3.3. Population change – temporal, demographics, other species

Dr John Henstridge, Anna Munday, Shauna Trafalski, Rian Caccianiga

Data Analysis Australia Pty Ltd
97 Broadway, Nedlands, Western Australia 6009

Abstract

Cage trapping data on woylies collected through a number of studies between 1994 and 2007 at fifteen sites in the Upper Warren region was analysed to better understand population trends and in particular to test the hypothesis that the population is currently in decline. To the extent that this analysis used data from independent studies, it was a meta-analysis and needed to cope with significant variation in the quality and detail of the data. However the raw nightly trap data was used in all cases and the analysis used both linear regression and a generalised linear model approach with a "quasibinomial" error term to allow for the variation between studies. The trapping data provides statistically strong evidence that woylie numbers have been in decline since 2002. The data is less clear on what might be the cause of this decline. A significant positive correlation was found with trapping of quenda, but no strong association was found with koomal or chuditch. Inconsistent trends were observed in the proportion of males captured at each site and the condition indices showed no significant pattern with regards to time or site. Since almost all the woylies caught were adults (95%), little could be said about trends in population structure. Similarly, no significant patterns were found in their weights or size except for the expected sex and age differences.

3.3.1. Introduction

Data Analysis Australia was contracted by the Department of Environment and Conservation to provide a meta-analysis of live cage-trapping data they collected within the Upper Warren region (east of Manjimup).

The woylie (*Bettongia penicillata*) was removed from the endangered list after the *Western Shield* fox baiting program and translocations lead to a recovery in woylie numbers. Recent investigations have suggested that there may be a substantial decline in the abundance of woylies in the southwest forests of Western Australia. Although this decline has not yet been statistically verified, indications suggest the decline to be extreme enough that immediate action needs to be taken, including the possible reinstalment of woylies to the endangered species list.

Trapping data within the Upper Warren region includes long-term monitoring research (P. Christensen and N. Burrows), the 'Kingston Study' into timber harvesting impacts and associated research (A. Wayne), *Western Shield* monitoring transects and other Donnelly District activities (I. Wilson).

The work undertaken by Data Analysis Australia has two aims:

1. A definitive and independent review of the historical trapping data to give an objective statement regarding the decline (or otherwise) of the woylie population; and
2. An exploration of the nature of the decline is needed, assuming that statistical evidence of a decline is found in the first stage. This exploration includes an analysis of the population demographics as well as other measures collected during the monitoring program.

3.3.2. Data

Monitoring programs have been set up as part of the Western Shield program and DEC Science Division research projects to monitor for changes in native fauna. Road transects were commonly chosen on the basis of practical considerations such as accessibility. Usually these transects are repeated but are not always consistent and are generally carried out over 4 consecutive nights. The majority of the data was collected during the autumn months.

The information available for analysis consisted of trapping data relating to the number and characteristics of woylies and other species collected from selected sites during discrete time intervals from March 1994 until April 2007. Data was only included for 'CS' (cage small) traps where universal bait was used.

Table 3.3.1 lists the survey units that constituted each site, together with the time period over which data was available for that particular site. Table 3.3.2 lists the trapping quantities that were used in the analyses, namely the total number of trapping sessions that occurred for each site and the total number of traps that were set for each site. For the purposes of these analyses, a single trapping session for the site in question refers to the total number of trapping nights that occurred in a particular month and year. For example, Balban's three trapping sessions occurred on November 2004, March 2006 and March 2007. Table 3.3.3 and Table 3.3.4 illustrate the gender and age distribution of the woylies that were captured at each site.

The data collected at each site was done by different personnel, for different programs, thus different levels of detail was recorded for each individual woylie. For example, the age and sex of individuals subsequently retrapped (i.e. repeated captures) within the same trap session are not routinely recorded by some operators. This largely explains the differences in the proportion of captured woylies with either unknown (not recorded) gender or unknown (not recorded) age. While this does not necessarily invalidate the analysis that follows, it does suggest a degree of caution is required when comparing sites.

Earlier data from the Boyicup and Yendicup sites that dated back to 1974 could not be used as the total number of sample points corresponding to each trapping session was not recorded in the database. This made it impossible to determine the number of traps available or calculate capture rates for these two data sets.

Table 3.3.1. Summary of data available for analyses.

Site	Survey Unit	Data Available
Balban	51FMC/02	Nov 2004 - Mar 2007
Boyicup	51BOY/01	Mar 1998 - Mar 2007
Camelar	51FMC/01	Nov 2000 - Mar 2007
Chariup	51CHP/01	Mar 1998 - Mar 2007
Corbal	51COR/01	Dec 2005 - Apr 2007
Keninup1	51WSK-01	Jan 1999 - Jul 2002
Keninup2	51KEN/01	Nov 2005 - Mar 2007
Kingston	C1-C4, KC-5, KC-6	Mar 1994 - May 2005
Moopinup	51POS/01	Mar 1996 - Mar 2007
Warrup1	ED, K5NB, K5WB, NFK, SR1-SR3, WL, WRP	Mar 1994 - Aug 1998
Warrup2	51WAR/01	Feb 2001 - Apr 2007
Winnejup1	KNW, KN1, KN2, LJN, TWR	Apr 1994 - Aug 1998
Winnejup2	WEB, WNB	Apr 1994 - Apr 2007
Yackelup	51YAU/01	Oct 2000 - Mar 2007
Yendicup	51YEU/01	Mar 2000 - Mar 2007

Prior to analysis, data was aggregated on a monthly basis for each site. Thus time was recorded in terms of month and year. For ease of analysis, this was converted to a continuous variable by assigning the number 1 to the month of January 1994, number 2 to the month of February 1994 and so on until the number 160 was assigned to the month of April 2007.

Table 3.3.2. Number of trapping sessions and number of traps per site that were used in the analyses.

Site	Trapping Sessions	Number of Traps
Balban	3	600
Boyicup	12	2,400
Camelar	9	1,800
Chariup	11	2,300
Corbal	4	800
Keninup1	7	175
Keninup2	4	800
Kingston	36	6,480
Moopinup	14	2,684
Warrup1	22	7,038
Warrup2	9	1,800
Winnejup1	21	3,446
Winnejup2	24	4,818
Yackelup	14	1,050
Yendicup	15	1,125

Table 3.3.3. Gender distribution of captured woylies.

Site	Captured Woylies		
	Males	Females	Unknown
Balban	158	91	1
Boyicup	458	308	2
Camelar	191	77	16
Chariup	512	280	9
Corbal	72	38	2
Keninup1	40	20	1
Keninup2	247	163	11
Kingston	807	587	29
Moopinup	483	304	4
Warrup1	1,092	724	209
Warrup2	239	149	7
Winnejup1	788	592	132
Winnejup2	495	355	132
Yackelup	252	116	20
Yendicup	317	214	26

Table 3.3.4. Age distribution of captured woylies including new and recaptured individuals, and retrap events of the same individual within the same session.

Site	Captured Woylies				
	Adult	**Subadult**	**Juvenile**	**Infant**	**Unknown**
Balban	232	5	1	1	11
Boyicup	750	5	9		4
Camelar	265	5	10	1	3
Chariup	753	12	16		20
Corbal	94	1	1	2	14
Keninup1	60		1		
Keninup2	350	14	9	12	36
Kingston	1,318	8	35	9	53
Moopinup	764	21	3		3
Warrup1	1,051	23	117	3	831
Warrup2	365	7	7	6	10
Winnejup1	732	17	56	6	701
Winnejup2	467	10	30	3	472
Yackelup	340	1	17		30
Yendicup	505	1	16	1	34

3.3.2.1. Issues

Data Analysis Australia noted several key issues from this work. The lack of data available for each site would restrict the accuracy of the model in terms of the temporal and demographic characteristics of woylies. Trapping was also not performed consistently, with temporal gaps where traps had not been laid at some sites for a number of years. In addition, sites such as Winnejup and Warrup underwent changes such that the number of traps laid in later years was only a subset of those that had been laid in previous years. Such gaps in the data limit the ability of any model to estimate when a decline in the woylie population may have occurred.

The data available was not collected specifically for the purpose of this analysis, explaining some of the inconsistencies found in the dataset. Trapping data was entered by various individuals, increasing the potential for errors resulting from data entry and the varying perceptions that different individuals had when determining such demographics as the age of a woylie. The Department of Environment and Conservation has been processing and validating the data to overcome such issues although this process had not been completed at the time of the analysis.

A particular issue related to the classification of adult female woylies as breeding or not breeding. This breeding status was not recorded consistently at individual sites and consideration of a number of data fields was required to perform this calculation.

Breeding was assumed to be occurring if, for a particular woylie, at least one of the following was recorded in the data:

- Pouch activity described as active, lactating or suckling;
- Number of pouch young ≥ 1;
- Crown rump length of pouch young provided;
- Number of elongated teats ≥ 1; or
- Comments field made reference to elongated/enlarged teats, pregnancy or condition of the young.

In the raw data, zeros in the relevant data fields were sometimes used to indicate that a woylie was not breeding whilst, on other occasions, data fields were simply left blank. It is unknown whether data fields were kept blank as a result of the woylie's breeding status not being recorded or because the woylie was not currently breeding. In both instances, a woylie was assumed to not be breeding. For the purposes of analysis, the assumption had to be made that the lack of recording of breeding status was consistent across the various sites.

This resulted in the creation of a new variable that assigned a value of 1 to those adult female woylies that were breeding and 0 to those that were not.

In saying this, the data that has been collected is extensive and is the richest source of woylie data available for the analysis. Despite its limitations, the data was sufficient to undertake substantial analysis and draw meaningful results – the results simply need to be interpreted with the data limitations in mind.

3.3.2.2. Statistical techniques

A multistage conditional approach was adopted for the analysis, examining in sequence the population size, then the demographics (age and gender) and finally condition (weight and size). By making each analysis conditional on the previous stages relationships could be examined using generalised linear models, an extension to standard regression.

Linear regression attempts to model a numeric response variable, y, by a linear combination of predictor variables x_j, for j=1…p. Each of these variables was observed for the same n observations. The fitted values are the sum of the coefficients β_j multiplying each of the x_j plus an intercept β_0. In other words:

$$y \sim \beta_0 + \beta_1 x_1 + \dots\dots + \beta_p x_p$$

Using the standard statistical theory the model for the ith observation can be written as:

$$y_i = \beta_0 + \sum_{j=1}^{p} \beta_j x_{ij} + \varepsilon_i$$

and by making the following assumptions:

1. the ε_i are independently and identically distributed;
2. the ε_i have mean zero and (finite) variance σ^2; and
3. the ε_i are distributed according to the normal distribution.

This model was used to evaluate the numeric response variables: weight, hindfoot length and head length as part of the woylie population health analysis.

However, the data also contained many factor variables. Factor variables are those in which one coefficient is given for each level. The coding of factors into the model involves replacing the factor by one "dummy" variable for each level – namely, a numeric variable taking the value 1 wherever the factor takes on that level, and 0 for all other observations. For example, this analysis involved the factor variable Sex, in which *XMale* is set to 1 for all Male observations and *XFemale* is set to 1 for all Female observations. Therefore, the model becomes:

$$y \sim \beta_0 + \beta_1 XMale + \beta_2 XFemale\,.$$

Occasionally, the parameterisation of a term may need to be handled explicitly. For a factor with k levels, k-1 such linear combinations are possible. A particular choice of these linear combinations is called a contrast, or *reference group*. Any choice of reference group for factors alters the specific individual coefficients in the model but does not change the overall contribution of the term to the fit. In terms of the analysis completed on the trapping data, the site Kingston was chosen as the reference group for all the models as it contained the most data points when compared to the other sites that were monitored and had a low proportion of trapped woylies for which the gender or age were not recorded.

Due to the discrete response variables involved a generalised linear model was employed to look at changes in the woylie population and demographics. This was a natural progression from using linear regression models. Generalised linear models deal with issues such as binary response data (i.e. where 1 = success and 0 = failure) by using re-parameterisation to induce linearity and by allowing a non-constant variance to be directly incorporated into the analysis. Many of the variables used in the analysis can be interpreted as being one of two outcomes, i.e. success or failure, or as a binary response.

When dealing with binary data, the logit link function, $\log\{\mu/(1-\mu)\}$, is employed which is used to describe how the mean depends on linear predictors. This link guarantees that μ is in the interval (0,1), which is appropriate since μ is a proportion.

The introduction of a quasibinomial model allows for the distribution to be specified entirely by the mean and variance functions for binary variables, whilst allowing for additional variation in the data compared to that which would be expected under the binomial distribution. This additional variation is expected for variables such as the trapping rates since it is expected that each trap night at a site is statistically dependent of other trap nights. The deviation above that of the binomial distribution is given by the dispersion parameter with a value of 1 equalling the binomial distribution and larger values showing a larger variation. In tests for the significance of relationships the quasibinomial model correctly accounts for the additional variation whereas the more common binomial model tends to over state the significance.

3.3.2.3. Condition index

The (body) condition index attempts to quantify various attributes, which describe the general health and fitness of individuals within a population. This index relates body mass (weight) to sex, length (both hindfoot and head length were assessed) and the interaction between these two attributes.

For the adult woylie individuals involved in this study, there were multiple measures of the same individual over time. In this model, within- and between- woylie variation was accounted for by using a linear mixed model in which woylie identity (ID) was included as a random effect. Fixed effects included the sex, hindfoot and head length of the individual and the interaction between the length parameter and sex.

Both the fixed effects model and the fixed effects model with a random effect were assessed and it was found that the model that incorporated the random effect was a better model based on the goodness-of-fit.

The sites chosen for this analysis were based on their underlying quadratic structure, as the condition index is best represented with reference to time (discussed further in Section 3.3.3).

Two models were formulated based on the type of length measurement used. It was found that head length was a better measurement than hindfoot length in characterising the condition index of individual woylies. Therefore the final model used in calculating the condition index involved the fixed effects sex, head length and their interaction, and the random effect ID. The residuals of this model provided a condition index that was specific for each individual and relative to its own 'usual' condition. This model showed a significant relationship between head length ($p<0.001$), sex ($p<0.01$) and their interaction ($p<0.01$).

Exploratory plots were conducted on the condition index to assess what the most appropriate parameter would be to use in the population decline model.

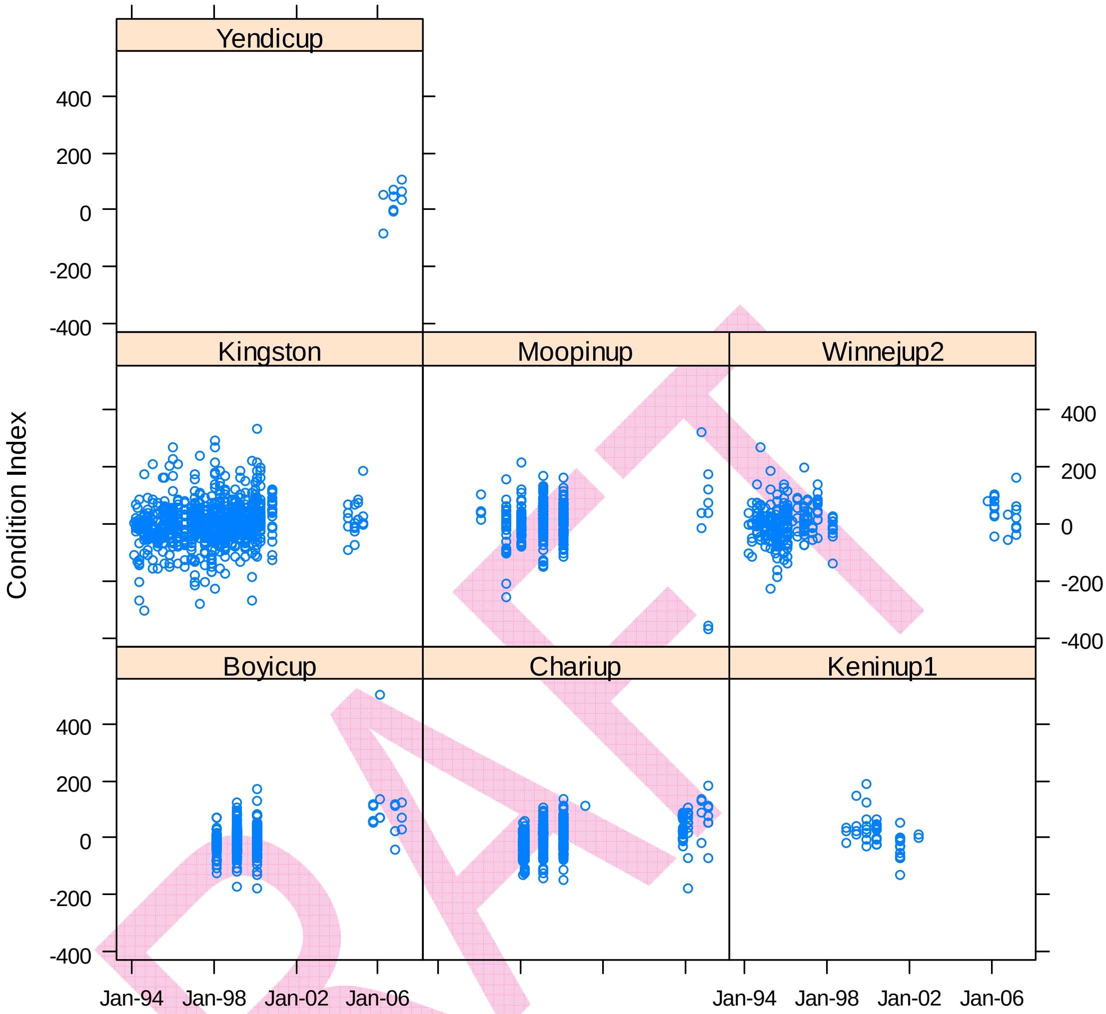

Figure 3.3.1. The condition index for individual adult woylies over time for each site.

The condition index showed that the majority of the adult woylie individuals were between ±200 grams of their 'usual' condition. Figure 3.3.1 also shows that there is no obvious inherent pattern in the dataset.

To further ascertain if there are any trends in the data, the average and standard deviation of the condition index was evaluated for each site at each time where data was available.

Inspection of the average condition index (Figure 3.3.2) shows that there appears to be an increasing trend in some sites over time. This suggests that there may be an increase in the overall health of the population at the sites Boyicup, Chariup, Kingston and Yendicup, whereas the sites (Moopinup and Winnejup2) are more static. Keninup1 is the only site to have experienced a possible decrease in their condition index over a short amount of time.

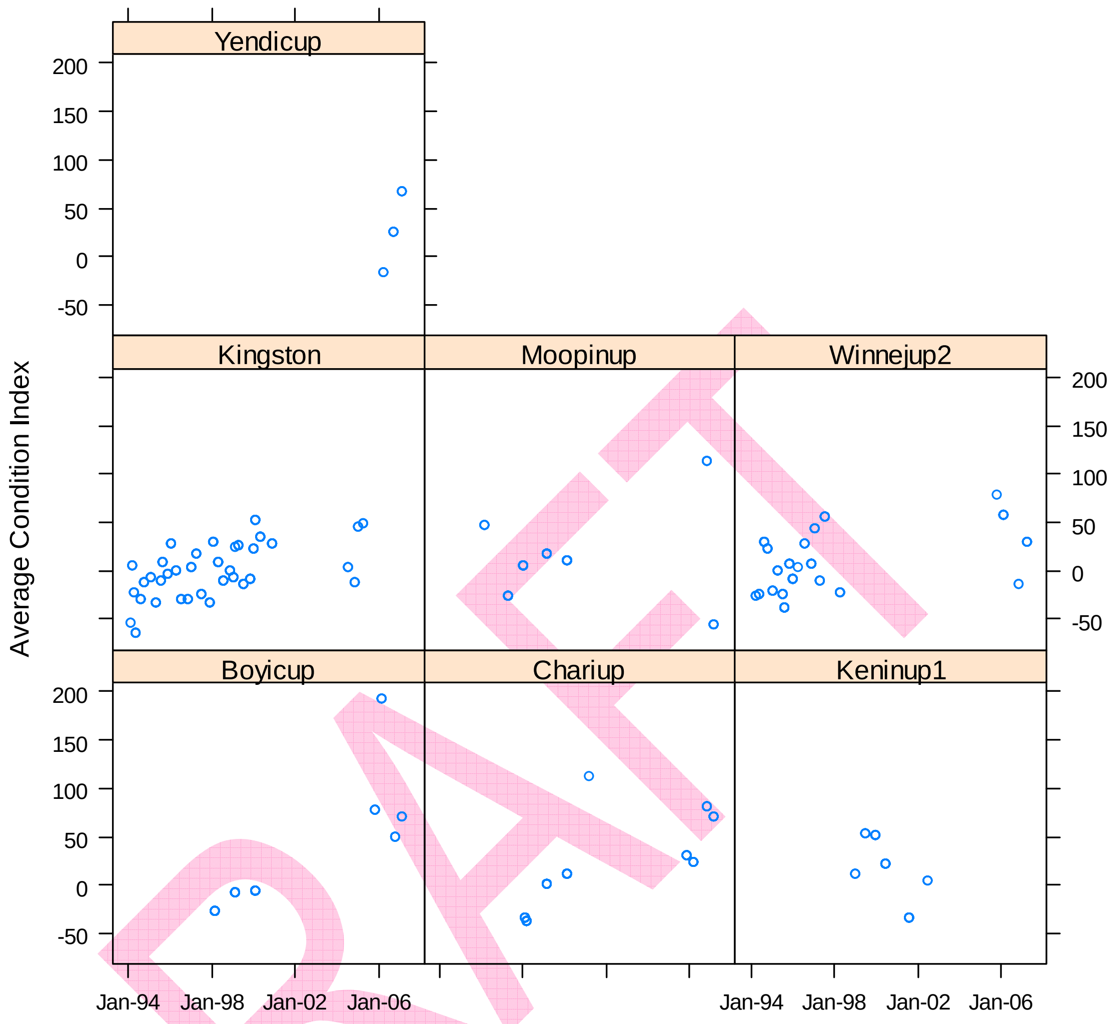

Figure 3.3.2. The average condition index over time for each site.

The standard deviation of the condition index was also examined and it was found that there was no apparent change over time for the sites Boyicup, Chariup, Keninup1, Kingston, Moopinup, Winnejup2 and Yendicup.

3.3.3. Population decline

A generalised linear model was developed in an attempt to characterise the trapping of woylies, investigate whether there has been a population decline and determine the significant factors that may have contributed to this decline. Essentially the probability of catching a woylie was modelled, based on time and other potential explanatory variables. While this is not a direct measure of population size, under all standard models for trapping rates it is closely associated with population size and is expected to have more understandable statistical properties than other measures.

The trapping of a woylie was modelled in terms of successes and failures. A success was defined as the capture of a woylie, irrespective of whether it was new, recaptured, escaped, not tagged or had not been identified under any of these categories. A failure was defined as not capturing a woylie and could therefore be either an empty trap or a trap that had captured a species other than a woylie.

The model was only applied to data from a selected number of sites.
Table 3.3.5 shows the sites that were included and those that were excluded from the model.

Table 3.3.5. Sites on which the model of population decline was based.

Sites Included	Sites Excluded
Boyicup	Balban
Chariup	Camelar
Keninup1	Corbal
Kingston	Keninup2
Moopinup	Warrup1
Winnejup2	Warrup2
Yackelup	Winnejup1
Yendicup	

Sites were excluded when the period of data collection showed that the population of woylies, denoted by the probability of successfully capturing a woylie, was either monotonically increasing (i.e. strictly increasing or non-decreasing) or monotonically decreasing (i.e. strictly decreasing or non-increasing) rather than covering the likely timing of when the population changed (based on that observed at other sites). These monotonic patterns are shown in Figure 3.3.3 where the probability of success of capturing a woylie was plotted for each of these excluded sites over time.

The probability of success of capturing a woylie was then plotted over time for each of the remaining sites that were included in the model and displayed in Figure 3.3.4. The pattern in the data in Figure 3.3.4 suggests there is a period of increase in the numbers of woylies caught, followed by a decrease in the number of woylies caught. This is in stark contrast to the monotonic nature of the data from the excluded sites shown in Figure 3.3.3.

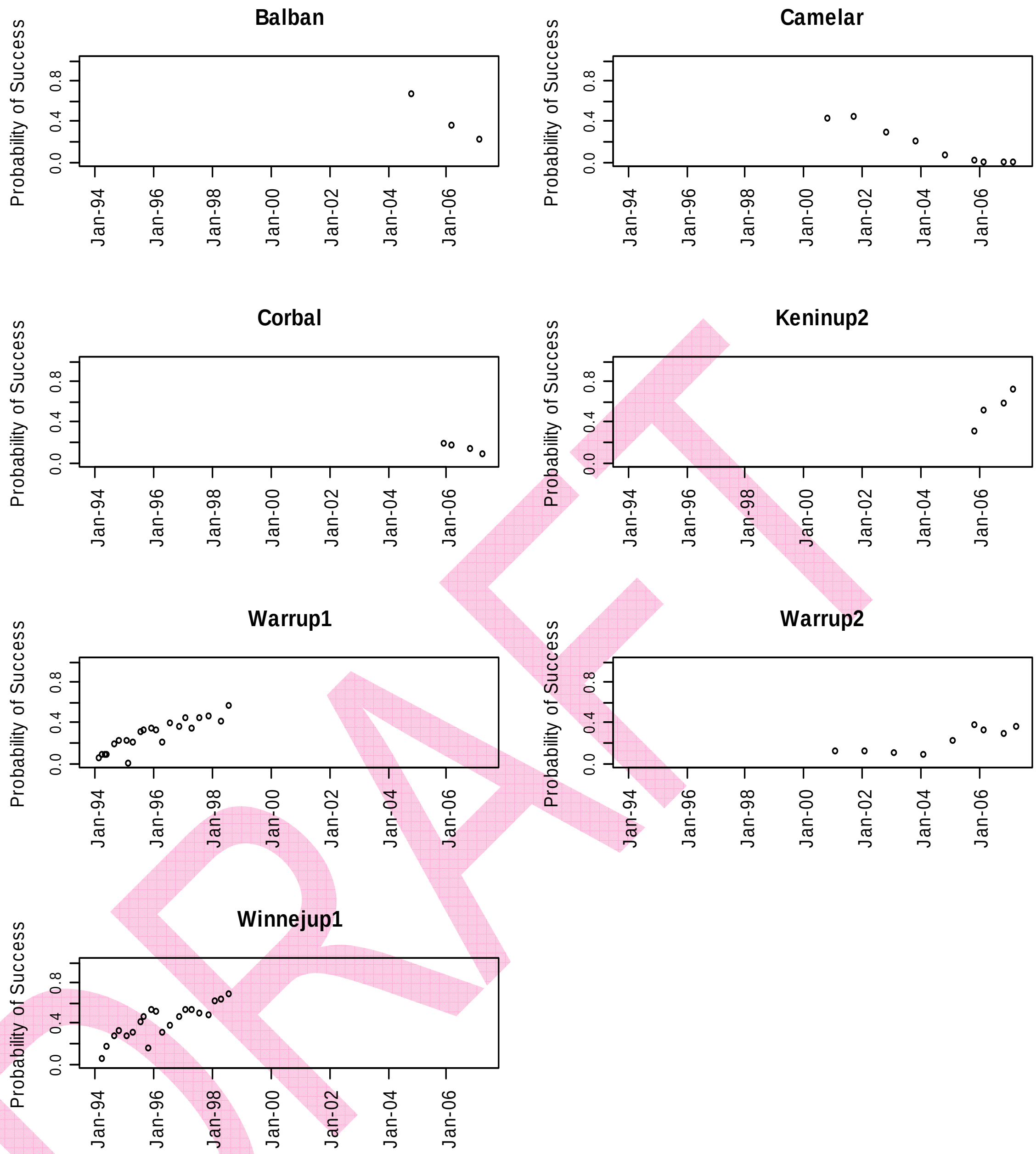

Figure 3.3.3. Probability of success (catching a woylie) over time for sites Balban, Camelar, Corbal, Keninup2, Warrup1, Warrup2 and Winnejup1.

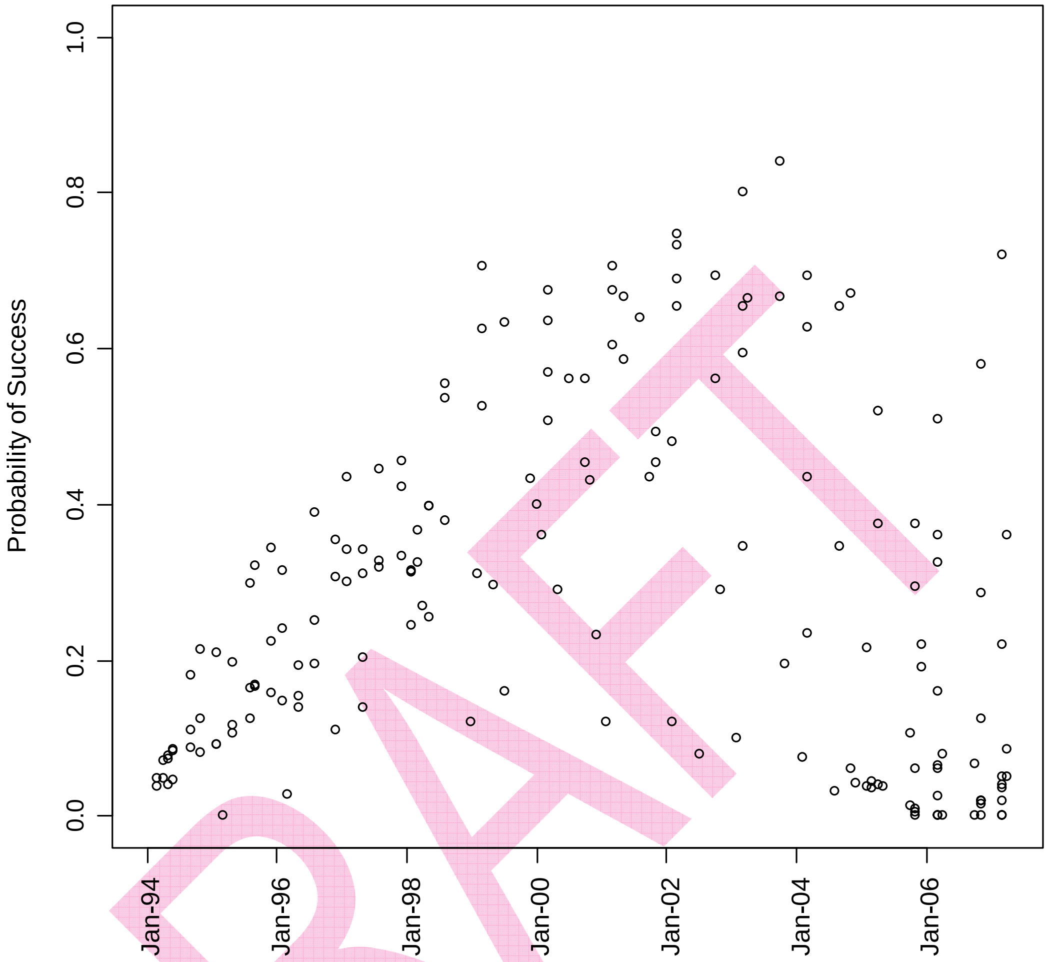

Figure 3.3.4. Probability of capturing a woylie over time for selected sites that were included in the model of population decline of woylies.

Data was only available for three or four trapping sessions for sites such as Balban, Corbal and Keninup2. As the plots for these sites clearly show, there is insufficient data available to indicate when the probability of capturing a woylie shifted from an increase to a decrease. For sites such as Warrup1 and Winnejup1 it was not possible to accurately estimate the time of the decline in numbers of woylies, since the probability of catching a woylie followed an increasing trend and no data was available after 1998. The absence of data prior to 2001 for Camelar and Warrup2 also made it impossible to accurately estimate a decline in the woylie population. For these reasons, these sites were excluded from the model.

The resulting model of population decline, based on the selected sites, is shown in Table 3.3.6.

The statistically significant variables that were used in the model to explain the capture of a woylie consisted of Time, $Time^2$, $Time^3$, Site and the interaction between time and site (Time*Site).

Table 3.3.6. Quasibinomial model where successful capture of a Woylie = Time+Time^2+Time^3+Site+Time*Site and failure is an empty trap or a species captured other than a woylie. ('*' Pr<0.001, '**' Pr<0.01, '*' Pr<0.05)**

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-2.545	0.277	-9.21	1.84E-15	***
Time	0.026	0.014	1.85	0.07	.
Time_squared	3.96E-04	2.14E-04	1.85	0.07	.
Time_cubed	-4.96E-06	9.11E-07	-5.45	2.96E-07	***
SiteBoyicup	0.128	0.5673	0.23	0.82	
SiteChariup	-2.058	0.4759	-4.33	3.27E-05	***
SiteKeninup1	-2.335	2.3680	-0.99	0.33	
SiteMoopinup	-1.481	0.4550	-3.26	0.00	**
SiteWinnejup2	-0.414	0.2714	-1.53	0.13	
SiteYackelup	-2.097	1.2460	-1.68	0.10	.
SiteYendicup	-3.748	0.9846	-3.81	0.00	***
Time:SiteBoyicup	0.012	7.06E-03	1.75	0.08	.
Time:SiteChariup	0.041	6.31E-03	6.50	2.14E-09	***
Time:SiteKeninup1	0.029	0.028	1.03	0.30	
Time:SiteMoopinup	0.029	6.05E-03	4.82	0.00	***
Time:SiteWinnejup2	0.020	5.59E-03	3.65	0.00	***
Time:SiteYackelup	0.036	0.012	2.98	0.00	**
Time:SiteYendicup	0.056	9.70E-03	5.80	6.07E-08	***

Dispersion parameter for quasibinomial family taken to be 6.447442

Residual deviance: 637.18 on 115 degrees of freedom

The terms that were significant in explaining the capture of a woylie all had a p-value of 0.004 or less and included the following:

- Time^3,
- Sites of Chariup, Moopinup and Yendicup;
- Interaction of Time with the sites of Chariup, Moopinup Winnejup2, Yackelup and Yendicup.

Other explanatory variables were investigated for the model such as cosine[1] and sine terms to model any possible seasonal variation in the data, and the average condition index. However, these were found to be not significant.

The proportion of adult woylie females that had been recorded as breeding (represented as a proportion of the total number of adult female woylies captured) was also investigated as an explanatory variable for the model yet it was not found to be significant.

It was not appropriate to include explanatory variables in the model such as the numbers of various other species captured since these other species are included in the definition of a failure. Instead an alternative model was developed that was restricted to the same sites as the model described in Table 3.3.6 yet enabled the significance of other captured species to be tested. The capture of a woylie was modelled in terms of successes and failures. However, whilst the definition of a success remained the same, a failure was now defined as an empty trap. In other words, the model was only taking into account the available traps that remained after another

[1] The cosine and sine terms were calculated according to the equations:

cosine term=cos((2*pi* Time)/12),

sine term=sin((2*pi* Time)/12),

Such terms give the model a seasonal component. This definition of the cosine and sine terms was used throughout this paper for all models investigated.

species had been captured. This was in contrast to the model shown in Table 3.3.6 that considered all traps that had been set. The resulting model in which the capture of a woylie is explained by the statistically significant variables Time, $Time^3$, Site and the Time*Site interaction term, is shown in Table 3.3.7.

Table 3.3.7. Quasibinomial model where successful capture of a woylie = Time + $Time^2$ + $Time^3$ + Trap Rate for koomal + Trap Rate for quenda + Site + Time*Site and failure is an empty trap. ('*' Pr<0.001, '**' Pr<0.01, '*' Pr<0.05)**

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-3.072	0.445	-6.90	3.22E-10	***
Time	0.041	0.018	2.32	0.02	*
Time_squared	3.93E-04	2.60E-04	1.51	0.13	
Time_cubed	-5.40E-06	1.13E-06	-4.79	5.06E-06	***
TrapRate_BTP	1.639	0.841	1.95	0.05	*
TrapRate_Quenda	4.232	1.450	2.92	0.00	**
SiteBoyicup	0.069	0.707	0.10	0.92	
SiteChariup	-2.234	0.596	-3.75	0.00	***
SiteKeninup1	-2.199	2.472	-0.89	0.38	
SiteMoopinup	-1.464	0.560	-2.61	0.01	*
SiteWinnejup2	-0.736	0.356	-2.07	0.04	*
SiteYackelup	-2.422	1.376	-1.76	0.08	.
SiteYendicup	-4.277	1.059	-4.04	9.79E-05	***
Time:SiteBoyicup	9.07E-03	7.60E-03	1.19	0.24	
Time:SiteChariup	0.040	6.66E-03	6.02	2.24E-08	***
Time:SiteKeninup1	0.022	0.029	0.76	0.45	
Time:SiteMoopinup	0.025	6.53E-03	3.85	0.00	***
Time:SiteWinnejup2	0.021	6.11E-03	3.51	0.00	***
Time:SiteYackelup	0.034	0.013	2.72	0.01	**
Time:SiteYendicup	0.057	0.010	5.62	1.41E-07	***

Dispersion parameter for quasibinomial family taken to be 6.736329

Residual deviance: 614.27 on 113 degrees of freedom

The models shown in Table 3.3.6 and Table 3.3.7 were very similar with all variables that were significant in the first model also being significant in the second model. In addition Time, Winnejup2, the Trap Rate for common brushtail possums (defined as the number of common brushtail possums caught divided by the number of traps available) and the Trap Rate for quenda (defined as the number of quenda caught divided by the number of traps available) were also significant in the second model.

Other explanatory variables such as cosine and sine terms, the average condition index and the proportion of adult woylie females that were recorded as breeding were again investigated for the model yet these were not found to be statistically significant. Whilst the trap rate for quenda and common brushtail possum was significant in explaining the capture of woylies, thus indicating that there is some level of association with woylies, the trap rate for chuditch was found to be not significant.

Since both of the models described in Table 3.3.6 and Table 3.3.7 are quasibinomial, it is difficult to determine, in absolute terms, how well the models fit the data. If it was not necessary to allow for additional variation in the data and hence a binomial model could be applied then the goodness-of-fit could be ascertained according to whether the variance in the data was higher or lower than the expected variance from the binomial distribution. Whilst a quasibinomial model assumes that the variance in the data will deviate from the variance under the binomial distribution, the actual value of this expected variance is unknown. Thus an absolute measure of goodness-of-fit cannot be determined.

In addition, the absence of any genuine replication within the trapping data results in the data being too sparse and this consequently renders the p-values generated by any goodness-of-fit tests to be invalid. Whilst the residual deviance may provide a relative measure of the goodness-of-fit, when compared to the residual deviance produced by other models that were applied to the dataset, a large residual deviance could be explained by a poor fitting model or by the variation in the data being naturally greater than that assumed by the model.

Based on the model, Table 3.3.8 shows the approximate time at which the population of woylies began to decline at each site. The table lists sites in order of the earliest site to show a decline that was estimated by the model, through to the most recent site.

Table 3.3.8. Estimated commencement dates of decline according to model using selected sites versus visually estimated date of decline.

Site	Modelled Date of Peaking	Visually Estimated Date of Decline
Kingston	August 2000	1999
Boyicup	January 2001	2002 to 2003
Keninup1	July 2001	2001 to 2002
Winnejup2	July 2001	1998 to 2005
Moopinup	September 2001	2001 to 2002
Yackelup	January 2002	2004
Chariup	March 2002	2002 to 2004
Yendicup	October 2002	2004
Balban	NA	Pre 2006
Corbal	NA	Pre 2006
Camelar	NA	2002 or earlier
Keninup2	NA	Increasing trend in data
Warrup1	NA	Increasing trend in data
Warrup2	NA	Increasing trend in data
Winnejup1	NA	Increasing trend in data

Separate plots of the probability of success of capturing a woylie over time were produced for each site that was included in the model. These plots are shown in Figure 3.3.5. The estimated time of decline in the number of woylies for each site is shown by the vertical line and is only approximate as issues with the data made it difficult to estimate the time of decline in the number of woylies. There was only limited data available and inconsistency in trapping resulted in missing data for some sites due to traps not being set in all years. For example, a decline in the woylie population at Winnejup2 could have occurred any time between December 1998 and November 2005 since no traps were laid at that site during that time period.

There was also difficulty in estimating the time of decline in numbers of woylies for Yackelup and Yendicup due to the erratic nature of the data. Figure 3.3.5 shows that, whilst the probability of capturing a woylie appears to decline at Yackelup after approximately December 2003, the alternating increasing and decreasing probabilities prior to this date result in an estimated date of decline in March 2001. Figure 3.3.5 also exhibits a similar scenario for Yendicup.

For the models in Table 3.3.6 and Table 3.3.7, sites 1 and 2 for Keninup, Warrup and Winnejup were kept separate. This separation represented changes in the sampling methodology where trapping methods had changed such that site 2 was only a subset of the number of traps that were laid for site 1. Sites 1 and 2 were combined for Keninup, Warrup and Winnejup and a model was applied to the resulting dataset, using the same definition of failure as the model in Table 3.3.7. Table 3.3.However, as Table 3.3.9 shows, this resulted in less accurate and realistic estimated times for the decline in the population of woylies at the various sites when these were compared to the rough estimates for the time of decline that were obtained by visually inspecting the plot of successes over time for that site that are shown in Figure 3.3.3 or Figure 3.3.5.

When combining sites we must be reasonably sure that the changes between sites 1 and 2 are small or they can somehow be incorporated into the model. Changes in sampling methodology may or may not cause substantial changes in the data. The less accurate model estimates for the time of the population decline that were produced after combining the sites (shown in Table 3.3.9), compared to those times estimated by the model where the sites remained separate (shown in Table 3.3.8), suggest that there are differences in the data from sites 1 and 2 that extend over and above the changes in sampling methodology. For this reason, it is recommended that sites 1 and 2 should be kept separate for Keninup, Warrup and Winnejup.

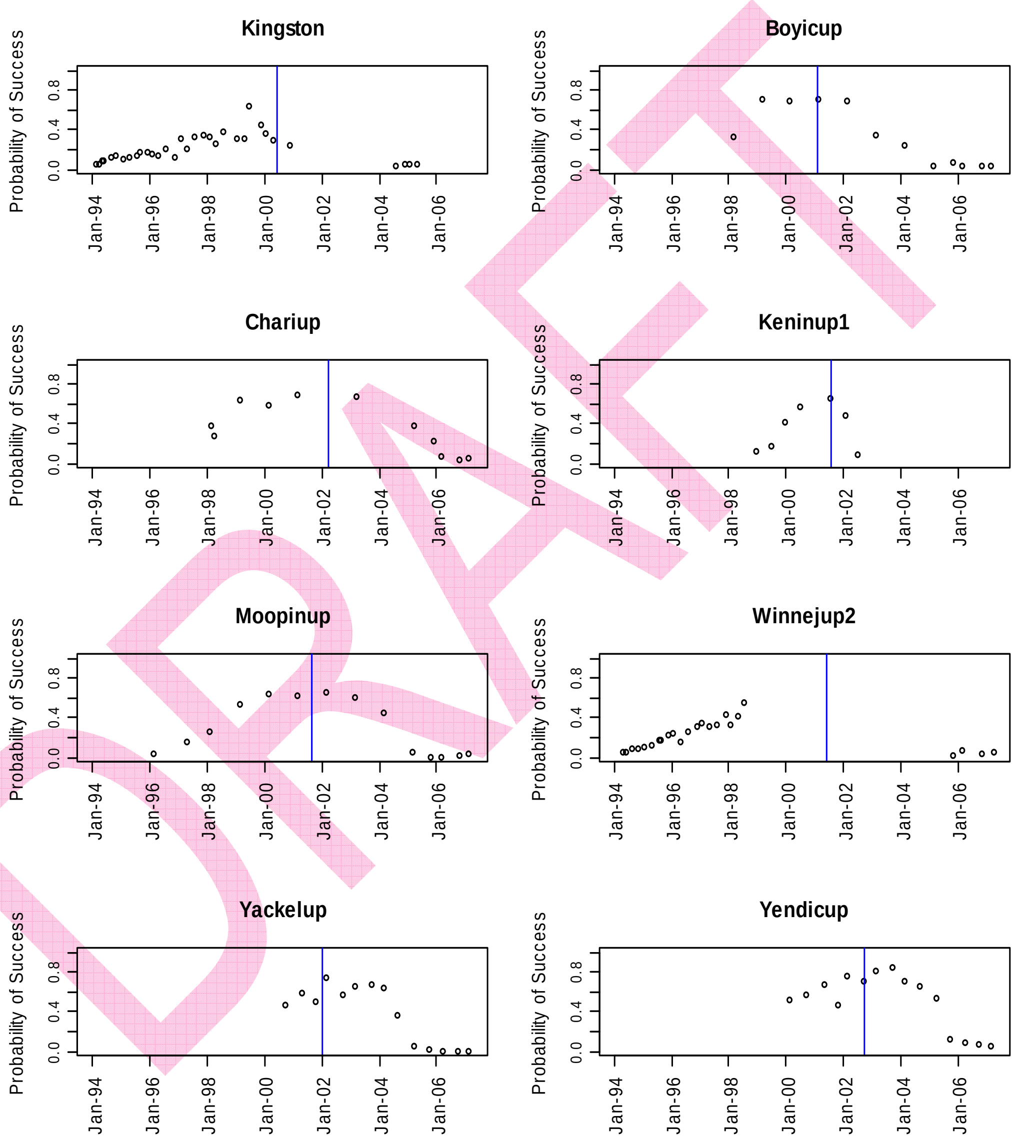

Figure 3.3.5. Probability of success (catching a woylie) over time for sites Kingston, Boyicup, Chariup, Keninup1, Moopinup, Winnejup2, Yackelup and Yendicup.

Table 3.3.9. Estimated commencement dates of decline according to model using joined sites versus visually estimated date of decline.

Site	Modelled Date of Peaking	Visually Estimated Date of Decline
Kingston	August 1999	1999
Balban	June 1999	Pre 2006
Boyicup	March 1999	2002 to 2003
Camelar	October 1997	20002 or earlier
Chariup	February 2001	2002 to 2004
Corbal	October 2001	Pre 2006
Keninup	January 2005	2001
Moopinup	November 2000	2001 to 2002
Warrup	June 2000	1998 to 2001, 2006
Winnejup	October 1999	1998 to 2006
Yackelup	April 1999	2004
Yendicup	December 2000	2004

3.3.4. Population demographics and biometrics

3.3.4.1. Sex ratio

A generalised linear model was used in identifying any changes that have occurred with regards to the sex ratio both over time and between sites. For a number of captured woylies sex wasn't recorded, therefore the dataset was restricted to those woylies where sex was recorded (approximately 95%). Success was defined as catching a male woylie and failure was defined as catching a female woylie. Male woylie individuals constituted 60% of the overall dataset. This bias in sex ratio was also evident in previous studies (Start *et al*., 1995).

Models were fitted where overlapping sites (for example Warrup1 and Warrup2) were combined into the one site (for example Warrup), however, these models showed worse fits than when the sites were left separate. Due to the significance of time variables in the model, only those sites that were retained for the earlier trend analysis were retained in the final model. The selected sites were Kingston, Boyicup, Chariup, Keninup1, Moopinup, Winnejup2, Yackelup (these were chosen as the period of data collection at these sites was long enough to exhibit an increase then a decrease in the number of woylies). This final model is shown in Table 3.3.10 and was a better fit than the previous models explored.

The explanatory variables used initially in this model consisted of various time parameters (including Time, $Time^2$, $Time^3$), site, the interaction term Time*Site, trap rate (to determine if the sex ratio is dependent on abundance), the proportion of adult woylie females that had been recorded as breeding and, a cosine and sine term (to check for any seasonal fluctuations that may be significant). The reference site was Kingston. Time, Site and the interaction between Site and Time were found to be significant. The resulting model is shown Table 3.3.10.

Table 3.3.10. Quasibinomial model where Success of Male woylies = Time+ Site+Time*Site. ('*' Pr<0.001, '**' Pr<0.01, '*' Pr<0.05)**

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.272	0.113	2.413	0.018	*
Time	0.001	0.002	0.595	0.553	
SiteBoyicup	-0.848	0.264	-3.211	0.002	**
SiteChariup	0.462	0.216	2.144	0.034	*
SiteKeninup1	-0.342	1.554	-0.220	0.826	
SiteMoopinup	0.587	0.252	2.334	0.021	*
SiteWinnejup2	0.004	0.148	0.024	0.981	
SiteYackelup	-0.604	0.662	-0.912	0.364	
SiteYendicup	0.423	0.403	1.050	0.296	
Time:SiteBoyicup	0.010	0.003	2.767	0.007	**
Time:SiteChariup	-0.003	0.003	-1.145	0.255	
Time:SiteKeninup1	0.007	0.019	0.393	0.695	
Time:SiteMoopinup	-0.006	0.003	-2.021	0.046	*
Time:SiteWinnejup2	-0.001	0.002	-0.231	0.818	
Time:SiteYackelup	0.009	0.006	1.404	0.163	
Time:SiteYendicup	-0.004	0.004	-0.977	0.331	

Dispersion parameter for quasibinomial family taken to be 0.5797085

Residual deviance: 65.129 on 107 degrees of freedom

The factors that were significant in explaining the sex ratio of the woylie population were:

- Sites Boyicup, Chariup and Moopinup
- The interaction between Time and the Sites Boyicup and Moopinup

Sites with a positive parameter estimate have a higher proportion of male woylies than Kingston and sites with a negative parameter estimate have a lower proportion of male woylies than Kingston.

The proportion of male woylies caught over time were found to increase at the sites Keninup, Kingston (slow increase), Winnejup (slow increase), Yackelup and Boyicup, whereas the proportion of males decreased over time for the sites Moopinup, Yendicup and Chariup.

Further analysis of this model involved looking at the validation of the model. Firstly the trap rate (defined as the number of woylies caught divided by the number of traps available) was examined with respect to the proportion of male woylies caught at these intervals. Figure 3.3.6 shows that there is no visual relationship between the trapping rate and the sex of the woylie caught (except for Camelar and Warrup2, which showed a potential slight decrease and Chariup, which showed a potential slight increase in the number of males caught as the trapping rate increased). The results shown in Figure 3.3.6 reiterate the reason why trap rate was found to be not significant.

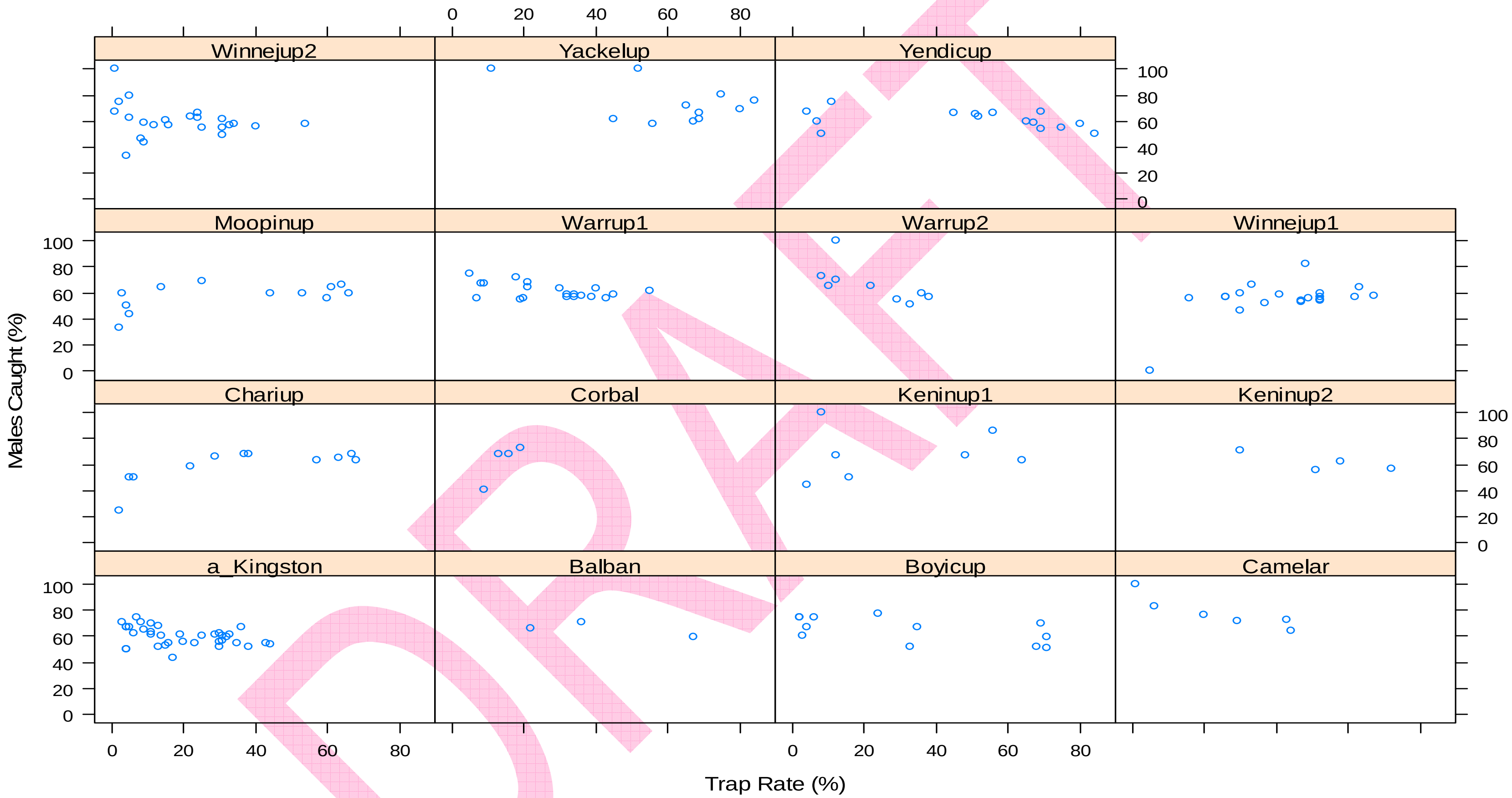

Figure 3.3.6. Percentage of males caught versus trap rate (percentage of woylies caught) for all sites.

The residuals shown in Figure 3.3.7 further emphasise the validity of the final model. The majority of the residuals only showed a slight deviation of between 0% - 20% from the observed percentages, which indicates that the model is a reasonable fit.

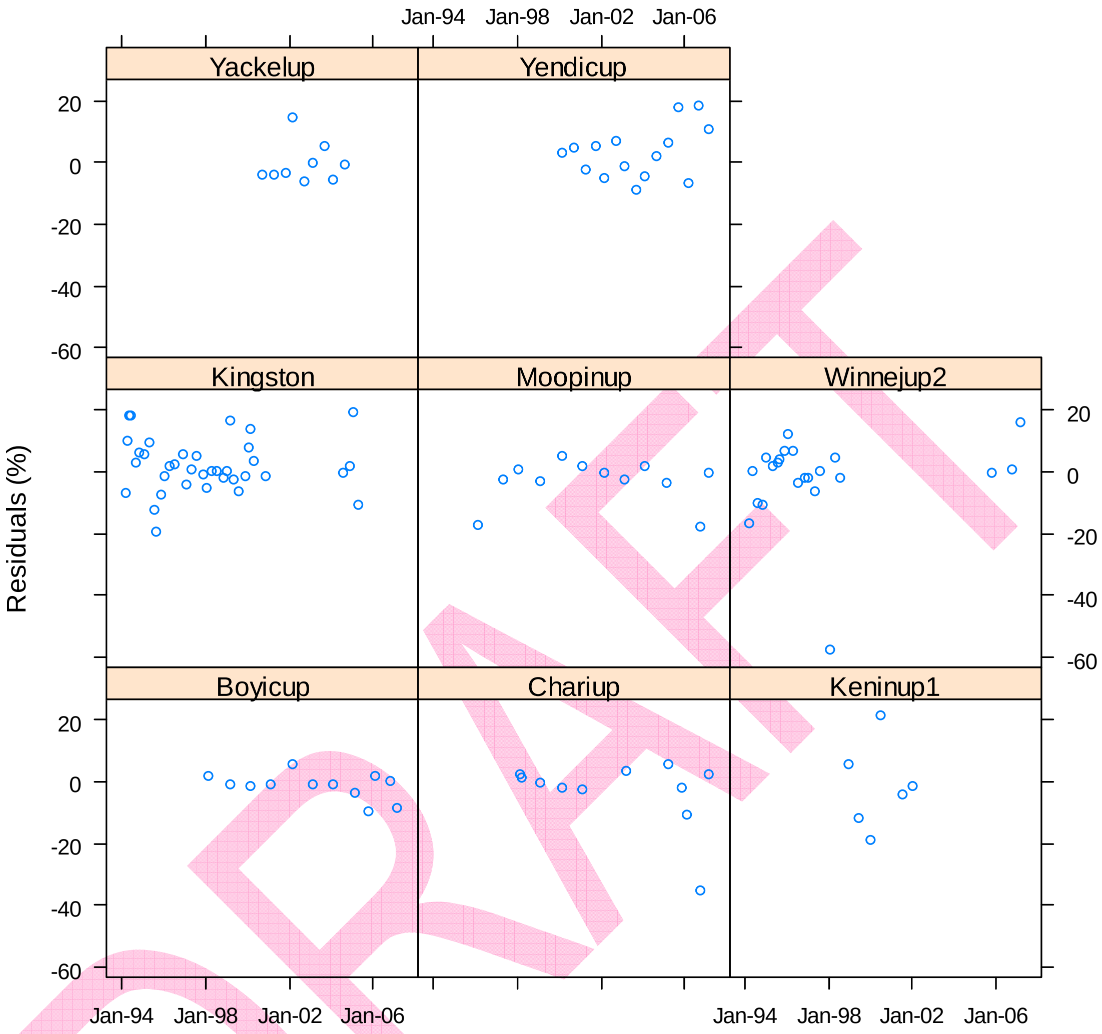

Figure 3.3.7. The residuals of the final model for each site used in the model.

3.3.4.2. Age structure

A generalised linear model was used in identifying any changes that have occurred with regards to the age structure of the woylie population both over time and between sites.

Success was defined as catching an adult woylie and failure was defined as not catching an adult woylie (i.e. the individual could be a subadult, juvenile or infant). Adult individuals made up 95% of the dataset and therefore Data Analysis Australia suggests it would be ideal if this 'Adult' category were broken down into smaller groupings, however it recognises the intrinsic difficulties in being able to do this in practice. It would however enable better evaluation of the change in age structure of the woylie population over time.

Models were tried where overlapping sites (for example Warrup1 and Warrup2) were combined into the one site (for example Warrup), these models showed worse fits than when the sites were left separate. As time was not significant in this model, the sites with a shorter period of data collection could be retained for this analysis. This final model is shown in Table 3.3.11 and, as Figure 3.3.8 suggests, the model is of reasonable fit.

Again, other explanatory variables were introduced into the model such as cosine and sine terms to model any possible seasonal variation in the data, trap rate, the proportion of adult woylie females that had been recorded as breeding and various time parameters. However these were found to be not significant. Hence, Site was the only factor that was retained in the final model.

Table 3.3.11. Quasibinomial model where Success of Adults = Site. ('*' Pr<0.001, '**' Pr<0.01, '*' Pr<0.05)**

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	2.508	0.165	15.245	<2.00E-16	***
SiteBalban	0.558	0.382	1.460	0.147	
SiteBoyicup	0.854	0.356	2.400	0.018	*
SiteCamelar	0.026	0.342	0.075	0.940	
SiteChariup	0.371	0.283	1.313	0.192	
SiteCorbal	0.354	0.598	0.592	0.555	
SiteKeninup1	0.057	1.172	0.049	0.961	
SiteKeninup2	-0.331	0.261	-1.267	0.208	
SiteMoopinup	0.715	0.294	2.434	0.017	*
SiteWarrup1	-0.474	0.197	-2.409	0.018	*
SiteWarrup2	-0.211	0.329	-0.643	0.522	
SiteWinnejup1	-0.248	0.218	-1.136	0.259	
SiteWinnejup2	-0.247	0.254	-0.972	0.333	
SiteYackelup	0.123	0.319	0.386	0.700	
SiteYendicup	0.044	0.319	0.138	0.891	

Dispersion parameter for quasibinomial family taken to be 1.485833
Residual deviance: 139.67 on 103 degrees of freedom

The sites that were found to be significant were: Boyicup, Moopinup and Warrup1. Sites with a positive parameter estimate have a higher proportion of adult woylies than Kingston and sites with a negative parameter estimate have a lower proportion of adult woylies than Kingston. There was an indication that more adult woylies were caught at Balban, Boyicup, Camelar, Chariup, Corbal, Keninup1, Moopinup, Yackelup and Yendicup and less at Keninup2, Warrup1, Warrup2, Winnejup1 and Winnejup2.

Further analysis of this model involved looking at the trap rate (defined as the number of woylies caught divided by the number of traps available). This was examined with respect to the proportion of adult woylies caught at these intervals. Figure 3.3.9 shows that there is no visible relationship between the trapping rate and the age of the woylie caught. The results shown in Figure 3.3.9 reiterate the reason why trap rate was found to be not significant.

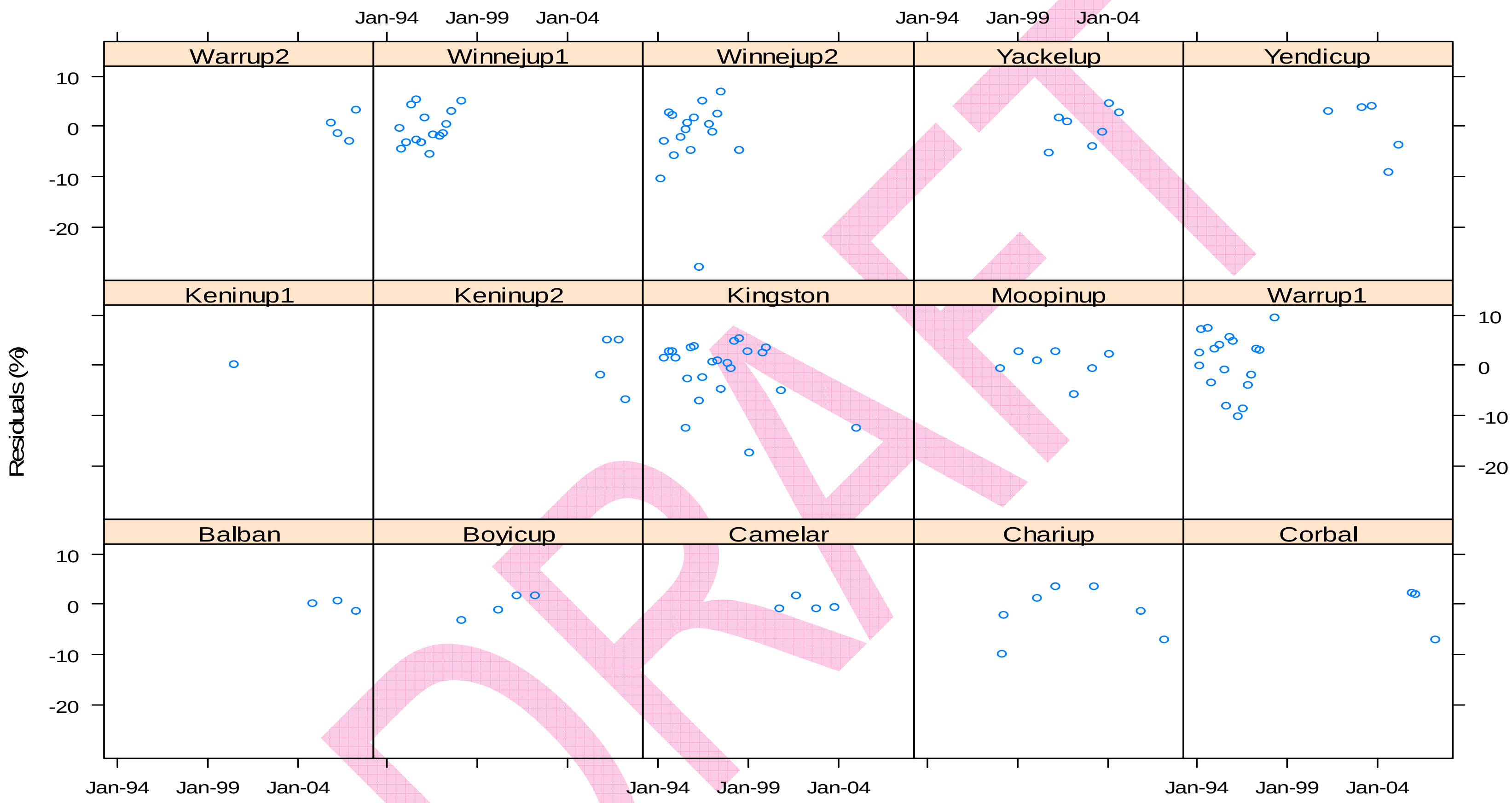

Figure 3.3.8. The residuals of the final model for each site used in the model plotted against time.

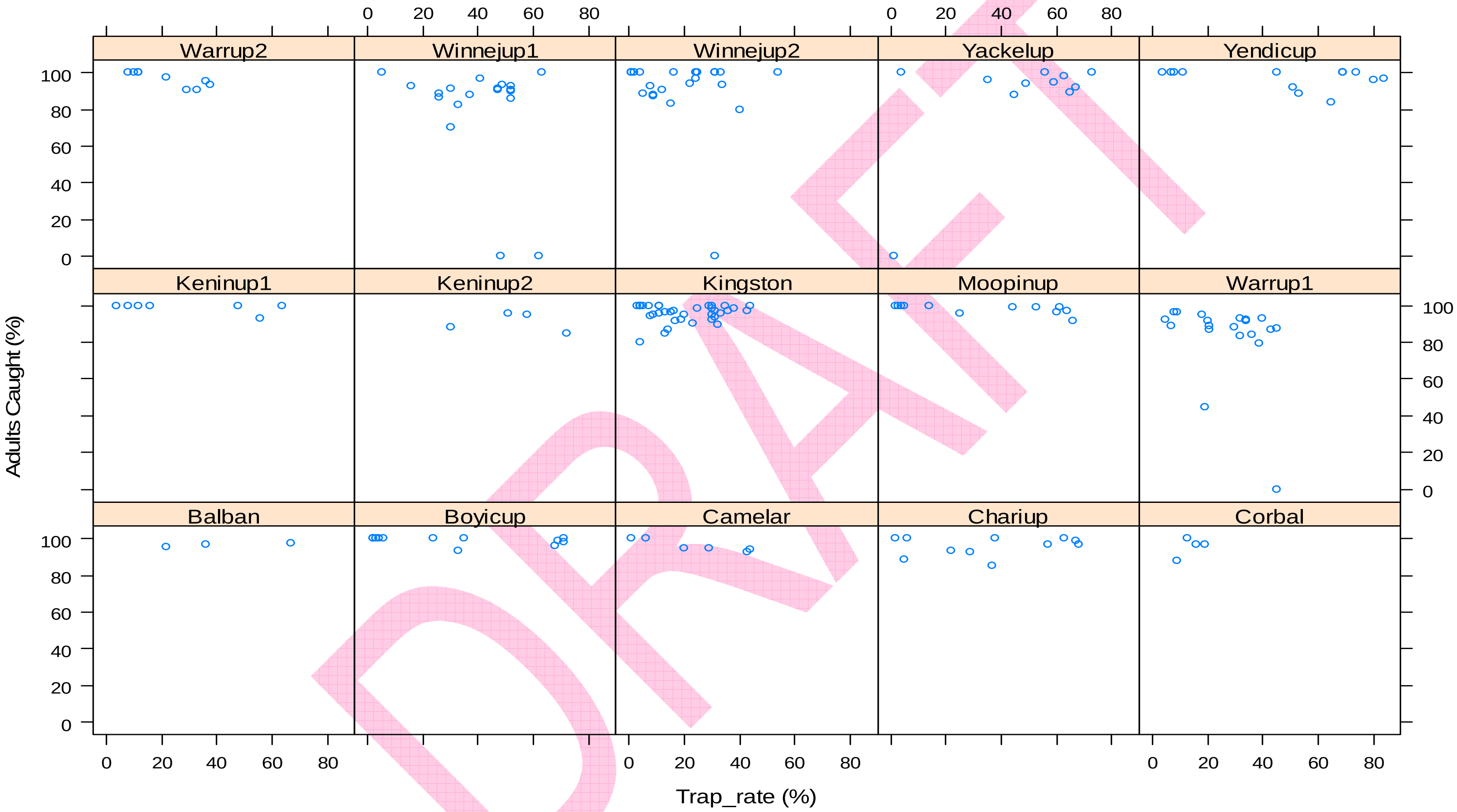

Figure 3.3.9. Percentage of adults caught versus trap rate (percentage of woylies caught) for all sites.

3.3.4.3. Weight

A linear model was used to identify any changes in the weights recorded for woylies caught since January 1994 for all sites. All sites were incorporated into the model initially, however due to the significance of the Time/Site interaction the sites were then selected on the basis of their underlying quadratic nature.

The explanatory variables used in the initial model were Time, $Time^2$, $Time^3$, Site, Age, Sex, Trap Rate, the proportion of adult woylie females that had been recorded as breeding and the interaction term between Time and Site. Other explanatory variables were introduced into the model such as cosine and sine terms to model any possible seasonal variation in the data. The resulting model is shown below in Table 3.3.12.

The reference group included the site Kingston, female woylie and adult woylie.

Table 3.3.12. Linear model where Weight = Cosine term + Sine term + Site + Age + Sex + Time*Site. ('*' Pr<0.001, '**' Pr<0.01, '*' Pr<0.05)**

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	1330.199	9.385	141.73	2.07E-03	***
Infant	-1271.597	46.346	-27.44	2.07E-03	***
Juvenile	-1055.401	14.564	-72.46	2.07E-03	***
Subadult	-411.082	17.438	-23.58	2.07E-03	***
Unknown Age	-44.786	14.531	-3.08	2.07E-03	**
Male	-20.797	3.888	-5.35	9.22E-08	***
Unknown Sex	-52.663	23.736	-2.22	0.03	*
SiteBoyicup	-160.095	20.979	-7.63	2.79E-14	***
SiteChariup	-70.710	17.432	-4.06	5.06E-05	***
SiteKeninup1	469.030	121.637	3.86	1.17E-04	***
SiteMoopinup	51.483	19.642	2.62	0.01	**
SiteWinnejup2	-5.723	13.870	-0.41	0.68	
SiteYackelup	-284.559	52.393	-5.43	5.87E-08	***
SiteYendicup	45.153	48.922	0.92	0.36	
Time	0.221	0.163	1.36	0.17	
cosine_term	12.005	3.905	3.07	2.12E-03	**
sine_term	5.804	3.377	1.72	0.09	.
SiteBoyicup:Time	1.692	0.262	6.45	1.20E-10	***
SiteChariup:Time	0.932	0.222	4.21	2.61E-05	***
SiteKeninup1:Time	-4.707	1.433	-3.28	1.03E-03	**
SiteMoopinup:Time	-0.393	0.246	-1.60	0.11	
SiteWinnejup2:Time	1.069	0.298	3.59	3.40E-04	***
SiteYackelup:Time	2.888	0.507	5.69	1.31E-08	***
SiteYendicup:Time	-0.630	0.447	-1.41	0.16	

Residual standard error: 130.2 on 4788 degrees of freedom

Multiple R-Squared: 0.6014, Adjusted R-squared: 0.5995

F-statistic: 314 on 23 and 4788 DF, p-value: < 2.2e-16

The factors that are significant when looking at changes in the weight of woylies are:

- All age parameters
- All sex parameters
- The cosine term (therefore seasonality is a contributing factor)
- The sites Boyicup, Chariup, Keninup1, Moopinup and Yackelup

- The interaction between Time and the sites Boyicup, Chariup, Keninup1, Winnejup2 and Yackelup

In general, female adult woylies were found to be heavier than male adult woylies, however, woylies of unknown sex were found to be even lighter. The weights of woylies differed between sites. The weights of woylies at the northeastern sites (Keninup, Moopinup and Yendicup) at the beginning of the study were heavier than those individuals found at Kingston (reference group), however, the weights at these sites have decreased over time relative to Kingston. The southeastern sites (Boyicup, Chariup and Yackelup) were less weighty than those individuals found at Kingston, however these woylies have increased in weight over time relative to Kingston individuals.

Further analysis of model included examining the residuals (dispalyed in Figure 3.3.10). The residuals show that the model is a reasonable fit to the dataset, with the majority of the residuals lying between ± 500 grams of the 'actual' data points.

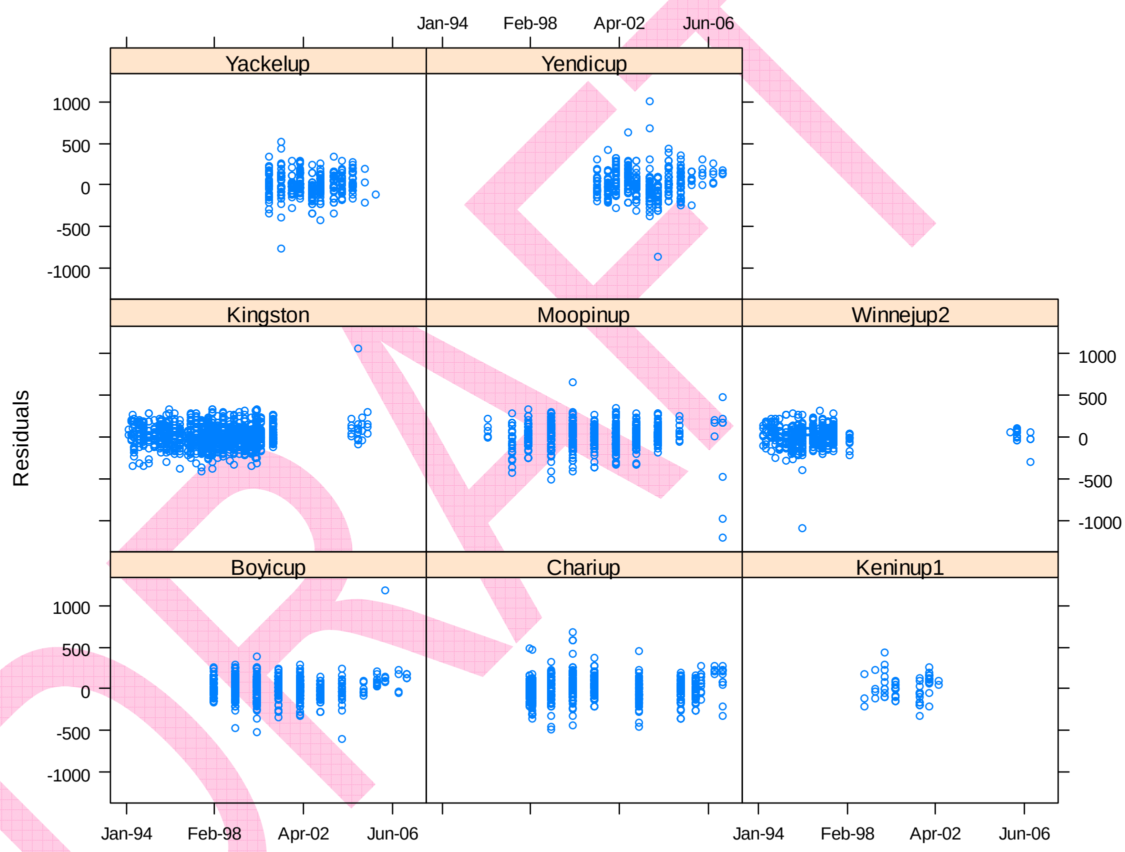

Figure 3.3.10. The residuals of the final model for each site used in the model plotted against time.

Further analysis of this model involved looking at the trap rate (defined as the number of woylies caught divided by the number of traps available). This was examined with respect to the weight of the woylies caught at these intervals. Figure 3.3.11 shows that there is no visible relationship between the trapping rate and the weight of the woylie caught. The results shown in Figure 3.3.11 reiterate the reason why trap rate was found to be not significant.

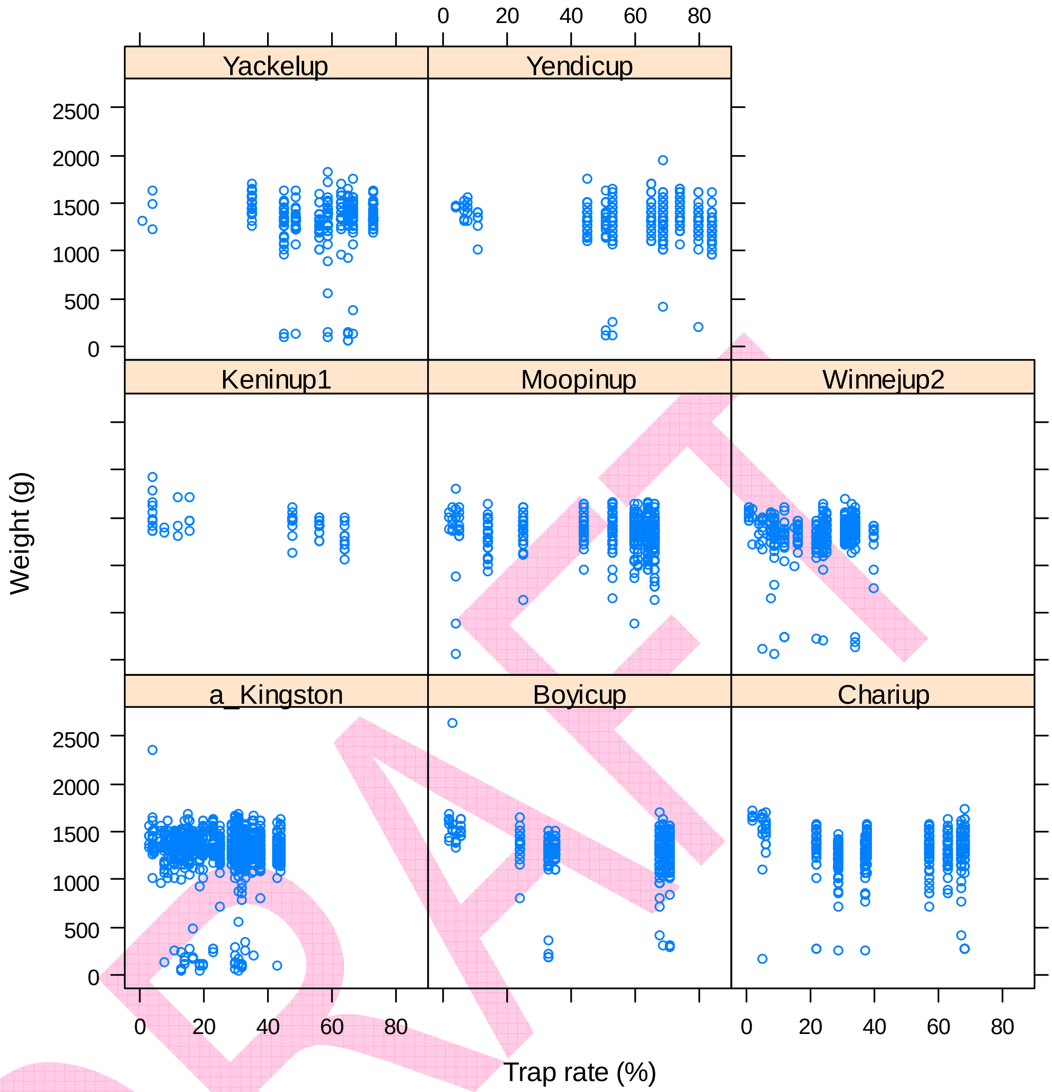

Figure 3.3.11. Weight versus trap rate (percentage of woylies caught) for all sites.

3.3.4.4. Hindfoot length

A linear model was used to identify any changes in hindfoot length recorded for individual woylies caught since January 1994 for all sites. Again, the reference group included Kingston, female woylie and adult woylie.

All sites were incorporated into the model initially, however due to the significance of the Time/Site interaction the sites were then selected on the basis of their underlying quadratic nature.

The explanatory variables used in the initial model were Time, Site, Age, Sex, and the interaction term between Time and Site. Other explanatory variables were introduced into the model such as cosine and sine terms to model any possible seasonal variation in the data, $Time^2$, $Time^3$, Trap Rate, the proportion of adult woylie females that had been recorded as breeding and the Time/Sex interaction. However, these variables were found to be not significant. The final model is shown in Table 3.3.13.

Table 3.3.13. Linear model where Hindfoot Length = Time + Site + Age + Sex + Time*Site. ('*' Pr<0.001, **' Pr<0.01, '*' Pr<0.05)**

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	107.847	0.374	288.29	<2.00E-16	***
Infant	-56.878	1.943	-29.27	< .00E-16	***
Juvenile	-21.586	0.651	-33.14	< .00E-16	***
Subadult	-2.824	0.835	-3.38	7.27E-04	***
Unknown Age	-1.507	1.470	-1.03	0.31	
Male	0.920	0.211	4.36	1.35E-05	***
Unknown Sex	-3.296	2.911	-1.13	0.26	
Time	0.007	0.006	1.17	0.24	
SiteBoyicup	-5.466	1.007	-5.43	6.32E-08	***
SiteChariup	-4.235	0.758	-5.58	2.67E-08	***
SiteKeninup1	2.617	5.354	0.49	0.63	
SiteMoopinup	0.449	1.015	0.44	0.66	
SiteWinnejup2	-0.147	0.563	-0.26	0.79	
SiteYendicup	64.786	73.125	0.89	0.38	
Time:SiteBoyicup	0.040	0.014	2.80	5.24E-03	**
Time:SiteChariup	0.043	0.011	4.05	5.26E-05	***
Time:SiteKeninup1	-0.023	0.066	-0.35	0.72	
Time:SiteMoopinup	-0.017	0.015	-1.11	0.27	
Time:SiteWinnejup2	0.013	0.011	1.15	0.25	
Time:SiteYendicup	-0.428	0.471	-0.91	0.36	

Residual standard error: 4.732 on 2095 degrees of freedom

Multiple R-Squared: 0.5033, Adjusted R-squared: 0.4988

F-statistic: 111.7 on 19 and 2095 DF, p-value: < 2.2e-16

The factors that are significant when looking at changes in the hindfoot length of woylies are:

- The age parameters Infant, Juvenile and Subadult
- The sex parameter Male
- Sites Boyicup and Chariup
- The interaction between Time and the sites Boyicup and Chariup

Male adult woylies have a larger hind foot length than female adult woylies and tended to be larger in the same sites where the weights were found to be heavier.

Further analysis was conducted of the hindfoot length with regards to the residuals produced by this model. Figure 3.3.12 indicates that the model is a good fit to the data as the majority of the residuals show a ±30mm difference between the fitted values of the model and the 'actual' data. Yackelup is missing due to the absence of hindfoot length measurements in the dataset.

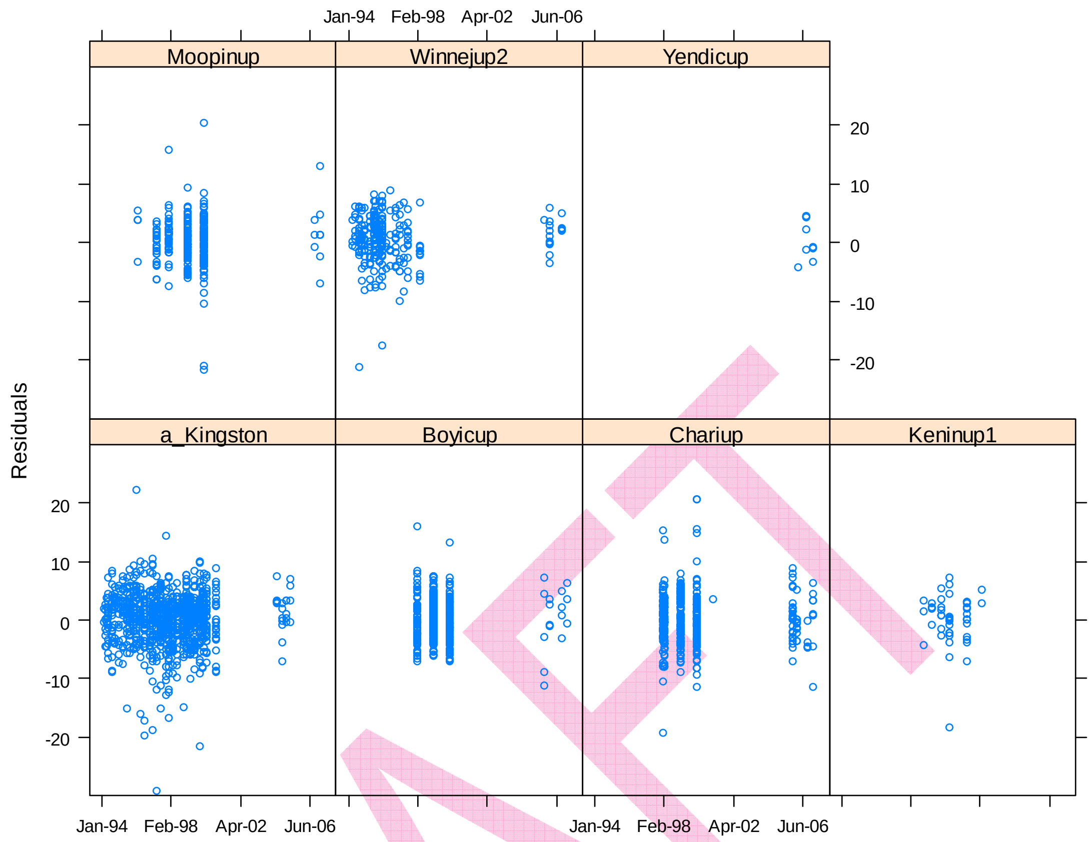

Figure 3.3.12. The residuals of the final model for each site used in the model plotted against time.

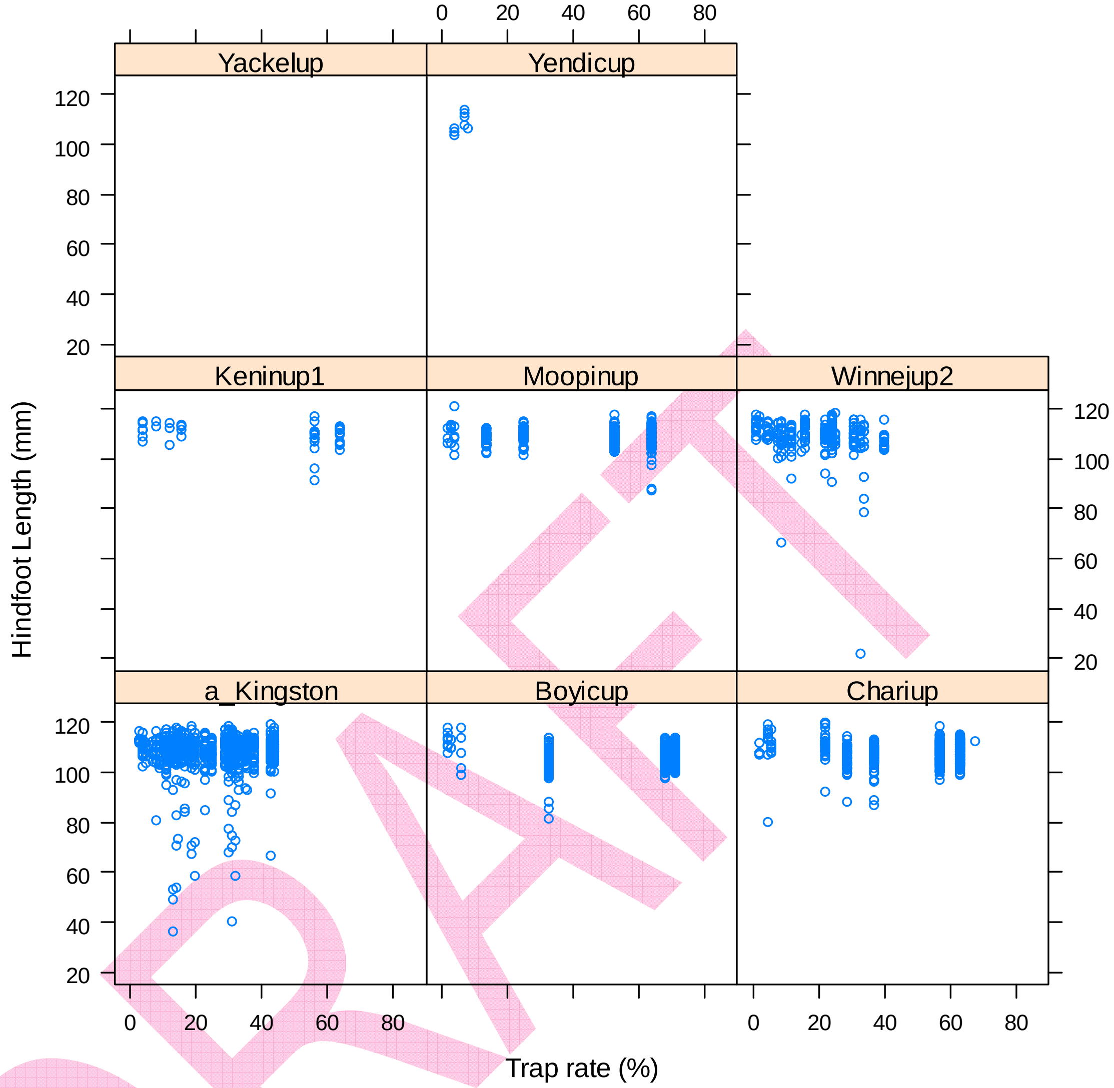

Figure 3.3.13. Hindfoot length versus trap rate (percentage of woylies caught) for all sites.

3.3.4.5. Head length

A linear model was used to identify any changes in head length recorded for woylies caught since January 1994 for all sites. Again, the reference group included Kingston, female woylie and adult woylie.

The explanatory variables used in the initial model were Time, Time^2, Time^3, Site, Time, Age, Sex, Trap Rate and the interaction terms Time*Site and Time*Sex.

Other explanatory variables were introduced into the model such as the proportion of adult woylie females that had been recorded as breeding, and, cosine and sine terms to model any possible seasonal variation in the data. However these were not found to be significant.

All sites were included in this model, however in all models explored the sites themselves were found to be not significant regardless of whether they were combined, separated or selected on the basis of their underlying quadratic nature. The resulting model is shown in Table 3.3.14.

Table 3.3.1. Linear model where Head Length = Age. ('*' Pr<0.001, '**' Pr<0.01, '*' Pr<0.05)**

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	84.46489	0.08297	1018.051	<2.00E-16	***
Infant	-46.1649	1.31379	-35.139	<2.00E-16	***
Juvenile	-29.1456	0.49817	-58.506	<2.00E-16	***
Subadult	-6.54065	0.65089	-10.049	<2.00E-16	***
Unknown Age	-3.53156	1.07378	-3.289	0.001	**

Residual standard error: 3.709 on 2103 degrees of freedom
Multiple R-Squared: 0.6906, Adjusted R-squared: 0.69
F-statistic: 1173 on 4 and 2103 DF, p-value: < 2.2e-16

All age parameters were found to be significant in the model.

Further examination of the residuals is shown in Figure 3.3.14. This indicates that the model is a good fit to the data as the majority of the residuals show a ± 20mm difference between the fitted values of the model and the 'actual' data. Yackelup is missing due to the absence of head length measurements in the dataset for this site.

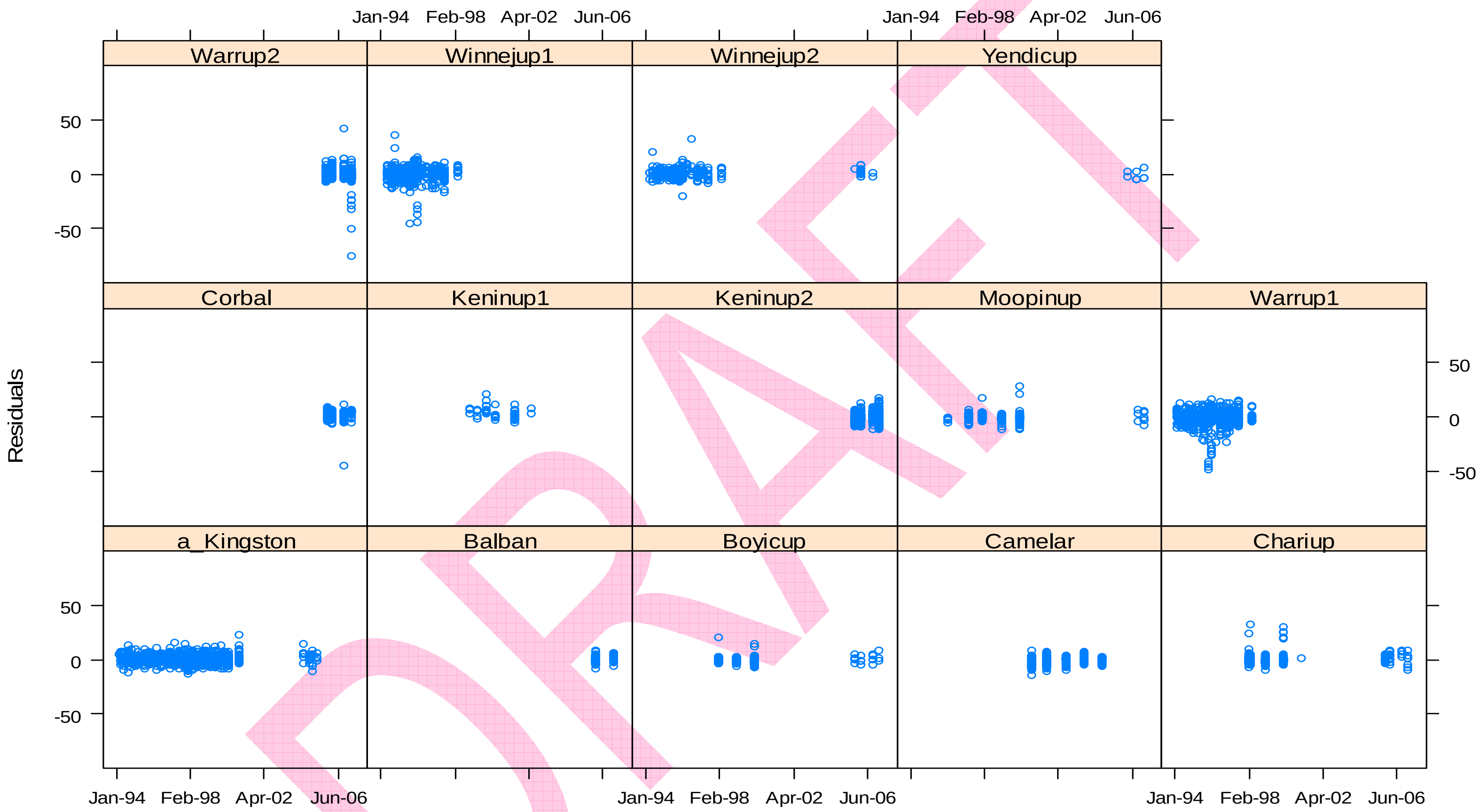

Figure 3.3.14. The residuals of the final model for each site used in the model plotted against time

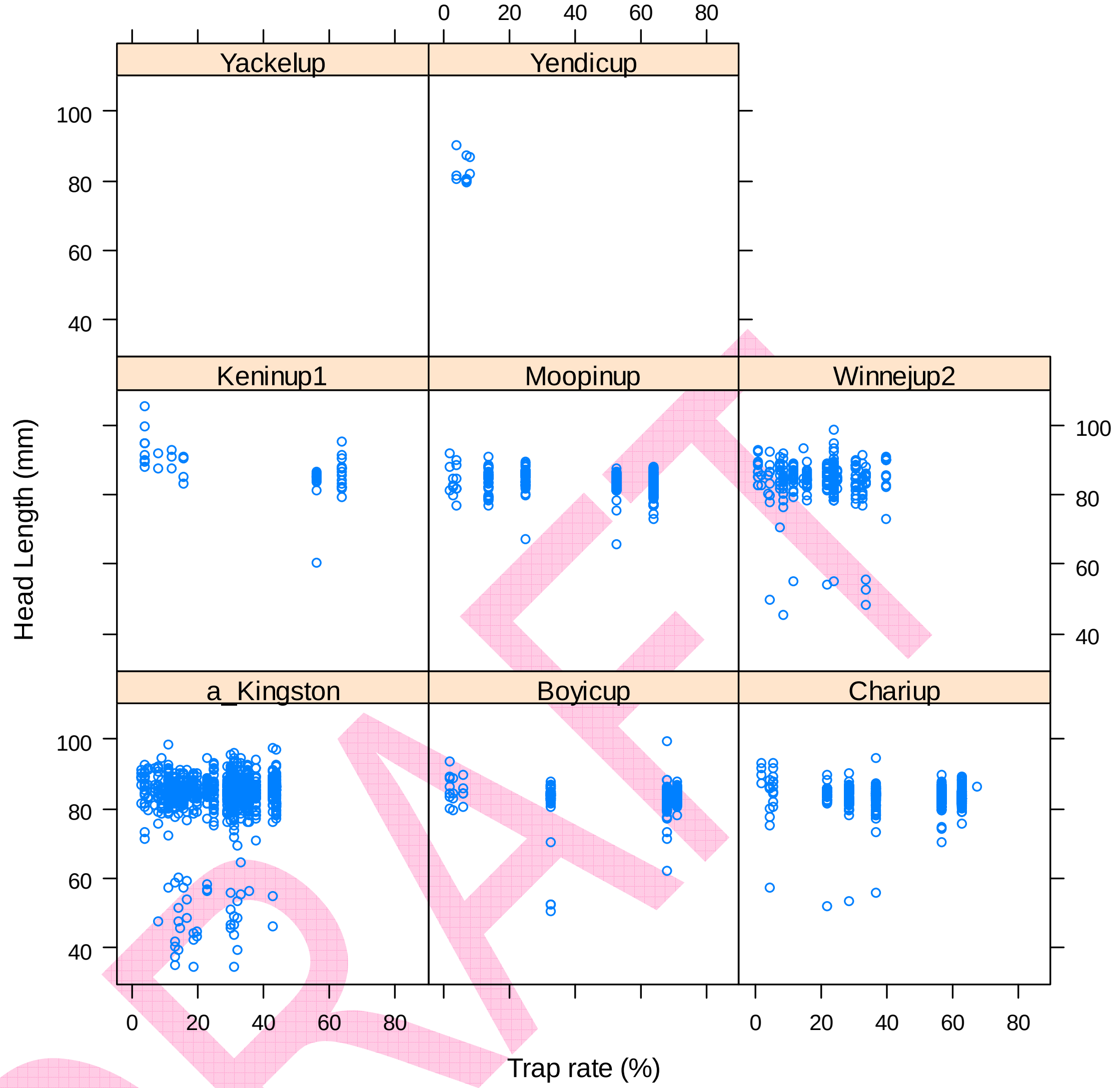

Figure 3.3.15. Head length versus trap rate (percentage of woylies caught) for all sites.

3.3.4.6. Condition index

The condition index was used in a linear model to assess whether the body condition of adult woylie individuals has changed with regards to time, seasonality (cosine and sine terms), site and sex of the woylie individual. Sites were selected on the basis of their underlying quadratic nature.

The explanatory variables used in the initial model were Time, $Time^2$, $Time^3$, Site, Sex, cosine term, sine term, Time*Site and Site*Sex. This model showed some evidence of an increase in condition index for the sites Kingston, Boyicup, Chariup, Winnejup2 and Yendicup and a decrease in condition index for the sites Keninup1 and Moopinup. However, given the variation in the condition index of individuals no reasonable model could be formulated to predict the condition index of an adult woylie.

3.3.4.7. Breeding adult female woylies

The definition of a breeding woylie was outlined in Section 3.3.2.1. An exploratory plot of the proportion of breeding female woylies over time (Figure 3.3.16) did not show any visual relationship for the sites Kingston, Boyicup, Chariup Warrup1, Keninup2, Keninup1 and Winnejup1. The sites Warrup2, Winnejup2, Yackelup, Corbal, Moopinup, Camelar and Balban showed some indication of a possible increase or decrease in the proportion of breeding adult female woylies over time.

The proportion of breeding adult female woylies was then modelled using a generalised linear model to assess if there were any trends over time, differences between sites and any relationships with demographic and biometric variables. Success was defined as an adult female woylie that was recorded as breeding and failure was defined as an adult female woylie that was not recorded as breeding.

A number of models were attempted to fit the data however the models generated were not reliable or conclusive in showing trends over time. It was found that the different models gave vastly different results, the dispersion parameters were extreme and the residuals showed poor fits. This indicates that any model produced using time, demographic or biometric variables would not be robust and may lead to incorrect conclusions being drawn. The only consistent result was that site differences were always evident. This inability to fit a reliable model in which one could be confident in the results is not surprising considering the difficulties involved in calculating accurate measures of the breeding rates as discussed in Section 3.3.2.1.

As a site difference was evident a simplified model using site only as an explanatory variable was fitted and gave a strong indication that there are differences in breeding rates between sites. However, this model should only be used to provide an idea of differences between sites and should not be used in predicting the proportion of adult female woylies that are breeding. The results are shown in Table 3.3.15 and the reference site was Kingston.

Table 3.3.15. Quasibinomial model where Success of Breeding = Site. ('*' Pr<0.001, '**' Pr<0.01, '*' Pr<0.05)**

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.283	0.027	10.390	<2.00E-16	***
SiteBoyicup	-0.754	0.038	-19.898	<2.00E-16	***
SiteChariup	-0.951	0.041	-23.084	<2.00E-16	***
SiteKeninup1	1.145	0.393	2.914	0.004	**
SiteMoopinup	-1.154	0.041	-28.479	<2.00E-16	***
SiteWinnejup2	0.389	0.063	6.201	6.05E-10	***
SiteYackelup	1.019	0.091	11.171	<2.00E-16	***
SiteYendicup	1.231	0.072	17.173	<2.00E-16	***

Dispersion parameter for quasibinomial family taken to be 5.823072

Residual deviance: 33275 on 5222 degrees of freedom

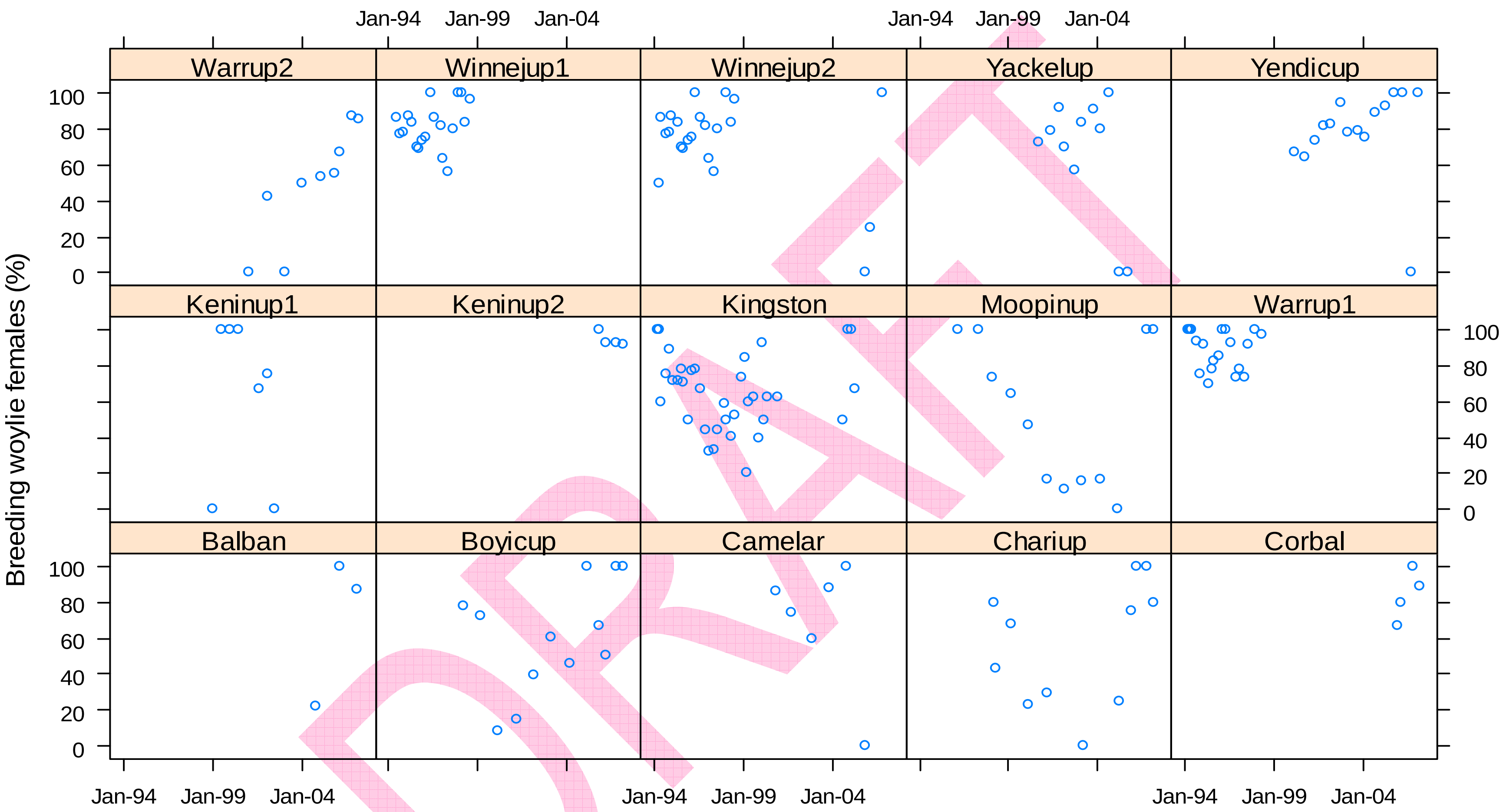

Figure 3.3.16. Percentage of female adult woylies that are breeding over time for all sites.

3.3.5. Conclusions

Population change was modelled via a generalised linear model. The high dispersion shown for each of the models produced demonstrates that the use of a quasibinomial family was the most appropriate in producing these models. Multiple models were investigated and showed similar results, which verified the robustness of the models used in assessing population change.

One of the key questions asked in this analysis was "what can be objectively said regarding the decline (or otherwise) of the woylie population?" The answer is provided in the model shown in Table 3.3.7. The highly statistically significant $Time^3$ term models the strong decline (shown in Figure 3.3.3) that has occurred in the woylie population since 2002. This model is a reasonable approximation of the past twelve years of woylie trapping data. Assuming trapping data is a good indicator of woylie population, this model provides strong evidence of a major decline in the woylie population since 2002.

Any associations the woylies have with other species were not definitive. Quenda were shown to be significant (a positive association) in explaining the capture of a woylie yet common brushtail possums were only barely significant (again positive) and chuditch were not found to be significant.

The average condition index showed an increasing trend in the sites Boyicup, Chariup, Kingston and Yendicup. This increase in condition index was further emphasised when the condition index of individuals were modelled against time and other variables. In the population decline model, the average condition index was fitted as an explanatory variable and was found to be not significant in explaining the decline. This suggests that the decline is not influenced by the body condition of the woylie population.

More male woylies were caught over the duration of the study with approximately 60% of individuals caught being male. The proportion of male woylies caught over time were found to increase at the sites Keninup, Kingston (slow increase), Winnejup (slow increase), Yackelup and Boyicup, whereas the proportion of males decreased over time for the sites Moopinup, Yendicup and Chariup.

The majority of the woylies caught were adults (95%) which restricted the analysis that could take place with respect to the age of the woylie individuals. Using Kingston as a reference group the proportion of adult woylies was investigated at each site. . There was an indication that more adult woylies were caught at Balban, Boyicup, Camelar, Chariup, Corbal, Keninup1, Moopinup, Yackelup and Yendicup and less at Keninup2, Warrup1, Warrup2, Winnejup1 and Winnejup2.

In general, female adult woylies were found to be heavier than male adult woylies, however, woylies of unknown sex were found to be even lighter. The weights of woylies differed between sites. The weights of woylies at the northeastern sites (Keninup, Moopinup and Yendicup) at the beginning of the study were heavier than those individuals found at Kingston (reference group), however, the weights at these sites have decreased over time relative to Kingston. The southeastern sites (Boyicup, Chariup and Yackelup) were less weighty than those individuals found at Kingston, however these woylies have increased in weight over time relative to Kingston individuals.

Other measures of size used in the models were hind foot length and head length. Male adult woylies have a larger hind foot length than female adult woylies and tended to be larger in the same sites where the weights were found to be heavier. Head length was found to be affected by age only.

Investigation was conducted into whether trap capture rates were related to woylie biometrics and demographics (including proportion of adult females in breeding condition), however, no significant statistical relationship was found. Differences were found between the proportion of breeding adult female woylies at different sites, however, no other conclusive relationships could be found with time, demographic or biometric variables with regards to the proportion of breeding adult female woylies.

3.3.6. References

Start, T., A. Burbidge and D. Armstrong. 1995. Woylie Recovery Plan: Wildlife Management Program No 16. Department of Conservation and Land Management, South Australian Department of Environment and Natural Resources, and Australian National Parks and Wildlife Service.