Diet of kakapo in breeding and non-breeding years on Codfish Island (Whenua Hou) and Stewart Island

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CONTENTS

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ABSTRACT

Plant remains found in faecal droppings of kakapo (*Strigops habroptilus*), collected between 1977 and 1999 on Codfish Island (Whenua Hou) and Stewart Island, were analysed with statistics to identify patterns in the birds' diet related to breeding. Subsets of the data were used to address specific questions. Females were more likely to have eaten podocarp fruit or leaves of trees or shrubs; males to have eaten fern and *Lycopodium* rhizomes, monocotyledons (in breeding years), and manuka fruit (in non-breeding years). Podocarp fruits were much more prevalent in kakapo diets in breeding than in non-breeding years. When podocarp fruits were available in breeding years, kakapo were less likely to have eaten several other foods. Conversely, *Blechnum* fern fronds appeared more frequently in the droppings of females in breeding than in non-breeding years. As podocarp fruits increased in prevalence in the diets of both males and females during the summers of breeding years, the incidence of many other foods declined. The incidence of Hall's totara leaf in the diet of females increased during summer in non-breeding years, but decreased in breeding years. These results will be helpful in formulating hypotheses about kakapo diet that can be tested from future data. Kakapo droppings should continue to be collected so that specific questions about diet may be answered in future. They should be collected monthly from at least 10 different females and 10 different males on each island or group of islands. In breeding years, collecting droppings monthly from at least 10 birds that breed and 10 that do not would allow comparisons between the diets of successful and unsuccessful breeders.

Keywords: kakapo, *Strigops habroptilus*, *Blechnum*, Hall's totara, podocarps, faecal analysis, successful breeding, seasonal effects, New Zealand.

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1. Introduction

At the request of the Department of Conservation (DOC) National Kakapo Team, Landcare Research analysed data of the plant remains found in faeces of kakapo (*Strigops habroptilus*), to identify patterns in the birds' diet related to breeding. The data were collected between 1977 and 1999 on Codfish Island (Whenua Hou) and Stewart Island by DOC staff, and are held by the National Kakapo Team's Senior Scientist in Nelson. The statistical analyses reported here were done on a subset of the data, in consultation with G. Elliott and R. Moorhouse (DOC), between approximately June and September 2003.

1.1 BACKGROUND

Kakapo usually breed only in years when certain plant species, particularly trees and shrubs in the podocarp family, produce large crops of protein-rich seeds and fruit (Powlesland et al. 1992; Elliott et al. 2001). However, providing birds with protein-rich supplementary food in other years is not sufficient to induce breeding (Elliott et al. 2001). Therefore, the goal of this study was to investigate possible dietary changes associated with breeding, to determine foods that might be important at different stages of breeding. This objective was approached by statistically analysing data of plant species and parts identified in 576 droppings collected from 40 adult kakapo on Codfish and Stewart Is. These data have been described and analysed graphically in short unpublished reports by A. Grant and N. Parker, but no statistical analyses have previously been done.

1.2 OBJECTIVES

- Compare the incidence of fruit and other common foods in faeces from male and female kakapo.
- Compare the incidence of these foods between kakapo breeding years and non-breeding years.
- Identify changes in kakapo diet just before and during the breeding season.

2. Methods

2.1 FOOD TYPES

Up to 150 different microscopic fragments of plant material had been identified in each kakapo dropping. No mineral or animal remains had been found. Each fragment had been classified as one of 84 plant species or, when precise identification was impossible, as a higher taxonomic group. Food provided by wildlife managers on Codfish Island was coded as supplementary food or kumara. Each fragment had also been classified as one of 30 plant parts, including leaf cuticle, fruit, seed, flower, etc.

Fifteen food types, which were either common in droppings or of particular interest (i.e. fruits), were chosen from all the combinations of plant species and plant parts described above. The presence and absence of these 15 foods in kakapo droppings was statistically analysed. Fruit was defined to include all items coded in the database as fruit, seed, or nut. Scientific names of the following species are given in Appendix 1.

- Fruit of all species combined
- Podocarp fruit (fruit of rimu, Hall's totara, miro, pink pine, and yellow-silver pine combined)
- Podocarp leaf (leaves of above species)
- *Dracophyllum* leaf
- *Blechnum* frond
- *Blechnum* rhizome
- *Lycopodium* rhizome
- Hall's totara leaf
- Manuka leaf
- Manuka fruit
- Mingimingi fruit
- Leatherwood leaf
- Rata leaf
- Monocotyledons (all grasses, sedges and rushes combined)
- Supplementary food provided by wildlife managers (Codfish I. only).

2.2 SUBSET OF DATA ANALYSED

A subset of the complete dataset was selected for analysis, based on age of the birds and confidence in the data. Only droppings from adult kakapo, i.e. birds that could potentially breed, were used. Droppings from unknown birds or those for which confidence in which bird produced the dropping was coded as 'Probably' or 'Maybe' were ignored. Only droppings that could accurately be assigned to a year and season were considered, i.e. those not coded as 'Old'. Finally, data from Maud I. were excluded because they were available only from late in a single breeding year. The database contained a small number of records from Nukuwaiata and Pearl Is, but after these exclusions, all the data analysed were from Codfish or Stewart Is.

Data from throughout the breeding season (December–April) of all years were used in most statistical analyses. Most droppings had been collected during this period. However, for comparing diets between males and females, only December–March data were selected, because no droppings from females were collected in April in breeding years. In addition, data from females from May to July were analysed separately, to represent times when females would be raising offspring late in breeding years.

Finally, only Codfish I. data were used to answer questions about supplementary food in the diet, since managers fed kakapo on that island only. Few data were available for Codfish I. males. Therefore, the incidence of supplementary food was not compared between males and females, and data from males from all months were combined in comparisons between years.

2.3 COMBINING DATA TO MINIMISE PSEUDOREPLICATION

Based on inspection of the data, droppings collected close together in time from the same bird contained the remains of many of the same foods. Therefore, to minimise pseudoreplication (Hurlbert 1984), data from droppings from the same bird within the same month were combined into a single observation. In this way, data from 576 droppings were combined into 272 monthly observations of diet. Sample sizes used in each statistical test are given in sections 3.1 and 3.2 and Table 4.

Most variation in these 272 data occurred between observations of the same bird, with little additional variation explained by other factors (island, month and bird, Appendix 2). That is, although diets of the same bird in different months were not strictly independent, they were not highly correlated. This result supports the approach taken to moderate the effects of pseudoreplication in the study design by combining data as described above.

2.4 BREEDING AND NON-BREEDING YEARS

In a breeding year, kakapo mate as early as late December, and the first eggs are laid in January (G.P. Elliott, pers. comm.; Powlesland et al. 1992). For the purpose of statistical analyses, a year was considered to span the period from August prior to the breeding season to the July following. For example, because birds laid eggs beginning in January 1997 on Codfish I., droppings collected there between August 1996 and July 1997 were considered to come from a breeding year. Data from the breeding and non-breeding years listed in Table 1 were analysed. The 576 droppings came from 40 different birds (15 females, 25 males).

TABLE 1. DATA FROM KAKAPO BREEDING AND NON-BREEDING YEARS, CODFISH AND STEWART IS.

ISLAND	YEAR	BREEDING YEAR? (APPROX. JAN–APR)	NO. OF DROPPINGS (AUG–JUL)
Codfish	1987	No	1
Codfish	1996	No	1
Codfish	1997	Yes	108
Codfish	1998	No	65
Stewart	1981	Yes	11
Stewart	1982	No	31
Stewart	1983	No	29
Stewart	1984	No	75
Stewart	1985	Yes	171
Stewart	1986	No	59
Stewart	1987	No	21
Stewart	1997	No	4
Total			576

2.5 STATISTICAL METHODS

The frequencies of remains of each food type in droppings (combined for each bird within each month as described above) were compared between: males and females; and breeding and non-breeding years, with 2 × 2 contingency tables. Because significant differences were found between male and female droppings, the between-year comparisons were done separately for males and females. This simple statistical method was chosen because the data were too sparse for more complex analyses like logistic regression. The Fisher exact test (Zar 1996, p. 547–549) was used to calculate probabilities because small sample sizes made chi-square tests unreliable. Computations were done with S-PLUS (Insightful Corporation 2001).

Table 2 is an example of a contingency table, showing the numbers (in bold type) and percentages of diets of female kakapo with podocarp fruit absent and present, from December to April on both islands in all years. In non-breeding years podocarp fruit was found in only 18% (in regular type) of diets, whereas in breeding years it was found in 54% of diets. The difference in these proportions was significant, based on a Fisher exact test ($P = 0.006$).

TABLE 2. EXAMPLE OF A CONTINGENCY TABLE FOR FEMALE KAKAPO DIETS.

		BREEDING YEAR?				ROW
		NO		YES		TOTALS
Podocarp fruit	Absent	**27**	82 %	**13**	46 %	**40**
	Present	**6**	18 %	**15**	54 %	**21**
COLUMN TOTALS		**33**	100 %	**28**	100 %	**61**

Increasing or decreasing trends in the incidence of foods during the breeding season (December–March for females and December–April for males) were examined with the chi-square test for linear trend (Zar 1996, p. 562–565). This test, which is relatively powerful, was appropriate even though sample sizes were often small. The computations were programmed in Microsoft® Excel. Few data were available from Stewart I. prior to December in most years. However, for the breeding year 1997 on Codfish I., droppings of females were collected from August 1996 to March 1997. Therefore, in order to show dietary changes prior to breeding, trends during this period on Codfish I. were also examined.

Table 3 shows the incidence of podocarp fruit in diets of male kakapo on both islands, from December to April in breeding years only. The percentage of diets with podocarp fruit increased from 43% in December to 100% in April. The chi-square test for linear trend for these data gave $\chi^2_1 = 5.0$, $P = 0.025$, indicating a significant linear increase from December to April in the frequency of podocarp fruit in the diets of male birds in breeding years.

TABLE 3. INCIDENCE OF PODOCARP FRUIT (NUMBER AND PERCENTAGE OF DIET SAMPLES) IN MALE KAKAPO DIETS IN BREEDING YEARS.

		DEC		JAN		FEB		MAR		APR		ROW TOTALS
Podocarp fruit	Absent	**4**	57%	**4**	50%	**0**	0%	**2**	33%	**0**	0%	**10**
	Present	**3**	43%	**4**	50%	**6**	100%	**4**	67%	**5**	100%	**22**
COLUMN TOTALS		**7**	100%	**8**	100%	**6**	100%	**6**	100%	**5**	100%	**32**

2.6 SIGNIFICANCE LEVEL AND MULTIPLE COMPARISONS

The objective of the statistical analyses was to search for patterns in the diet, rather than to test a limited number of a priori hypotheses. A significance level of 0.1 was therefore chosen, to minimise the chance of missing important results due to Type II errors (failing to reject a false null hypothesis). However, Type I errors (rejecting a true null hypothesis) were likely, owing both to the many statistical comparisons done and to the high significance level. Statistically significant results should therefore be interpreted with caution and with reference to patterns in the other sex, other food types, and other times of year, and may need to be verified in future field studies.

3. Results

Results that were found to be significant ($P < 0.1$) as described in Section 2 are given below. The results of tests for plant species other than those listed, and for supplementary food, were not significant ($P > 0.1$).

3.1 DIFFERENCES BETWEEN DIETS OF MALES AND FEMALES

In December to March of breeding years (n = 21 females, 27 males), female kakapo were more likely than males to have eaten podocarp fruit (P = 0.034), *Dracophyllum* leaf (P = 0.045), Hall's totara leaf (P = 0.095), and rata leaf (P = 0.073). Males were more likely to have eaten *Lycopodium* rhizomes (P = 0.005) and monocotyledons (P = 0.058).

During the same period in non-breeding years (n = 29 females, 43 males), females were more likely than males to have eaten podocarp leaf (P = 0.013) and podocarp fruit (P = 0.014). Males were more likely to have eaten manuka fruit (P = 0.047) and rhizomes of *Blechnum* ferns (P = 0.041) and *Lycopodium* (P = 0.0001).

3.2 DIFFERENCES BETWEEN DIETS IN BREEDING AND NON-BREEDING YEARS

Female kakapo (n = 21 in breeding years, 40 in non-breeding years) were more likely to have eaten podocarp fruit (P = 0.006) and *Blechnum* frond (P = 0.009), and less likely to have eaten *Dracophyllum* leaf (P = 0.079) and leatherwood leaf (P = 0.037), in December to April of breeding years compared with non-breeding years. Females were more likely to have eaten all fruits combined in May to July of breeding years compared with non-breeding years (n = 19 in breeding years, 8 in non-breeding years; P = 0.044).

Male birds (n = 32 in breeding years, 50 in non-breeding years) were more likely to have eaten podocarp fruit ($P < 0.0001$) and less likely to have eaten *Dracophyllum* leaf (P = 0.019) and *Lycopodium* rhizome (P = 0.067) in December to April of breeding years compared with non-breeding years.

3.3 TRENDS IN DIET DURING THE BREEDING SEASON

In breeding years, the frequency of all fruits combined and of podocarp fruits in the droppings of female birds increased linearly from December to March, whereas the frequency of Hall's totara leaf declined (Fig. 1, Table 4). In the diets of male birds, frequencies of podocarp fruits, *Dracophyllum* leaf and rata leaf

TABLE 4. STATISTICALLY SIGNIFICANT ($P < 0.1$) LINEAR TRENDS IN FREQUENCY OF FOODS IDENTIFIED IN DIETS OF KAKAPO DURING THE BREEDING SEASON ON CODFISH AND STEWART IS.

Table entries show χ^2_1 and P values from chi-square tests for trend; blank entries indicate non-significant test results. Sample sizes (n) per month are also shown.

FOOD TYPE	BREEDING YEARS		NON-BREEDING YEARS		DIRECTION OF TREND
	FEMALES	MALES	FEMALES	MALES	
	Dec–Mar n = 6,5,3,7	Dec–Apr n = 7,8,6,6,5	Dec–Mar n = 8,10,9,2	Dec–Apr n = 18,5,10,10,7	
All fruits	3.3, 0.068				Up
Podocarp fruit	10.4, 0.001	5.1, 0.025			Up
Dracophyllum leaf		4.0, 0.045		5.2, 0.023	Breeding years: Up Non-breeding years: Down
Blechnum rhizome		7.5, 0.006			Down
Lycopodium rhizome		3.6, 0.057		3.6, 0.057	Down
Manuka leaf		6.8, 0.009			Down
Manuka fruit		11.5, 0.001			Down
Hall's totara leaf	5.2, 0.023		5.6, 0.018		Breeding years: Down Non-breeding years: Up
Leatherwood leaf		5.7, 0.017	3.2, 0.072	20.8, < 0.0001	Down
Rata leaf		5.0, 0.026			Up

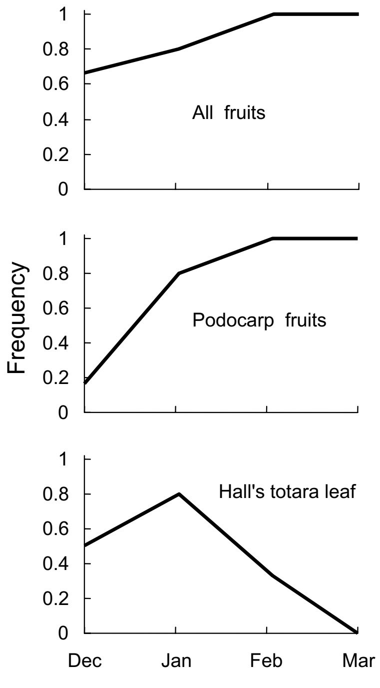


Figure 1. Frequencies of food types for which there was a significant linear trend during the breeding season (breeding years only) in the diet of female kakapo.

increased, but frequencies of *Blechnum* rhizome, *Lycopodium* rhizome, manuka leaf, manuka fruit and leatherwood leaf declined from December to April in breeding years (Fig. 2, Table 4).

In non-breeding years, the frequency of Hall's totara leaf in the diets of female birds increased linearly from December to March, and the frequency of leatherwood declined (Table 4). The frequency of *Dracophyllum* leaf, *Blechnum* rhizome and leatherwood leaf decreased in the diets of male birds from December to April in non-breeding years (Table 4).

3.4 DIET OF CODFISH ISLAND FEMALES, AUGUST TO MARCH 1997

In the 1997 breeding year on Codfish I., the frequency of podocarp fruits (χ^2_1 = 15.6, P = 0.0001), Hall's totara leaf (χ^2_1 = 3.0, P = 0.082) and monocotyledons (χ^2_1 = 3.8, P = 0.051) in the droppings of female birds increased linearly from August–September 1996 to February–March 1997 (Fig. 3; n = 7, 12, 8, 5 in each sequential pair of months, respectively). The frequencies of podocarp leaf and

Figure 2. Frequencies of food types for which there was a significant linear trend during the breeding season (breeding years only) in the diet of male kakapo.

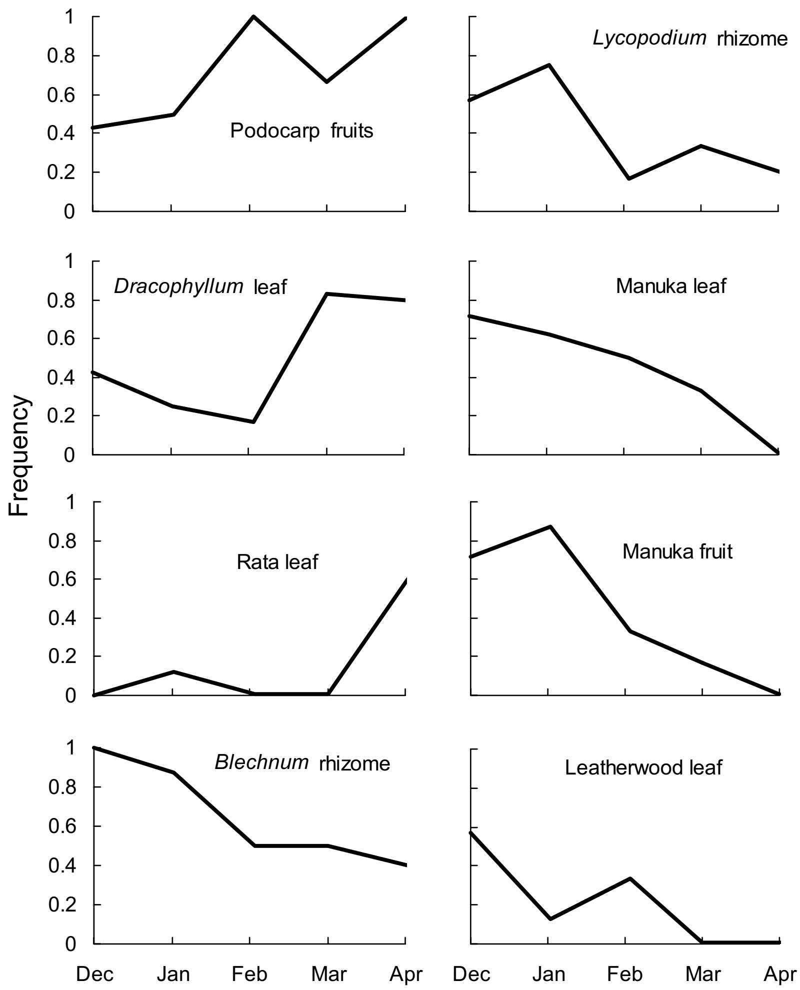
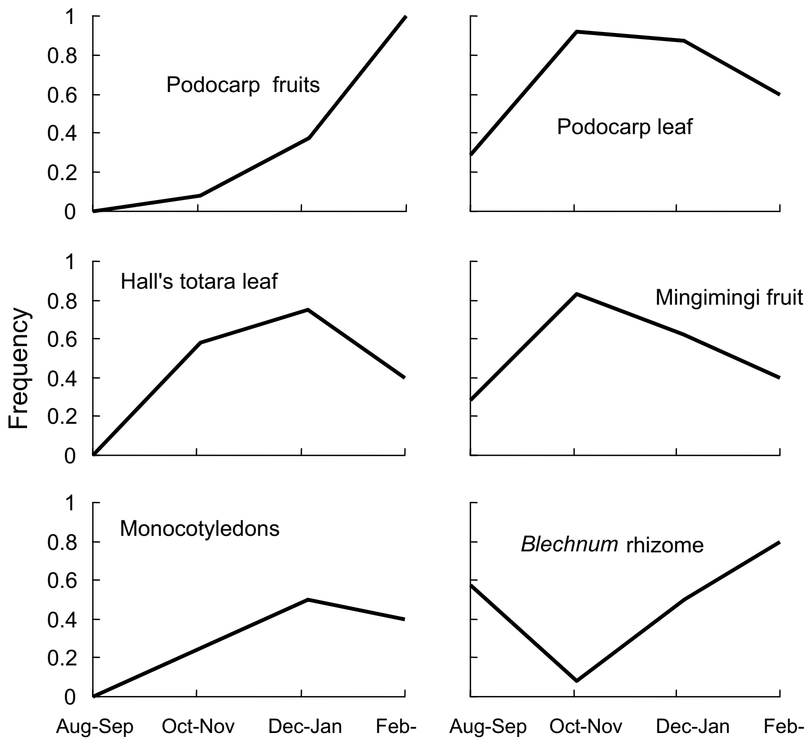


Figure 3. Frequencies of food types in the diet of females on Codfish I. from Aug–Sep 1996 to Feb–Mar 1997 (a breeding year). The linear trends over this period were statistically significant ($P < 0.1$) for podocarp fruits, Hall's totara leaf, and monocotyledons, but not for the other species shown.



mingimingi fruit remains followed no significant linear trends, but first increased from Aug–Sep to Oct–Nov and then declined, and the frequency of *Blechnum* rhizome showed the reverse pattern (Fig. 3).

4. Conclusions and recommendations

4.1 DIFFERENCES BETWEEN DIETS OF MALES AND FEMALES

Diets differed between female and male kakapo in both breeding and non-breeding years. Females were more likely to have eaten podocarp fruit and leaves of trees and of *Dracophyllum*. Males were more likely to have eaten fern and *Lycopodium* rhizomes, monocotyledons (in breeding years), and manuka fruit (in non-breeding years). These results may reflect differences in foraging behaviour by the birds, particularly in breeding years, when females gather food for their chicks while males are active on the ground in lek breeding areas (Powlesland et al. 1992).

4.2 DIFFERENCES BETWEEN DIETS IN BREEDING AND NON-BREEDING YEARS

As expected, podocarp fruits were much more prevalent in the diets of kakapo of both sexes in breeding years than in non-breeding years. When podocarp fruits were available in breeding years, kakapo were less likely to have eaten several other, perhaps less preferred, foods: *Dracophyllum* leaf (both sexes), leatherwood leaf (females), and *Lycopodium* rhizome (males). Conversely, *Blechnum* fronds appeared more frequently in the droppings of females in breeding than in non-breeding years.

4.3 TRENDS IN DIET DURING THE BREEDING SEASON

As podocarp fruits became increasingly prevalent in the diets of both males and females during the summer of breeding years, the incidence of many other foods declined. These declines were more apparent in the case of males, possibly as a result of larger sample sizes.

Two foods, *Blechnum* rhizome and leatherwood leaf, declined during summer in the diets of males in both breeding and non-breeding years. Leatherwood also declined in the diets of females in non-breeding years. Perhaps in all years enough seeds and fruits became available as summer progressed to lessen the need for these two foods. However, *Blechnum* rhizome did not decline in the diet of females on Codfish I. in the 1997 breeding season. This contrasting trend may indicate different requirements or behaviour of males and females, but it is also possible that some of these patterns may have occurred by chance.

The incidence of Hall's totara leaf in the diet of females increased during summer in non-breeding years, but decreased in breeding years. On Codfish I. in the 1997 breeding year, Hall's totara also increased in frequency in the diet of females from Aug–Sep to Dec–Jan. The reason for this pattern may be that the birds spent more time in totara trees searching for fruit in seasons and years when other fruits were scarce, eating the leaves of the trees at the same time.

4.4 TOPICS FOR FURTHER STUDY

Several interesting dietary patterns have been identified in this report. Some of these patterns warrant further exploration, in order to clarify their seasonal timing and whether they are unique to one sex. For example, the incidence of *Blechnum* rhizomes declined during the breeding season in the diets of males, but appeared to first decline and then increase in the diets of females on Codfish I. in the 1997 breeding year. Do these rhizomes provide starch or some other nutrient needed by breeding females? Similarly, the decline in frequency of Hall's totara leaf from January to March in the diet of breeding females, coupled with the increase in Hall's totara leaf in the diet of females on Codfish I. from Aug–Sep 1996 to Dec–Jan 1997, suggests the leaves or fruits of this tree may be important outside the breeding season.

In future studies, it will be possible to draw stronger conclusions from statistical analyses by formulating a limited number of a priori hypotheses. The results in this report provide a partial foundation for building testable hypotheses, and predictions based on them, that can be tested with new data. For example,

Hypothesis 1: Breeding female kakapo rely on fern rhizomes for dietary starch.

Prediction: The frequency of fern rhizomes in the diets of breeding female kakapo increases in December and decreases in April.

Hypothesis 2: Female kakapo rely on the leaves or fruits of Hall's totara for nutrition outside the breeding season.

Prediction: The frequency of totara leaf or totara fruit in the diet of females decreases in December and increases in April.

The statistical analyses in this report were weakened by small sample sizes, particularly for females in breeding years. This difference in sample size between the sexes may in part explain why more statistically significant patterns were found in the diet of male birds than females. One reason the sample sizes used for statistical analyses were small was that data from multiple faecal pellets were combined in order to avoid pseudoreplication. A sampling procedure that aims to collect droppings from different birds would alleviate this problem.

It would be useful, therefore, if kakapo droppings continued to be collected so that questions about diet may be answered in future. Doing so may be especially important as the birds are moved to new locations where the availability of foods differs even slightly from Codfish and Stewart Is. The faecal material can be kept frozen until new questions emerge or until the resources to analyse it are available. Only fresh or recent droppings from birds of known sex should be collected. Based on the statistical analyses reported here, collecting one dropping from at least 10 different females and 10 different males monthly in each region (island or group of islands) should yield strong statistical results. In breeding years, collecting droppings monthly from 10 birds of each sex that breed and 10 that do not, if possible, would allow comparison of diets between successful and unsuccessful breeders. Such comparisons were not possible in the present analysis because of small sample sizes. Although it may not be feasible to collect droppings every month, sampling from November to May in both breeding and non-breeding years would permit dietary changes before, during, and after breeding to be examined.

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I thank Graeme Elliott and Ron Moorhouse for helpful discussions and information, and Guy Forrester and Jennifer Hoeting for advice and assistance with statistical analyses. Guy's help with the variance components analysis was especially appreciated. Internal DOC reports by Andy Grant and Nadine Parker, describing and discussing the kakapo diet data, were extremely useful in designing this study.

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Appendix 1

Scientific names of plants referred to in the report

Blechnum	*B. novae-zealandiae, B. procerum* and unidentified species
Dracophyllum	*D. longifolium, D. pearsonii, D. politum*
Grasses[1]	*Chionochloa* spp., *Lepidosperma australe* and unidentified grasses
Hall's totara[2]	*Podocarpus hallii*
Leatherwood	*Olearia colensoi*
Lycopodium	*L. ramulosum, L. varium* and unidentified species
Manuka	*Leptospermum scoparium*
Mingimingi	*Cyathodes juniperina*
Miro[2]	*Prumnopitys ferruginea*
Pink pine[2]	*Halocarpus biformis*
Rata	*Metrosideros umbellata*
Rimu[2]	*Dacrydium cupressinum*
Rushes[1]	*Empodisma minus*
Sedges[1]	*Carex appressa, C. dissita, Gahnia procera, G. setifolia, Uncinia* spp.
Yellow-silver pine[2]	*Lepidothamnus intermedius*

[1] Monocotyledons

[2] Podocarps

Appendix 2

Analysis of variance components

A variance components analysis was used to test whether variation between observations of the same bird in different months was small compared with variation between different birds. The analysis was repeated for three food types: podocarp fruit, *Blechnum* rhizome, and totara leaf. The number of droppings from each bird in each month that contained a particular food type (X), relative to the total number of droppings from that bird in that month (n), were transformed as follows (Zar 1996, p. 183):

$$p = 0.5\left[\arcsin\sqrt{\frac{X}{n+1}} + \arcsin\sqrt{\frac{X+1}{n+1}}\right]$$

This equation is a variation of the arcsine transformation commonly used to normalise proportional data. The resulting 272 transformed monthly proportions (p) of droppings containing a food type corresponded to the 272 data of presence or absence of a food type that were used for the other statistical analyses in this report (Section 4.3).

The variation in p within individual birds (the residual variation), between different birds within months, between months within islands, and between islands was calculated. 'Island', 'month' and 'bird' were considered to be random nested effects. Whether or not the data came from a breeding year ('breed'), and the sex of the bird, were considered to be fixed effects. The 'varcomp' procedure with restricted maximum likelihood estimation (reml) in S-PLUS was used for these calculations (Insightful Corporation 2001, p. 590; Crawley 2002, p. 372–375), as follows:

varcomp(p ~ breed * sex + island/month/bird, method="reml").

The following variance components were estimated with 'varcomp' for the three food types tested:

SOURCE OF VARIATION	PODOCARP FRUIT	*BLECHNUM* RHIZOME	TOTARA LEAF
Island	2	17	0.4
Month within island	132	16	21
Bird within month	< 0.1	4	14
Residual (within bird)	257	501	284

In all three food types, most variation occurred within birds (i.e. between observations of the same bird in different months), with little additional variance explained by the variables 'island', 'month' or 'bird'. Therefore diets of the same bird in different months were not highly correlated. In the case of podocarp fruit remains, the residual variance component was about twice that due to months, in spite of the seasonal availability of fruit. This analysis suggests that the approach taken to moderate the effects of pseudoreplication in the study design, by combining data from droppings from the same bird within the same month into a single observation, was satisfactory.