A STATISTICAL STUDY OF SPECTRAL SENSITIVITY IN THE ONION FLY, *DELIA ANTIQUA*

by

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ABSTRACT

The Generalized linear Model(GLIM) was employed to analyze spectral senstivity in the onion fly, *Delia antiqua*. Onion flies were trapped in greater numbers in traps with lower ultraviolet reflectance. Total visible reflectance had some impact on number of flies, both males and females. The GLIM analysis partially, but not entirely, confirmed a previous ad hoc analysis based on transformation to an approximate linear model.

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CHAPTER 1

INTRODUCTION

Many entomologists believe that insects can be highly discriminating while foraging for food or oviposition sites. Much behavioral work has focused on the chemical aspects of host-plant discrimination by phytophagous(plant eating) insects. Most attention has been given to the role of visual stimuli in this process. Of those visual characteristics associated with particular plant resources, color, perhaps because of its apparentness to humans, has received the most attention from entomologists studying host-plant selection behavior by insects. When interpreting the importance of resource color(spectral reflectance) in the foraging behavior of any phytophagous insects, the spectral sensitivity and the photic environment of that insect are important. In general, most insects studied have shown a spectral sensitivity which extends from ca. 300 nm (longwave or near ultraviolet, henceforth labelled as (UV) to yellow-orange at ca. 650 nm. The photic environment of most diurnal, terrestrial insects, is composed of light which spans this range of insect spectral sensitivity.

In this regard, several studies have investigated various wavelength-specific behaviors in the onion fly, *Delia antiqua* (Meigen). The entomologist, G.J.R. Judd, believes that if one wants to interpret accurately the role of spectral reflectance in *Delia antiqua's* food or oviposition host-plant selection, it is necessary to examine wavelength sensitivity more completely. Hence G.J.R. Judd, J.H. Borden, and A.D. Wynne performed a series of experiments to study *Delia antiqua's* response to UV wavelengths and the possible role of this factor in host-plant discrimination. From these studies of the influence of UV wavelength reflectance on the spontaneous alightment behavior of *Delia antiqua* in the field, they tried to obtain answers to the following questions:

<1> Does UV reflectance influence the visual response of *Delia antiqua* during alightment behavior?

<2> Does the VISIBLE reflectance have any additional impact on the response?

1.1 MATERIALS AND METHODS OF THE EXPERIMENTS

The following descriptions were summarized from Judd (1986).

General Methods: The influence of UV wavelength (350-400nm) reflectance on the spontaneous alightment behavior of wild, adult *Delia antiqua* was examined by comparing their response to various high-UV- and low-UV- reflecting achromatic and chromatic visual traps. High-UV-reflecting pigments were specially formulated. Low-UV-reflecting, titanium dioxide(TiO_2)-based, white semi-gloss enamel paint was mixed in varying proportions with a UV-reflecting lead carbonate[$(PbCO_3)_2.PbCOH_2$] white paste, to produce a 6-step UV-reflecting white pigment series. Treatments were evaluated above a mixed background of dark mulchland soil and 10-to 25-cm-high onions, during May-June(1984 and 1985) in commercial onion fields near Cloverdale, B.C.. For consistency, all traps were set 25 cm above the ground and always faced north and south. Traps within individual fields were always separated by 5 meters. Reflectance from 350-650nm (the insect visible spectrum) was measured as a percentage relative to the reflectance from a white M_gO standard.

EXPERIMENT 1 : WHITE SERIES

Experiment 1 was conducted to compare the alightment of *Delia antiqua* on achromatic surfaces with similar high intensity VISIBLE wavelength reflectance, by varying intensities of UV reflectance. As treatments differ only in the intensity of UV reflectance, this experiment is designed to test whether *Delia antiqua* is sensitive to UV reflectance during alightment behavior. Traps were arranged in linear, randomized complete blocks replicated 10 times. The experiment was concluded after five days of trapping.

EXPERIMENT 2 : GREY SERIES

Experiment 2 was conducted to determine if *Delia antiqua's* response to UV-reflecting stimuli was influenced by the quantity of VISIBLE wavelength reflectance, when the relative spectral distribution was held constant. Together, experiments 1 and 2 were designed to determine whether *Delia antiqua* response to achromatic UV-reflecting stimuli depended primarily on overall increases in total reflectance(350-650 nm), on total UV reflectance(350-400 nm), or on changes in the ratio of VISIBLE to UV reflectance, when UV wavelengths were added. Alightment of *Delia antiqua* on eight non-UV-reflecting achromatic surfaces was compared to their alightment on eight similar, but UV-reflecting surfaces. All sixteen treatments were compared simultaneously using a 4-by-4, square balanced lattice replicated with five fields (Montgomery 1984).

EXPERIMENTS 3-5 : BLUE, GREEN, AND YELLOW SERIES

Experiments 3-5 were designed to test whether *Delia antiqua's* response to UV-reflecting stimuli is a function of the quality of VISIBLE spectrum reflectance. Highly saturated paints of blue, green and yellow hues were chosen to represent distinct regions of the VISIBLE spectrum. Each experiment consisted of 12 treatments; six from the appropriate non-UV-reflecting series, and six from the corresponding UV-reflecting series. Each experiment was conducted using a 3-by-4, rectangular balanced lattice with 8, 7, and 8 replications respectively.

EXPERIMENT 6 : SATURATED BLUE HUES + UV

Experiment 6 was designed to examine the response of *Delia antiqua* to UV+BLUE reflectance without increasing VISIBLE spectrum reflectance >500 nm. Four blue pigments were compared : a non-UV-reflecting(E871); UV-reflecting Poster Board(BPB) and two UV-reflecting water paints, Brilliant(BB) and Fluores Blue(FB). TiO_2-white paint traps with and without acetate covering were included as standards for comparison. Treatments were arranged in linear, randomized complete blocks replicated 12 times.

In the next chapter, some possible models will be discussed. The corresponding likelihood, score functions, and information will be derived. The analysis of data, estimates of the parameters and hypothesis testing will be given in Chapter Three. Diagnostic tests of the models based primarily on residual plots will be found in Chapter Four. Finally, conclusions will be presented in Chapter Five.

CHAPTER 2

POSSIBLE MODELS AND METHODS FOR ESTIMATING THE PARAMETERS

Judd(1986) reported how a complicated model was fitted. He stated that the response count of *Delia antiqua* to all treatments ought to have Poisson distribution. This assumption can be justified by the Law of Rare Events. Now, let us state a fact without proof. Let M be a large number of independent Bernoulli trials where the probability p of success on each trial is small and constant from trial to trial. $Y_{M,p}$ denotes the total number of successes in the M trials. Hence, $Y_{M,p}$ follows the binomial distribution.

$$\Pr(Y_{M,p} = k) = \frac{M!}{k!\,(M-k)!} p^k (1-p)^{M-k} \quad \text{for } k=0,1,2,\ldots M.$$

We consider the limiting situation in which M --> ∞ and p --> 0 in such a way that $Mp=\lambda > 0$ where λ is constant. We have

$$\lim_{\substack{M \to \infty \\ p \to 0}} \Pr(Y_{M,p} = k) = \frac{e^{-\lambda} \lambda^k}{k!} \quad \text{for all finite k.}$$

A formal discussion of this phenomenon could be found in Feller(1968). In words, the law says that when there are a large number M of independent Bernoulli trials with a small probability p of success on each trial (constant from trial to trial), then the total number of successes should follow, approximately, the Poisson distribution. As mentioned in Chapter One, there were few traps set in a vast open field with traps always separated by at least 5 meters. It is not unrealistic to assume that there exist a vast number of onion flies in any particular field and that the chance that a fly should land on a trap is comparatively small and constant. Thus, it is reasonable to assume that the number of *Delia antiqua* captured in each trap is a Poisson variate. However, the mean may well depend upon the type of trap, field, time of experiment, etc..

Judd used a square root(N+0.5) transformation to normalize all the data before analysis. This transformation will approximately stabilize the variance. For the comparison between experiments, the response of *Delia antiqua* to all treatments was standardized by expressing the response relative to a TiO_2-white paint trap. That is, the transformed number of *Delia antiqua* trapped on each treatment within a field was divided by the transformed number of *Delia antiqua* trapped on the TiO_2-white trap within the same field. The methods of data analysis were regression and correlation analysis. However, as we know, neither the quotient of two Poisson random variables, nor the quotient of two normal random variables is distributed normally. Judd's method needs more careful study to be justified. In this paper, an alternative to Judd's model based on the assumption that the response count of *Delia antiqua* in each trap has a Poisson distribution, is investigated.

Before discussing possible models for these experiments, some mathematical symbols are needed. These will be used consistently throughout the paper.

NOTATION :

$M_{ij\cdot}$ = a potentially vast unknown number of insects available to be trapped in field j experiment i.

N_{ijk} = number of insects trapped in experiment i, field j, and trap type k. Where $i=1,2,...6$; $j=1,2,...J_i$; and $k=1,2,...K_i$, with J_i = the number of fields used in experiment i, and K_i = the number of different trap types used in experiment i.

P_{ijk} = probability of an individual insect will be trapped by trap type k in experiment i and field j.

$N_{ij\cdot} = \sum_{k=1}^{K_i} N_{ijk}$ = number of insects trapped within field j,

experiment i.

2.1 MODEL

Existing knowledge of *Delia antiqua's* visual behavior is not sufficiently advanced to point to a theoretical function for the behavioral response of *Delia antiqua* under natural conditions to visual stimuli containing both UV and VISIBLE spectrum wavelengths. Our aim, in this project, is to try to find a descriptive model which can give a better picture of the insects' wavelength sensitivity. As mentioned earlier, the N_{ijk}'s can be assumed to be approximately independent Poisson variables. These take the discrete values 0, 1, 2, . . . and their means must be non-negative. A classical additive model for the mean, μ , will not be satisfactory because if $\mathbb{E}(N) = \mu = \xi + \sum_{L=1}^{p} \beta_L X_L$, where $\beta=(\beta_1,\beta_2,...\beta_p)$ are unknown parameters and X's are p-dimensional explanatory covariates, an estimated mean may be negative. This defect can be avoided by setting the logarithm of the expectation equal to $\xi + \sum_{L=1}^{p} \beta_L X_L$, to get $\log(E(N)) = \xi + \sum_{L=1}^{p} \beta_L X_L$, which is a typical log-linear model developed for counts of events in a Poisson or Poisson-like process where the upper limit to the number is infinite or effectively so. Thorough discussion is given by McCullagh and Nelder (1983).

Male and female *Delia antiqua* may have different spectral sensitivity. Also the sex ratio might vary from field to field. It is therefore sensible to examine the six experiments one by one separately for each sex. For example, in experiment 1, ten different fields were used to study the effects of six different UV-reflecting white pigments. In each experiment, all treatments were replicated in each chosen field. Consider N_{1jk} = the number caught in field j with trap type k. The variable manipulated in this experiment is the percentage UV-reflectance, $\%UV_{1jk}$. Expected trap counts will also vary from field to field (primarily through differing insect densities). Hence, one must include a field effect, ζ_{1j}. The log-linear model then yields

$$\log[\mathcal{E}(N_{1jk})] = \zeta_{1j} + X_{1jk}\beta, \quad \text{or} \quad \mathcal{E}(N_{1jk}) = e^{\zeta_{1j}} e^{X_{1jk}\beta} = \lambda_{1j} e^{X_{1jk}\beta}$$

where the X_{1jk}'s are p-dimensional non-linear functions of $\%UV_{1jk}$ and β is the vector of unknown parameters. The multiplicative interaction is reasonable if, all else being equal, a trap in a field with twice the density of insects should have about twice as many insects trapped. The log-linear influence of $\%UV_{1jk}$ is arbitrarily assumed. With this assumption in place, a well-known statistical program GLIM(Generalized Linear Interactive Modelling) can be used for estimate the parameters of the proposed model. The estimates obtained in GLIM are by means of the maximum likelihood method. The method will be illustrated in section 2.2.1.

It would simplify the model analysis if the λ_{ij}'s could be eliminated. These parameters are of no direct interest in this project. Their removal would result in simpler analysis, including a smaller Fisher information matrix but (if done in the following way) in the same estimates of β. Given $N_{1j\cdot} = \sum_{k=1}^{K_1} N_{1jk}$, i.e. the total number of flies captured in a particular field j, we have $(N_{1j1}, N_{1j2}, \ldots N_{1jK})$ is conditionally multinomial$(N_{1j\cdot}, \theta_{1j1}, \theta_{1j2}, \ldots \theta_{1jK})$ and the $N_{1j\cdot}$'s are independent between fields, where

$$\theta_{1jk} = \frac{P_{1jk}}{\sum_{h=1}^{K_1} P_{1jh}}, \quad \text{with } P_{1jk} = \frac{\exp(X_{1jk}\beta)}{\sum_{h=1}^{K_1} \exp(X_{1jh}\beta)}, \quad \text{and hence}$$

$$\theta_{1jk} = \frac{\exp(X_{1jk}\beta)}{\sum_{h=1}^{K_1} \exp(X_{1jh}\beta)}$$

The motivation for the multinomial distribution is that each of the M_{1j} flies in each field j has chance p_{1jk} of being trapped in trap k, and chance p_{1jo} of not being captured. (N_{ijo} is not observed.) It follows that $(N_{1jo}, N_{1j1},...N_{1jk})$ is Multinomial$(M_{1j\cdot}; p_{1j\cdot})$. So $(N_{1j1}, N_{1j2},...N_{1jk} | \sum_{h=1}^{K_1} N_{1jh} = N_{1j\cdot}) \sim$ multinomial$(N_{1j\cdot}, \frac{p_{1jk}}{1-p_{1jo}})$ or multinomial$(N_{1j\cdot}, \theta_{1jk})$ where $k=1,2,...K_1$.

This model has some advantages over the Poisson model, especially with the interest in the comparison of the rate of response for all treatments relative to TiO_2- white traps. The appropriate ratio $\frac{\theta_{1jk}}{\theta_{1js}}$ would lead to the corresponding modified model :

$$\frac{\theta_{1jk}}{\theta_{1js}} = \exp((X_{1jk}-X_{1js})\beta)$$

which Judd was indirectly analyzing. The MLE estimates for the β's and the Fisher information matrix for the multinomial model will be found in section 2.2.2.

2.2 MAXIMUM LIKELIHOOD ESTIMATES AND FISHER INFORMATION MATRIX

2.2.1 POISSON MODEL

The Poisson model in 2.1, will be fitted for each experiment separately for males and females. Maximum likelihood estimates will now be derived. For simplicity, only the estimates for males in experiment 1 will be derived in this section and in section 2.2.2. Let

N_{1jk} be the number of male *Delia antiqua* trapped in experiment 1, field j in trap type k. This is assumed to be Poisson distributed with mean $\mu_{1jk} = \lambda_{1j}\exp(X_{1jk}\beta)$, where λ_{1j} is the j field factor, and X_{1jk} is the p-dimensional covariates of trap type k in field j. Hence, the likelihood function for N_{1jk}, j=1,2,...10, k=1,2,...6.

$$L = \prod_{j=1}^{10} \prod_{k=1}^{6} \frac{\exp(-\mu_{1jk})(\mu_{1jk})^{N_{1jk}}}{N_{1jk}!}$$

$$= \prod_{j=1}^{10} \prod_{k=1}^{6} \frac{\exp[-\lambda_{1j}\exp(X_{1jk}\beta)]\,[\lambda_{1j}\exp(X_{1jk}\beta)]^{N_{1jk}}}{N_{1jk}!}$$

The log likelihood function is therefore

$$\log(L) = -\sum_{j=1}^{10}\sum_{k=1}^{6} \lambda_{1j}\exp(X_{1jk}\beta) + \sum_{j=1}^{10}\sum_{k=1}^{6} N_{1jk}\{\log(\lambda_{1j}) + X_{1jk}\beta\}$$

$$- \sum_{j=1}^{10}\sum_{k=1}^{6} \log(N_{ijk}!) \qquad \text{...............(2.1)}$$

The first derivatives of this log likelihood function with respect to parameters, λ_{1j} and β, are expressed as follows :

$$\frac{\partial \log(L)}{\partial \lambda_{1j}} = -\sum_{k=1}^{6} \exp(X_{1jk}\beta) + \sum_{k=1}^{6} \frac{N_{1jk}}{\lambda_{1j}} \qquad \text{..............(2.2)}$$

$$\frac{\partial \log(L)}{\partial \beta_s} = -\sum_{j=1}^{10}\sum_{k=1}^{6} \lambda_{1j}\exp(X_{1jk}\beta)\, x_{1jk_s}$$

$$+ \sum_{j=1}^{10}\sum_{k=1}^{6} N_{1jk}\, x_{1jk_s} \qquad \text{............(2.3)}$$

The MLE's, $\hat{\lambda}_{1j}$, $\hat{\beta}$'s can then be solved for by setting the above derivatives equal to zero.

Solving $\dfrac{\partial \log(L)}{\partial \lambda_{1j}} = 0$ for $\hat{\lambda}_{1j}$ yields $\hat{\lambda}_{1j} = \dfrac{\sum_{k=1}^{6} N_{1jk}}{\sum_{k=1}^{6} \exp(X_{1jk}\beta)}$.

By setting $\lambda_{1j} = \hat{\lambda}_{1j}$ in $\dfrac{\partial \log(L)}{\partial \beta_s}$, we obtain

$$\left.\frac{\partial \log(L)}{\partial \beta_s}\right|_{\hat{\lambda}_{1j}} = -\sum_{j=1}^{10}\sum_{k=1}^{6} (\hat{\lambda}_{1j})\exp(X_{1jk}\beta)\, x_{1jk_s}$$

$$+ \sum_{j=1}^{10}\sum_{k=1}^{6} N_{1jk}\, x_{1jk_s}$$

$$= -\sum_{j=1}^{10}\sum_{k=1}^{6} \left(\frac{\sum_{h=1}^{6} N_{1jh}}{\sum_{h=1}^{6} \exp(X_{1jh}\beta)}\right) \exp(X_{1jk}\beta)\, x_{1jk_s}$$

$$+ \sum_{j=1}^{10}\sum_{k=1}^{6} N_{1jk}\, x_{1jk_s}$$

$$= -\sum_{j=1}^{10} N_{1j\cdot} \sum_{k=1}^{6} \frac{(\exp(X_{1jk}\beta)\, x_{1jk_s})}{\sum_{h=1}^{6} \exp(X_{1jh}\beta)}$$

$$+ \sum_{j=1}^{10}\sum_{k=1}^{6} N_{1jk}\, x_{1jk_s}$$

We shall see that they are the same equations as those for the estimates in the multinomial model in section 2.2.2.

By evaluating the second derivatives of the log likelihood function (equation (2.2) and (2.3)) with respect to parameters, λ_{1j}, and the β's, a symmetric Fisher information matrix, **I**, is obtained as follows :

$$\begin{bmatrix} \mathcal{E}\left(\frac{-\partial^2 \log(L)}{\partial \lambda_{1j}^2}\right) \ldots\ldots \mathcal{E}\left(\frac{-\partial^2 \log(L)}{\partial \lambda_{1j} \partial \beta_p}\right) & \ldots\ldots & \mathcal{E}\left(\frac{-\partial^2 \log(L)}{\partial \beta_p \partial \beta_q}\right) \\ \ldots\ldots \quad \ldots\ldots \quad \ldots\ldots & \ldots\ldots & \vdots \\ \ldots\ldots \quad \ldots\ldots \quad \ldots\ldots & \ldots\ldots & \mathcal{E}\left(\frac{-\partial^2 \log(L)}{\partial \beta_p^2}\right) \end{bmatrix}$$

where, $\mathcal{E}$=expectation and the values of λ_{1j}, β's are the true parameter values.

The entries of the Fisher information matrix are shown below :

$$\mathcal{E}\left(\frac{-\partial^2 \log(L)}{\partial \lambda_{1j}^2}\right) = \sum_{k=1}^{6} \frac{\mathcal{E}(N_{1jk})}{(\lambda_{1j})^2} = \sum_{k=1}^{6} \frac{\exp(X_{1jk}\beta)}{\lambda_{1j}}$$

$$\mathcal{E}\left(\frac{-\partial^2 \log(L)}{\partial \lambda_{1j} \partial \beta_p}\right) = \sum_{k=1}^{6} \exp(X_{1jk}\beta) * x_{1jk_p}$$

$$\mathcal{E}\left(\frac{-\partial^2 \log(L)}{\partial \beta_p \partial \beta_q}\right) = \sum_{j=1}^{10} \sum_{k=1}^{6} \lambda_{1j} \exp(X_{1jk}\beta) * x_{1jk_p} * x_{1jk_q}$$

$$E\left(\frac{-\partial^2 \log(L)}{\partial \beta_p^{\ 2}}\right) = \sum_{j=1}^{10} \sum_{k=1}^{6} \lambda_{1j} \exp(X_{1jk}\beta) * x_{1jk_p} * x_{1jk_p}$$

The theoretical variance-covariance matrix is obtained by inverting the above Fisher information matrix.

2.2.2 MULTINOMIAL MODEL

As mentioned in section 2.1, for experiment 1 given $N_{1j\cdot} = \sum_{h=1}^{K_1} N_{1jh}$ in each field, $(N_{1j1}, N_{1j2}, \ldots N_{1jk}) \sim \text{multinomial}(N_{1j\cdot}, \theta_{1j1}, \theta_{1j2}, \ldots \theta_{1jk})$ with $N_{1j\cdot}$ independent between fields, and $\theta_{1jk} = \dfrac{\exp(X_{1jk}\beta)}{\sum_{h=1}^{k_1} \exp(X_{1jh}\beta)}$. Hence, the conditional log likelihood given $N_{1j\cdot}$ is :

$$\log(L(\beta; N_{1j\cdot}, N_{1j1}, N_{1j2}, \ldots N_{1j6})) = \sum_{j=1}^{10} \left\{ \log \binom{N_{1j.}}{N_{1j1} N_{1j2} \ldots N_{1j6}} + \sum_{k=1}^{6} N_{1jk} \log(\theta_{1jk}) \right\}$$

and $\log \theta_{1jk} = X_{1jk}\beta - \log(\sum_{k=1}^{6} \exp(X_{ijh}\beta))$. Then we get

$$\log(L(\beta; N_{1j\cdot}, N_{1j1}, N_{1j2}, \ldots N_{1j6})) = \sum_{j=1}^{10} \log \binom{N_{1j.}}{N_{1j1} N_{1j2} \ldots N_{1j6}}$$

$$+ \sum_{j=1}^{10} \sum_{k=1}^{6} N_{1jk} \{ X_{1jk}\beta - \log[\sum_{h=1}^{6} \exp(X_{ijh}\beta)] \}$$

Recall the log likelihood function (2.1) in the Poisson model in section 2.2.1 for (λ_{1j},β)

$$\log(L) = \sum_{j=1}^{10}\sum_{k=1}^{6} -\lambda_{1j}\exp(X_{1jk}\beta) + \sum_{j=1}^{10}\sum_{k=1}^{6} N_{1jk}\{\log(\lambda_{1j}) + X_{1jk}\beta\} + \text{constant}$$

Take the transformation

$$\tau_j = \sum_{k=1}^{6}\lambda_{1j}\exp(X_{1jk}\beta) = \lambda_{1j}\sum_{k=1}^{6}\exp(X_{1jk}\beta) \quad \text{and}$$

$$\log\tau_j = \log(\lambda_{1j}) + \log(\sum_{k=1}^{6}\exp(X_{1jk}\beta)$$

Hence the log likelihood becomes

$$\text{Log}(L) = -\sum_{j=1}^{10}\tau_j + \sum_{j=1}^{10}\sum_{k=1}^{6} N_{1jk}\{\log\tau_j - \log[\sum_{k=1}^{6}\exp(X_{1jk}\beta)]\}$$

$$+\sum_{j=1}^{10}\sum_{k=1}^{6} N_{1jk}X_{1jk}\beta + \text{constant}$$

$$= \sum_{j=1}^{10}[N_{1j\cdot}\log\tau_j - \tau_j] + \sum_{j=1}^{10}\sum_{k=1}^{6} N_{1jk}[X_{1jk}\beta - \log(\sum_{h=1}^{6}\exp(X_{ijh}\beta))]$$

$$+ \text{constant}$$

The expression $\sum_{j=1}^{10}[N_{1j\cdot}\log\tau_j - \tau_j]$ is the Poisson log likelihood for the conditional field total $N_{1j\cdot}$, and $\sum_{j=1}^{10}\sum_{k=1}^{6} N_{1jk}\{X_{1jk}\beta - \log[\sum_{h=1}^{6}\exp(X_{ijh}\beta)]\}$ is the multinomial log likelihood as above. It is clear that $\hat{\beta}$ and cov($\hat{\beta}$) based on Poisson model and multinomial model are the same. This result demonstrates the connection between the Poisson model and the multinomial response model. It shows that the field totals give no information concerning β. It makes sense that the field totals themselves give no information concerning the trap type effects. General discussion can be found in McCullagh and Nelder(1983 p.140).

CHAPTER 3

STATISTICAL ANALYSIS OF EXPERIMENTAL DATA

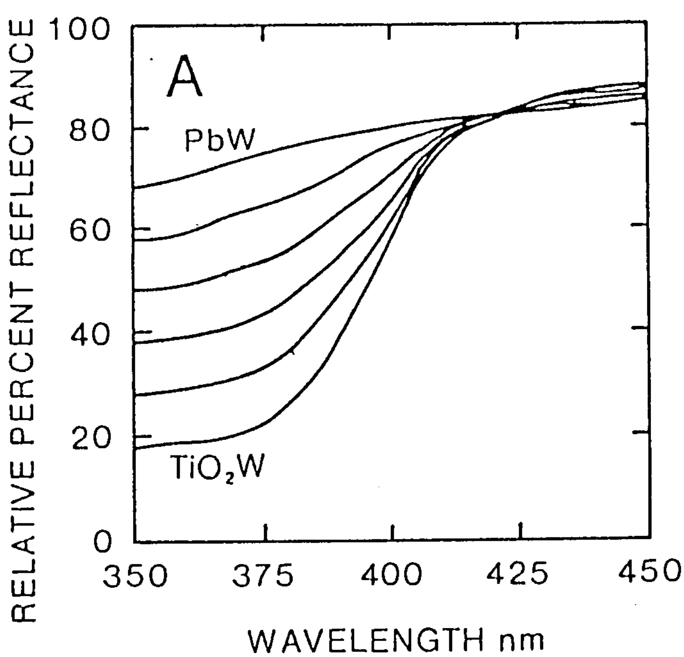
The source of the data for this project has been described in chapter 1. There are six different, designed experiments. The proposed log-linear models discussed in chapter 2 were fitted separately for each sex and experiment. The problems of hypothesis testing are complicated by the nature of the likelihood function and by the fact that maximum likelihood estimates cannot be expressed in explicit algebraic form. The comparison of the parameter estimates with their standard errors is justified only by asymptotic theory. The adequacy of this approximation is not yet well known. The standard errors do not provide 'exact' p-values for significance tests. They must be viewed only as a general guide to the accuracy of the estimates. Usually a parameter estimate that is less than its standard error will be insignificant, and one that is more than 3 times its standard error will be significant. (see GLIM manual part I)

A measure of discrepancy (or goodness of fit) is obtained by comparing the likelihood of the current model, L_c, to the likelihood of the full model, L_f, with the given data. In terms of a GLM, a measure of the reasonableness of the current model relative to that of the full model, is by mean of log likelihood-ratio statistic, $\Lambda = -2\log(\frac{L_c}{L_f})$. This statistic is called the <u>scaled deviance</u>. It is also the <u>deviance</u> for a Poisson distribution with a log link function.(GLIM manual part I) In GLIM, it states that if certain assumed regularity conditions hold, then $\Lambda = -2\log(\frac{L_c}{L_f})$ is distributed under the current model as χ^2_ν with ν degree of freedom where $\nu = t_f - t_c$, t_f(or t_c) is the number of independent parameters estimated under the corresponding hypothesis. This distribution is only approximate.(See GLIM for further details) The results will be given in sections 3.1 to 3.6.

3.1 EXPERIMENT 1 WHITE SERIES

This experiment was designed to find how sensitive *Delia antiqua* is to UV reflectance during alightment behavior. The response of *Delia antiqua* to various UV reflectance levels (a percentage measure relative to the reflectance from a white M_gO standard) could be presented as a (10 X 6) (field X trap) cross-classification with rows representing fields and columns representing trap types. Results are given in table 3.1.A(male and female). Figure 3.I displays the UV-blue spectral reflectance curves for the white pigments used in this experiment (note: all spectral reflectance curves were produced by Judd). The row margins in these tables are random. They give information about the relative size of the total population of *Delia antiqua* in the different fields but provide no direct information about the response of the flies to the different trap types.

FIGURE 3.I UV-blue spectral reflectance curves for white pigment in Experiment 1



The fitted male's response is used as an example. The fitted values to the data are :

I POISSON MODEL

$\mathcal{E}(N_{jk}) = \varphi_{jk} = \lambda_j \, EXP(-0.02904 \ \%UV_k)$ or

$\log(\mathcal{E}(N)) = \zeta_j - 0.02904 \ \%UV_k$. (note $\zeta_j = \log(\lambda_j)$ where j=1,2,...,10.) ,

or in words :

log(expected frequency of *Delia antiqua* landing in a given trap) =

some field factor - 0.02904 $\%UV_k$.

II MULTINOMIAL MODEL

The estimated conditional probability that an individual insect will be trapped in a particular trap is :

$$\theta_k = \frac{EXP(-0.02904 \ \%UV_k)}{\sum_{h=1}^{6} EXP(-0.02904 \ \%UV_h)}$$

As discussed in chapter 2, the MLE's of the β's in both the Poisson and multinomial models are the same. The estimates of β and the standard error are obtained via GLIM. The fitted values and the corresponding estimated standard errors and p-values are summarized in tables 3.I.B(males) and 3.I.B(females). The estimated effect of UV reflectance in the six specified traps are:

$\%UV_k$	31	38	47	56	65	74
θ_k	0.28	0.23	0.18	0.13	0.10	0.08

The response count of male *Delia antiqua* was negatively related with increasing UV reflectance from white traps, while the response count of females shows insignificant pattern to the UV-reflecting white series. The discrepancy may be an indication of the sexual difference of *Delia antiqua* response to UV reflectance during alightment behaviour. The fits agree with Judd's analysis. However, he could not fit a significant linear equation for females. Perhaps males are more sensitive to the increases in UV reflectance from white color than females.

Table 3.I.A Observed frequency count in experiment 1

		Average %UV reflectance levels in each trap													
		31%		38%		47%		56%		65%		74%		Total	
		M	F	M	F	M	F	M	F	M	F	M	F	M	F
	1	6	6	7	3	2	2	4	2	4	3	2	1	25	17
	2	10	2	4	1	5	1	4	2	4	3	2	0	29	9
F	3	9	1	4	0	6	1	2	1	2	3	2	0	25	6
I	4	5	1	8	2	3	1	2	2	1	2	1	2	20	10
E	5	13	5	9	2	9	3	4	4	6	4	3	3	44	21
L	6	10	4	14	2	7	2	3	5	6	1	7	0	47	14
D	7	6	3	4	4	3	3	4	4	2	5	2	2	21	21
S	8	20	6	9	5	9	4	4	5	3	4	4	1	49	25
	9	11	2	9	1	6	6	9	1	7	3	1	1	43	14
	10	8	1	7	4	8	3	6	3	6	5	1	0	36	16
TOTAL		98	31	75	24	58	26	42	29	41	33	25	10	339	153

Table 3.I.B(male) Experiment 1

Coefficients of the fitted log-linear model, standard deviations and deviances after the fit for male.

$$\log(\Phi_{jk}) = \hat{\xi}_j + \hat{\beta}\ \%UV_{jk}$$

where $\Phi_{jk} = E(N_{jk})$ the expected male frequencies at the given k type trap.

Parameter	Estimates	Standard erroe	P-value
$\hat{\beta}$	-0.02904	0.003860	0.000

Deviance of fitted model	Degree of freedom	P-value
34.30	49	0.945

Note: $\hat{\xi}_j$ the estimated field factor which is not of direct interest

Table 3.I.B(female) Experiment 1

Coefficients of the fitted log-linear model, standard deviations and deviances after the fit for female.

$$\log(\Phi_{jk}) = \hat{\xi}_j + \hat{\beta}\ \%UV_{jk}$$

where $\Phi_{jk} = E(N_{jk})$ the expected female frequencies at the given k type trap.

Parameter	Estimates	Standard erroe	P-value
$\hat{\beta}$	-0.009776	0.005444	0.072

Deviance of fitted model	Degree of freedom	P-value
46.75	49	0.565

3.2 EXPERIMENT 2 GREY SERIES

This experiment was designed to examine *Delia antiqua*'s response to UV-reflecting stimuli and non-UV-reflecting stimuli with the relative grey intensity held constant. (See figure 3.II) The percentage measure of blue and green are highly correlated. The correlation coefficient of percentage blue and percentage green is 0.998. Take a closer look to the data. Besides the fact that %blue and %green are highly correlated, the non-UV-reflecting traps trapped more than the UV-reflecting traps. (It has been found in experiment 1.) The ratios between %UV and %blue are less than 1 in non-UV-reflecting traps and very close to 1 in UV-reflecting traps. Judd(1986) mentions that many plants have longwave/shortwave ratio (longwave >500 nm, shortwave <500 nm) larger than one, and a small ratio associates with sky light. Nevertheless, no theoretical model has been proven to be valid in *Delia antiqua* alightment. The input covariates, including %UV, %blue, %green, $\frac{\%\text{blue}}{\%\text{UV}}$, $\frac{\%\text{green}}{\%\text{UV}}$, $\frac{(\%\text{blue}+\%\text{green})/2}{\%\text{UV}}$, ..., have been tried with many possible combinations. The input covariate UV/VISIBLE = $\frac{\%\text{UV}}{\frac{1}{2}(\%\text{Blue}+\%\text{Green})}$, not surprisingly, was found to be the best explanatory variate in the given model. The 'best' was determined by the amount of deviance reduced.

Both male and female data sets did not fit the model well. The p-values for both fitted models were obtained as 0.0044 and 0.0045 respectively. That is, if the assumed model is correct, the chance of obtaining data as deviant from the model prediction as that in hand is about 44 in every 10,000 experiments. We cannot therefore accept the assumed hypothesis. The poor fit to the males may be attributable to an outlier. With an extraordinarily high count from a black trap omitted, the corresponding deviance dropped from 109.8 with 74 degrees of freedom to 85.65 with 73 degrees of freedom. (The p-value jumped from 0.0044 to 0.1477). No similar improvement could be found for females.

The observed data are in tables 3.II.A(males) 3.II. A(females). Summary information is in 3.II.B(males) and 3.II.B(females).

A Poisson model requires that the variance of the response be equal to the expectation of the response, var(N)= $\mathbb{E}$(N), over the entire range of parameter values. However, GLIM gave the scale parameters to be 1.483 and 1.482 in males and females respectively. These estimates are quite a bit higher than those for the other experiments. (The rest are ranged from 0.700 to 1.182.) It may be more accurate to estimate the var(N) by multiplying $\mathbb{E}$(N) by the scale parameter.

FIGURE 3.II Spectral reflectance curves, for non-UV-reflecting grey pigments(A) and UV-reflecting grey pigments(B) in Experiment 2.

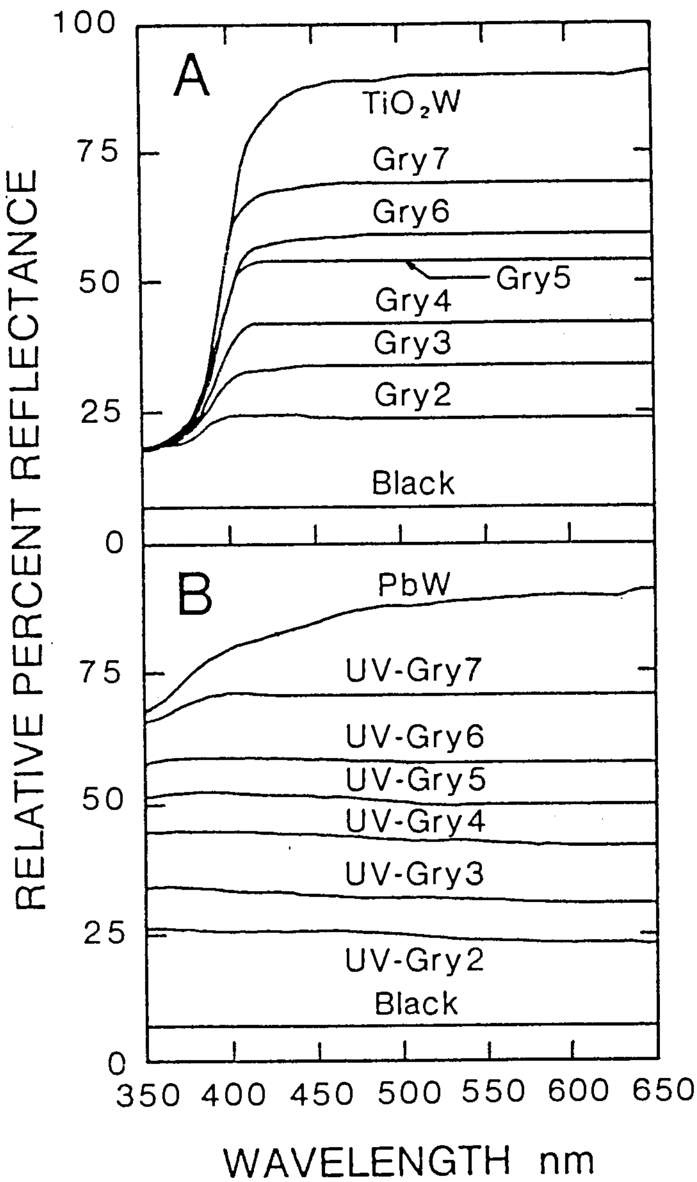


Table 3.II.A(male). Observed frequency counts in experiment 2

	Average %UV %BL %GR reflectance level in each trap																
%UV	30	30	28	27	24	23	21	7	7	74	69	59	52	45	34	26	
%BL	84	68	58	54	42	34	24	7	7	84	71	58	51	43	32	24	Total
%GR	90	68	58	54	42	34	24	7	7	90	71	58	51	43	32	24	
F 1	26	16	19	12	7	1	3	1	3	4	0	4	1	1	1	0	99
E 2	4	4	0	3	0	0	2	0	1	1	0	1	0	1	0	0	17
I 3	13	11	7	10	5	7	2	0	2	2	2	2	0	0	3	0	66
D 4	9	5	7	4	4	1	2	0	0	2	1	0	0	1	2	4	42
S 5	4	5	1	2	2	2	1	7	0	2	1	1	0	0	0	0	28
Total	56	41	34	31	18	11	10	8	6	11	4	8	1	3	6	4	252

Table 3.II.A(female) Observed frequency counts in experiment 2

	Average %UV %BL %GR reflectance level in each trap																
%UV	30	30	28	27	24	23	21	7	7	74	69	59	52	45	34	26	
%BL	84	68	58	54	42	34	24	7	7	84	71	58	51	43	32	24	Total
%GR	90	68	58	54	42	34	24	7	7	90	71	58	51	43	32	24	
F 1	18	18	13	6	5	12	5	1	0	4	4	1	0	1	4	1	93
I 2	2	6	6	3	4	0	1	1	0	1	0	0	0	0	0	2	26
E 3	15	18	4	12	4	8	4	3	1	0	2	4	4	5	3	7	94
L D 4	10	5	8	4	5	4	2	1	0	2	2	0	1	0	4	0	48
S 5	4	4	2	3	5	1	2	3	0	2	0	0	1	1	1	1	30
Total	49	51	33	28	23	25	14	9	1	9	8	5	6	7	12	11	291

Table 3.II.B(male) EXPERIMENT 2

Coefficients of the fitted log-linear model, standard deviations and deviances after the fit for males

$$\text{Log}(\Phi_{jk}) = \hat{\xi}_j + \hat{\beta}\frac{\%UV}{(\%BL+\%GR)/2}$$

where $\Phi_{jk} = E(N_{jk})$ the expected male frequencies at the given k type trap.

Parameter	Estimates	Standard error	P-value
$\hat{\beta}$	-3.534	0.2735	0.000
* $\hat{\beta}$	-3.753	0.2853	0.000

Deviance of fitted model	Degree of freedom	P-value
109.8	74	0.004
* 85.7	73	0.148

Note : * the fitted value after deletion of outlier.

Table 3.II.B(female) Experiment 2

Coefficients of the fitted log-linear model, standard deviations and deviances after the fit for female.

$$\log(\Phi_{jk}) = \xi_j + \hat{\beta}\frac{\%UV}{(\%BL+\%GR)/2}$$

where $\Phi_{jk} = E(N_{jk})$ the expected female frequencies at the given k type trap.

Parameter	Estimates	Standard erroe	P-value
$\hat{\beta}$	-2.833	0.2896	0.000

Deviance of fitted model	Degree of freedom	P-value
109.7	74	0.004

3.3 EXPERIMENT 3 BLUE SERIES

This experiment was conducted to determine Delia antiqua's response to UV-reflecting stimuli in the blue regions of the VISIBLE spectrum. There is an interesting phenomenon : Similar fitted models for both sex have been found in this spectral region. The best models for males and females were obtained by a similar model fitting strategy as used in experiment 2. The fitted equations were found to be:

$$\text{males}: \quad \log(\varphi_{jk}) = \text{field factor} -2.855 \left(\frac{\%UV}{\%Blue}\right)_k - 0.01193\ (\%Green)_k$$

$$\text{females}: \quad \log(\varphi_{jk}) = \text{field factor} -2.713 \left(\frac{\%UV}{\%Blue}\right)_k - 0.01299\ (\%Green)_k$$

The negative sign found related with %green indicated that VISIBLE wavelength (>500nm) actually cause a negative effect in *Delia antiqua* on blue traps in an onion field. Anyway, the traps in this experiment trapped the highest frequencies, both in males and females, relative to green and yellow series in experiments 4 and 5. Spectral reflectance curves are in figure 3.Ⅲ. Data are in table 3.ⅢA(males) and 3.ⅢA(females). Summaries are in tables 3.ⅢB(males) and 3.ⅢB(females)

FIGURE 3.III Spectral reflectance curves, for non-UV-reflecting blue pigments(A) and UV-reflecting blue pigments(B) in Experiment 3.

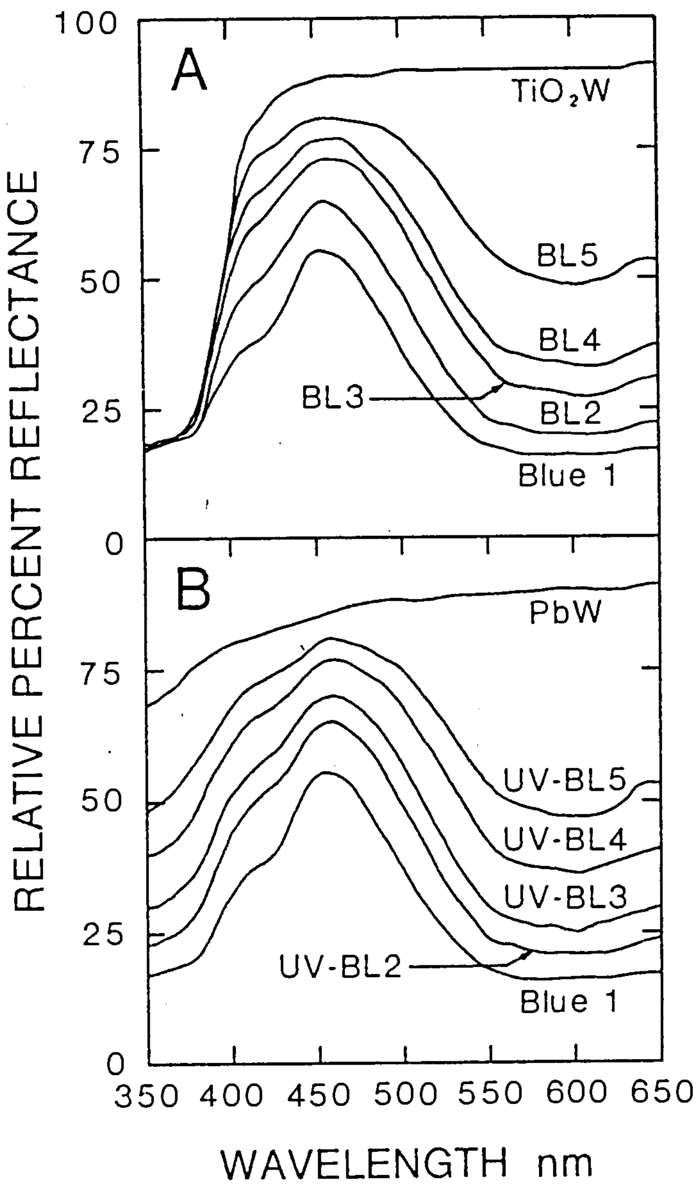


Table 3.III.A(males) Observed frequency counts in experiment 3

		Average %UV %BL %GR reflectance level in each trap												
	%UV	30	29	29	27	25	23	23	74	57	48	38	31	
	%BL	84	76	70	65	55	45	45	84	76	71	62	56	
	%GR	90	57	41	36	26	20	20	90	55	45	33	27	Total
FIELDS	1	4	5	5	3	9	6	8	1	3	2	5	4	55
	2	2	9	9	14	8	4	4	1	5	4	1	5	66
	3	6	5	4	5	9	6	8	0	8	4	4	7	66
	4	6	7	2	5	7	1	3	0	0	5	2	1	39
	5	4	1	7	4	4	5	6	0	1	5	0	5	42
	6	0	3	2	5	2	4	5	0	0	1	4	2	28
	7	2	8	6	9	6	7	5	0	3	2	2	6	56
	8	2	3	6	3	6	2	3	0	2	2	1	1	31
Total		26	41	41	48	51	35	42	2	22	25	19	31	383

Table 3.III.B(male) Experiment 3

Coefficients of the fitted log-linear model, standard deviations and deviances after the fit for male

$$\log\{\Phi_{jk}\} = \xi_j + \hat{\beta}1(\%UV/\%BL)_{jk} + \hat{\beta}2(\%GR)_{jk}$$

where $\Phi_{jk} = E(N_{jk})$ the expected male frequencies at the given k type trap.

Parameter	Estimates	Standard erroe	P-value
$\hat{\beta}1$	-2.855	0.4687	0.000
$\hat{\beta}2$	-0.1193E-1	0.2607E-2	0.000

Deviance of fitted model	Degree of freedom	P-value
101.7	86	0.1187

Table 3.III.A(females) Observed frequency counts in experiment 3

		Average %UV %BL %GR reflectance level in each trap												
%UV		30	29	29	27	25	23	23	74	57	48	38	31	
%BL		84	76	70	65	55	45	45	84	76	71	62	56	
%GR		90	57	41	36	26	20	20	90	55	45	33	27	Total
FIELDS	1	3	3	8	10	7	10	4	0	1	2	8	3	59
	2	8	4	8	14	5	8	4	0	4	5	8	4	72
	3	7	1	7	8	11	11	8	0	2	9	8	8	80
	4	4	8	10	9	14	10	10	1	3	6	7	6	88
	5	3	5	6	6	5	4	3	0	3	4	4	4	47
	6	4	6	6	5	5	2	3	1	3	0	3	3	41
	7	1	6	7	9	5	8	8	2	1	1	2	4	54
	8	3	7	3	4	4	1	3	2	0	1	1	7	36
Total		33	40	55	65	56	54	43	6	17	28	41	39	477

Table 3.III.B(female) Experiment 3

Coefficients of the fitted log-linear model, standard deviations and deviances after the fit for female.

$$\log(\Phi_{jk}) = \xi_j + \hat{\beta}1(\%UV/\%BL)_{jk} + \hat{\beta}2(\%GR)_{jk}$$

where $\Phi_{jk} = E(N_{jk})$ the expected female frequencies at the given k type trap.

Parameter	Estimates	Standard erroe	P-value
$\hat{\beta}1$	-2.713	0.4197	0.000
$\hat{\beta}2$	-0.1299E-1	0.2368E-2	0.000

Deviance of fitted model	Degree of freedom	P-value
93.38	86	0.275

3.4 EXPERIMENT 4 GREEN SERIES

This experiment was conducted to investigate the alightment frequency of *Delia antiqua* to UV-reflecting stimuli in the green region of the VISIBLE spectrum. There were no clear patterns in the responses of males or females with UV wavelength intensity or VISIBLE wavelength intensities. Similarly the trial and error method applied to the UV-reflecting grey series (experiment 2) gave different best fits for both sex.

$$\text{male}: \log(E(N_{jk})) = \text{field factor} - 42.46\left[\frac{\%UV}{\%GR}\right]_k + 33.91\left\{\left(\frac{\%UV}{\%GR}\right)_k\right\}^2$$

$$\text{female}: \log(E(N_{jk})) = \text{field factor} - 4.271\left[\frac{\%UV}{\%GR}\right]_k$$

The fits are very different. The estimated ratios, θ_{jk}, as derived in the multinomial model, are given for comparison. The different fits may be a bi-product of the fact that %green and %blue are highly correlated (r=0.969). The estimated θ_k are given as follow :

Male	Female
0.262686	0.293325
0.172757	0.171995
0.141900	0.139825
0.110218	0.097352
0.108646	0.074693
0.036832	0.035741
0.036832	0.035741
0.052973	0.031315
0.015829	0.029078
0.014372	0.029121
0.017331	0.027159
0.029624	0.034667

Figure 3.IV. gives the spectral reflectance curves. Tables 3.IV.A(males), 3.IV.A(females), 3.IV.B(males) and 3.IV.B(females) contain the observed data and summaries respectively.

FIGURE 3.IV Spectral reflectance curves, for non-UV-reflecting green pigments(A) and UV-reflecting green pigments(B) in Experiment 4.

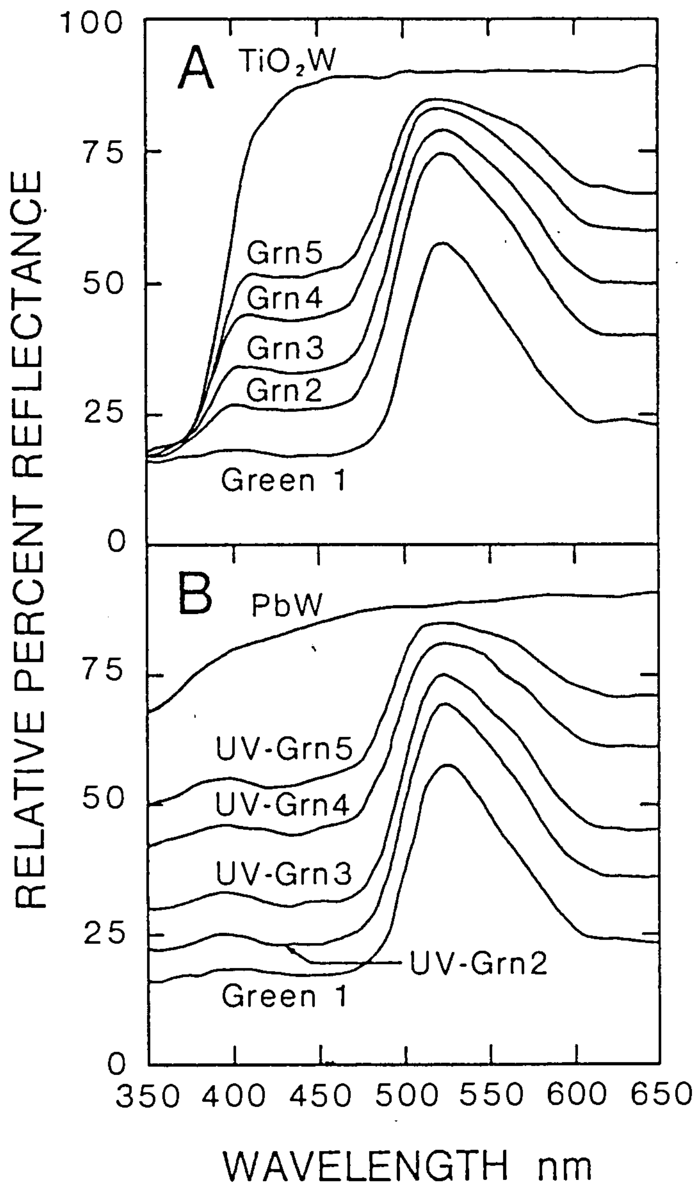


Table 3.IV.A(males) Observed frequency counts in experiment 4

		Average %UV %BL %GR reflectance level in each trap												
	%UV	30	27	26	24	21	17	17	74	53	44	32	24	
	%BL	84	56	49	39	31	20	20	84	59	49	35	28	
	%GR	90	76	71	63	55	37	37	90	78	70	58	50	Total
FIELDS	1	8	2	1	2	1	1	2	1	0	0	0	1	19
	2	5	2	1	3	0	1	0	1	0	0	0	1	14
	3	12	3	3	2	4	2	2	1	0	0	0	0	29
	4	3	2	0	3	3	1	2	1	0	0	0	1	16
	5	1	2	2	0	1	0	0	0	0	0	0	0	6
	6	3	1	0	0	1	0	0	1	0	0	0	0	6
	7	4	1	2	1	0	1	1	1	0	2	1	1	15
Total		36	13	9	11	10	6	7	6	0	2	1	4	105

Table 3.IV.A(females) Observed frequency counts in experiment 4

Average %UV %BL %GR reflectance level in each trap

FIELDS	%UV %BL %GR	30 84 90	27 56 76	26 49 71	24 39 63	21 31 55	17 20 37	17 20 37	74 84 90	53 59 78	44 49 70	32 35 58	24 28 50	Total
	1	3	4	2	2	3	1	0	0	0	0	1	0	16
	2	3	3	3	1	1	1	0	1	0	0	0	3	16
	3	3	2	1	2	0	0	1	0	1	0	0	0	10
	4	5	1	3	0	1	0	4	1	1	0	0	0	16
	5	3	1	2	1	0	2	0	0	0	0	1	0	10
	6	5	3	1	0	0	1	0	0	0	1	0	0	11
	7	5	2	1	1	0	0	0	0	0	0	1	1	11
Total		27	16	13	7	5	5	5	2	2	1	3	4	90

Table 3.IVB.B(male) Experiment 4

Coefficients of the fitted log-linear model, standard deviations and deviances after the fit for male.

$$\log(\Phi_{jk}) = \xi_j + \hat{\beta}1 \frac{\%UV}{\%GR} + \hat{\beta}2\left(\frac{\%UV}{\%GR}\right)^2$$

where $\Phi_{jk} = E[N_{jk}]$ the expected male frequencies at the given k type trap.

Parameter	Estimates	Standard erroe	P-value
$\hat{\beta}1$	-42.46	7.007	0.000
$\hat{\beta}2$	33.91	6.238	0.000

Deviance of fitted model	Degree of freedom	P-value
63.60	75	0.823

Table 3.IV.B(female) Experiment 4

Coefficients of the fitted log-linear model, standard deviations and deviances after the fit for female.

$$\log(\Phi_{jk}) = \xi_j + \hat{\beta} \frac{\%UV}{\%BL}$$

where $\Phi_{jk} = E[N_{jk}]$ the expected female frequencies at the given k type trap.

Parameter	Estimates	Standard erroe	P-value
$\hat{\beta}$	-4.271	0.5484	0.000

Deviance of fitted model	Degree of freedom	P-value
74.52	76	0.526

3.5 EXPERIMENT 5 YELLOW SERIES

This experiment was conducted to study the UV-reflecting stimuli in the yellow region of the VISIBLE spectrum. There were two equations fitted for male response. The first one fitted was $\log(\varphi_{jk}) = \zeta_j - 4.489 \left[\frac{\%UV}{\%Blue}\right]_k$. Another one was :

$$\log(\varphi_j) = \text{field factor} - 13.69 \left\{\frac{\%UV_k}{\frac{1}{2}(\%Green+\%Blue)_k}\right\} + 8.670 \left[\frac{\%UV_k}{\%Green_k}\right]^2 - 0.4834 \left(\frac{\%Green}{\%Blue}\right)_k$$

The deviances given by GLIM were 86.63 with 87 degrees of freedom and 80.26 with 85 degrees of freedom respectively. For females a different equation was obtained from GLIM. The best equation for females was found to be

$$\log(\varphi_{jk}) = \text{field factor} - 17.87 \frac{\%UV_k}{\frac{1}{2}(\%Blue+\%Green)_k} + 14.26 \left(\frac{\%UV}{\%Green}\right)_k$$

In all equations, a negative response of *Delia antiqua* to %UV was found. Comparing experiments 3, 4 and 5, substantially more flies were trapped in the blue series. Probably, the blue intensity does play an important role in *Delia antiqua* 's alightment. The fit for males $\log(\varphi_{jk}) = \zeta_j - 4.489 \left(\frac{\%UV}{\%Blue}\right)_k$ was subjectively chosen and reported for future investigation, since in experiment 3 and 4 $\frac{\%UV}{\%blue}$ was found significant. Spectral reflectance curves are in figure 3.V. Data and summaries are in tables 3.V.A(males), 3.V.A(females),3.V.B(males) and 3.V.B(females).

FIGURE 3.V Spectral reflectance curves, for non-UV-reflecting yellow pigments(A) and UV-reflecting yellow pigments(B) in Experiment 5.

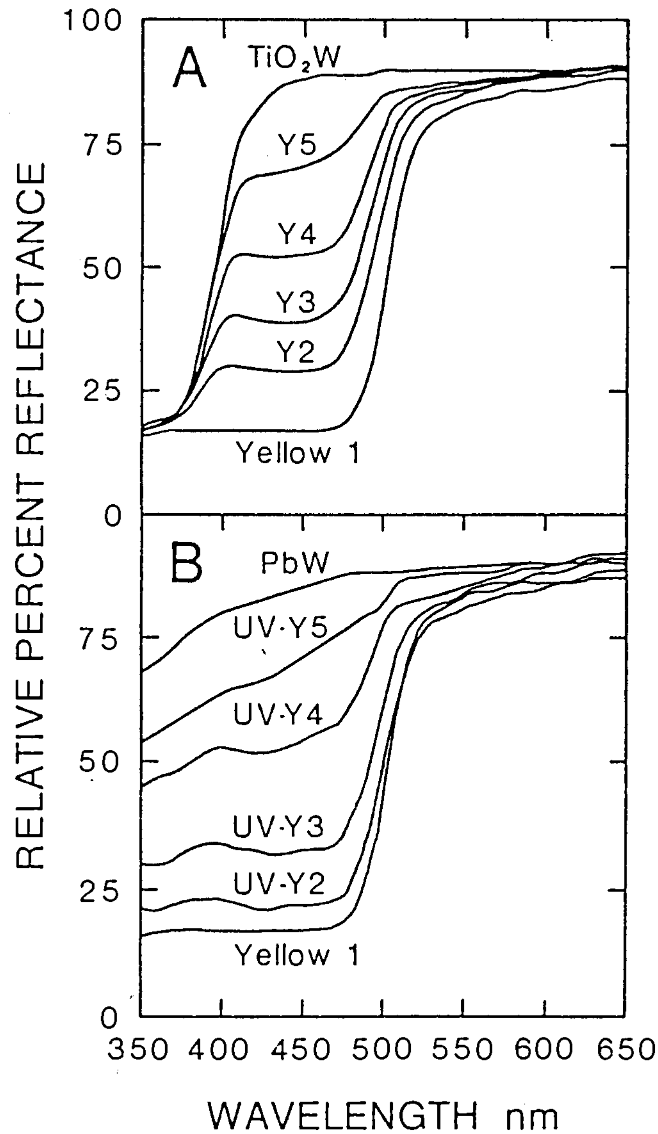


Table 3.V.A(males) Observed frequency counts in experiment 5

	Average %UV %BL %GR reflectance level in each trap												
%UV	30	29	27	25	22	17	17	74	59	49	32	22	
%BL	84	71	57	45	35	20	20	84	72	58	37	26	
%GR	90	88	87	86	84	80	80	90	89	86	83	80	Total
Field													
1	5	2	5	3	3	0	2	1	0	1	0	0	22
2	4	3	1	3	0	1	0	2	0	0	0	0	14
3	12	10	6	5	1	1	1	2	1	0	0	3	42
4	3	5	6	5	0	3	2	0	0	0	2	2	28
5	3	1	1	1	0	0	0	0	0	0	0	0	6
6	2	2	2	2	0	0	1	1	0	0	0	1	11
7	8	6	4	2	1	1	0	0	1	0	0	1	24
8	4	4	0	1	0	1	0	1	1	0	0	0	12
Total	41	33	25	22	5	7	6	7	3	1	2	7	159

Table 3.V.A(females) Observed frequency counts in experiment 5

	Average %UV %BL %GR reflectance level in each trap												
%UV	30	29	27	25	22	17	17	74	59	49	32	22	
%BL	84	71	57	45	35	20	20	84	72	58	37	26	
%GR	90	88	87	86	84	80	80	90	89	86	83	80	Total
FIELDS 1	4	1	5	2	0	3	2	2	2	1	1	0	23
2	3	6	2	1	1	1	3	0	0	0	0	0	17
3	5	2	5	4	0	2	1	0	0	0	1	1	21
4	8	6	0	3	0	1	2	1	0	0	0	1	22
5	4	6	0	1	0	0	0	1	1	0	1	1	15
6	5	1	1	1	1	0	2	0	1	0	1	0	13
7	5	4	1	1	0	0	1	2	0	0	0	0	14
8	1	4	2	1	0	1	1	0	0	0	0	0	10
Total	35	30	16	14	2	8	12	6	4	1	4	3	135

Table 3.V.B(male) Experiment 5

Coefficients of the fitted log-linear model, standard deviations and deviances after the fit for male.

$$\log\{\varphi_{jk}\} = \xi_j + \hat{\beta}\frac{\%UV}{\%BL}$$

where $\varphi_{jk} = E\{N_{jk}\}$ the expected male frequencies at the given k type trap.

Parameter	Estimates	Standard erroe	P-value
$\hat{\beta}$	-4.489	0.4405	0.000

Deviance of fitted model	Degree of freedom	P-value
86.63	87	0.491

Table 3.V.B(female) Experiment 5

Coefficients of the fitted log-linear model, standard deviations and deviances after the fit for female.

$$\log\{\varphi_{jk}\} = \xi_j + \hat{\beta}1\frac{\%UV}{(\%BL+\%GR)/2}_{jk} + \hat{\beta}2\frac{\%UV}{\%GR}_{jk}$$

where $\varphi_{jk} = E\{N_{jk}\}$ the expected female frequencies at the given k type trap.

Parameter	Estimates	Standard erroe	P-value
$\hat{\beta}1$	-17.87	1.993	0.000
$\hat{\beta}2$	14.26	1.926	0.000

Deviance of fitted model	Degree of freedom	P-value
96.20	86	0.212

3.6 EXPERIMENT 6 BLUE HUES + UV

There was some significant effect found in the percentage of UV-reflectance in the blue pigment (Figure 3.VI). The responses of males and females (Table 3.VI.A(males), Table3.VI.A(females)) were not similar to each other. The best statistical models found here are in tables 3.VI.B(males) and 3.VI.B(females). For this experiment, Judd (1986) reported that the VISIBLE/UV ratio was a better explanatory variable. For the given data, the UV/Blue ratio were found significant in both sexes. A review of the six experiments shows that the ratio, UV/VISIBLE, shows a significant association with the flies' response in the studied spectral range.

FIGURE 3.VI Spectral reflectance curves (A) measured through acetate covering, for enamel paints (TiO_2W and E871-blue), water based paints (Brilliant [BB] and Fluorescent blue [FB]), and blue Poster Board (BPB) in Experiment 6.

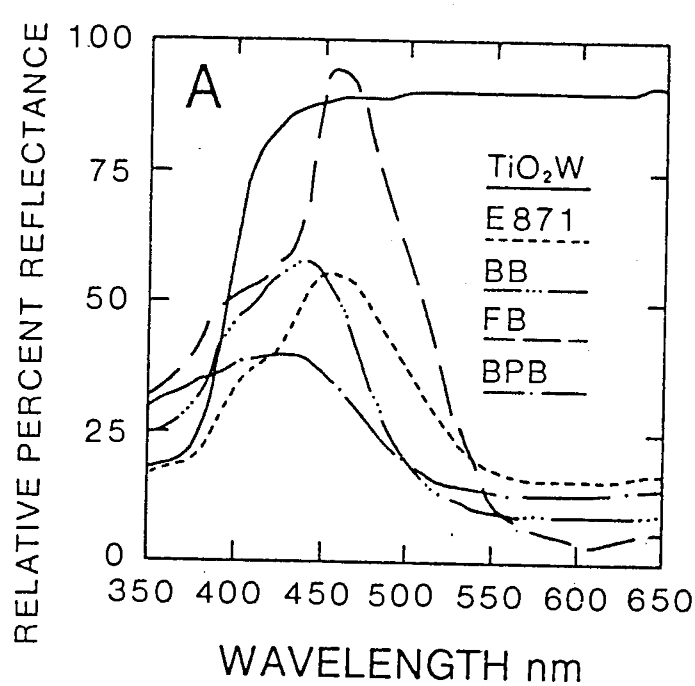


Table 3.VI.A(males) Observed frequency counts in experiment 6

		Average %UV %BL %GR reflectance level in each trap						
	%UV	30	30	33	41	34	23	
	%BL	84	84	44	70	33	45	
	%GR	90	90	11	16	14	20	Total
	1	2	5	7	8	2	0	24
	2	3	4	2	8	3	7	27
F	3	6	3	3	5	4	2	23
	4	3	5	5	9	3	5	30
I	5	3	1	7	4	3	9	27
E	6	9	10	10	3	3	13	48
L	7	2	0	3	1	0	5	11
D	8	4	5	4	3	0	3	19
	9	4	3	2	5	1	5	20
S	10	5	1	3	3	1	1	14
	11	5	2	5	5	2	0	19
	12	4	7	2	3	4	3	23
Total		50	46	53	57	26	53	285

Table 3.VI.B(male) Experiment 6

Coefficients of the fitted log-linear model, standard deviations and deviances after the fit for male.

$$\log(\varphi_{jk}) = \xi_j + \hat{\beta}1 \frac{\%UV}{\%BL}_{jk} + \hat{\beta}2 \left(\frac{\%UV}{\%BL}\right)^2_{jk}$$

where $\varphi_{jk} = E(N_{jk})$ the expected male frequencies at the given k type trap.

Parameter	Estimates	Standard erroe	P-value
$\hat{\beta}1$	4.331	1.702	0.011
$\hat{\beta}2$	-3.741	1.280	0.003

Deviance of fitted model	Degree of freedom	P-value
79.97	58	0.030

Table 3.VI.A(females)   Observed frequency counts in experiment   6

		Average %UV %BL %GR reflectance level in each trap						
	%UV	30	30	33	41	34	23	
	%BL	84	84	44	70	33	45	
	%GR	90	90	11	16	14	20	Total
	1	3	4	6	3	2	3	21
	2	0	2	2	0	2	1	7
F	3	5	2	4	5	1	2	19
I	4	3	4	4	0	2	3	16
	5	1	2	3	3	0	1	10
E	6	1	3	7	8	2	6	27
L	7	3	3	5	4	1	5	21
D	8	3	2	4	3	1	2	15
	9	3	5	3	2	3	8	24
S	10	1	3	4	3	3	7	21
	11	4	5	5	8	3	1	26
	12	3	3	4	5	1	6	22
Total		30	38	51	44	21	45	229

Table 3.VI.B(female)   Experiment   6

Coefficients of the fitted log-linear model, standard deviations and deviances after the fit for female.

$$\log(\Phi_{jk}) = \xi_j + \hat{\beta}1 \left(\frac{\%UV}{\%BL}\right)_{jk} + \hat{\beta}2\left(\frac{\%UV}{\%BL}\right)^2_{jk}$$

where $\Phi_{jk} = E(N_{jk})$ the expected female frequencies at the given k type trap.

Parameter	Estimates	Standard erroe	P-value
$\hat{\beta}1$	6.541	1.906	0.001
$\hat{\beta}2$	-5.151	1.423	0.000

Deviance of fitted model	Degree of freedom	P-value
49.98	58	0.764

CHAPTER 4

MODEL DIAGNOSIS VIA GRAPHICS

Residuals are widely used in many procedures to detect various types of disagreement between data and an assumed model. For example, the scatter plot of residuals versus fitted values that accompanies a linear least square fit is a standard tool to diagnose nonconstant variance, curvature and outliers. The residuals carry important information concerning the appropriateness of assumptions. Many analyses include informal graphics to display general features of the residuals as well as formal tests to detect specific departures from underlying assumptions. Both procedures have a place in residual analysis. Our emphasis is on graphical methods rather than on formal testing, since informal graphical procedures can give a general impression of the acceptability of assumptions as well as the presence of outliers.

To assess the appropriateness of the studied model, it is important to determine if the assumptions about the errors are reasonable. Since the errors ε are not observable, they are analyzed indirectly using residuals. A residual, R, is defined as :

$$R = \text{observed value} - \text{fitted value}$$

It is bounded below by the negative of the fitted value. If the assumed Poisson model is appropriate, the plot of residuals versus the fitted values should having a fan-like structure, i.e. the points should fit roughly inside a parabola. As we know, the variance of a Poisson variate is equal to it's mean which is estimated by the fitted value. Thus, the standardized residual, $S = \frac{R}{\sqrt{\text{fitted value}}}$, when plotted against the fitted values should show a structureless plot if the model is adequate. These plots are shown in Figure 4.1.1M, 4.1.2M, 4.1.3M, 4.1.1F, 4.1.2F,. . . , 4.6.3F on the following pages.

The plots of residuals vs. fitted values are roughly speaking satisfactory. There is no obvious curvature. In Figure 4.2.1M, there are markedly three extreme residuals lying some distance from the main mass of data values on the top of the graph. The point close to the Y-axis is the observed value in a black trap. Because of the small fitted value (close to zero), it appears even further away from the main mass in Figure.4.2.2M, but not the other two points. Subsequent deletion of the observation brought down the deviance to an acceptable figure. However, the estimated value does not change substantially (see Table 3.II). This analysis demonstrates that points that deviate most from the pattern of the rest need not have large residuals, and points with large residuals may affect the fit very little. There is another defect of the residual plot which has been mentioned by McCullagh and Nelder(1983). The distribution of the residuals is noticeably skew, especially for small expected values less than 2. That would make the plot relatively 'over-interpreted'.

The plot of observed values vs. fitted values is another visual display to scan how good the fit is. If the fit is good, the points should crowd together along the 45° line running from SW to NE of the diagram. Other things being equal, the plot would produce a wider range of dispersion with a higher density of points. We could see a good fit is associated with a narrow plot as in Figure 4.1.3M.

FIGURE 4.1.1M
Plot of Residuals vs. Fitted Values for Males
in Experiment 1

```
  6.40     *
  6.00     *                                  R
  5.60     *
  5.20     *
  4.80     *
  4.40     *
  4.00     *
  3.60     *          R              R
  3.20     *        R    R
  2.80     *
  2.40     *        R R
  2.00     *                 R
  1.60     *     R    2  R R    R
  1.20     *      R    2      R
 0.800     *       2
 0.400     *   R                R         R
 0.0       *    3    2  R R
-0.400     *   R 2  2              R
-0.800     *      R R  R R     R   R
 -1.20     *    R  R         R  R         R
 -1.60     *             R    R
 -2.00     *      R     R R           R
 -2.40     *        R R    2         R
 -2.80     *
 -3.20     *               R
 -3.60     *                                 R
 -4.00     *
  .........*.........*.........*.........*.........*.........*
         0.0        4.00      8.00      12.0      16.0      20.0
```

FIGURE 4.1.2M
Plot of Standardized Residuals vs. Fitted Values
for Males in Experiment 1

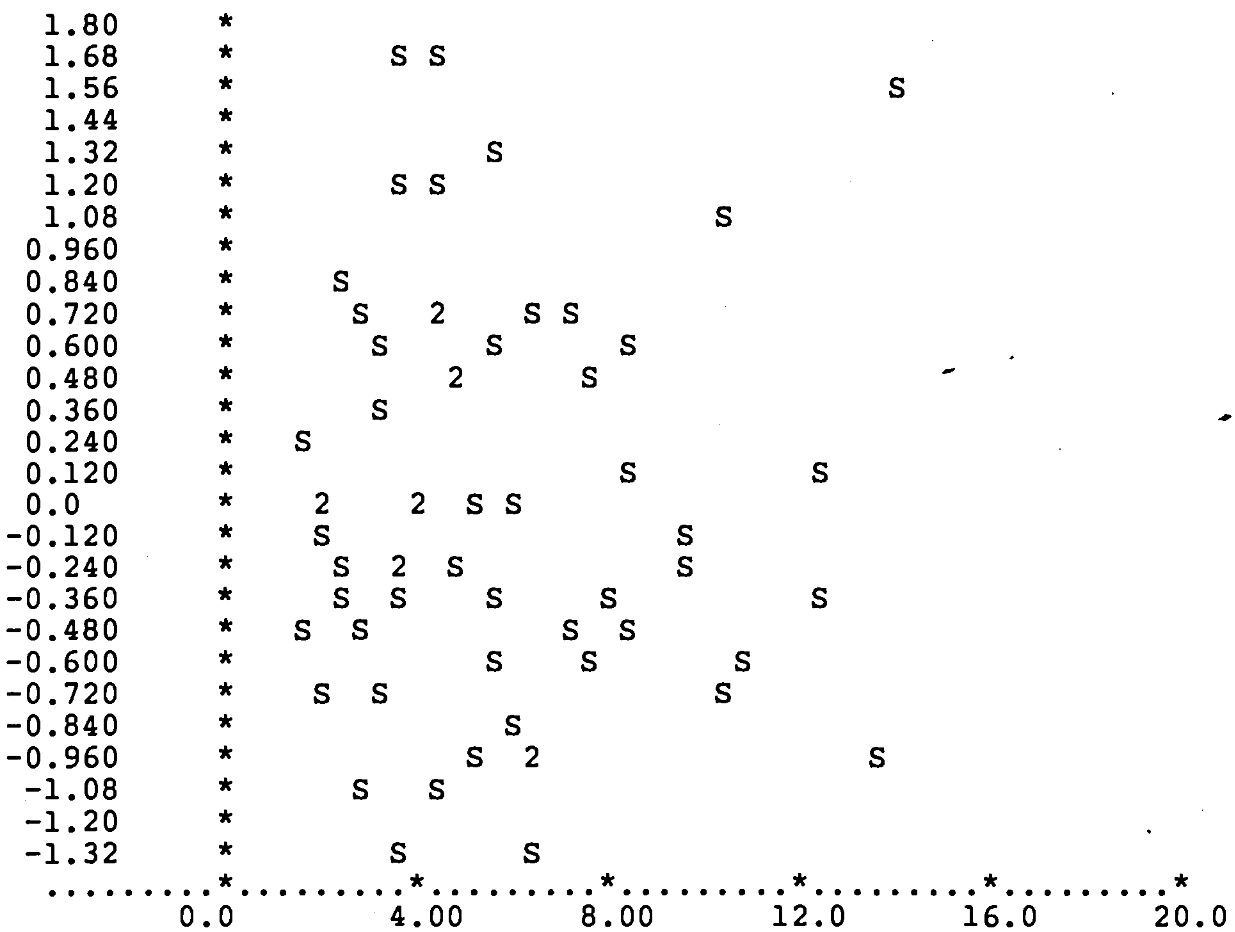


FIGURE 4.1.3M
Plot of Observed Values vs. Fitted Values
for Males in Experiment 1

```
 20.8     *
 20.0     *                                   O
 19.2     *
 18.4     *
 17.6     *
 16.8     *
 16.0     *
 15.2     *
 14.4     *                          O
 13.6     *
 12.8     *                               O
 12.0     *
 11.2     *                               O
 10.4     *                     O            O
 9.60     *
 8.80     *              O  OO  O  2  O
 8.00     *           O    O         O
 7.20     *         O O  O    OO
 6.40     *         O 22  O OO
 5.60     *
 4.80     *            OO
 4.00     *     002 2 O 002
 3.20     *         3  O   O
 2.40     *   03200   O
 1.60     *
0.800     *   OO O  O
0.0       *
 .........*.........*.........*.........*.........*.........*
        0.0        4.00      8.00      12.0      16.0      20.0
&?
```

FIGURE 4.1.1F
Plot of Residuals vs. Fitted Values for Females
in Experiment 1

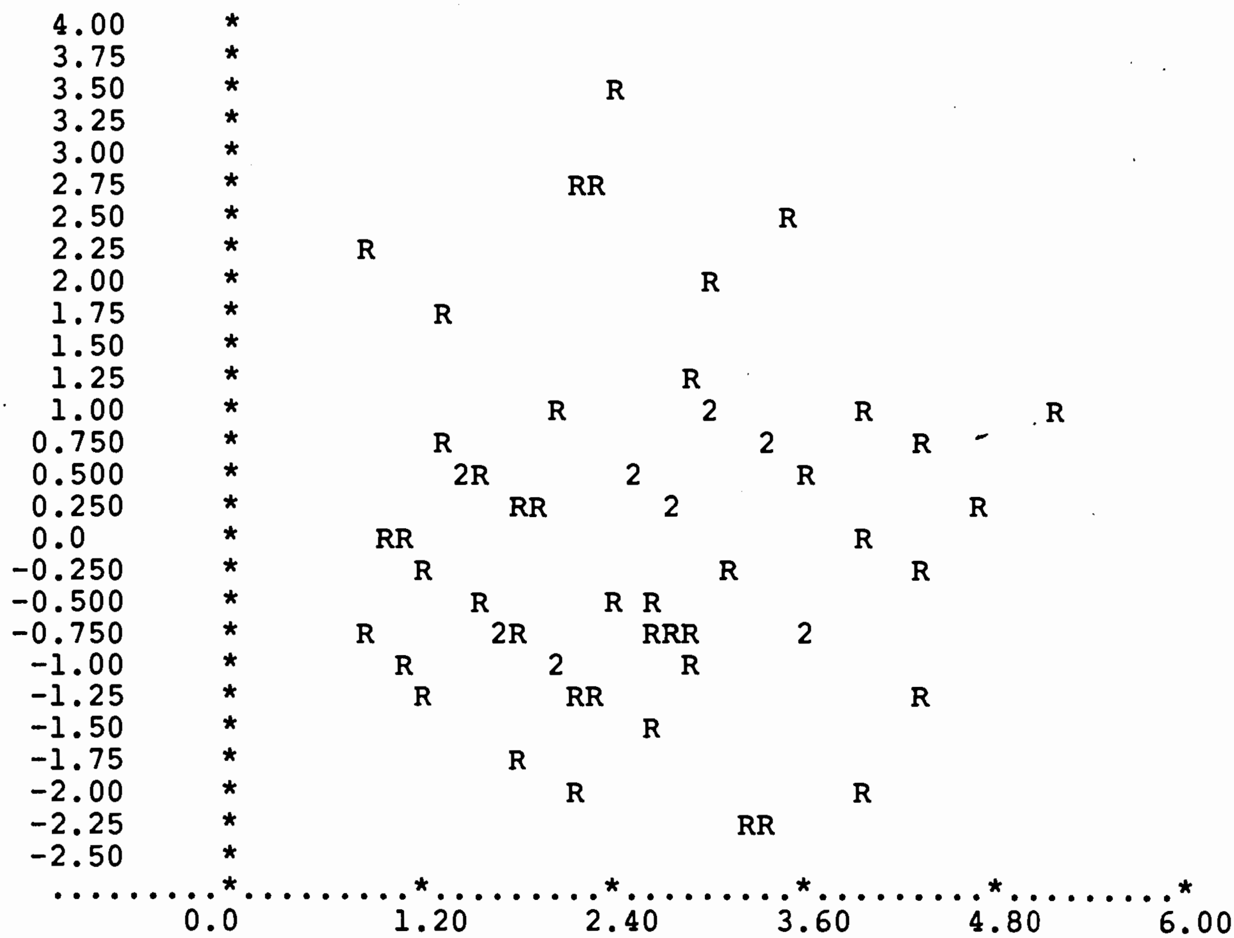


FIGURE 4.1.2F
Plot of Standardized Residuals vs. Fitted Values
for Females in Experiment 1

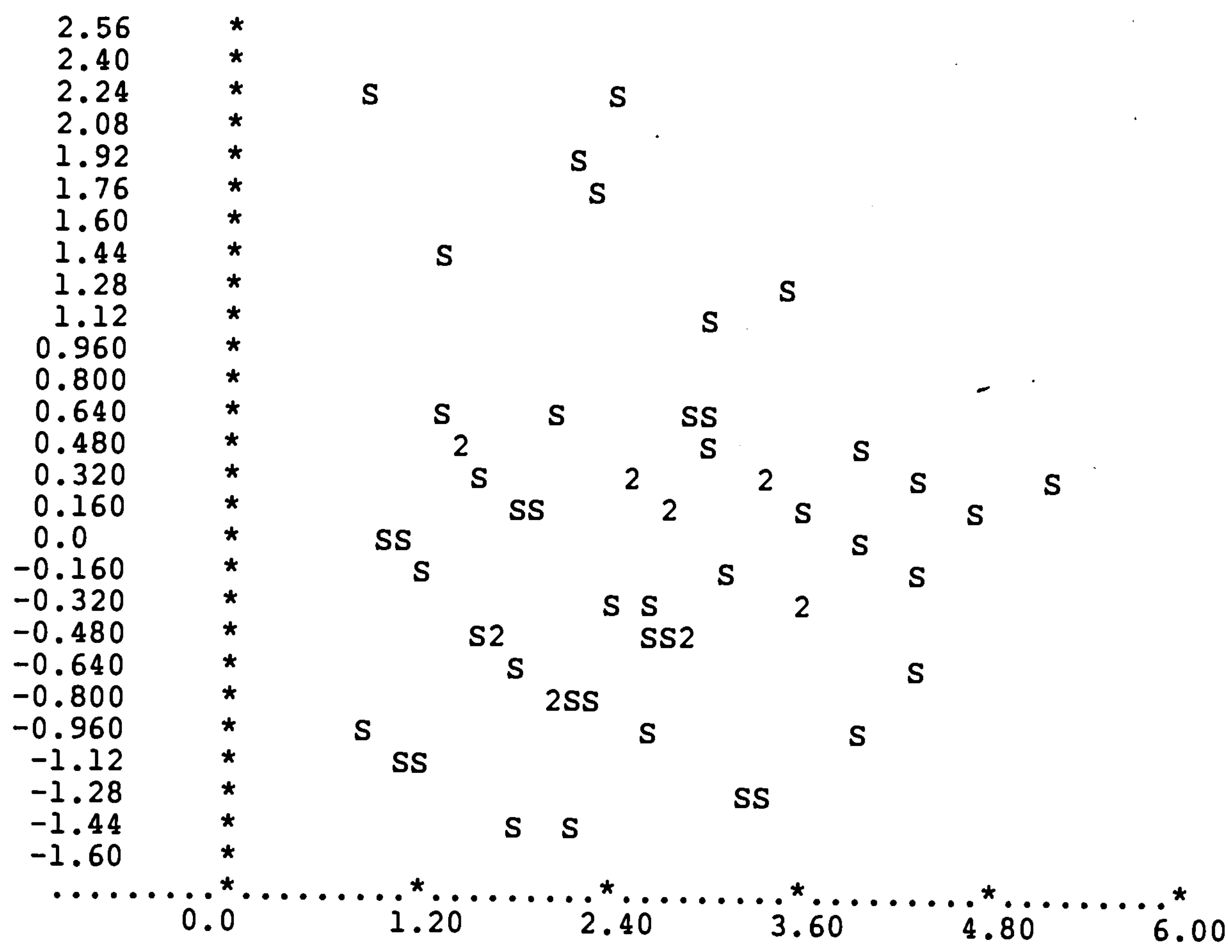


FIGURE 4.1.3F
Plot of Observed Values vs. Fitted Values
for Females in Experiment 1

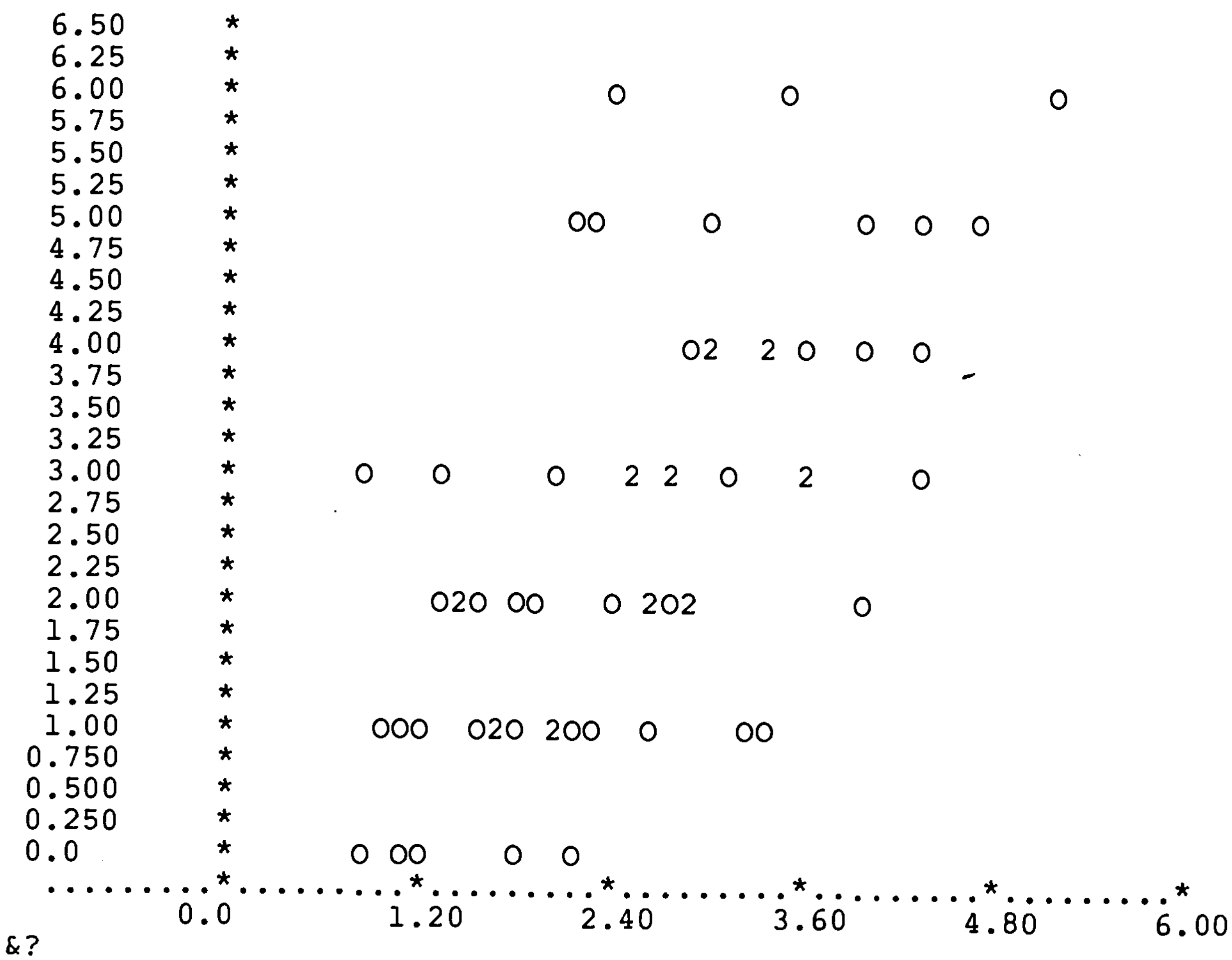


FIGURE 4.2.1M
Plot of Residuals vs. Fitted Values for Males
in Experiment 2

```
  7.00     *
  6.50     *R
  6.00     *                     R
  5.50     *
  5.00     *                                  R
  4.50     *
  4.00     *
  3.50     *R
  3.00     *
  2.50     *      R
  2.00     * RR         R
  1.50     *2  R    R
  1.00     * R2   R         R       R
 0.500     *74R  2
 0.0       * 2RRR R       R    R
-0.500     28 R2
 -1.00     *433     R             R
 -1.50     * 22  R   RR  R
 -2.00     *   RR    R
 -2.50     *   R R         R
 -3.00     *
 -3.50     *
 -4.00     *
 -4.50     *
 -5.00     *
 -5.50     *          R
 -6.00     *
  .........*.........*.........*.........*.........*.........*
         0.0        6.00      12.0      18.0      24.0      30.0
```

FIGURE 4.2.2M

Plot of Standardized Residuals vs. Fitted Values
for Males in Experiment 2

```
  9.50     *
  9.00     *
  8.50     *S
  8.00     *
  7.50     *
  7.00     *
  6.50     *
  6.00     *
  5.50     *
  5.00     *
  4.50     *
  4.00     *S
  3.50     *
  3.00     *
  2.50     *
  2.00     *SS
  1.50     *2 S   S              S
  1.00     *2S S                              S
 0.500     *443  SS S   S   S       S
 0.0       * 2S2SSS       S    S
-0.500     27 4S    SSS  S        S
-1.00      *55S SS   S     S
-1.50      *  S2 S
-2.00      *          S
-2.50      *
-3.00      *
-3.50      *
  .........*.........*.........*.........*.........*.........*
         0.0        6.00      12.0      18.0      24.0      30.0
```

FIGURE 4.2.3M

Plot of Observed Values vs. Fitted Values
for Males in Experiment 2

```
 26.0    *                                   O
 25.0    *
 24.0    *
 23.0    *
 22.0    *
 21.0    *
 20.0    *
 19.0    *                     O
 18.0    *
 17.0    *
 16.0    *                        O
 15.0    *
 14.0    *
 13.0    *                      O
 12.0    *                   O
 11.0    *                O
 10.0    *            O
 9.00    *              O
 8.00    *
 7.00    *O      O O     O O
 6.00    *
 5.00    *       O  OO
 4.00    *O OO 2O OO
 3.00    * O2 O
 2.00    *2523 O
 1.00    *724 OO    O
0.0      29522
.........*.........*.........*.........*.........*.........*
       0.0       6.00      12.0      18.0      24.0      30.0
&?
```

FIGURE 4.2.1F
Plot of Residuals vs. Fitted Values for Females
in Experiment 2

```
  5.50     *            R           2
  5.00     *   R
  4.50     *
  4.00     *
  3.50     *
  3.00     * R   R
  2.50     *    R R
  2.00     * R R R     R         R
  1.50     *R   3 R     R   R               R
  1.00     * R R R               R
 0.500     *4 2 R 2 R
   0.0     * 3 2 R 2
-0.500     *5 2   R
 -1.00     * 6 2 R
 -1.50     *  2 4 R   2 R                   R
 -2.00     *   R
 -2.50     *    2   R
 -3.00     *
 -3.50     *                R
 -4.00     *       R
 -4.50     *                    R
 -5.00     *                 R
 -5.50     *
 -6.00     *
 -6.50     *
 -7.00     *
 -7.50     *                      R
  .........*.........*.........*.........*.........*.........*
         0.0        5.00     10.0      15.0      20.0      25.0
```

FIGURE 4.2.2F
Plot of Standardized Residuals vs. Fitted Values
for Females in Experiment 2

```
  4.00     *
  3.75     *
  3.50     *   S
  3.25     *
  3.00     *
  2.75     * S
  2.50     * S
  2.25     *            S
  2.00     *S
  1.75     *    SS
  1.50     *                        2
  1.25     *   S SS
  1.00     *    3      S
 0.750     * SS  SS
 0.500     *S SS       S   S    2
 0.250     *3S  S 2 S                       S
 0.0       * 2 2 S 2
-0.250     *  2   S
-0.500     *     S    S S                   S
-0.750     *5  2S S   S
 -1.00     * 6  3
 -1.25     *  2S    S       S
 -1.50     *    2            S  S
 -1.75     *
 -2.00     *       S
 -2.25     *                      S
 -2.50     *
  .........*.........*.........*.........*.........*.........*
         0.0       5.00      10.0      15.0      20.0      25.0
```

FIGURE 4.2.3F

Plot of Observed Values vs. Fitted Values
for Females in Experiment 2

```
 20.8     *
 20.0     *
 19.2     *
 18.4     *                        2       O
 17.6     *
 16.8     *
 16.0     *
 15.2     *                                O
 14.4     *
 13.6     *
 12.8     *                     O
 12.0     *            O        O
 11.2     *
 10.4     *                O
 9.60     *
 8.80     *
 8.00     *           OO
 7.20     *   O
 6.40     *     OO             O
 5.60     *
 4.80     *    OOO O   O   O
 4.00     * O O3O22  2      O    O
 3.20     * O OOOO
 2.40     *OO22 OO O
 1.60     *
0.800     *43224
0.0       *56202  O
 .........*.........*.........*.........*.........*.........*
        0.0        5.00      10.0      15.0      20.0      25.0
&?
```

FIGURE 4.3.1M
Plot of Residuals vs. Fitted Values for Males
in Experiment 3

```
  6.40     *                                      R
  6.00     *
  5.60     *           R
  5.20     *
  4.80     *
  4.40     *
  4.00     *
  3.60     *
  3.20     *         R   R     R
  2.80     *          RR
  2.40     *                RR    2    R    3
  2.00     *         R    R              R
  1.60     *               R      R             R
  1.20     *         R        2    RR   R         R
 0.800     *     R   R    2 2            R     R
 0.400     *       R              2
 0.0       *    2        R R   R         R        R
-0.400     * RR   RR  RR    R     R    R  R
-0.800     *  2 R        3   R     R2   R   R
 -1.20     *    2     R    R2   R        RR    R
 -1.60     *      R      R                  R
 -2.00     *         R        RR
 -2.40     *                R    R
 -2.80     *              R        R              R
 -3.20     *                    2              2R
 -3.60     *                      R        R
 -4.00     *
  .........*.........*.........*.........*.........*.........*
         0.0        2.00      4.00      6.00      8.00      10.0
```

FIGURE 4.3.2M
Plot of Standardized Residuals vs. Fitted Values
for Males in Experiment 3

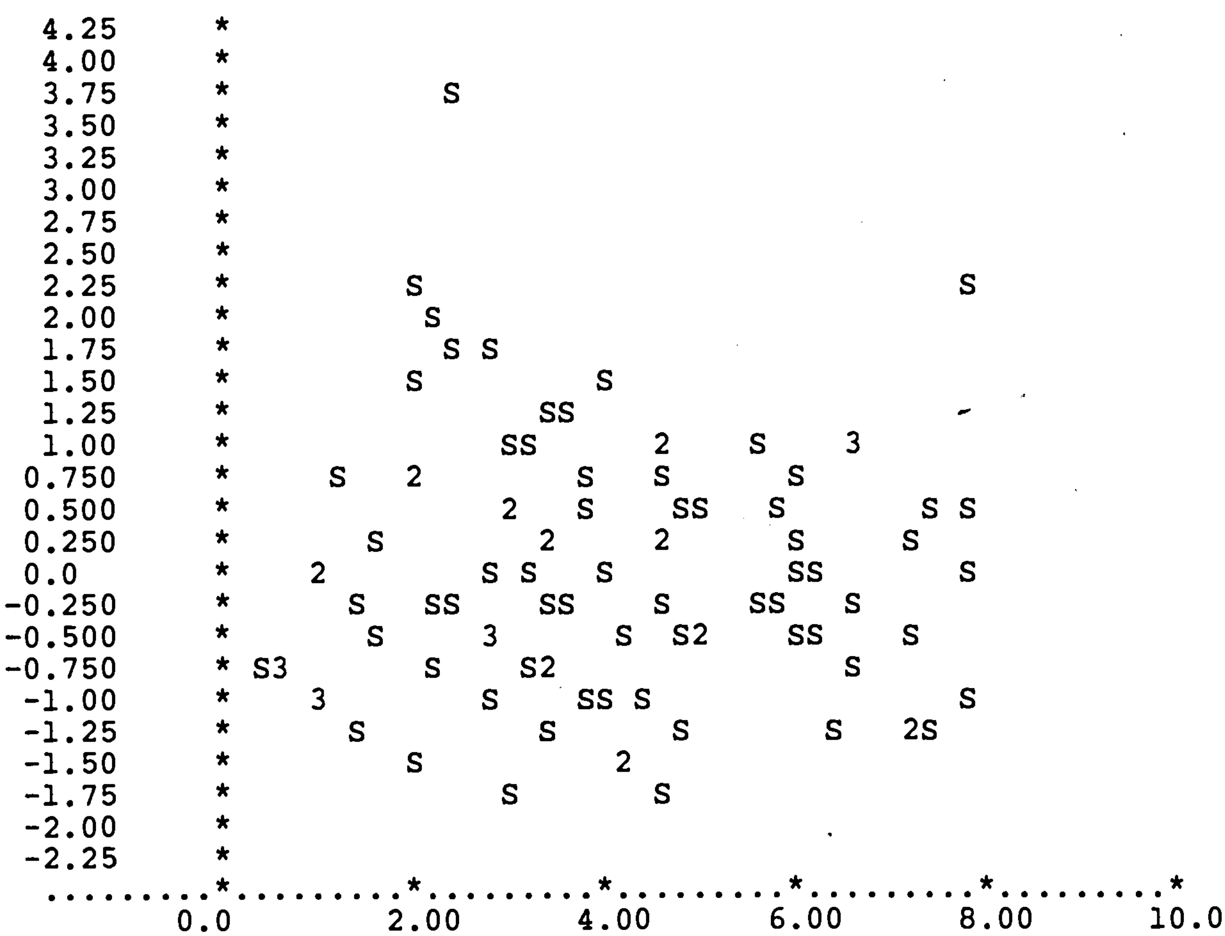


FIGURE 4.3.3M
Plot of Observed Values vs. Fitted Values
for Males in Experiment 3

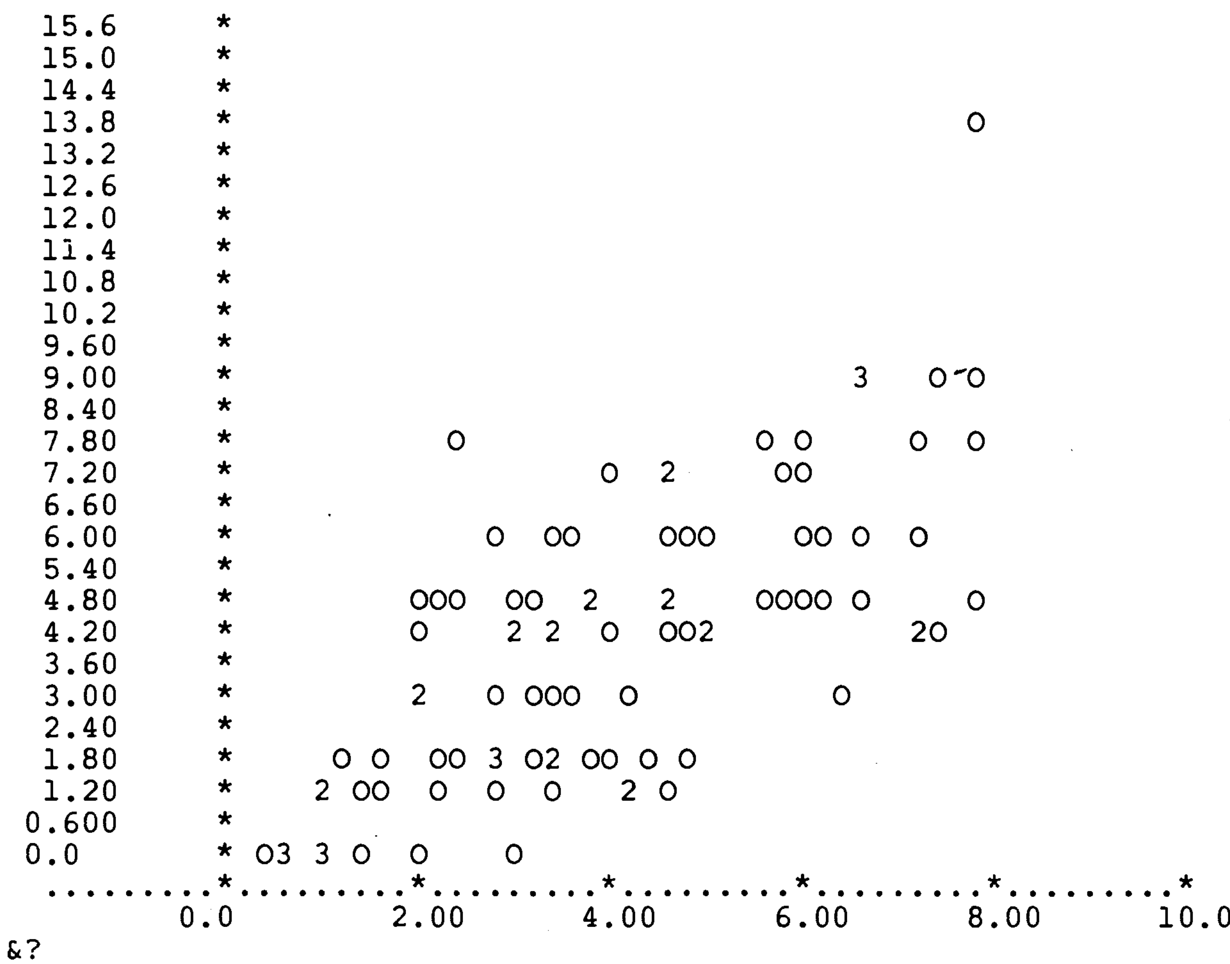


FIGURE 4.3.1F
Plot of Residuals vs. Fitted Values for Females
in Experiment 3

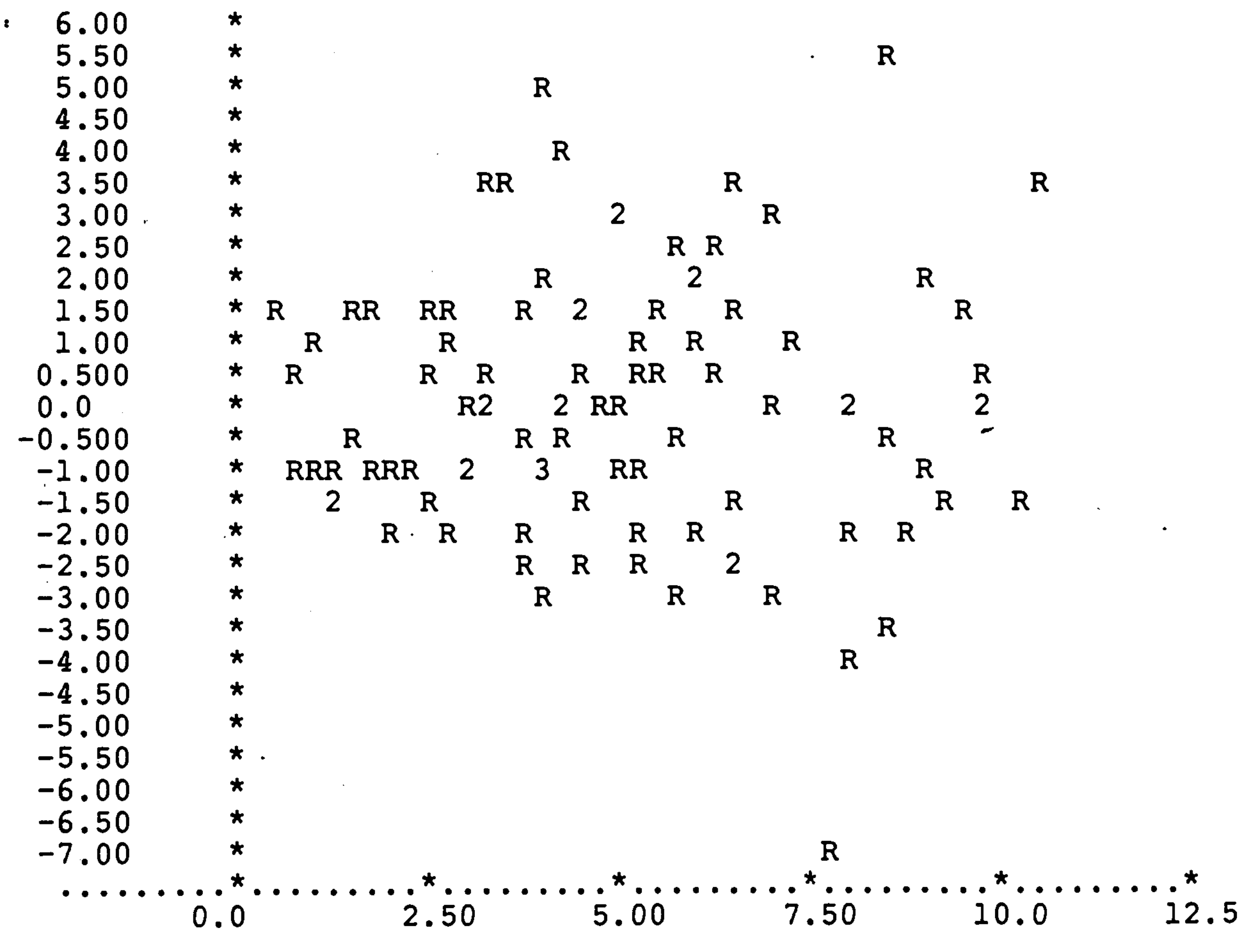


FIGURE 4.3.2F
Plot of Standardized Residuals vs. Fitted Values
for Females in Experiment 3

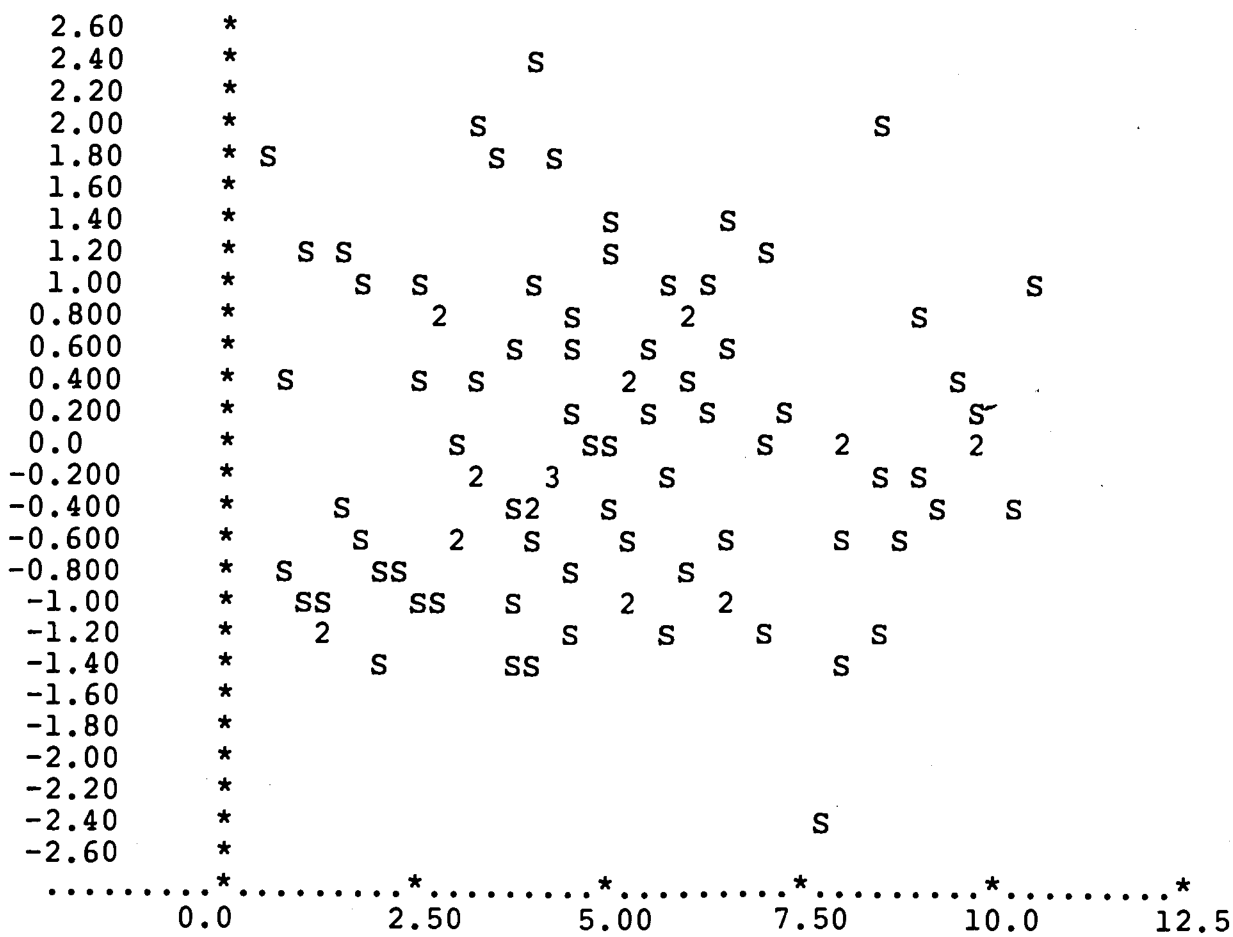


FIGURE 4.3.3F
Plot of Observed Values vs. Fitted Values
for Females in Experiment 3

```
 15.6     *
 15.0     *
 14.4     *
 13.8     *                                 O       O
 13.2     *
 12.6     *
 12.0     *
 11.4     *
 10.8     *                                   O O
 10.2     *                         O O          3
 9.60     *
 9.00     *               O        O               O
 8.40     *
 7.80     *                O  2  02 O  O  2 O OO
 7.20     *            OO       O OO  O      O
 6.60     *
 6.00     *               O 2  20         O
 5.40     *
 4.80     *              O  OOO  O  O       O
 4.20     *         02 O   3  OO  O 2 O   O
 3.60     *
 3.00     *     OO  O 02 03 O  2 O
 2.40     *
 1.80     * O O       2  O  O
 1.20     *  O  OOOOOO   OO              O
0.600     *
0.0       *  003  O
 .........*.........*.........*.........*.........*.........*
        0.0       2.50      5.00      7.50      10.0      12.5
&?
```

FIGURE 4.4.1M

Plot of Residuals vs. Fitted Values for Males in Experiment 4

```
  3.90     *
  3.60     *
  3.30     *
  3.00     *                 R
  2.70     *                   R
  2.40     *          R    R
  2.10     *     R     R    R
  1.80     *       R                 R            R
  1.50     *  R
  1.20     *   R2     R     R     R
 0.900     *      R2                R
 0.600     * 36    R
 0.300     *  2 5
 0.0       *    RR3    RR
-0.300     *292   R2R                 R
-0.600     *  65R    RR
-0.900     *    52                               R
 -1.20     *
 -1.50     *        2R    R
 -1.80     *          R      R           R
 -2.10     *                        R
 -2.40     *
 -2.70     *                R                       R
 -3.00     *
 -3.30     *                          R
 -3.60     *
 -3.90     *
  .........*.........*.........*.........*.........*.........*
         0.0        1.60      3.20      4.80      6.40      8.00
```

FIGURE 4.4.2M

Plot of Standardized Residuals vs. Fitted Values
for Males in Experiment 4

```
  2.24     *
  2.08     *  S  S
  1.92     *                 S
  1.76     *          S
  1.60     *   S       S   S   S
  1.44     * S  S  S
  1.28     * S  S           S
  1.12     *
 0.960     * S        S              S
 0.800     *  4   SS        S
 0.640     *  4    2              S               S
 0.480     *                        S
 0.320     *    3
 0.160     *    3      S
 0.0       *     SS     S
-0.160     *      32                  S
-0.320     *        S
-0.480     *25       SS                          S
-0.640     * 47
-0.800     *  S52                        S
-0.960     *    42        S         S               S
 -1.12     *        S        S
 -1.28     *        SSS
 -1.44     *
 -1.60     *                S         S
 -1.76     *
 -1.92     *
  .........*.........*.........*.........*.........*.........*.
          0.0       1.60      3.20      4.80      6.40      8.00
```

FIGURE 4.4.3M

Plot of Observed Values vs. Fitted Values
for Males in Experiment 4

```
 10.4     *
 10.0     *
 9.60     *
 9.20     *
 8.80     *
 8.40     *
 8.00     *                                      O
 7.60     *
 7.20     *
 6.80     *
 6.40     *
 6.00     *                 O O     O
 5.60     *
 5.20     *               OO     O O            O
 4.80     *
 4.40     *
 4.00     *          OO    O         O             O
 3.60     *
 3.20     *     O O  O                  O
 2.80     *
 2.40     *
 2.00     *  002 03   OO           O
 1.60     *
 1.20     * 38 6042000   O  O        O
0.800     *
0.400     *
0.0       *298562  200     O
 .........*.........*.........*.........*.........*.........*
        0.0        1.60      3.20      4.80      6.40      8.00
&?
```

FIGURE 4.4.1F
Plot of Residuals vs. Fitted Values for Females
in Experiment 4

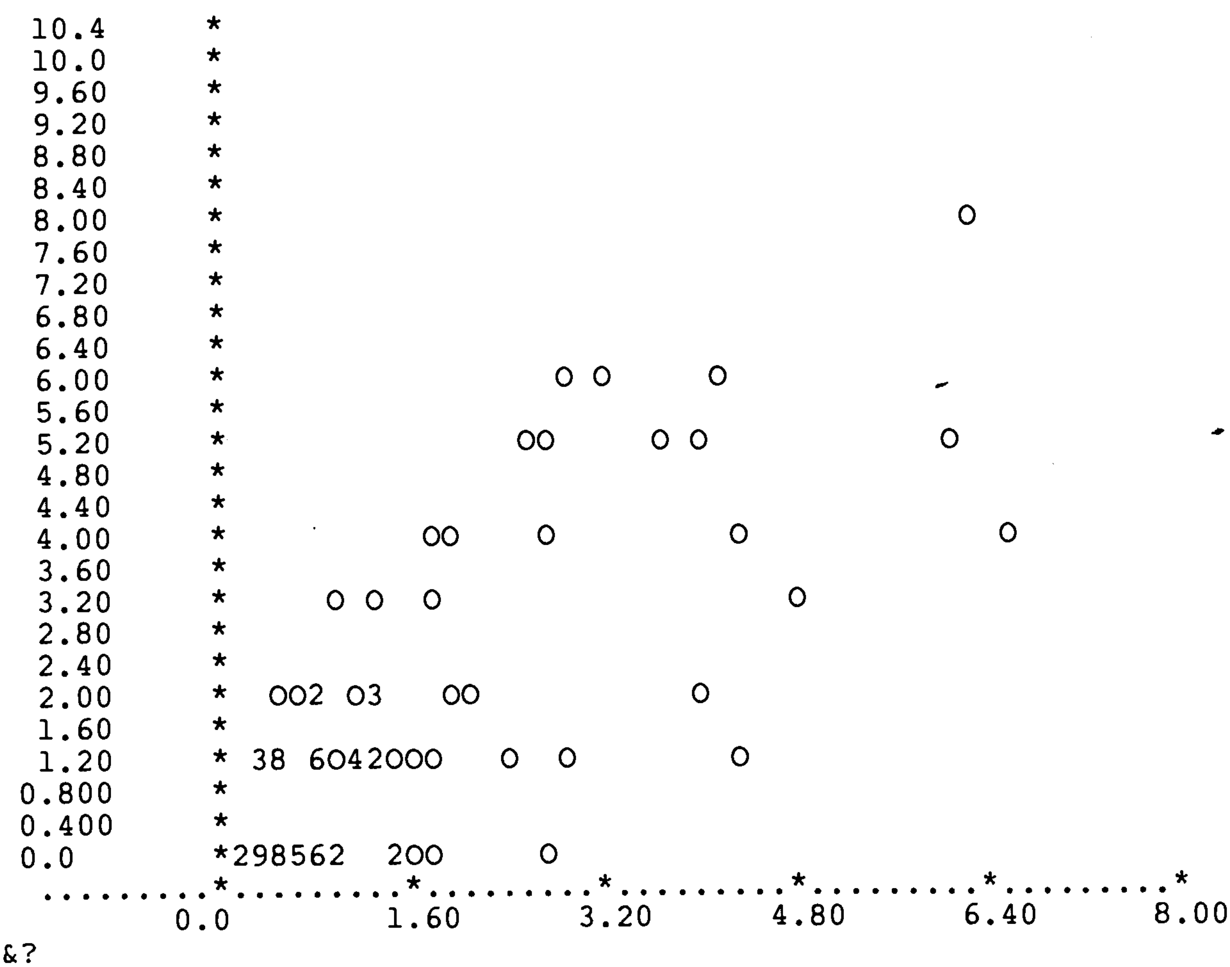
```
  3.90     *
  3.60     *
  3.30     *
  3.00     *                 R
  2.70     *                   R
  2.40     *          R    R
  2.10     *     R     R    R
  1.80     *       R                 R            R
  1.50     *  R
  1.20     *   R2     R     R     R
 0.900     *      R2                R
 0.600     * 36    R
 0.300     *  2 5
 0.0       *    RR3    RR
-0.300     *292   R2R                 R
-0.600     *  65R    RR
-0.900     *    52                               R
 -1.20     *
 -1.50     *        2R    R
 -1.80     *          R      R           R
 -2.10     *                        R
 -2.40     *
 -2.70     *                R                       R
 -3.00     *
 -3.30     *                          R
 -3.60     *
 -3.90     *
  .........*.........*.........*.........*.........*.........*
         0.0        1.60      3.20      4.80      6.40      8.00
```

FIGURE 4.4.2F

Plot of Standardized Residuals vs. Fitted Values
for Females in Experiment 4

```
  2.24     *
  2.08     *  S  S
  1.92     *                 S
  1.76     *          S
  1.60     *   S       S   S   S
  1.44     * S  S  S
  1.28     * S  S           S
  1.12     *
 0.960     * S        S              S
 0.800     *  4   SS        S
 0.640     *  4    2              S               S
 0.480     *                        S
 0.320     *    3
 0.160     *    3      S
 0.0       *     SS     S
-0.160     *      32                  S
-0.320     *        S
-0.480     *25       SS                          S
-0.640     * 47
-0.800     *  S52                        S
-0.960     *    42        S         S               S
-1.12      *        S        S
-1.28      *        SSS
-1.44      *
-1.60      *                S         S
-1.76      *
-1.92      *
  .........*.........*.........*.........*.........*.........*
         0.0        1.60      3.20      4.80      6.40      8.00
```

FIGURE 4.4.3F
Plot of Observed Values vs. Fitted Values
for Females in Experiment 4



&?

FIGURE 4.5.1M

Plot of Residuals vs. Fitted Values for Males in Experiment 5

```
  5.10     *
  4.80     *
  4.50     *                                     R
  4.20     *
  3.90     *
  3.60     *
  3.30     *
  3.00     *                        R
  2.70     *
  2.40     *
  2.10     *
  1.80     *R
  1.50     *  R    2
  1.20     *  RR    2        R
 0.900     *    3          R
 0.600     *R4R
 0.300     *  73
 0.0       42   2    RR        R
-0.300     *94         R
-0.600     * R4    3
-0.900     *   2     R   R
 -1.20     *         R     2    2
 -1.50     *       2    R
 -1.80     *            R
 -2.10     *                        R
 -2.40     *          R
 -2.70     *
  .........*.........*.........*.........*.........*.........*
         0.0        2.00      4.00      6.00      8.00      10.0
```

FIGURE 4.5.2M

Plot of Standardized Residuals vs. Fitted Values
for Males in Experiment 5

```
  4.50     *
  4.25     *
  4.00     *
  3.75     *S
  3.50     *
  3.25     *
  3.00     *
  2.75     *
  2.50     *
  2.25     *
  2.00     *
  1.75     *  S
  1.50     *S S                                  S
  1.25     * S S   2                S
  1.00     * S  3   2
 0.750     * 2S              S
 0.500     *  6            S
 0.250     *  S3
 0.0       *    2    SS        S
-0.250     42          S
-0.500     *93     3     S      2
-0.750     * 24      2     2
-1.00      *   2        2           S
-1.25      *       2
-1.50      *          S
-1.75      *
-2.00      *
  .........*.........*.........*.........*.........*.........*
         0.0        2.00      4.00      6.00      8.00      10.0
```

FIGURE 4.5.3M
Plot of Observed Values vs. Fitted Values
for Males in Experiment 5

```
  13.0     *
  12.5     *
  12.0     *                                     O
  11.5     *
  11.0     *
  10.5     *
  10.0     *
  9.50     *
  9.00     *
  8.50     *
  8.00     *                        O
  7.50     *
  7.00     *
  6.50     *
  6.00     *
  5.50     *
  5.00     *                 O
  4.50     *
  4.00     *               O   O
  3.50     *
  3.00     *       22           2   O
  2.50     *
  2.00     *O 2O3    OOO O 2
  1.50     *
  1.00     *O4832  3 2  2
 0.500     *
 0.0       49542   2  O
  .........*.........*.........*.........*.........*.........*
         0.0        2.00      4.00      6.00      8.00      10.0
&?
```

FIGURE 4.5.1F
Plot of Residuals vs. Fitted Values for Females in Experiment 5

```
  3.40     *    R
  3.20     *
  3.00     *
  2.80     *
  2.60     *
  2.40     *    R
  2.20     *
  2.00     *
  1.80     *         R                2
  1.60     *  R
  1.40     *
  1.20     *               R      R
  1.00     *       R
 0.800     * 3                2
 0.600     *  42       R
 0.400     *   22       R                         R
 0.200     *             R R      R
 0.0       *       RR              2
-0.200     * 5       2        R
-0.400     *  97       R
-0.600     *   R5       3
-0.800     *     22      R
 -1.00     *        R
 -1.20     *
 -1.40     *
 -1.60     *            R                         2
 -1.80     *                      R
  .........*.........*.........*.........*.........*.........*
         0.0       1.20      2.40      3.60      4.80      6.00
```

FIGURE 4.5.2F

Plot of Standardized Residuals vs. Fitted Values
for Females in Experiment 5

```
  5.00     *
  4.75     *
  4.50     *    S
  4.25     *
  4.00     *
  3.75     *
  3.50     *
  3.25     *    S
  3.00     *
  2.75     *  S
  2.50     *
  2.25     *
  2.00     *
  1.75     *         S
  1.50     * S
  1.25     * 2S
  1.00     *  3    S                  2
 0.750     *   4           S      S
 0.500     *    2      S      2
 0.250     *            SS        S               S
 0.0       *       SS      S       2
-0.250     *         2 S      S
-0.500     * 59         3S
-0.750     *  3852                                2
-1.00      *      2 S             S
-1.25      *            S
-1.50      *
  .........*.........*.........*.........*.........*.........*
         0.0        1.20      2.40      3.60      4.80      6.00
```

FIGURE 4.5.3F
Plot of Observed Values vs. Fitted Values
for Females in Experiment 5

```
5.20      *
5.00      *                          2           O
4.80      *
4.60      *
4.40      *
4.20      *
4.00      *    O                 O
3.80      *
3.60      *
3.40      *
3.20      *
3.00      *    O    O     O  2   O2              2
2.80      *
2.60      *
2.40      *
2.20      *
2.00      *  O    O   OOO O  O
1.80      *
1.60      *
1.40      *
1.20      *
1.00      * 3442  OO2 O3O        O
0.800     *
0.600     *
0.400     *
0.200     *
0.0       * 598522 O   O
 .........*.........*.........*.........*.........*.........*
        0.0        1.20      2.40      3.60      4.80      6.00
&?
```

FIGURE 4.6.1M
Plot of Residuals vs. Fitted Values for Males
in Experiment 6

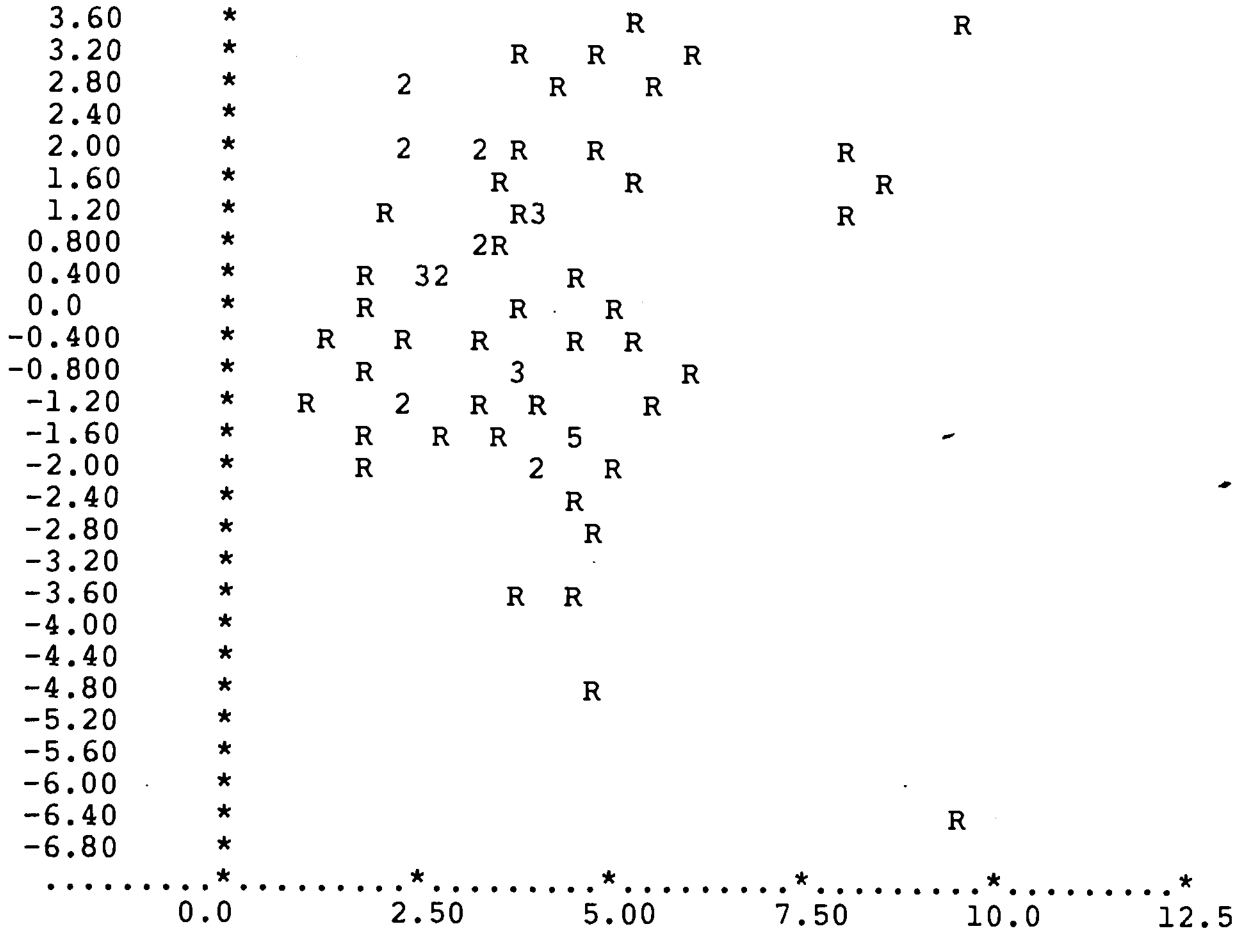


FIGURE 4.6.2M
Plot of Standardized Residuals vs. Fitted Values for Males in Experiment 6

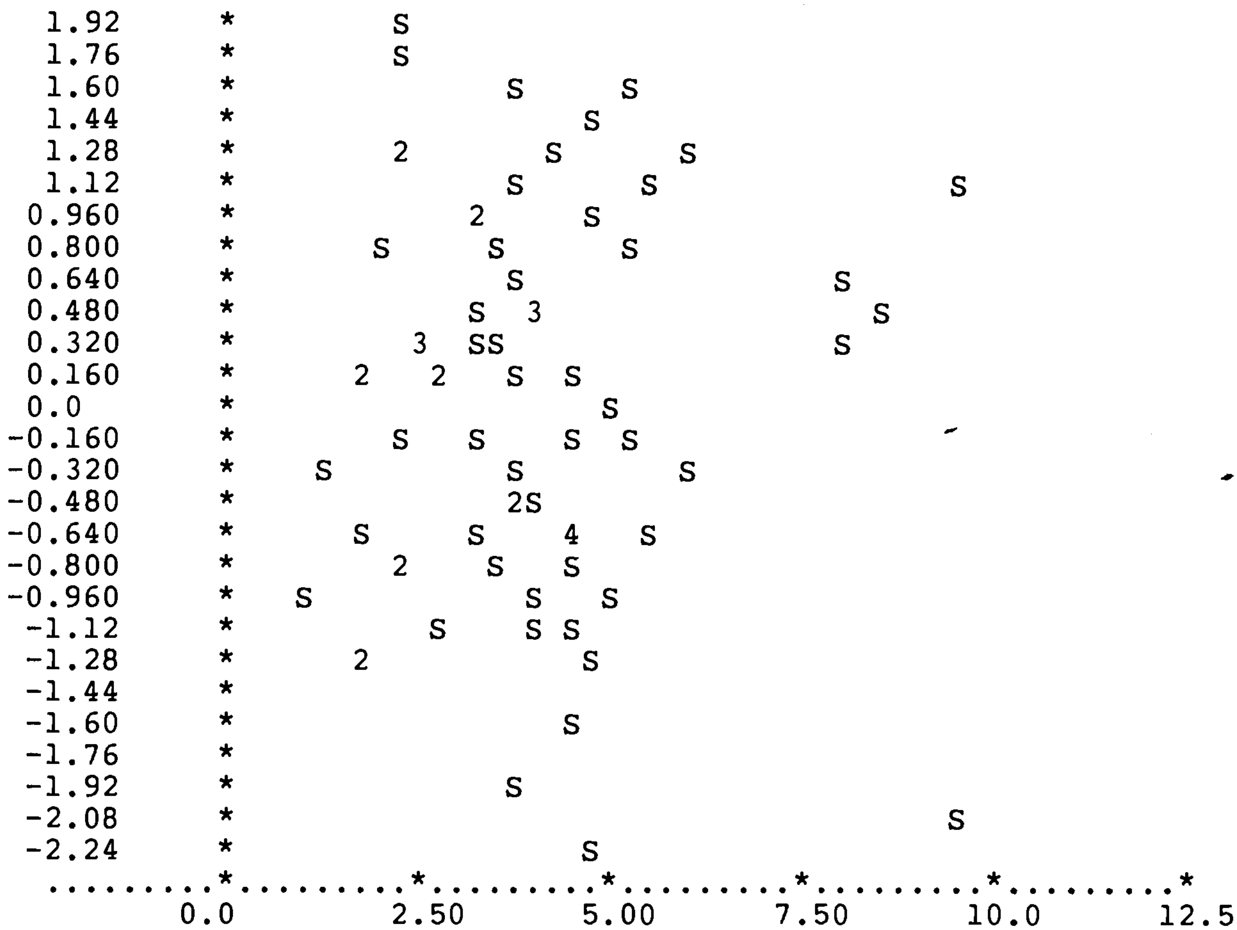
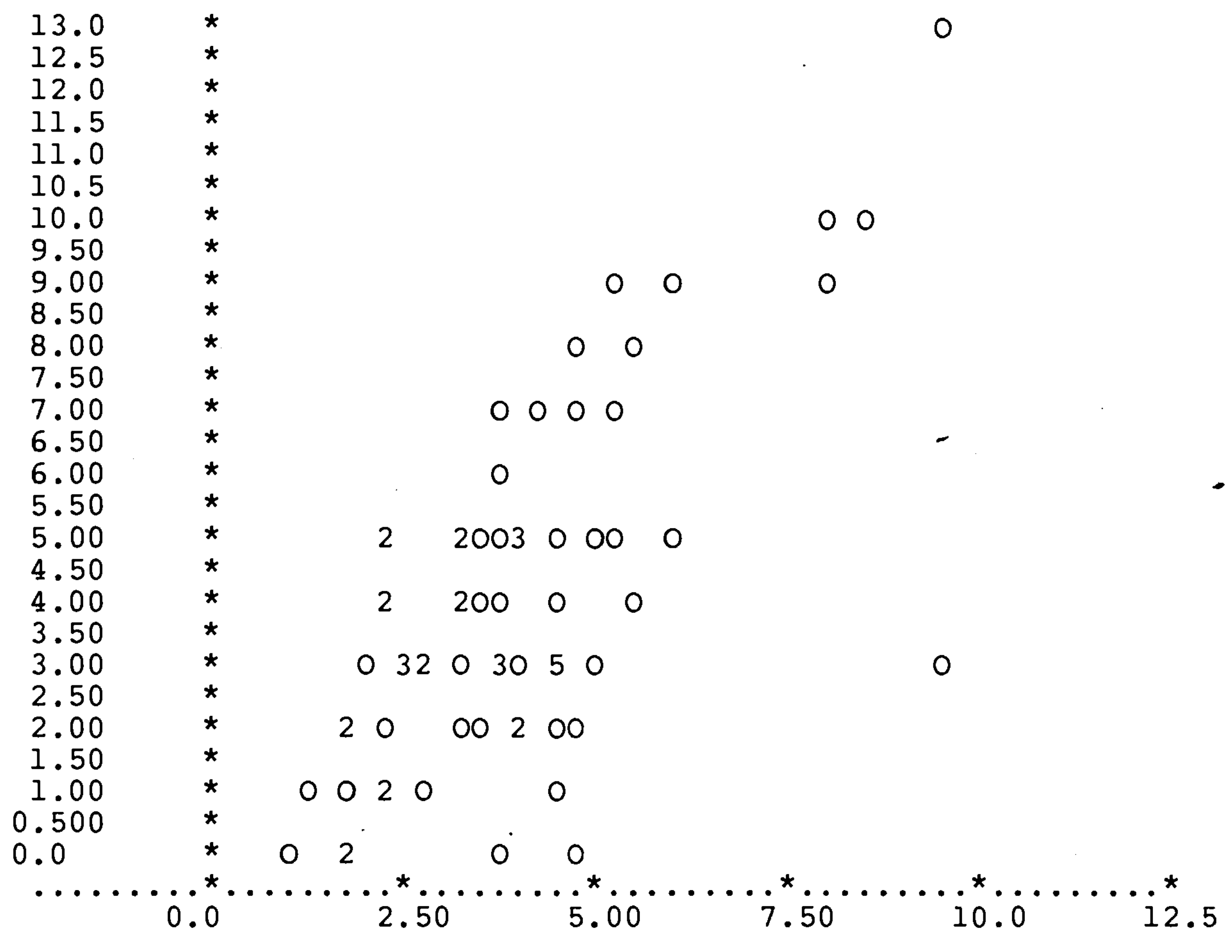


FIGURE 4.6.3M
Plot of Observed Values vs. Fitted Values
for Males in Experiment 6



&?

FIGURE 4.6.1F
Plot of Residuals vs. Fitted Values for Females
in Experiment 6

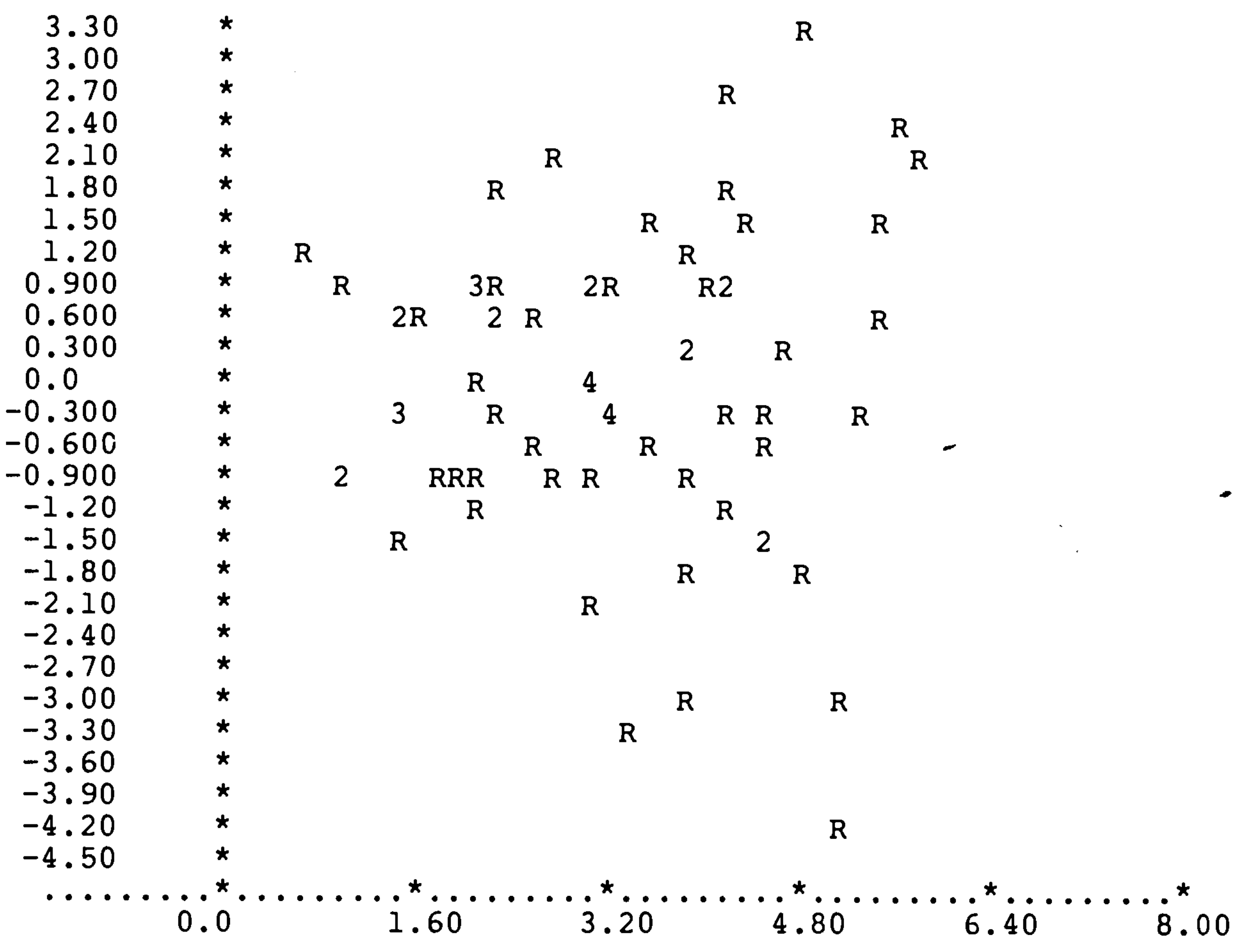


FIGURE 4.6.2F
Plot of Standardized Residuals vs. Fitted Values
for Females in Experiment 6

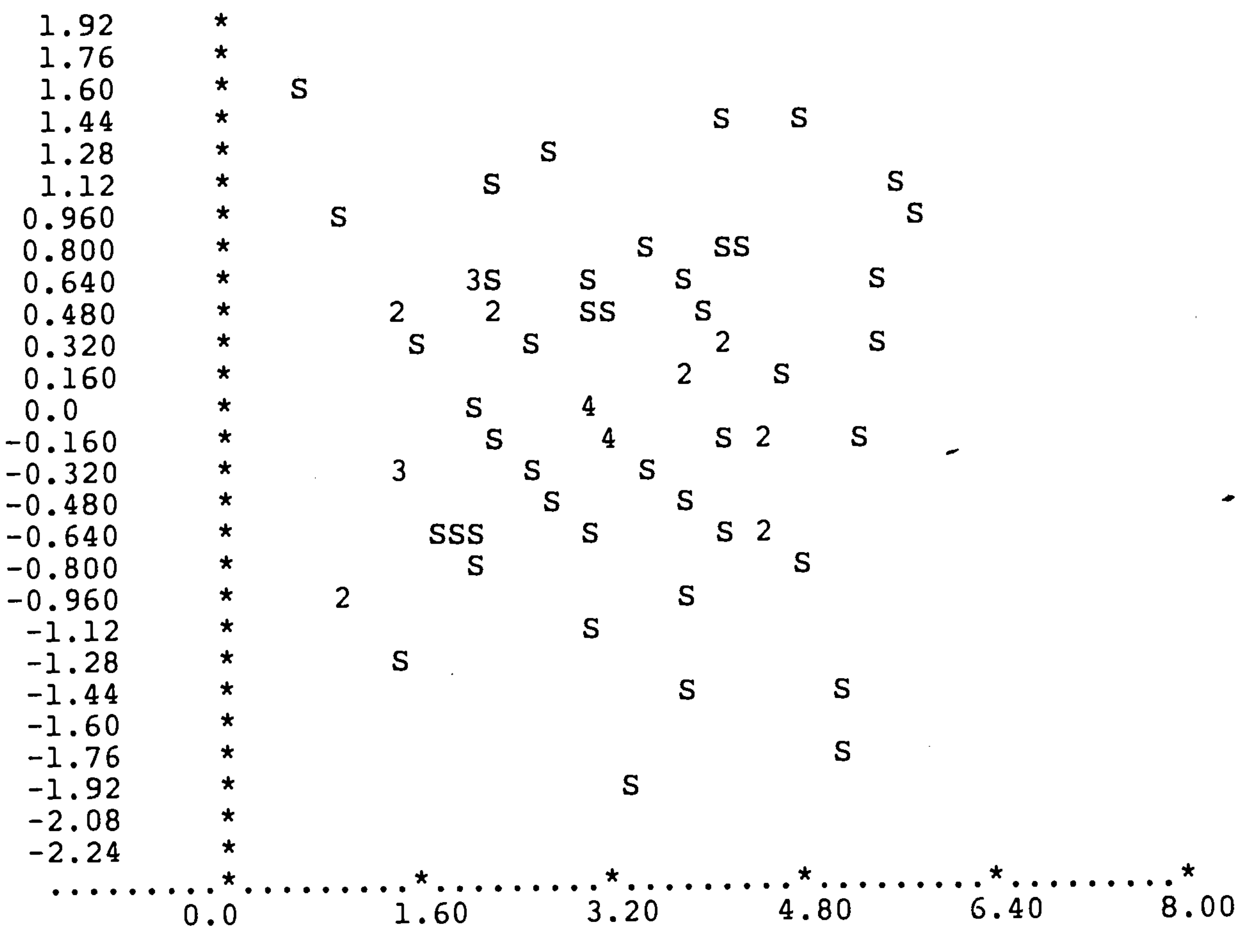


FIGURE 4.6.3F
Plot of Observed Values vs. Fitted Values
for Females in Experiment 6

```
 10.4     *
 10.0     *
 9.60     *
 9.20     *
 8.80     *
 8.40     *
 8.00     *                             O    OO
 7.60     *
 7.20     *                         O       O
 6.80     *
 6.40     *
 6.00     *                         OO      O
 5.60     *
 5.20     *                O    O OO2  O   O
 4.80     *
 4.40     *
 4.00     *             O    2O   2 O 2
 3.60     *
 3.20     *            33 O  44 O O O 2 O
 2.80     *
 2.40     *
 2.00     *   O O  2O  OO OO O    O       O
 1.60     *
 1.20     *        3 OO2     O    O       O
0.800     *
0.400     *
0.0       *     2  O           O
 .........*.........*.........*.........*.........*.........*
        0.0        1.60      3.20      4.80      6.40      8.00
&?
```

CHAPTER 5

CONCLUSION

This project studies the statistical analysis of the spectral discrimination by onion flies(*Delia antiqua*) in an onion field. The log-linear model applied here belongs to the class of *Generalized Linear Models*. McCullagh and Nelder(1983) give detailed discussion about the connection between log-linear models for independent Poisson random variables and multinomial response models for proportions. Also, in section 2.2, we have seen that the estimate of β in a multinomial model is identical to the one based on the Poisson log likelihood $L(N..., \zeta, \beta)$. In other words, the conditional distribution is independent of ζ. One point that we need to mention is that under the log-linear model,

$$\log(\mu_{ijk}) = \zeta_{ij} + X_{ijk}\beta \ ,$$

the number of parameters is (J+K). As J goes to infinity, maximum likelihood estimates may not necessarily have the usual asymptotic properties. However, $\hat{\beta}$ is still a consistent estimate. In section 2.2.2, it has shown that all information concerning β is contained in the term $\sum_{j=1}^{J_i} \sum_{k=1}^{K_i} N_{1jk}\{X_{1jk}\beta - \log[\sum_{h=1}^{K_i}\exp(X_{ijh}\beta)]\}$ (p.14). This shows that as J --> ∞, β is consistently estimated but not ζ. (See Palmgren(1981) and McCullagh & Nelder(1983))

In general, it is appropriate to deal with the observed conditional total when the parameter of interest is a ratio of Poisson means. The discussion in section 2.2.2 shows that as far as parameter estimates $\hat{\beta}$ and $\text{cov}(\hat{\beta})$ are concerned, the same solution will be obtained whether or not we condition on the totals which lead to a multinomial(binomial) model or the Poisson log-linear model provided that the appropriate nuisance parameters are included in the log-linear model. For example, in experiment 1, we would like to find if UV wavelength reflectance influences, quantitatively, the visual response of *Delia antiqua*. We estimated that the male response ratio changed by -0.029 for every unit percent increase in intensity of UV reflectance with p-value equal to 0.000. Negative effects in UV wavelength reflectance have also been reported in Judd's paper(1986). He proposed 350,450 and 560 nm, as representative wavelength variables, with multiple regression, to predict the mean relative response defined as follows:

$$\hat{Y} = 0.612 - 0.012\%UV_{350} + 0.013\%BL_{450} - 0.006\%GR_{560}$$

where $\hat{Y}_{ijk} = \frac{\text{square root of } N_{ijk}+0.5}{\text{square root of } N_{ijTiO_2\text{-white}}}$. For the six experiments as a whole %UV does appear as a dominant explanatory variable. The estimates associated with %UV were highly significant (more than 3 standard deviations from 0) for males in all experiments, except experiment 6. On the other hand, females were not so significantly affected by %UV. It appears that females were more attracted by blue reflectance surfaces. The summary of the conclusions in comparison to Judd's regression models is given below:

Experiment 1 white series

Judd

male: $\hat{Y} = 1.34 - 0.011\%UV$

female: no significant model has been obtained

Poisson

male: $E(N) = \exp(\text{some field factor} - 0.02904\%UV)$

female: $E(N) = \exp(\text{some field factor} - 0.009776\%UV)$ (not significant)

Experiment 2 grey series

Judd

male: $\hat{Y} = 0.304 + 0.008(\frac{\%BL+\%GR}{2})$

female: $\hat{Y} = 0.371 + 0.007(\frac{\%BL+\%GR}{2})$

(Both sexes were fitted only with non-UV grey traps)

Poisson

male: $E(N) = \exp\{\text{some field factor} - \frac{3.534\%UV}{(\%BL+\%GR)/2}\}$

female: $E(N) = \exp\{\text{some field factor} - \frac{2.833\%UV}{(\%BL+\%GR)/2}\}$

Experiment 3 blue series

Judd

male: $\hat{Y} = 1.52 - 0.0137\%UV$

female: $\hat{Y} = 1.53 - 0.0124\%UV$

(Both sexes were fitted only with UV-blue traps)

Poisson

male: $E(N) = \exp\{\text{some field factor} - \frac{2.855\%UV}{\%BL} - 0.01193\%GR\}$

female: $E(N) = \exp\{\text{some field factor} - \frac{2.713\%UV}{\%BL} - 0.01299\%GR\}$

Experiment 4 green series

Judd

male: $\hat{Y} = 0.1735 + 0.0095(\frac{\%BL+\%GR}{2})$

female: $\hat{Y} = 0.13 + 0.01(\frac{\%BL+\%GR}{2})$

(Both sexes were fitted only with non-UV green traps)

Poisson

male: $E(N) = \exp\{\text{some field factor} - \frac{42.46\%UV}{\%GR} + 33.91(\frac{\%UV}{\%GR})^2\}$

female: $E(N) = \exp\{\text{some field factor} - \frac{4.271\%UV}{\%BL}\}$

Experiment 5 yellow series

Judd

male: $\hat{Y} = -0.4181 + 0.0163(\frac{\%BL+\%GR}{2})$

female: $\hat{Y} = -0.7226 + 0.0198(\frac{\%BL+\%GR}{2})$

(Both sexes were fitted only with non-UV yellow traps)

Poisson

male: $E(N) = \exp\{\text{some field factor} - 4.489(\frac{\%UV}{\%BL})\}$

female: $E(N) = \exp\{\text{some field factor} - \frac{17.87\%UV}{(\%BL+\%GR)/2}\} + 14.26\frac{\%UV}{\%GR}\}$

Experiment 6 blue hues+UV series

Judd

male: no significant model has been obtained

female: no significant model has been obtained

Poisson

male: $E(N) = \exp\{\text{some field factor} + \frac{4.331\%UV}{\%BL} - 3.741(\frac{\%UV}{\%BL})^2\}$

female: $E(N) = \exp\{\text{some field factor} + \frac{6.541\%UV}{\%BL} - 3.741(\frac{\%UV}{\%BL})^2\}$

(Both significant at 5% level.)

The log-likelihood-ratio statistics and residual plots indicate the adequacy of the proposed models except for a couple of cases, such as experiment II(females), experiment VI(males). The problem in those experiments might be improved by introducing non-Poisson variance structure, or a different link function (Baker and Nelder, 1978). However, the analysis could then become much more complex. Preliminary investigations of this nature have been carried out.

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