
**Veronica persica*	seed	0.3	1	0.0	0	0.0	0	1.2	1	0.0	0

Taxon	Food type	all		summer		autumn		winter		spring	
PLANTAE											
†Non-food item	amber, bark or charcoal	20.7	69	31.0	27	13.8	11	3.7	3	33.3	28
†Plantae: unidentified bulb	bulb	0.6	2	1.1	1	0.0	0	0.0	0	1.2	1
†Plantae: unidentified flower part	flower bud	2.7	9	2.3	2	5.0	4	1.2	1	2.4	2
†Plantae: unidentified fruit	fruit flesh	4.8	16	6.9	6	2.5	2	2.4	2	7.1	6
†Plantae: unidentified kernel	kernel	0.9	3	1.1	1	0.0	0	1.2	1	1.2	1
†Plantae: unidentified seed	seed	18.6	62	8.0	7	23.8	19	25.6	21	17.9	15
†Plantae: unidentified vegetative material	vegetative	4.2	14	5.7	5	2.5	2	6.1	5	2.4	2
INSECTA											
†Coleoptera: immature stage	Coleopteran larva	7.2	24	3.4	3	10.0	8	6.1	5	9.5	8
†Diptera: immature stage	Dipteran larva	9.0	30	1.1	1	18.8	15	7.3	6	9.5	8
†Hemiptera, non-Psylloidea	immature Hemipteran stage	3.0	10	3.4	3	6.3	5	2.4	2	0.0	0
†Insecta: unidentified	adult insect	6.0	20	3.4	3	11.3	9	2.4	2	7.1	6
†Insecta: unidentified	immature insect stage	7.2	24	1.1	1	12.5	10	3.7	3	11.9	10
†Lepidoptera: immature stage	insect larva	11.1	37	1.1	1	23.8	19	15.9	13	4.8	4
Psyllidae, unidentified	psyllid nymph or lerp	1.8	6	2.3	2	5.0	4	0.0	0	0.0	0
Spondyliaspidinae	nymph or lerp	11.7	39	11.5	10	25.0	20	2.4	2	8.3	7
Triozidae: *Schedotrioza marginata*	triozid nymph	4.5	15	0.0	0	0.0	0	18.3	15	0.0	0
Triozidae: *Schedotrioza multitudinea*	triozid nymph	11.7	39	2.3	2	0.0	0	14.6	12	29.8	25

APPENDIX 2

Percent volume of foods in crops of Adelaide Rosellas.
The values shown for each food represent the total volume of the food for each seasonal period expressed as a percentage of the volume of all foods for each period. A total of 333 birds were collected in and around commercial cherry orchards in the Adelaide Hills between 1985 and 1992. The number of bird crops examined in each season were 87 in summer, 80 in autumn, 82 in winter and 84 in spring. Introduced species are indicated by * and species of uncertain origin by †.

		Percent volume				
Taxon	Food type	summer	autumn	winter	spring	all
AMARANTHACEAE						
**Amaranthus cruentus*	seed	0	0.01	2.11	0.01	0.51
**Amaranthus* sp.	seed	0	0.01	0.01	0	0.01
BORAGINACEAE						
**Echium plantagineum*	seed	3.2	0.45	0	0.54	0.81
CARYOPHYLLACEAE						
**Cerastium semidecandrum*	seed	0.01	0.01	0	4.26	1.07
**Silene gallica*	seed	0	0	0.3	0.01	0.07
**Stellaria media*	seed	0.01	0	2.16	6.92	2.26
CHENOPODIACEAE						
**Chenopodium album*	seed	0	6.04	7.38	0.01	3.86
COMPOSITAE						
**Arctotheca calendula*	seed	0.01	0.01	0	1.6	0.41
**Carduus tenuifolius*	seed	0.33	0.21	0	0.26	0.19
**Hypochoeris radicata*	seed	1.1	1.44	0.05	0.01	0.69
**Senecio vulgaris*	seed	0.52	0.01	0.14	0.03	0.13
**Sonchus oleraceus*	seed	0.42	0.35	0.01	0.45	0.3
**Taraxacum officinale*	seed	0.01	0.01	0	0.03	0.01
CRUCIFERAE						
**Raphanus raphanistrum*	seed	10.97	8.91	6.7	11.45	9.35
FAGACEAE						
**Castanea* sp.	kernel	0	0.08	0.95	0	0.25
**Quercus* sp.	kernel	0	1.18	0	0	0.41
GERANIACEAE						
**Erodium moschatum*	seed	0.01	0	0	2.65	0.67
**Geranium molle*	seed	0.51	0	0	0	0.08
Geranium solanderi	seed	0.87	0.04	0	0.21	0.21
GRAMINAE						
**Avena* spp.	seed	3.78	0.34	0	2.7	1.41
**Briza* spp.	seed	6.32	1.75	0.15	0.11	1.69
Danthonia sp.	seed	0.07	0.01	0	0.03	0.02
**Digitaria sanguinalis*	seed	0	0.02	0	0	0.01
**Echinochloa crus-galli*	seed	0	0.08	0	0	0.03
**Ehrharta longiflora*	seed	0	0.28	0	0.17	0.14
**Hordeum vulgare*	seed	0.17	0.34	8.72	0	2.24
**Lolium* sp.	seed	1.61	0.04	0.83	0.18	0.52
**Phalaris* spp.	seed	0.14	0.01	0	0	0.02
**Poa annua*	seed	0.12	0.01	1.67	4	1.42
**Setaria verticillata*	seed	0	0.01	0	0	0.01
Stipa sp.	seed	0.64	1.19	0	0	0.52
**Triticum aestivum*	seed	0	0	0.07	0	0.02

Taxon	Food type	Percent volume summer	autumn	winter	spring	all
HYPERICACEAE						
**Hypericum perforatum*	seed	5.6	9.31	1.09	0.01	4.4
IRIDACEAE						
**Romulea* spp.	seed	1.4	0.01	0	0.59	0.38
LEGUMINOSAE						
Acacia pycnantha	seed, aril	8.13	0	0	0	1.32
†*Acacia* sp.	seed, aril	2.9	0	0	0	0.47
**Medicago* spp.	seed	1.6	0	0.24	0.54	0.45
**Trifolium* spp.	seed	6.8	10.22	15.22	0.48	8.42
**Vicia sativa*	seed	0.18	0	0	0.04	0.04
LINIACEAE						
**Linum trigynum*	seed	0.02	0.02	0.27	0	0.07
MYRTACEAE						
Eucalyptus obliqua/ E.baxteri	seed	0.35	1.6	0.14	0.56	0.78
†*Eucalyptus* sp.	seed	0	0.03	0.05	0	0.02
Eucalyptus viminalis	seed	0.35	1.48	0	0.46	0.69
**Melaleuca armillaris*	seed	0.02	0.23	0.27	0.01	0.15
OLEACEAE						
**Olea europaea*	kernel	0	2.64	0.42	1.25	1.33
**Olea europaea*	fruit	1.12	5.72	0.78	10.91	5.1
OXALIDACEAE						
Oxalis perennans	seed	0.01	0.33	0	0.04	0.12
**Oxalis pes-caprae*	flower bud	0	0	1.94	4.93	1.71
**Oxalis pes-caprae*	bulb	0.04	1.1	0.11	15.64	4.35
**Oxalis pes-caprae*	stem	0	0.17	3.06	6.16	2.34
PITTOSPORACEAE						
Bursaria spinosa	seed	0	0.02	0	0	0.01
POLYGONACEAE						
**Acetosella vulgaris*	seed	0	0.04	0.01	0.01	0.01
**Polygonum aviculare*	seed	0.08	1.59	1.18	0.07	0.87
**Rumex crispus*	flower bud	0.02	0	0	0	0.01
**Rumex crispus*	seed	0	0	0.03	0	0.01
PRIMULACEAE						
**Anagallis arvensis*	seed	0.15	0.02	0.26	0.54	0.23
ROSACEAE						
**Crataegus monogyna*	fruit	0	0	0	0.21	0.05
**Crataegus monogyna*	seed	0	0.13	0.01	0.42	0.15
**Malus sylvestris*	fruit	10.76	27.02	18.22	11.14	18.28
**Malus sylvestris*	seed	1.71	10.31	17.91	1.74	8.58
**Prunus avium*	flower bud	0	0.14	1.93	0.15	0.55
**Prunus avium*	fruit	20.14	0	0	2.91	4
**Pyracantha crenato-serrata*	seed	0.01	0.44	0	0	0.15
**Rubus fruticosus*	achene	2.57	1.91	0.82	0	1.27
**Rubus fruticosus*	fruit	0.51	0.18	0	0	0.15
SCROPHULARIACEAE						
**Kicksia elatine*	seed	0	0.58	0	0	0.2
**Veronica persica*	seed	0	0	0.01	0	0.01

		Percent volume				
Taxon	Food type	summer	autumn	winter	spring	all
ANGIOSPERMAE						
†unidentified bulb	bulb	0.11	0	0	0.02	0.02
†unidentified flower part	flower part	0.02	0.01	0.2	0.01	0.06
†unidentified kernel	kernel	0.09	0	0.08	0.46	0.15
†unidentified seed	seed	0.12	0.58	0.69	1.58	0.79
PLANTAE						
†unidentified fruit	fruit	1.09	0.74	2.24	1.78	1.42
†unidentified plant tissue	plant	1.16	0.01	0.08	0.13	0.24
INSECTA						
Psylloidea: nymph or lerp	insect	0.22	0.33	0.86	1.47	0.73
†insect (immature)	insect	1.85	0.26	0.6	0.18	0.58
†insect (adult)	insect	0.11	0.04	0.07	0.01	0.05