USE OF BINARY AND TRUNCATED REGRESSION MODELS IN THE ANALYSIS OF RECREATIONAL FISH CATCHES

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ONE OF AUSTRALIA'S FAVOURITE PAST TIMES: RECREATIONAL FISHING
STATEMENT OF ORIGINALITY

I declare, to the best of my knowledge and belief, the work contained in this thesis is my own work, except as acknowledged in the text. Furthermore, this material has not been submitted, either in whole or in part, for a degree at this or any other university.

Michael O’Neill
ACKNOWLEDGMENTS

This study would not have been possible without the support offered by many people. I would like to especially thank my supervisors, Professor Malcolm Faddy (The University of Birmingham) and Professor John Eccelston (The University of Queensland), for their enthusiasm and guidance throughout the duration of my MSc. I also thank the Department of Primary Industries, Queensland for the opportunity to use departmental facilities and data.

The accomplishment of the recreational fishing survey was only possible with the hard work of Mr Chris Barber, Mr Barry Burgum and Mr Peter Jovic. They helped interview numerous recreational fishers.

The support from many recreational anglers made the information available that is presented here.

I dedicate this thesis to my parents Arthur and Kath for providing continued support towards my education and to my wife, Erica, who has been the source of all my inspiration.
ABSTRACT

Estuaries provide one of the most popular areas for commercial and recreational anglers to fish. At present, no estuary-specific study of recreational fisheries resources has been attempted in southern Queensland, Australia. The work reported in this thesis provides a detailed analysis on the recreational catch of the yellowfin bream (*Acanthopagrus australis*), dusky flathead (*Platycephalus fuscus*) and sand whiting (*Sillago ciliata*) resources in the Burnett River, Maroochy River and Pumicestone Passage. Recreational fishing data typically contain a large proportion of zero values and show variability or dispersion greater than that allowed for in many standard regression models (e.g., Normal and Poisson) and the assumptions required for these analyses will not be valid. In this thesis a two-stage regression approach involving a binary (non-zero/zero catch) response and the non-zero catches was used for analysing recreational fish catches to account for the extra zeros and over-dispersion present in the data. Also, the statistical bootstrap method was utilised to estimate confidence intervals on total recreational catch given the large proportion of zero catches.

Unlike the Queensland commercial fisheries, which provide catch returns, the recreational catch was unknown and needed to be estimated. Recreational catch and fishing effort data from roving creel surveys were collected between June 1997 and August 1998. This method involved a person on the water counting and interviewing boat and shore fishers at a variety of locations and times. The number of people fishing and the resulting harvest differed between estuaries. More people fished during winter than at any other time of the year. Annual recreational fishing effort was of the order of 13 000 angler visits to the Burnett River, 28 000 to the Maroochy
River, and 41 000 to the Pumicestone Passage. Catch rates were generally less than one fish per group fishing hour. Binary and truncated regression models were effective in analysing the catch data, which exhibited many zero values. Boat fishing groups with large numbers of anglers were less likely to catch fish than smaller groups. However, groups with more fishing lines had more chance of catching fish compared to similar sized groups with fewer lines. Estimated daytime recreational catch of yellowfin bream, dusky flathead and summer whiting was greater in Pumicestone Passage than in the Maroochy River or Burnett River. A summary of estimated total recreational catches is given in Table 1. The results highlight the magnitude of recreational fishing in Australian estuaries, and reinforce the concept that future assessment of fish stocks should include the recreational fishery.

Table 1 Summary of total recreational catch estimates. Note: Recreational catch was estimated for the daytime period 6am to 6pm from September 1997 to August 1998 (95% bootstrap confidence intervals shown in parentheses).

<table>
<thead>
<tr>
<th>Fishing Effort</th>
<th>Burnett River</th>
<th>Maroochy River</th>
<th>Pumicestone Passage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recreational (daily boat numbers)</td>
<td>10 (8-11)</td>
<td>15 (13-18)</td>
<td>43 (38-49)</td>
</tr>
<tr>
<td>Recreational (daily shore fisher numbers)</td>
<td>17 (14-20)</td>
<td>48 (43-54)</td>
<td>27 (22-33)</td>
</tr>
<tr>
<td>Yellowfin bream</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreational Catch (tonnes)</td>
<td>5.5 (4.4-6.7)</td>
<td>12.9 (9.6-17.0)</td>
<td>22.7 (19.1-27.0)</td>
</tr>
<tr>
<td>Dusky Flathead</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreational Catch (tonnes)</td>
<td>2.6 (1.8-3.3)</td>
<td>2.3 (1.4-3.1)</td>
<td>10.6 (7.9-13.0)</td>
</tr>
<tr>
<td>Summer Whiting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreational Catch (tonnes)</td>
<td>1.4 (1-1.9)</td>
<td>5.2 (4.2-6.2)</td>
<td>9.8 (8.1-11.7)</td>
</tr>
</tbody>
</table>
PUBLICATIONS


PRESENTATIONS

The Department of Primary Industries, Queensland, Seminar Series, Southern Fisheries Centre, May 2000.

The Queensland Subtropical Fish Management Advisory Committee, Brisbane, March 2000.

The Department of Primary Industries, Queensland, Biometry Conference, March 1999.


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Chapter 1. GENERAL INTRODUCTION

Species abundance data in the form of discrete counts are probably the most common type collected in fishery research surveys. The frequent occurrence of these data has led to the use of generalized linear models for analysing them. These models are often based upon Normal, Poisson and Negative Binomial distributions. However, data collected from recreational fishing surveys often contain a large proportion of zero counts and different methods are required to accurately analyse such data.

1.1 REGRESSION MODELS FOR COUNT DATA

McCullagh and Nelder (1989) have outlined a number of regression models for analysing count data. They include the Poisson, truncated Poisson and Negative Binomial distributions, and Quasi-Likelihood estimation. Of these, the Poisson model is the simplest, but assumes counts result from individuals being randomly dispersed. The Poisson regression model is a natural choice to analyse count data given that it assigns probabilities of occurrence to non-negative integers. However, the assumption that counts arise from random processes is rarely supported by fisheries data. Usually fish abundance is clustered and related to specific habitat and seasonal characteristics.

Another similar model, the truncated Poisson, has the same assumption as the Poisson but is applied to data where the zero counts have been purposely excluded or have not been recorded. This model will usually display less variation than the standard Poisson due to the absence of zeros from the data. David and Johnson (1952), Johnson et al (1992) and Welsh (1996) have detailed the truncated Poisson model. Welsh (1996) found the truncated Poisson regression model provided a satisfactory analysis.
of the abundance of Leadbeater’s Possum. However, data generally contain more variation than can be explained by the Poisson and truncated Poisson models and other methods are required in these cases.

In situations when data shows extra variation relative to the Poisson distribution or variance in excess of the mean, Negative Binomial regression can be used. The Negative Binomial can be viewed as a form of Poisson regression that includes a random component reflecting the uncertainty about the true rates at which events occur for individual cases (Gardner et al, 1995). Negative Binomial regression has become increasingly popular as a more flexible alternative to the Poisson, especially when it is doubtful whether the strict requirements, particularly independence, for Poisson regression will be satisfied (Johnson et al, 1992). Lawless (1987) reviewed Negative Binomial regression and compared results from this analysis with McCullagh and Nelder’s quasi-likelihood analysis on incidence of ship damage. Their analysis did not show strong evidence of extra-Poisson variation under either model. Similar parameter values were estimated, but the Negative Binomial model produced larger standard errors. Lawless (1987) highlighted that when the residual degrees of freedom from the regression is not large, the dispersion parameter may not be estimated very precisely and different methods can lead to rather different standard errors. Gardner et al (1995) also examined the Negative Binomial regression and compared results on community rates of violence with Poisson regression. They found the Negative Binomial model fitted the data more closely than the Poisson as it better explained the large number of patients with no incidents. In their data the observed number of zeros was 55% and the Negative Binomial regression predicted 45% compared to 18% predicted by Poisson regression. Negative Binomial regression has
also been used on fisheries data. Stobutzki et al (2000) used the estimates of mean catch rates of fish and variance from the Negative Binomial regression for a power analysis to estimate the number of trawls required to detect declines in catch rates of fish from a baseline trawl survey. Here their data contained extra zeros and they calculated for some fish species that in excess of 1000 trawls were required to detect a decline of 50% at significance $p<0.05$. This estimate of sample size was extremely large and the result was quite negative about the ability to monitor changes in fish catch rates. Alternatively, in their case, superior models were probably needed to estimate the mean catch rates and variances more accurately, and deal with the influence of extra zeros in the data.

There have been a number of methods proposed for analysing data which show extra Poisson variation and exhibit many zero values. These methods have generally considered a two-stage approach for analysis. The two-stage approach basically separates the zeros from the non-zero values. Under the two-stage analysis, the presence or absence of individuals is modelled using a logistic regression model. The non-zero data are then modelled with a truncated residual distribution. Some examples of two-stage models include the Binomial - truncated Negative Binomial (Welsh et al. 1996 and Welsh et al. 2000) and the extended Poisson Process (Faddy 1997a, 1997b and 1998; Bosch and Ryan 1998) models.

When extra Poisson variation is present in two-stage analyses, sometimes the use of specific truncated distributions cannot adequately model the data. Here, extended Poisson process models can be applied. These models have the benefit that they can admit variation ranging from below truncated Poisson, in between truncated Poisson
and truncated Negative Binomial, to in excess of truncated Negative Binomial. They allow for better control of the residual variation as covariates are included in the regression model and thus more faithfully describe the data. Faddy (1998) compared the performance of an extended Poisson Process model with the Leadbeater’s possum analysis of Welsh (1996). The extended Poisson Process model suggested that with no covariate effects in the regression model the truncated Poisson model was suitable. However, when all seven covariates were included in the model less residual variation was present. Comparison of the predicted means showed that the truncated Poisson would underestimate the mean for large covariate values, but would overestimate for small covariate values. For this reason, it may not be clear how covariates influence the mean and variance relationship when incorporated in a regression model. Given the difficulties of trying to account for extra Poisson variation in data, output from a range of regression models should be compared to have greater confidence in any statistical inferences made. A summary of different regression models for analysing count data is given in Table 1.1.
**Table 1.1** Summary of regression models for analysing counts.

<table>
<thead>
<tr>
<th>Type of data</th>
<th>Suggested Method</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>For all data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>variance = mean</td>
<td>Poisson</td>
<td>McCullagh and Nelder 1989</td>
</tr>
<tr>
<td>variance &gt; mean</td>
<td>Negative Binomial</td>
<td>Engel 1984; Lawless 1987; McCullagh and Nelder 1989; Gardner et al. 1995</td>
</tr>
<tr>
<td></td>
<td>Extra Poisson</td>
<td>Gardner et al. 1995</td>
</tr>
<tr>
<td></td>
<td>Quasi Likelihood</td>
<td>McCullagh and Nelder 1989; Lee and Nelder 1999</td>
</tr>
<tr>
<td></td>
<td>Extended Poisson Process</td>
<td>Faddy 1997a</td>
</tr>
<tr>
<td>variance &lt; mean</td>
<td>Extended Poisson Process</td>
<td>Faddy 1997a</td>
</tr>
<tr>
<td><strong>For truncated data – zero counts excluded</strong></td>
<td>These models involve truncated versions of the above distributions.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Truncated Poisson</td>
<td>David and Johnson 1952; Johnson et al. 1992; Welsh et al. 1996</td>
</tr>
<tr>
<td></td>
<td>Truncated Negative Binomial</td>
<td>Johnson et al. 1992; Welsh et al. 1996; Welsh et al. 2000</td>
</tr>
<tr>
<td></td>
<td>Extended Poisson Process</td>
<td>Bosch and Ryan 1998; Faddy 1997a, 1997b and 1998</td>
</tr>
</tbody>
</table>

### 1.2 Recreational Fishing Surveys

In Australia there has been increased interest in assessing the magnitude of recreational fishing. This interest comes from the demands placed on management authorities to allocate a fair share of fish resources to the recreational fishing sector. To address this issue, information is required on total catches and the economic value of both the commercial and recreational fishing sectors. Fish stock assessment methods also require data on total commercial and recreational catches in order to estimate reference points, such as fishing harvest rates, for sustainable management of fisheries. Present fisheries legislation in Queensland (Fisheries Act, 1994) outlines
these requirements and has placed emphasis on the principles of Ecological Sustainable Development (ESD). The main objectives of this legislation were to:

- ensure fisheries resources are harvested in a sustainable way,
- ensure that optimum community and economic benefits are obtained from fisheries resources and
- ensure access to fisheries resources is fair.

To achieve these objectives, estimates of the total fish catch taken by each sector are required.

There have been relatively few results published comparing commercial and recreational catches. Two studies by Caputi (1976) and West and Gordon (1994) compared recreational and commercial catches and showed that the recreational harvest of several inshore fish species was larger than the commercial catch. In southern Queensland, the commercial harvest of yellowfin bream, dusky flathead and summer whiting has averaged about 200, 70 and 300 tonnes per year respectively (Williams, 1997). Dramatic increases in recreational fishing effort have occurred in recent years due to population growth throughout Australia (Lai et al 1992). In 1999, recreational catches estimated from angler diary records were substantial and in the order of 700 tonnes of yellowfin bream, 300 tonnes of dusky flathead and 300 tonnes of summer whiting in southern Queensland (Higgs, 1999). However, fishing data collected through diary records suffer from a number of sampling, response and non-response errors (Pollock et al 1994). This creates uncertainty about the accuracy of these estimates, even though the relative standard errors were about 10%.
Recreational fisheries have a number of complexities that make estimating total catch difficult. These complexities are associated with the collection of data on recreational fishing effort (eg. number of people or groups fishing per unit of time) and catch rates (eg. number of fish caught per unit of fishing effort) so that they can be multiplied together to estimate total catch. The critical aim here is to correctly measure the units of fishing effort in order to produce an accurate estimate. Collections of recreational fishing data have traditionally been done using creel surveys to count and interview anglers while they fish or as they just leave their fishing location (called on-site surveys, Pollock et al 1994). However, angler surveys by telephone, mail or diaries are being used more often (off-site surveys). On-site surveys are recommended for collecting fishing data over off-site methods (Pollock et al 1994). On-site methods generally have greater coverage of specific fishing regions, low recall bias and low refusal rates to interviews. This study used recreational fishing data collected by the on-site roving creel method.

1.3 THE STUDY AREAS AND HISTORICAL COMMENTS

1.3.1 Burnett River

The Burnett River drains a catchment of 33 150 km$^2$ (Bucher and Saenger 1989). It flows through Bundaberg, 24.8°S, about 350 km north of Brisbane in southern Queensland (Figure 1.1). Estuarine conditions extend 26 km upstream from the river mouth. Mixed mangrove areas consisting of *Avicennia marina*, *Aegiceras corniculatum* and *Rhizophora stylosa* occur in this section.
The riverine environment has been severely disturbed by barrage construction, siltation and pollution (Dredge 1983). In 1933, the Bingera Weir was constructed 42 km from the Burnett River mouth. This became the upper limit of tidal flow. The area of tidal penetration was reduced again in 1976 with construction of another weir ‘The Ben Anderson Barrage’ located 26 km from the river mouth. A new mouth to the Burnett River was dredged deep enough to help large vessels access the sugar wharf facilities in 1958. As part of the river mouth reconstruction, rock walls were constructed to block off the original mouth to the Burnett River. Waterfront vegetation and foreshores have been encroached upon by both agricultural and urban land uses, and most of the estuary’s drainage channels and creeks have been seriously degraded.

Historical comments on fishing in the Burnett River have not been well documented. Local commercial fishers state the Burnett River produced large commercial catches of banana prawns and mullet prior to the 1970s. Also occasional catches of barramundi and king salmon were taken. The only historical recreational fishing data available are club records. These data indicate variable catches of yellowfin bream, dusky flathead and summer whiting taken between 1977 and 1983.
Figure 1.1 Map of the locations of each estuary surveyed in this study.
1.3.2 Maroochy River

The Maroochy River 26.6°S is situated on the Sunshine Coast, in south east Queensland (Figure 1.1). The Maroochy River and its tributaries drain an area of approximately 400 km$^2$ and extend about 22 km inland (Anderson 1993). The Maroochy River has a small estuary compared with other rivers in Queensland. Mixed *Avicennia marina*, *Aegiceras corniculatum* and *Rhizophora stylosa* mangrove communities occur along the river. Recreational use of the river is relatively high.

Most modifications to the riverine environment have been through encroachment of urban and agricultural land uses (Anderson 1993). Deterioration of water quality is also a concern. The river has suffered from two major fish kills, in 1993 and 1994.

Since the late 1800s, river usage has increased as a result of settlement and tourism. In the late 1800s early settlers relied on fish and mud crabs from the Maroochy River as their main source of food. The first recorded commercial fisher worked in the Maroochy River in 1897. The Marine Department first granted official commercial fishing endorsements to 10 fishers in 1920. During the early 1900s commercial fishers mostly netted mullet, usually with a boat crew of two, with one catch made at night. During the winter months, in peak mullet season, an average catch netted fifty to seventy pounds (20 - 30 kg) of marketable mullet. On some occasions the net could be so laden with mullet that the crew were not able to haul it to the bank. Such large catches of mullet at times would take hours to be cleared from the net. Large bream and whiting were also marketed if caught. Fish caught from the Maroochy were sold locally and at the Brisbane markets. At times as many as 1000 cases (mainly mullet) were sent per fortnight to be sold fresh at the Brisbane markets. In the 1950s the
fishing potential of the river encouraged organised recreational fishing competitions. Yellowfin bream, tailor, summer whiting and school jew were caught regularly by keen anglers. These comments were summarised from Alcorn (1994).

Fish populations in the Maroochy River were first considered to be declining in 1934 (Alcorn 1994). Although net fishermen took mainly mullet from the waterway, many people considered commercial fishing to be the cause of perceived declines of all species (Alcorn 1994). Currently two restrictions exist on commercial fishing in the river:

- Since 1960 the area upstream of the junction between northern and southern Maroochy River branches has been closed to commercial fishing;
- Since 1987 the area inside the mouth of the Maroochy River upstream to the public boat ramp known as the Cod Hole, the waters of the outer bar and the foreshore 400m north and south of the river mouth have been closed to commercial fishing.

Even with these commercial restrictions some fishers claimed that the resource was not as large as it used to be. This viewpoint was not unanimous (Alcorn 1994).

1.3.3 Pumicestone Passage

Pumicestone Passage is the water body located between Bribie Island and the mainland, and extends from Caloundra in the north to Toorbul Point in the south (Figure 1.1). The Passage is a large diverse estuarine system some 45 km long, with a catchment area of 665.8 km² (Bucher and Saenger 1989). Mixed *Avicennia marina*, *Aegiceras corniculatum*, *Rhizophora stylosa* and *Bruguiera gymnorhiza* mangrove
communities occur along the Passage, as well as areas of *Zostera capricorni* and *Halophila spp* seagrass. The Passage provides important habitat areas for juvenile and adult fish of commercial and recreational significance.

Modifications to the Passage environment have been restricted mostly to the northern and southern ends. These changes mainly resulted from encroached urban land use. Runoff and water quality is of concern given low tidal exchange in some areas of the Passage (QDEH 1993).

Comments by Petrie (1980) and Tutt (1986) on fish abundance in the Passage highlighted plentiful supplies of sea mullet available for commercial harvest in the early 1900s. Early traditional fishers could catch more mullet than they could eat, which appears not to be the case now (Petrie 1980). In 1898, a fish cannery was built adjacent to the Passage. Tutt (1986) records that ‘sea mullet were so plentiful that the owner of the fish cannery, Charles Godwin, could say in the evening, “We need another hundred cases for tomorrow,” and the hundred cases would be netted’. At Howard’s Hole, off Golden Beach, ‘the glint of mullet in late afternoon looked like snow falling’ (Tutt 1986). Recreational fishing clubs recognised the fishing potential for yellowfin bream, dusky flathead and summer whiting in the 1950s (QFMA 1997).

In October 1995 the Passage was closed to all forms of commercial fishing following a review of policy on recreational fishing. The passage became the first ‘recreational only’ fishing estuary in Queensland. Restrictions now apply to all forms of fishing in Tripcony Bight in the Passage. Under the Marine Parks (Moreton Bay) Zoning Plan 1997, the Tripcony Bight area is a Protection (National Park) Zone within the
Moreton Bay Marine Park, prohibiting all forms of fishing. The purpose of the zone is to provide for the permanent preservation of the zone’s biological diversity and natural condition to the greatest possible extent. The rest of the Passage, except for the Caloundra area, is declared a Fish Habitat Area (under the Fisheries Act 1994) and a Conservation Park Zone. This allows recreational fishing to be undertaken, but prohibits any disturbance to marine and intertidal habitats.

1.4  **BIOLOGY OF THE FISH SPECIES**

The following sections describe the biology of the fish species covered in this study (Williams 1997).

**1.4.1  Yellowfin Bream**

The yellowfin bream *Acanthopagrus australis* is a member of the family Sparidae. Yellowfin bream grow to a maximum size of 50 cm total length, with female bream maturing at about 24 cm, and males at a slightly smaller size. Yellowfin bream reach legal minimum size (23 cm) at about three years of age. The proportion of female bream in the population increases with fish size. Yellowfin bream spawn between May and August in southern Queensland waters in the vicinity of surf bars. Each female produces between 300 000 and 3 million eggs from a single spawning each
year. Juvenile bream occur in areas associated with seagrass and mangroves in estuaries. Yellowfin bream are omnivorous, eating small crustaceans, molluscs and fish as well as algae, seagrass and mangrove litter.

\section*{1.4.2 Dusky Flathead}

The dusky flathead \textit{Platycephalus fuscus} is a member of the family Platycephalidae. Dusky flathead are reasonably fast growing (maximum size 1 metre), with length at first maturity in Moreton Bay for females being 45 cm total length, at about 3 years of age. Minimum legal size is 30 cm. Females grow to a greater size and at a faster rate than males. Fecundity estimates range from about 0.3 to 3.9 million eggs in fish from 42 to 80 cm total length respectively. In southern Queensland dusky flathead appear to spawn at estuarine entrances between September and February. The species is dependent on estuarine or inshore coastal habitat throughout its life cycle. Flathead are ambush style predators that eat mainly fish and crustaceans.
1.4.3 Sand Whiting

The sand whiting *Sillago ciliata* is a member of the fish family Sillaginidae. In southern Queensland sand whiting spawn from September to March at the mouths of estuaries, in open sea or on shallow banks close to the breaking surf. Sand whiting probably spawn twice a year, producing 31 000 to 380 000 eggs at each spawning. Estimated lengths at first maturity for male and female sand whiting range from 20 to 28 cm total lengths. Age at first maturity is about two to three years old. Legal minimum size is 23 cm and sand whiting grow to a maximum size of about 45 cm. Juvenile and adolescent sand whiting prefer shallow waters in rivers and creeks over seagrass beds, and in mangroves. The sand whiting is a benthic carnivore that usually feeds on yabbies, prawns, soldier crabs, marine worms and pipis.

The sand whiting is a similar species to the golden-lined whiting (*Sillago analis*). These two whiting species can be difficult for anglers to separate. The main reason for this problem is their similarity in shape and colouration. The two whiting species are therefore generally grouped under the one common name, summer whiting. Species identification was not always possible between the sand whiting and golden-lined whiting in the data analysed. The results were therefore grouped under the common name summer whiting in some sections of this thesis.
1.5 Thesis Aims

Historical data on recreational fish catches are sparse for Queensland estuarine waters. This study addresses the paucity of data available. The information collected in this study was used to address the broad aims of a) investigate possible techniques for analysing recreational fish catches, and b) determine the level of recreational catch, and fishing effort directed at the key fish species. The study explores five questions:

1. What types of regression models can be used to analyse recreational fish catches which exhibit many zero catches?

2. What factors are important in determining recreational fish catches?

3. What units of recreational fishing effort should be used to estimate total catch?

4. Can recreational fish catch rates be used to effectively monitor estuarine fish resources?

5. What is the potential recreational harvest of fish from the three southern Queensland estuaries?

The first question is addressed in chapters 2 and 3. In chapter 2, regression models for a two-stage analysis are presented and discussed. Statistics for hypothesis testing, determining model goodness of fit and predicting mean catch rates are outlined in chapter 3. Questions two, three and four are covered in Chapter 4. This chapter makes use of the large number of fishing group interviews in an analysis applying the methods from chapters 2 and 3. Chapter 5 presents estimates of total recreational catch and fishing effort from the estuaries of the Burnett River, Maroochy River and Pumicestone Passage, computed from bootstrap methods which have not previously been widely applied to recreational fishing data.
Chapter 2. **REGRESSION MODELS**

Recreational fishing data typically contain a large proportion of zero values and variability or dispersion greater than that allowed for in many standard regression models (e.g., Normal and Poisson) and the assumptions required for these analyses will not be valid. A two-stage approach used in later chapters for analysing recreational fish catches is outlined and discussed in this chapter. The regression models presented account for both extra zeros and over-dispersion in the data.

2.1 **INTRODUCTION**

Analysis of recreational fishing data is often complicated because of the high frequency of small catches compared to infrequent large catches. A typical data set for a species of interest will usually include a large proportion of zero catches. Analyses of such data using Normal or Poisson residual distributions in generalised linear models are likely to be invalid. The assumption of constant variance for the normal distribution is questionable, even after various transformations, and the pattern of fish catches is usually non-random causing dispersion not adequately described by the Poisson distribution. Therefore, to understand the relationship of various factors and covariates that may affect recreational catches and to conduct reliable hypothesis testing other statistical models are necessary.

Generally, count data is analysed as a Poisson-like process (McCullagh and Nelder 1989). One example of this is the number of fish caught in a time interval of specified length. However, departures from this Poisson-like process are common. Often the
distributions of fish are aggregated with various levels of abundance through time and area. The underlying assumption of Poisson variation (i.e., variance is equal to the mean) will not hold true. If the recorded fish catches resulted from fish that were clustered, the variance will be greater than the mean. This case is described as "over-dispersion" relative to the Poisson distribution. If the fish catches arose from fish that were more evenly dispersed, the variance will be smaller than the mean. This case is described as "under-dispersion" relative to the Poisson distribution. Over-dispersion is a phenomenon more commonly observed in data than under-dispersion (McCullagh and Nelder 1989).

Analyses that deal with over-dispersion are essential to accurately assess the significance of model variables. In recent years there has been a great deal published on methods of analysis for over-dispersed data relative to the Poisson distribution. Bishop et al. (2000) used generalised estimating equations (GEE) with Poisson errors and then used the square root of the mean deviance (8.8 in this case) to inflate the parameter standard errors to account for over-dispersion; Lawless (1987) examined the use of negative-binomial regression models as an alternative to the Poisson; Gardner et al. (1995) analysed count data comparing results from Poisson, over-dispersed Poisson and Negative Binomial regression models; Welsh et al. (1996) and Faddy (1997 and 1998) presented models for dealing with species abundance data that contain many zero values and account for variable dispersion. Analyses that fail to account for extra zeros and variable dispersion will result in unreliable model parameter estimates and standard errors. Standard errors in the presence of over-dispersion will be under-estimated and too many significant differences found - type I errors may occur if true null hypotheses are rejected. In the presence of under-
dispersion, standard errors will tend to be over-estimated and too few significant differences will be found – type II errors may occur with false null hypotheses accepted.

The purpose of this chapter is to outline generalised linear models for analysing recreational fishing data that include many zero values. A two-stage analysis is described –

- First to analyse the presence or absence of a fish species using binary regression.
- Second to analyse the non-zero fish catches (ie counts>0) with a choice of three truncated regression models. One of the non-zero models assumes Poisson variation, while the other two allow for over-dispersion.

2.2 TWO-STAGE ANALYSIS

Examination of the recreational catch data (Chapter 4) revealed that many fishing groups caught no fish for a given species. Histograms of these catches showed a considerable spike in the frequency of the zero class, indicating that there were far more zeros than would be predicted by standard statistical distributions. The challenge was then to determine how the frequency of extra zeros could be accounted for in an analysis, to allow for possible over-dispersion, and to allow parameters of any statistical distribution to depend on various explanatory factors and covariates to assess their significance. The approach to this problem was to analyse the number of fish caught as having two-states: a state in which no fish were caught and a state in which fish were caught. For the first state, corresponding to presence or absence of the fish species in the catch, a binary regression model was applied. Given that the
fish species occurred in the catch (the second state), the number of fish caught was 
analysed using a truncated discrete distribution. The models for each state were 
applied separately, but the results from both can be used together to make predictions 
of fish catches for various explanatory factor levels and covariates.

2.3 Binary Regression

The analysis used a logistic model for binary regression (McCullagh and Nelder 
1989). Binary regression models were applied to all data $y_i$, coded with one of two 
values, 1 (for fish caught) or 0 (for no fish caught). The capture of a fish species by a 
fishing group occurred according to the probabilities $P($caught$) = p$ and $P($not caught$) 
= 1 - p$. The probability $p$ was modelled using a logistic link function and was related 
through the linear function of factors and covariates (2.1).

$$\log \left( \frac{p_i}{1 - p_i} \right) = x^T \beta = \beta_0 + \beta_1 x_1 + \ldots + \beta_i x_i \quad (2.1)$$

where $x^T$ was the design matrix identifying the explanatory variables (factors and 
covariates) and $\beta$ was the vector of parameters to be estimated for each factor level 
and covariate.

The log-likelihood function for maximum likelihood fitting of the binary regression 
model was

$$\log \ell(p; y) = \sum_{i=1}^{n} \left( y_i \log(p_i) + (1 - y_i) \log(1 - p_i) \right) \quad (2.2)$$

The mean and variance were

$$E(y_i) = p_i \text{ and } Var(y_i) = p_i(1 - p_i) \quad (2.3)$$
The deviance function was
\[ D(y; p) = 2 \sum_{i=1}^{n} \left( y_i \log \left( \frac{y_i}{p_i} \right) + (1 - y_i) \log \left( \frac{1 - y_i}{1 - p_i} \right) \right) \] (2.4)

2.4 Regression models for the non-zero catches

This analysis was for only those catches where a number of fish were caught and
retained (i.e., response \( y_i > 0 \)). Three different models were proposed to analyse the
 catches. The models predicted each fishing group’s non-zero catch \( E(y_i) \), dependent
on the log-linear function of explanatory variables (2.5).

\[ \mu_i = \exp \left( x^T \beta \right) = \exp \left( \beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k \right) \] (2.5)

where \( x^T \) was again the design matrix identifying the explanatory variables (factors
and covariates) for each fishing group’s catch and \( \beta \) was the vector of parameters to
be estimated for each factor level and covariate. The log-likelihood, mean and
variance equations for the three models are outlined below. Calculation of the
deviance statistic is outlined in chapter 3.

2.4.1 Truncated Poisson

Poisson models are often used for the analysis of species count data. The truncated
model was valid for data where the zero catches had been excluded (i.e., \( y_i = 1, 2, \ldots \)).

The truncated Poisson model assumes the observed fish catches are distributed
according to probabilities:

\[ \Pr(Y = y; \mu) = \frac{\mu^y e^{-\mu}}{y! (1 - e^{-\mu})}, y = 1, 2, \ldots \]
The log-likelihood for the data $y_i$ was

$$\log \ell(\mu; y) = \sum_{i=1}^{n} \left( y_i \log(\mu_i) - \mu_i - \log(\mu_i) - \log(1 - e^{-\mu_i}) \right)$$  \hspace{1cm} (2.6)$$

The mean catch and variance were

$$E(y_i) = \frac{\mu_i}{1 - e^{-\mu_i}} \quad \text{and} \quad Var(y_i) = \frac{\mu_i^2 + \mu_i}{1 - e^{-\mu_i}} - \left( \frac{\mu_i}{1 - e^{-\mu_i}} \right)^2$$  \hspace{1cm} (2.7)$$

Note for this truncated distribution the log-linear equation (2.5) was not strictly a link function, because $\mu_i$ does not represent the mean catch $E(y_i)$.

### 2.4.2 Truncated Negative Binomial

Departures from the truncated Poisson model can occur due to non-random variation in fish abundance and their catchability. The net effect is that the observed number of fish caught is more variable than the Poisson model can predict ($Var(y_i) > E(y_i)$). If there was evidence of extra variation in the truncated Poisson models, called over-dispersion, the truncated negative binomial model could be used. The truncated negative binomial model essentially corresponded to over-dispersion relative to the truncated Poisson. The truncated version of the Negative Binomial model again omits the probability of fishing groups catching no fish (ie $y_i = 1, 2, \ldots$), and uses probabilities:

$$Pr(Y = y; \mu, \delta) = \frac{\Gamma(y + \delta^{-1})}{y!\Gamma(\delta^{-1})} \left( \frac{\delta\mu}{1 + \delta\mu} \right)^y \left( \frac{1}{1 + \delta\mu} \right)^{\delta^{-1}} \left( \frac{1}{1 - (1 + \delta\mu)^{-\delta^{-1}}} \right), y = 1, 2, \ldots$$
The log-likelihood for the data $y_i$ was

$$\log \ell(\mu; y) = \sum_{i=1}^{n} \left( \log \Gamma(y_i + \delta^{-1}) - \log \Gamma(\delta^{-1}) + y_i \log(\delta \mu_i) - y_i \log(y_i) - \log(1 - (1 + \delta \mu_i)^{-\delta^{-1}}) \right) \quad (2.8)$$

Here, $\Gamma(.)$ is the gamma function which was approximated by Stirling's Formula (Abramowitz and Stegun, 1965)

$$\Gamma(z) \approx e^{-z} z^{z-0.5} (2\pi)^{0.5} \left[ 1 + \frac{1}{12z} + \frac{1}{288z^2} - \frac{139}{51840z^3} - \frac{571}{2488320z^4} + \cdots \right]$$

$$\quad (z \to \infty \text{ in } |\arg z| < \pi),$$

and $\delta$ was an additional parameter to be estimated.

The mean catch and variance were

$$E(y_i) = \frac{\mu_i}{1 - (1 + \delta \mu_i)^{-\delta^{-1}}} \quad \text{and} \quad Var(y_i) = \frac{\mu_i(1 + \delta \mu_i)}{1 - (1 + \delta \mu_i)^{-\delta^{-1}}} - \frac{\mu_i^2(1 + \delta \mu_i)^{-\delta^{-1}}}{(1 - (1 + \delta \mu_i)^{-\delta^{-1}})^2} \quad (2.9)$$

Note again for this truncated distribution the log-linear equation (2.5) is not strictly a link function, because $\mu$ does not represent the mean $E(y_i)$.

### 2.4.3 Extended Poisson Process

The extended Poisson Process model again applied only to the non-zero catches and was based on a generalisation of the Markov birth process called extended Poisson process modelling (Faddy 1997 and 1998 and Podlich 1999). The technique has the advantage that data can be modelled under a variety of truncated discrete distributions in relation to the truncated Poisson. Here, the equation (2.10) describes a Markov process $\{y(t); t \geq 0\}$ over time $(t)$ with $y(0) = 0:

$$\Pr(y(t + \delta t) = n + 1 \mid y(t) = n) = \lambda_n \delta t + o(\delta t) \quad (2.10)$$

where $\lambda_n$ is some function of $n$. The probabilities can be determined for $y(t)$, for any arbitrary $t$, which may be taken to be $1$. 23
In the extended Poisson Process model each probability (2.10) was related through a log-linear function \((\mu_i)\) of the covariates and factors as defined in equation (2.5) using:

\[
\lambda_n = \log\left(1 + \delta \mu_i \left(\frac{1}{\delta} + n + \frac{c}{d + n}\right)\right), \text{ for } n = 0, 1, 2, \ldots \quad (2.11)
\]

Here, \(c = 1\) corresponds to the negative binomial model. Values of \(c < 1\) would allow for more general dispersion properties than provided by the negative binomial distribution.

Another form for \(\lambda_n\) derived from Faddy (1997b) was also used:

\[
\lambda_n = \log\left(1 + \delta \mu_i \left(\frac{1}{\delta} + n + \frac{c}{d + n}\right)\right), \text{ for } n = 0, 1, 2, \ldots \quad (2.12)
\]

where \(d\) is an extra parameter. Here, \(c = 0\) reduces equation (2.12) to the form 2.11 with \(c = 1\). For non-zero values of \(c\) a distribution other than truncated negative binomial will be formed.

It remains to calculate the probabilities \(p_i = P(y(t) = i)\) associated with the Markov process (2.10). The \(\lambda_n\)'s were set-up in a matrix:

\[
Q_i = \begin{bmatrix}
-\lambda_0 & \lambda_0 & 0 & 0 & \ldots & 0 & 0 \\
0 & -\lambda_1 & \lambda_1 & 0 & \ldots & 0 & 0 \\
0 & 0 & -\lambda_2 & \lambda_2 & \ldots & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\
0 & 0 & 0 & 0 & \ldots & -\lambda_{i-1} & \lambda_{i-1} \\
0 & 0 & 0 & 0 & \ldots & 0 & -\lambda_i
\end{bmatrix} \quad (2.13)
\]

and the probability \(p_i\) was determined from the final element in the vector

\[
p_i(t) = (1 \ 0 \ \ldots \ 0) \exp\{Q_i\} \quad (2.14),
\]
where the exponential of the $Q$-matrix was calculated from the power series expansion

$$\exp(Q) = I + Q + \frac{Q^2}{2!} + \frac{Q^3}{3!} + \cdots \quad (2.15),$$

and $I$ was the identity matrix.

The probability distribution (2.14) then had to be truncated

$$\frac{p_i}{1 - p_0}, \text{ for } i = 1, 2, \ldots \quad (2.16)$$

to describe non-zero catches, where $p_0$ is the first element of 2.14.

All parameters in the extended Poisson Process model were estimated from data $y_1, y_2, \ldots, y_n$ by minimising the negative of the log-likelihood:

$$-\log \ell = -\sum_{i=1}^{n} \log \left( \frac{p_i}{1 - p_0} \right) \quad (2.17)$$

Unfortunately, there were no tractable expressions for the mean and the variance of this model and so the deviance had to be calculated using numerical routines to estimate the mean (2.18) and variance (2.19) (described in chapter 3).

$$E(y) = \sum_{i=1}^{n} \frac{ip_i}{1 - p_0} \quad (2.18)$$

$$\sigma^2_y = \sum_{i=1}^{n} (i - \mu)^2 \frac{p_i}{1 - p_0} \quad (2.19)$$
2.5 Model Fitting

2.5.1 Binary Regression

The statistical software Genstat 5 (1998) was used to fit this model. The software allowed for this analysis under the generalised linear model framework. The binary analysis used a weighted least-squares algorithm, and provided asymptotic standard errors for all estimates.

2.5.2 Truncated Poisson and Truncated Negative Binomial Regressions

The statistical software Genstat 5 (1999) was used to carry out the estimation by maximum likelihood, and provide asymptotic standard errors. The regression models were fitted using a non-linear Newton-Raphson search routine. The following algorithm was used:

1. Compute initial parameter estimates $\beta$ and $\delta_i$ for example from a standard non-truncated negative binomial model.
2. Calculate $\mu_i$ using log-linear equation (2.5).
3. Compute $-2*$log-likelihood using equation (2.6 or 2.8).
4. Minimise $-2*$log-likelihood by changing the parameter estimates $\beta$ using the Newton-Raphson iteration method.

2.5.3 Extended Poisson Process Regression

The ‘fminsearch’ MATLAB (2001) simplex search routine was used to carry out the numerical computations. The following algorithm was used:
1. Compute initial parameter estimates \( \beta \), from the truncated negative binomial model fit.

2. Calculate \( \mu_t \) using the log-linear equation (2.5).

3. Compute \( \lambda_n \) (2.11 or 2.12), \( Q_t \) (2.13), \( \exp\{Q_t\} \) (2.15) and \( p_t \) (2.14) and its truncation (2.16) for each fishing group.

4. Minimise the negative of the log-likelihood (2.17) by changing the parameter estimates \( \beta \), \( 1/\delta \) and \( c \), or \( \beta \), \( 1/\delta \), \( c \) and \( d \) updating \( \lambda_n \), \( Q_t \), \( \exp\{Q_t\} \), \( p_t \) and its truncation using the simplex iteration method. The parameters \( 1/\delta \) only in (2.11) and \( d \) in (2.12) are of necessity positive and estimated on the exponential scale.

2.6 DISCUSSION

The two-stage methodology provided a technique for analysing recreational fish catch data that exhibit many zeros. Firstly, analysis of the data coded as presence/absence responses allowed for simple interpretation of the variables influencing the probability of catching fish. Second, the process of analysing the non-zero catches using the truncated regressions allowed separate assessment of those variables that influenced fish catches. Overall, given the properties of recreational fish data, more reliable analyses should be possible using this two-stage procedure.

Omission of the zero class is probably the commonest form of truncation (Johnson et al 1992). The process of excluding the zero catches reduces variability or dispersion, and is done for general catch sizes of \( i \) according to \( \Pr(Y_i = y_i) = \Pr(Y_i = y_i|Y_i > 0) \).

The general mean and variance relationship for this truncated model with the mean
catch $E(y_i)$, variance $\text{Var}(y_i) = \sigma_i^2$ and probability of catching no fish $P(y_i = 0) = p_0$ were

$$E(y_i|y_i > 0) = \frac{\mu_i}{1-p_0}, \text{ and } E(y_i^2|y_i > 0) = \frac{\sigma^2 + \mu_i^2}{1-p_0},$$

so that

$$\text{Var}(y_i|y_i > 0) = \frac{\sigma^2}{1-p_0} - \frac{\mu_i^2 p_0}{(1-p_0)^2} \quad (2.20).$$

These expressions were used to define the mean and variance for the truncated Poisson and truncated negative binomial regression models.

The maximum likelihood analysis using the truncated Poisson and truncated negative binomial regression models was done using the Newton-Raphson non-linear minimiser in Genstat (2000) (Appendix 8.2). The Poisson process model was fitted using Matlab (2001) (Appendix 8.2). Extensive attempts were made to program this model in Genstat, but the non-linear modelling did not readily allow calculation of matrix exponentials. The Genstat command "OWN" was investigated to possibly link external Fortran code or Sidje's expokit (Sidje 1998) to calculate the matrix exponentials. However, this option was only possible in the UNIX version of Genstat, not the MS Windows version available for this thesis. E-mail communications with the Lawes Agricultural Trust, Rothamsted UK, said that the linking of external code would be addressed in future releases of Genstat for MS Windows.
In the previous chapter the methods for fitting three truncated regression models to estimate parameters were outlined. This chapter describes the statistics used for measuring the goodness of fit of each truncated model, measuring the precision of the parameters estimated, testing hypotheses, predicting mean fish catches and finding confidence intervals.

3.1 INTRODUCTION

In chapter 2, three truncated regression models were outlined for analysing recreational fish catches where the zero data had been excluded. Having fitted a particular regression model, the parameters estimated need to be assessed against their relative precision to ensure each term in the model was appropriate for the data. A range of statistics was also needed to measure the goodness of fit between the observed fish catches and the catches predicted by the model.

Parameter estimates are the values that maximise the log-likelihood of the regression for the data observed. If the parameter estimates describe the data well, their level of precision should be high. The resulting log-likelihood will be greater compared with a less appropriate model’s log-likelihood. McCullagh and Nelder (1989) cover a range of statistics used to measure the goodness of fit of a model. The most commonly used is the residual deviance statistic (or just deviance). Welsh et al (1996) reported the residual deviance statistics for the truncated Poisson and truncated negative binomial
analyses of the abundance of Leadbeater’s Possum. No over-dispersion was evident in this data set. However, if over-dispersion had been evident, other measures, such as the generalised Pearson $\chi^2$ statistic, may also be useful in assessing the model’s goodness of fit.

Catch statistics are used regularly in many fisheries to provide assessments of fish resources. Because catch is the product of fishing effort and abundance, trends in catch over time may reflect changes in the proportion of the fish population harvested, changes in fish abundance, or both (Quinn and Deriso, 1999). Use of catch data in its raw form can bias estimates owing to different practises used by fishing groups. Predictions of mean catches from a regression model can reduce the unwanted biases or variation in the data.

Prediction is concerned with estimating the averages from a set of likely values for the predicting variables. For example, following the collection of recreational fish data classified by different areas, time periods and fishing methods, an estimate of mean catch standardised across these variables may be required for an index of fish abundance. This type of standardised prediction is commonly used in fish stock assessment to compare catches over time (Hilborn and Walters, 1992).

The purpose of this chapter was to provide the mathematical detail for measuring the goodness of fit of a model, determining parameter standard errors, parameter significance testing and predicting average fish catches from the truncated regression models.
3.2 Measuring goodness of fit

The aim of fitting a model was to predict catches with a set of fitted values \( E(y) \). The fitted model should have an appropriate combination of parameters and a reliable level of accuracy to make predictions over a variety of conditions. Accurate predictions from the model are needed for reliable significance testing of factors and covariates. The discrepancy between the predicted catches and the observed catches needed to be measured and a decision made on whether the discrepancy was acceptable or not.

The measure of goodness of fit of a model is usually assessed from the logarithm of a ratio of log-likelihoods called the residual deviance statistic (McCullagh and Nelder 1989), or just deviance (3.1).

\[
D(\mu; y) = -2 \left( \log \ell_{\text{fitted model}} - \log \ell_{\text{saturated model}} \right) \quad \text{(3.1)}
\]

The deviance was measured as twice the difference between the fitted model log-likelihood and the maximum that can be achieved by a saturated model. The saturated model essentially has the same number of parameters as observations and so provides a complete description of the data for the statistical distribution used. Therefore, the log-likelihood for the saturated model was calculated for parameter values such that the predicted catches \( E(y) \) equalled the observed catches exactly. Note that for all the truncated regression models, \( E(y) \) was a function of the log-linear predictor \( \mu_i = \exp(x^T \beta) \) and values of \( \mu_i \) needed to be calculated numerically so that predicted catches equalled the observed catches. The calculation of the saturated log-likelihood is detailed in the following section.
The deviance statistic for the truncated Poisson regression model was used to indicate how different the model's predictions were from the observed catches. The difference was gauged using a goodness of fit test comparing the deviance with $\chi^2$ values using the residual degrees of freedom. A good model fit was one that had a deviance approximately equal to its expectation, the residual degrees of freedom. This meant the model adequately predicted the observed catches, with little over or under dispersion. In addition, measures of goodness of fit for these models were also formed from a number of other statistics as follows:

- Log-likelihood values, which were compared between model types. The contrast provided by comparing log-likelihoods between the truncated Poisson model, the truncated negative binomial model (an over-dispersed model) and the extended Poisson process model (a variable dispersion model) allowed for the appropriateness of a model fit to be gauged. The model with a smaller negative log-likelihood indicated a better fit.
- Deviance statistic, which was compared against the residual degrees of freedom
- Generalised Pearson $\chi^2$ statistic, with the form

$$\chi^2 = \sum_i (y_i - E(y_i))^2 / Var(y_i)$$

which was compared against the residual degrees of freedom. $E(y_i)$ represented the predicted catches and $Var(y_i)$ was the variance. The variance for each model was outlined in Chapter 2 under sections 2.7, 2.10 and 2.19, for the truncated Poisson, truncated negative binomial and extended Poisson process models.
respectively. A good model fit was gauged by the $\chi^2$ statistic being approximately equal to the residual degrees of freedom.

- Plot of standardised residuals against predicted values. The standardised residuals were calculated by

$$r_i = \frac{y_i - \bar{E}(y_i)}{\sqrt{\bar{Var}(y_i)}} \quad (3.3),$$

with the same definitions for $\bar{E}(y_i)$ and $\bar{Var}(y_i)$ as described for the generalised Pearson $\chi^2$ statistic.

### 3.3 Saturated Log-Likelihood

The saturated log-likelihood is the maximum log-likelihood that can be achieved from the regression model if all the observations were predicted exactly (ie. when the predicted catches $E(y_i)$ equal the observed catches $y_i$). The saturated log-likelihood was used to calculate the residual deviance statistic (equation 3.1).

The saturated log-likelihood for a standard non-truncated Poisson or Negative Binomial regression model is calculated by predicting the observed data $y_i$ exactly with the log-linear equation $E(y_i) = \mu_i = \exp(x_i^T \beta)$. However, for the zero truncated regression models $E(y_i)$ does not equal $\mu_i$ as the mean had to be adjusted for the probability of catching fish $(1-p_0)$. Here, $\mu_i$ had to be calculated numerically for the predicted catches $E(y_i)$ to equal the observed catches.
3.3.1 Truncated Poisson

The log-likelihood for the truncated Poisson regression model was

\[ \log \ell = \sum_{i=1}^{n} \left( y_i \log(\mu_i) - \mu_i - \log(y_i!) - \log(1 - e^{-\mu_i}) \right), \]

and the mean catch was

\[ E(y_i) = \frac{\mu_i}{1 - e^{-\mu_i}}. \]

The values of \( \mu_i \) needed to predict the observed catches exactly for use in the saturated log-likelihood are shown in Table 3.1 from numerical calculations. Note that for catches greater than 8 fish, a standard non-truncated Poisson model was adequate.

Table 3.1 Estimated values of \( \mu_i \) to predict the observed catches \( y_i \) for the truncated Poisson saturated log-likelihood.

<table>
<thead>
<tr>
<th>( \mu_i )</th>
<th>( y_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1.594</td>
<td>2</td>
</tr>
<tr>
<td>2.822</td>
<td>3</td>
</tr>
<tr>
<td>3.920</td>
<td>4</td>
</tr>
<tr>
<td>4.965</td>
<td>5</td>
</tr>
<tr>
<td>5.985</td>
<td>6</td>
</tr>
<tr>
<td>6.994</td>
<td>7</td>
</tr>
<tr>
<td>7.998</td>
<td>8</td>
</tr>
<tr>
<td>Use ( y_i )</td>
<td>9 \geq</td>
</tr>
</tbody>
</table>

3.3.2 Truncated Negative Binomial

The log-likelihood for the truncated negative binomial regression model was

\[ \log \ell = \sum_{i=1}^{n} \left( \log \Gamma(y_i + \delta^{-1}) - \log \Gamma(\delta^{-1}) + y_i \log(\delta \mu_i) - (y_i + \delta^{-1}) \log(1 + \delta \mu_i) - \log(y_i!) - \log(1 - (1 + \delta \mu_i)^{-\delta^{-1}}) \right), \]

and the mean catch was
The values of $\mu_i$ needed to calculate the saturated log-likelihood were dependent on the extra negative binomial parameter $\delta$. A non-linear routine was used to solve for the values of $\mu_i$ given the maximum likelihood estimate of $\delta$. Note that for very small $\delta (<0.001)$, the solution for $\mu_i$ is the same as for the truncated Poisson in Table 3.1.

### 3.3.3 Extended Poisson Process

The calculation of the saturated log-likelihood, for the solution of $\mu_i$ such that the predicted catches $E(y_i)$ equalled the observed catches $y_i$, was dependent on the maximum likelihood estimate of the parameters $\delta, c$ and $d$ (depending on the form of $A^*$ used). The regression models here used either the function

$$\lambda_n = \log(1 + \delta \mu_i) \left(\frac{1}{\delta} + n\right)^c$$  or  $$\lambda_n = \log(1 + \delta \mu_i) \left(\frac{1}{\delta} + n + \frac{c}{d + n}\right)$$

in the matrix of Markov transition rates ($Q$). The saturated log-likelihood was calculated by $\sum \ln \left(\frac{p_i}{1 - p_0}\right)$, where $p_n = (1 \ 0 \ 0)^\top \exp\{Q\}$ and

$$Q = \begin{bmatrix}
-\lambda_0 & \lambda_0 & 0 & 0 & \cdots & 0 & 0 \\
0 & -\lambda_1 & \lambda_1 & 0 & \cdots & 0 & 0 \\
0 & 0 & -\lambda_2 & \lambda_2 & \cdots & 0 & 0 \\
0 & 0 & 0 & 0 & \cdots & -\lambda_{n-1} & \lambda_{n-1} \\
0 & 0 & 0 & 0 & \cdots & 0 & -\lambda_n
\end{bmatrix}$$

To calculate the mean $\sum_{i=1}^{n} \frac{i p_i}{1 - p_0}$, a large value of $n$ (e.g. at least 15 times the maximum observed catch) was used to get sufficient accuracy. The value of $p_i$ for
each observed catch $y_i$ was determined by the $y_i$th element of vector $p_n$. A non-linear routine was again used to calculate the values of $\mu_i$ such that $E(y_i) = \sum n p_n = y_i$, given the maximum likelihood estimates of $1/\delta$, $c$ and $d$. Note that these calculations for the first form of $\lambda_n$ are only valid for $c \leq 1$. If $c > 1$, an improper probability distribution is formed with $Var(y) = \infty$. In this case, the second $\lambda_n$ form was used instead.

### 3.4 Parameter Standard Errors

Parameter standard errors were taken from the square root of the diagonal elements in the asymptotic covariance matrix. The asymptotic covariance matrix of the parameter estimates was given by

$$
\Sigma = -H^{-1} \quad (3.4),
$$

where $H$ was the matrix of second derivatives of the log-likelihood,

$$
H = \left[ \frac{\partial^2 \log \ell}{\partial \beta_i \partial \beta_j} \right] \quad (3.5),
$$

with respect to variation in model parameters evaluated at the maximum likelihood estimate. The non-linear Genstat algorithm was used to calculate asymptotic standard errors for all estimates from the truncated Poisson and truncated negative binomial regression models. An algorithm given in appendix 2 was used to estimate the matrix of second derivatives for the extended Poisson process models.
3.5 Dispersion Parameter

When using the Normal or gamma distribution, a dispersion parameter (measure of variance), $\phi$, is usually unknown and is assumed to be constant over all observations. For the normal distribution this is the assumption of constant variance, usually written as $\sigma^2$. However, the Poisson and Negative Binomial distributions do not have any specific dispersion parameter and in these generalised linear models it is fixed at 1. The effect of this is that the variance of an observation is a function of its mean.

Sometimes it may be appropriate to use the dispersion parameter to adjust the standard errors of the model parameters. If the goodness of fit for the model is poor (ie. the residual deviance is significantly different from the residual degrees of freedom), this may indicate dispersion problems. This problem is described as either over-dispersion (the residual deviance divided by the residual degrees of freedom is greater than 1) or under-dispersion (where this ratio is less than 1). The issue of over- or under-dispersion should be always considered. If ignored Type I and Type II errors in hypothesis testing may result. Detailed information about over- and under-dispersion is given in McCullagh and Nelder (1989). If over-dispersion was a suspected problem in a regression, then the parameter ($\beta$) standard errors were adjusted using

$$SE(\beta)_{\text{adjusted}} = \sqrt{\frac{\text{deviance}}{df}} \times se(\beta) \quad (3.6)$$

to conduct hypothesis testing.
3.6 **Hypothesis Testing**

In order to summarise the results of an analysis a series of t-tests were done using parameter estimates and their standard errors. The simplest form of t-test was used to examine the significance of each covariate and two-level factor in the regression model. The hypothesis tested was

\[ H_0: \beta_i = 0 \quad H_1: \beta_i \neq 0 \]

where \( \beta_i \) was a model coefficient. The t-statistic used was \( t = \frac{\beta_i}{SE_{\beta_i}} \), compared against the critical t-value for the probability level \( \alpha = 0.05 \) and the model residual degrees of freedom. Another t-test was used to assess the difference between levels for those factors with three or more levels. The hypothesis tested here was

\[ H_0: \beta_i = \beta_j \quad H_1: \beta_i \neq \beta_j \]

The t-statistic used was \( t = \frac{\beta_i - \beta_j}{SE(\beta_i - \beta_j)} \), again compared against the critical t-value for the probability level \( \alpha = 0.05 \) and the model residual degrees of freedom, where

\[
SE(\beta_i - \beta_j) = \sqrt{(SE_{\beta_i})^2 + (SE_{\beta_j})^2 - 2 \times corr(\beta_i, \beta_j) \times SE_{\beta_i} \times SE_{\beta_j}} \quad (3.7)
\]

3.7 **Prediction**

The predicted mean catch \( E(y) \), for the non-zero data, corresponding to the vector of covariates \( x \) was given by

\[
E(y) = \frac{\mu}{1 - e^{-\mu}} , \quad E(y) = \frac{\mu}{1 - \left(1 + \delta \mu\right)^{-\sigma}}, \quad E(y) = \sum_{n=1}^{np_n} \frac{np_n}{1 - p_0}
\]
for the truncated Poisson, truncated negative binomial and extended Poisson Process models respectively, where $\mu = \exp(x^T \beta)$. The mean catch for the Poisson process model was calculated using the probabilities $p_n$ from (2.14) and (2.11) or (2.12) as detailed previously for log-likelihood calculations.

Standard errors for the predicted mean catches $E(y)$, given a vector $x$ of covariates and factors, for all the truncated regression models, were calculated using the square root of the variance function

$$\sigma^2_x = \left( \frac{\partial E(y)}{\partial \beta} \right)^T \Sigma \left( \frac{\partial E(y)}{\partial \beta} \right), \quad (3.8)$$

where $\Sigma$ was the estimated covariance matrix for $\beta$. The vector of first derivatives $\frac{\partial E(y)}{\partial \beta}$ for the truncated Poisson (3.9) was

$$\frac{\partial E(y)}{\partial \beta} = \frac{1 - e^{-\mu} - \mu e^{-\mu}}{(1 - e^{-\mu})^2} \mu x \quad (3.9).$$

The vector of first derivatives for the truncated negative binomial model (3.10) was given by

$$\frac{\partial E(y)}{\partial \beta} = \left( \frac{1 - (1 + \mu \delta)^{-\sigma^{-1}} - \mu (1 + \mu \delta)^{-\sigma^{-1}}}{1 - (1 + \mu \delta)^{-\sigma^{-1}}} \right) \mu x \quad (3.10),$$

plus an additional term $\frac{\partial E(y)}{\partial \delta}$ for the extra parameter $\delta$

$$\frac{\partial E(y)}{\partial \delta} = \left[ \frac{-\mu}{1 - (1 + \mu \delta)^{-\sigma^{-1}}} \times \left[ \left( \sigma^{-1} \right)^2 \log(1 + \delta \mu) - \sigma^{-1} \frac{\mu}{1 + \delta \mu} \times (1 + \delta \mu)^{-\sigma^{-1}} \right] \right].$$

Similar derivatives for the extended Poisson process model had no tractable expressions and were calculated numerically (Appendix 8.2).
Approximate 100(1-\(\alpha\))% confidence intervals for the predicted non-zero mean catch \(E(y)\) were calculated from

\[
E(y) \pm t_{1-\alpha/2, \text{rdf}} \sigma_x 
\]

(3.11)

using percentage points from the \(t\)-distribution based on the model's residual degrees of freedom (\(\text{rdf}\)).
The decision on whether a model fitted the data adequately was sometimes difficult. Of the models for the non-zero catches presented, the truncated Poisson model fit was gauged using the residual deviance statistic. If the model suffered from over-dispersion, the deviance would highlight the lack of fit. However, the ability of the deviance to gauge the measure of fit for the truncated negative binomial and the extended Poisson process models was problematic. The deviance calculation for both of these models was reliant on the extra parameters in the saturated log-likelihood (e.g. $\delta$ and d). If a factor or covariate effect was removed or added to create a new model, the values for these extra parameters would change compared to the original model.

A range of other statistics was used to measure the model fit. Log-likelihoods from the three truncated models, residual deviance and generalised Pearson $\chi^2$ statistics were compared, as well as the histogram of standardised residuals to identify any outlying data.

There were two main reasons for using the truncated regression models for analysing recreational fish catches. They were to accurately estimate variables that affect the recreational catch and to predict mean catches adjusted for these variables. Prediction of mean catches from a generalised linear model can be used to provide a standardised index of fish abundance (Hilborn and Walters, 1989). In this chapter, the methods for estimating mean catches and their precision were provided. It should be recalled that the predictions from these truncated models are conditional on a non-zero catch. The
unconditional mean catch would also involve the probability of zero catch, which was
modelled separately. These models are probably the best tools for estimating catches
due to the large proportion of zero catches in the data. It should be remembered that if
the catch data is not proportional to fish abundance, then the predicted trend from the
model will not be proportional to abundance (Hilborn and Walters, 1989).
Chapter 4.  ANALYSIS OF RECREATIONAL FISH CATCHES

Recreational catches of yellowfin bream (*Acanthopagrus australis*), dusky flathead (*Platycephalus fuscus*) and summer whiting (*Sillago analis* and *S. ciliata*) were analysed. Data from roving creel surveys were collected between June 1997 and August 1998, and revealed highly skewed distributions of catches with many fishing trips resulting in no fish caught. Average catches were generally less than one fish caught per group fishing hour. Truncated negative binomial and extended Poisson process regression models were effective in analysing the non-zero catch data. Covariates were incorporated in the modelling, and a critical assessment of these has led to defining different measures of fishing effort for boat and shore based fishing.

4.1 INTRODUCTION

Analysis of recreational catch data can present problems because many fishing trips fail to catch any fish (e.g. Figure 4.4). The resulting data are generally highly skewed and even after various transformations may not meet the assumptions required for many standard statistical techniques. For example, the use of a log transformation and normal residual distribution (Watson et al, 1990; Robins et al, 1998) fails to take account of the discrete nature of catch data and this becomes more problematic when the catches are small which is fairly typical in recreational fishing surveys (e.g. Figure 4.4). Models based on discrete distributions such as the Poisson and Negative Binomial fit into the generalized linear modelling framework (McCullagh and Nelder, 1989) and use appropriate discrete residual distributions. However, the factors influencing zero catches may well be different from those that influence non-zero
catches; for example, recreational fishers may be less enthusiastic while they are not catching fish and if no fish are caught in a relatively short period of time they may go elsewhere.

Welsh et al. (1996) and Faddy (1998) presented models for dealing with discrete species abundance data that contain many zeros. The models represent extensions of the Poisson and negative binomial distributions to allow for extra zeros. Such models are essential for hypothesis testing given the properties of recreational survey data with many zero values: the importance of factors affecting the recreational catch may be under or over-stated if models of this type are not used, leading to unreliable inferences. The models used here are those that have a separate component for the zeros and not the mixture model of Lambert (1992), mentioned in Welsh et al. (1996); this allows possibly different factors to influence this component of the model, and also allows the zero and non-zero catch data to be analysed separately. Ye et al. (2001) have used a similar approach for analysing silver pomfret (*Pampus argenteus*) and hilsa shad (*Tenualose ilisha*) catches in the Kuwait drift net fishery, but with a continuous gamma distribution for the non-zero component; see also Pennington (1983) who used a continuous delta (log-normal) distribution for the non-zero values from an ichthyoplankton survey.

Regression models outlined in chapter 2 and the statistical methods described in chapter 3 were applied to analyse catches of the key target fish species yellowfin bream (*Acanthopagrus australis*), dusky flathead (*Platycephalus fuscus*) and summer whiting (*Sillago analis* and *S. ciliata*) from the Burnett River, Maroochy River and Pumicestone Passage estuaries in south-east Queensland, Australia. The results from
the analyses are used to discuss factors affecting the recreational catch and to suggest appropriate measures of fishing effort.

4.2 Survey Methods

Overall, a minimum of five weekdays and five weekend days or public holidays, selected at random, were surveyed each month in each estuary. These days were surveyed either in a morning shift (6am to 12noon) or afternoon shift (12noon to 6pm).

The Burnett River, Maroochy River and Pumicestone Passage estuaries were stratified into smaller areas to enable angler numbers to be counted (Figure 4.1, Figure 4.2 and Figure 4.3). Counts were recorded on each survey shift in each zone at random times. During a shift staff would drive their boat to a zone and count the number of boats and people actively fishing (with a line in the water). Once the count was complete, boat/shore anglers were randomly interviewed for a one-hour period. The following data were collected from each fishing group.

- Number of persons fishing.
- Actual fishing time (hours).
- Number of fishing lines used.
- Number and species of fish released.
- Species, number and size (total length in centimetres) of each fish retained.
Anglers from 5 to 8 randomly selected zones were interviewed in each shift. If no anglers were present in a scheduled interview zone, a zero count was recorded and another nearby zone was surveyed. The recreational catch and effort data in each estuary were split into five seasonal time periods, two day-types and two fishing platforms for analysis (Table 4.1)

Table 4.1 Survey seasons, day-types and fishing platforms used to partition the data into groups.

<table>
<thead>
<tr>
<th>Factor Groups</th>
<th>Factor Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seasons</td>
<td>1. June to August 1997 (Winter)</td>
</tr>
<tr>
<td></td>
<td>2. September to November 1997 (Spring)</td>
</tr>
<tr>
<td></td>
<td>3. December to February 1998 (Summer)</td>
</tr>
<tr>
<td></td>
<td>4. March to May 1998 (Autumn)</td>
</tr>
<tr>
<td></td>
<td>5. June to August 1998 (Winter)</td>
</tr>
<tr>
<td>Day-types</td>
<td>1. Weekdays</td>
</tr>
<tr>
<td></td>
<td>2. Weekend days and Public holidays</td>
</tr>
<tr>
<td>Fishing Platforms</td>
<td>1. Boat</td>
</tr>
<tr>
<td></td>
<td>2. Shore</td>
</tr>
</tbody>
</table>
Figure 4.1 Survey zones for the Burnett River, showing how the estuary was divided into thirteen smaller areas to enable boats and anglers to be counted.
Figure 4.2 Survey zones for the Maroochy River, showing how the estuary was divided into seventeen smaller areas to enable boats and anglers to be counted.
Figure 4.3 Survey zones for the Pumicestone Passage, showing how the estuary was divided into 26 smaller areas to enable boats and anglers to be counted.
4.3 Results

4.3.1 Data

Shown in Figure 4.4 are histograms of the observed catch distributions for the three fish species surveyed. High frequencies of zero catches are apparent along with considerable skewness in the upper tail of the non-zero catches, this latter feature being particularly noticeable for yellowfin bream and summer whiting.

Figure 4.4 Observed distributions of fish catches for the three species (a) yellowfin bream, (b) dusky flathead and (c) summer whiting.
4.3.2 Logistic regression of binary response zero/non-zero catches

Catches for each fish species showed low proportions of fishing groups actually catching fish. These proportions changed significantly ($p<0.05$) with the species tested, the estuary fished, the time of year and the fishing platform (Table 4.2). They were also dependent on the number of people in the fishing group, the time spent fishing and the number of fishing lines used (Table 4.2). In all three estuaries, more boat (25%, 12%, 19%) than shore fishing groups (15%, 4%, 5%) caught yellowfin bream, dusky flathead and summer whiting respectively. The proportion of fishing groups that caught fish was higher the longer they fished and the more fishing lines used (Figure 4.5 and Figure 4.6). However, the proportions of boat groups catching yellowfin bream and summer whiting decreased with the number of anglers, and the proportion of shore groups catching yellowfin bream also decreased with the number of anglers (Figure 4.7), but this latter effect was the least significant here with a p-value $\approx 0.033$. 
Table 4.2 Parameter estimates and standard errors from the binary regression analysis of the probability of a fishing group catching and keeping a yellowfin bream, dusky flathead and summer whiting.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Yellowfin Bream</th>
<th>Dusky Flathead</th>
<th>Summer Whiting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual df = 3679</td>
<td>Deviance = 3490</td>
<td>Deviance = 2365</td>
<td>Deviance = 2958</td>
</tr>
<tr>
<td>Intercept</td>
<td>Estimate (se)</td>
<td>Estimate (se)</td>
<td>Estimate (se)</td>
</tr>
<tr>
<td></td>
<td>-2.612 (0.205)</td>
<td>-3.007 (0.244)</td>
<td>-1.661 (0.209)</td>
</tr>
<tr>
<td>Estuary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burnett River</td>
<td>B -0.121 (0.109)</td>
<td>A -0.023 (0.130)</td>
<td>C -0.394 (0.124)</td>
</tr>
<tr>
<td>Maroochy River</td>
<td>A 0.281 (0.109)</td>
<td>B -0.495 (0.149)</td>
<td>A 0.281 (0.115)</td>
</tr>
<tr>
<td>Pumicestone Passage</td>
<td>B 0</td>
<td>A 0</td>
<td>B 0</td>
</tr>
<tr>
<td>Season</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter 1997</td>
<td>B 0.625 (0.146)</td>
<td>A 0.389 (0.187)</td>
<td>B,C -0.362 (0.163)</td>
</tr>
<tr>
<td>Spring 1997</td>
<td>C -0.176 (0.143)</td>
<td>A 0.362 (0.167)</td>
<td>A 0.237 (0.135)</td>
</tr>
<tr>
<td>Summer 1998</td>
<td>C -0.140 (0.147)</td>
<td>C -0.593 (0.202)</td>
<td>A,B -0.203 (0.147)</td>
</tr>
<tr>
<td>Autumn 1998</td>
<td>C 0</td>
<td>B 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Winter 1998</td>
<td>A 1.05 (0.127)</td>
<td>A 0.319 (0.163)</td>
<td>C -0.572 (0.149)</td>
</tr>
<tr>
<td>Day type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekday</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Weekend day</td>
<td>A -0.094 (0.086)</td>
<td>A 0.012 (0.110)</td>
<td>A 0.021 (0.096)</td>
</tr>
<tr>
<td>Fishing platform</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boat</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Shore</td>
<td>B -1.091 (0.277)</td>
<td>B -1.045 (0.447)</td>
<td>B -2.145 (0.363)</td>
</tr>
<tr>
<td>Covariates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours fished</td>
<td>+ 0.280 (0.023)</td>
<td>+ 0.235 (0.025)</td>
<td>+ 0.135 (0.023)</td>
</tr>
<tr>
<td>Number of boat fishers</td>
<td>-0.277 (0.056)</td>
<td>0 -0.065 (0.064)</td>
<td>-0.309 (0.061)</td>
</tr>
<tr>
<td>Number of shore fishers</td>
<td>-0.310 (0.145)</td>
<td>0 -0.109 (0.264)</td>
<td>0 0.163 (0.209)</td>
</tr>
<tr>
<td>Number of boat fishing lines</td>
<td>+ 0.399 (0.050)</td>
<td>+ 0.237 (0.058)</td>
<td>+ 0.262 (0.052)</td>
</tr>
<tr>
<td>Number of shore fishing lines</td>
<td>+ 0.343 (0.141)</td>
<td>0 0.233 (0.243)</td>
<td>0 0.143 (0.209)</td>
</tr>
</tbody>
</table>

The letters A, B and C denote groupings with significant differences between grouping in the probability of catching fish (p<0.05); letters that are the same indicate no significant differences. The symbols +, − and 0 respectively denote an increasing, decreasing or non-significant effect on the probability of catching fish.
Figure 4.5  Predicted probabilities, with 95% confidence intervals, of fishing groups catching and keeping a yellowfin bream during winter 1998, dusky flathead and summer whiting during spring 1997. Predictions represent the peak-fishing season averaged across the estuaries and the boat and shore fishing platforms.
Figure 4.6 Predicted probabilities, with 95% confidence intervals (dashed lines), of catching and keeping A) yellowfin bream, B) dusky flathead and C) summer whiting dependent on the number of fishing lines used by a two angler fishing group, for boat fishing and shore fishing. Predictions represent a two-hour fishing period averaged across all estuaries and seasons.
Figure 4.7 Predicted probability, with 95% confidence intervals (dashed lines), of different sized fishing groups catching and keeping A) yellowfin bream, B) dusky flathead and C) summer whiting, for boat fishing and shore fishing. Predictions represent a two-hour fishing period averaged across all estuaries and seasons.
4.3.3 Truncated regression of non-zero catches

Here, the data analysed were only those catches with at least one fish. In each estuary the average catch was generally less than one fish per group hour. However, groups fishing from a boat in the Maroochy River during winter 1998 had an average catch of 1.4 yellowfin bream per hour. Catches of dusky flathead were less than an average of 0.2 fish per group hour and catches of summer whiting were less than an average of one fish per group hour in all estuaries. There were significant differences in average catches due to some of the variables for each of the three fish species. Table 4.3, Table 4.4 and Table 4.5 contain the results from the different regression analyses.

Extended Poisson process model 1 refers to the $\lambda_n$ form in equation 2.12. If the estimate of $c$ here was greater than 1, $\lambda_n$ from equation 2.13 was applied (extended Poisson process model 2). The model with the smallest negative log-likelihood was used to estimate mean fish catches and make inferences.

Catches of yellowfin bream in the Maroochy River and Pumicestone Passage were significantly higher than in the Burnett River. Average catches of dusky flathead and summer whiting were not significantly different between estuaries. Average catches of yellowfin bream were highest during the winter months. Surprisingly, average catches of dusky flathead and summer whiting were not significantly different between seasons. For all species, there were no significant differences in average catches between boat and shore fishing groups and between weekends and weekdays. There was a significant positive effect of the time spent fishing on the average catch of all three fish species (Figure 4.8). For yellowfin bream shore fishing, there was a negative relationship between average catch and the number of anglers per group, but
This was the least significant effect in Table 4.3 with a p-value \(\approx 0.035\) (Figure 4.9). There was also no significant effect of the number of fishing lines in the group on average catches (Figure 4.10).

For all three fish species studied there was evidence of overdispersion relative to the truncated Poisson regression as indicated by the high deviance goodness of fit statistics and the estimate of \(c\) greater than zero in the extended Poisson process model (Table 4.3, Table 4.4 and Table 4.5). The deviance statistics relative to their degrees of freedom indicate adequate fits of both the truncated negative binomial and extended Poisson process models, but the Pearson statistics were slightly high for yellowfin bream. Figure 4.11 shows the plot of standardised residuals against the predicted average catches for yellowfin bream, dusky flathead and summer whiting. Given the non-zero data were highly skewed (very large upper tail) these residual plots were difficult to interpret. The plots show that the models predict the observed small catches quite well, but do tend to underestimate the few large catches present in the data. Table 4.6 lists the large standardised residuals in the analysis. These residuals represented only the large catches and the probability of these catch sizes occurring or larger were small for the observed fishing groups' covariate values. Having identified these extreme data points, then deleting any of these points from the analysis had little effect in the sense that the inferences were unchanged. For example, removing the largest yellowfin bream catch of 50 fish resulted in little change in the parameter estimates from the extended Poisson process model, suggesting that these models were reasonably forgiving of large observations.
The improvement in analysis by the extended Poisson process models over the truncated negative binomial model was difficult to measure. Interpretation of the log-likelihood values and the \( c \) parameter showed some inconsistency. The extended Poisson process model 2 log-likelihoods for yellow-fin bream and summer whiting indicated better model fits, and the log-likelihood for dusky flathead extended Poisson process model 1 indicated a similar model fit compared to the truncated negative binomial (Table 4.3, Table 4.4 and Table 4.5). However, the estimate of \( 'c' \) compared against its standard error indicated dispersion equivalent to truncated negative binomial for yellowfin bream and summer whiting, and for dusky flathead suggested dispersion between truncated Poisson and truncated negative binomial. Profile log-likelihood plots were constructed by minimising the negative of the log-likelihood for a range of fixed values of \( 'c' \) to investigate these apparent inconsistencies (Figure 4.12). The plots show asymmetric profiles and so the asymptotic standard errors will be unreliable indicators of the \( c \)-estimates precision. The yellowfin bream and summer whiting profile log-likelihood plots clearly show that improved model fits were achieved by assuming dispersion greater than truncated negative binomial (\( c>0 \)). However, the change in dusky flathead log-likelihood between the model estimate \( c=0.672 \) and \( c=1 \) was only slight. Figure 4.13 and Figure 4.14 show the estimated mean catches and their standard errors compared across the different models. It can be seen that the extended Poisson process and the truncated negative binomial models give similar estimated mean catches. However, the truncated negative binomial model tended to result in bigger standard errors of the large mean catches for yellowfin bream and summer whiting. In general the truncated Poisson model underestimated mean catches and their standard errors.
Overall, for yellowfin bream and summer whiting the second Poisson process regression analysis (using the form 2.12 for $\lambda_n$) was appropriate. However, for dusky flathead the truncated negative binomial regression was adequate. These assessments were based on the log-likelihood statistics.
Table 4.3 Parameter estimates and standard errors from the truncated regression analysis of the non-zero catches of yellowfin bream per fishing group.

<table>
<thead>
<tr>
<th>Yellowfin Bream</th>
<th>Truncated Poisson</th>
<th>Truncated Negative Binomial</th>
<th>Extended Poisson Process Model 1</th>
<th>Extended Poisson Process Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log-likelihood</td>
<td>-2060</td>
<td>-1643.7</td>
<td>-1638.4</td>
<td>-1637.1</td>
</tr>
<tr>
<td>Deviance</td>
<td>2471</td>
<td>799</td>
<td>908</td>
<td>1039</td>
</tr>
<tr>
<td>Pearson ( \chi^2 )</td>
<td>3277</td>
<td>1147</td>
<td>761</td>
<td>870</td>
</tr>
<tr>
<td>Degrees of freedom</td>
<td>873</td>
<td>872</td>
<td>871</td>
<td>870</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.0405 (0.182)</td>
<td>-0.664 (0.231)</td>
<td>-0.629 (0.189)</td>
<td>-4.045 (14.325)</td>
</tr>
<tr>
<td>Estuary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burnett River</td>
<td>B -0.201 (0.094)</td>
<td>B -0.349 (0.124)</td>
<td>B -0.286 (0.109)</td>
<td>B -0.355 (0.122)</td>
</tr>
<tr>
<td>Maroochy River</td>
<td>A 0.051 (0.085)</td>
<td>A -0.019 (0.115)</td>
<td>A -0.034 (0.092)</td>
<td>A -0.048 (0.111)</td>
</tr>
<tr>
<td>Pumicestone Passage</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Season</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter 1997</td>
<td>A 0.739 (0.143)</td>
<td>A 0.937 (0.163)</td>
<td>A 0.747 (0.178)</td>
<td>A 0.902 (0.165)</td>
</tr>
<tr>
<td>Spring 1997</td>
<td>B -0.325 (0.187)</td>
<td>B -0.317 (0.185)</td>
<td>B -0.275 (0.161)</td>
<td>B -0.295 (0.180)</td>
</tr>
<tr>
<td>Summer 1998</td>
<td>B 0.089 (0.177)</td>
<td>B 0.120 (0.185)</td>
<td>B 0.093 (0.158)</td>
<td>B 0.127 (0.179)</td>
</tr>
<tr>
<td>Autumn 1998</td>
<td>B 0</td>
<td>B 0</td>
<td>B 0</td>
<td>B 0</td>
</tr>
<tr>
<td>Winter 1998</td>
<td>A 0.914 (0.134)</td>
<td>A 1.161 (0.150)</td>
<td>A 0.895 (0.200)</td>
<td>A 1.079 (0.156)</td>
</tr>
<tr>
<td>Day type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekday</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Weekend day</td>
<td>A -0.078 (0.071)</td>
<td>A 0.016 (0.093)</td>
<td>A 0.022 (0.075)</td>
<td>A 0.031 (0.089)</td>
</tr>
<tr>
<td>Fishing platform</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boat</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Shore</td>
<td>A -0.177 (0.323)</td>
<td>A -0.050 (0.362)</td>
<td>A -0.089 (0.304)</td>
<td>A 0.009 (0.349)</td>
</tr>
<tr>
<td>Covariates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours fished</td>
<td>+ 0.120 (0.013)</td>
<td>+ 0.183 (0.025)</td>
<td>+ 0.135 (0.034)</td>
<td>+ 0.171 (0.024)</td>
</tr>
<tr>
<td>Number of boat fishers</td>
<td>0 0.006 (0.042)</td>
<td>0 -0.003 (0.057)</td>
<td>0 -0.020 (0.046)</td>
<td>0 -0.023 (0.059)</td>
</tr>
<tr>
<td>Number of shore fishers</td>
<td>0 -0.266 (0.186)</td>
<td>-0.417 (0.196)</td>
<td>-0.335 (0.174)</td>
<td>-0.409 (0.194)</td>
</tr>
<tr>
<td>Number of boat fishing lines</td>
<td>0 0.067 (0.036)</td>
<td>0 0.057 (0.048)</td>
<td>0 0.053 (0.039)</td>
<td>0 0.067 (0.047)</td>
</tr>
<tr>
<td>Number of shore fishing lines</td>
<td>0 0.193 (0.148)</td>
<td>0 0.221 (0.150)</td>
<td>0 0.193 (0.129)</td>
<td>0 0.212 (0.149)</td>
</tr>
<tr>
<td>Additional parameters</td>
<td>δ</td>
<td>1.222 (0.156)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/δ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>c</td>
<td></td>
<td>0.309 (0.443)</td>
<td>0.019 (0.281)</td>
</tr>
<tr>
<td></td>
<td>log d</td>
<td></td>
<td>1.240 (0.181)</td>
<td>0.121 (0.287)</td>
</tr>
</tbody>
</table>

The letters A, B and C denote groupings with significant differences (between groupings) in average catches \( p<0.05 \); letters that are the same indicate no significant difference. The symbols +, – and 0 respectively denote increasing, decreasing or non-significant effects on average catch. * indicates the model used to predict mean catches.
Table 4.4 Parameter estimates and standard errors from the truncated regression analysis of the non-zero catches of dusky flathead per fishing group.

<table>
<thead>
<tr>
<th>Dusky Flathead</th>
<th>Truncated Poisson Model</th>
<th>Truncated Negative Binomial Model</th>
<th>Extended Poisson Process Model 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log-likelihood</td>
<td>-383.4</td>
<td>-380.1</td>
<td>-379.9</td>
</tr>
<tr>
<td>Deviance</td>
<td>424</td>
<td>357</td>
<td>356</td>
</tr>
<tr>
<td>Pearson χ²</td>
<td>499</td>
<td>422</td>
<td>423</td>
</tr>
<tr>
<td>Degrees of freedom</td>
<td>422</td>
<td>421</td>
<td>420</td>
</tr>
<tr>
<td>Intercept</td>
<td>-0.907 (0.292)</td>
<td>-1.279 (0.401)</td>
<td>-1.353 (0.465)</td>
</tr>
<tr>
<td>Estuary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burnett River</td>
<td>A</td>
<td>A 0.260 (0.191)</td>
<td>A 0.303 (0.231)</td>
</tr>
<tr>
<td>Maroochy River</td>
<td>A -0.124 (0.218)</td>
<td>A -0.135 (0.253)</td>
<td>A -0.150 (0.280)</td>
</tr>
<tr>
<td>Pumicestone Passage</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Season</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter 1997</td>
<td>A 0.029 (0.235)</td>
<td>A 0.060 (0.279)</td>
<td>A 0.081 (0.329)</td>
</tr>
<tr>
<td>Spring 1997</td>
<td>A 0.203 (0.202)</td>
<td>A 0.244 (0.243)</td>
<td>A 0.293 (0.288)</td>
</tr>
<tr>
<td>Summer 1998</td>
<td>A -0.668 (0.348)</td>
<td>A -0.691 (0.387)</td>
<td>A -0.758 (0.444)</td>
</tr>
<tr>
<td>Autumn 1998</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Winter 1998</td>
<td>A -0.108 (0.208)</td>
<td>A -0.108 (0.243)</td>
<td>A -0.121 (0.291)</td>
</tr>
<tr>
<td>Day type</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Weekday</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Weekend day</td>
<td>A 0.126 (0.139)</td>
<td>A 0.139 (0.163)</td>
<td>A 0.161 (0.193)</td>
</tr>
<tr>
<td>Fishing platform</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boat</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Shore</td>
<td>A -2.039 (1.689)</td>
<td>A -2.120 (1.790)</td>
<td>A -2.238 (1.977)</td>
</tr>
<tr>
<td>Covariates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours fished</td>
<td>+ 0.084 (0.024)</td>
<td>+ 0.099 (0.033)</td>
<td>+ 0.121 (0.040)</td>
</tr>
<tr>
<td>Number of boat fishers</td>
<td>0 0.033 (0.072)</td>
<td>0 0.036 (0.090)</td>
<td>0 0.045 (0.109)</td>
</tr>
<tr>
<td>Number of shore fishers</td>
<td>0 -0.833 (1.014)</td>
<td>0 -0.910 (1.07)</td>
<td>0 -1.011 (1.176)</td>
</tr>
<tr>
<td>Number of boat fishing lines</td>
<td>0 0.069 (0.064)</td>
<td>0 0.071 (0.078)</td>
<td>0 0.077 (0.094)</td>
</tr>
<tr>
<td>Number of shore fishing lines</td>
<td>0 1.249 (1.248)</td>
<td>0 1.350 (1.340)</td>
<td>0 1.474 (1.481)</td>
</tr>
<tr>
<td>Additional parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>δ</td>
<td>—</td>
<td>0.418 (0.260)</td>
<td>—</td>
</tr>
<tr>
<td>log (1/δ)</td>
<td>—</td>
<td>—</td>
<td>0.069 (0.223)</td>
</tr>
<tr>
<td>c</td>
<td>—</td>
<td>—</td>
<td>0.672 (0.112)</td>
</tr>
</tbody>
</table>

The letters A, B and C denote groupings with significant differences (between groupings) in average catches (p<0.05); letters that are the same indicate no significant difference. The symbols +, − and 0 respectively denote increasing, decreasing or non-significant effects on average catch. * indicates the model used to predict mean catches.
Table 4.5 Parameter estimates and standard errors from the truncated regression analysis of the non-zero catches of summer whiting per fishing group.

<table>
<thead>
<tr>
<th></th>
<th>Truncated Poisson Model</th>
<th>Truncated Negative Binomial Model</th>
<th>Extended Poisson Process Model 1</th>
<th>Extended Poisson Process Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Log-likelihood</strong></td>
<td>-1510</td>
<td>-1186.5</td>
<td>-1181.5</td>
<td>-1181.1</td>
</tr>
<tr>
<td><strong>Deviance</strong></td>
<td>1858</td>
<td>509</td>
<td>-</td>
<td>652</td>
</tr>
<tr>
<td><strong>Pearson $\chi^2$</strong></td>
<td>2321</td>
<td>731</td>
<td>-</td>
<td>603</td>
</tr>
<tr>
<td><strong>Degrees of freedom</strong></td>
<td>590</td>
<td>589</td>
<td>588</td>
<td>587</td>
</tr>
<tr>
<td><strong>Estuary</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burnett River</td>
<td>A -0.117 (0.140)</td>
<td>A -0.068 (0.177)</td>
<td>A -0.065 (0.191)</td>
<td>A -0.111 (0.176)</td>
</tr>
<tr>
<td>Maroochy River</td>
<td>A 0.119 (0.099)</td>
<td>A 0.188 (0.135)</td>
<td>A 0.189 (0.156)</td>
<td>A 0.176 (0.135)</td>
</tr>
<tr>
<td>Pumicestone Passage</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td><strong>Season</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter 1997</td>
<td>A -0.050 (0.153)</td>
<td>A -0.055 (0.196)</td>
<td>A -0.051 (0.212)</td>
<td>A 0.010 (0.196)</td>
</tr>
<tr>
<td>Spring 1997</td>
<td>A 0.093 (0.121)</td>
<td>A 0.162 (0.163)</td>
<td>A 0.165 (0.180)</td>
<td>A 0.190 (0.162)</td>
</tr>
<tr>
<td>Summer 1998</td>
<td>A 0.061 (0.141)</td>
<td>A 0.083 (0.183)</td>
<td>A 0.084 (0.198)</td>
<td>A 0.082 (0.181)</td>
</tr>
<tr>
<td>Autumn 1998</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Winter 1998</td>
<td>A -0.108 (0.157)</td>
<td>A -0.095 (0.200)</td>
<td>A -0.088 (0.215)</td>
<td>A 0.027 (0.200)</td>
</tr>
<tr>
<td><strong>Day type</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekday</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Weekend day</td>
<td>A -0.047 (0.090)</td>
<td>A -0.115 (0.116)</td>
<td>A -0.118 (0.130)</td>
<td>A -0.101 (0.116)</td>
</tr>
<tr>
<td><strong>Fishing platform</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boat</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
<td>A 0</td>
</tr>
<tr>
<td>Shore</td>
<td>A -0.379 (0.576)</td>
<td>A -0.413 (0.627)</td>
<td>A -0.412 (0.672)</td>
<td>A -0.442 (0.619)</td>
</tr>
<tr>
<td><strong>Covariates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours fished</td>
<td>+ 0.133 (0.018)</td>
<td>+ 0.201 (0.032)</td>
<td>+ 0.203 (0.075)</td>
<td>+ 0.182 (0.033)</td>
</tr>
<tr>
<td>Number of boat fishers</td>
<td>0 -0.063 (0.051)</td>
<td>0 -0.097 (0.063)</td>
<td>0 -0.098 (0.070)</td>
<td>0 -0.090 (0.069)</td>
</tr>
<tr>
<td>Number of shore fishers</td>
<td>0 0.065 (0.286)</td>
<td>0 0.182 (0.326)</td>
<td>0 0.195 (0.350)</td>
<td>0 0.173 (0.321)</td>
</tr>
<tr>
<td>Number of boat fishing lines</td>
<td>0 0.085 (0.045)</td>
<td>0 0.115 (0.061)</td>
<td>0 0.115 (0.071)</td>
<td>0 0.107 (0.069)</td>
</tr>
<tr>
<td>Number of shore fishing lines</td>
<td>0 -0.084 (0.304)</td>
<td>0 -0.212 (0.387)</td>
<td>0 -0.226 (0.423)</td>
<td>0 -0.191 (0.378)</td>
</tr>
<tr>
<td><strong>Additional parameters</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$\delta$</td>
<td></td>
<td>1.462 (0.212)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1/\delta$</td>
<td></td>
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<td>-0.684 (0.866)</td>
<td>0.069 (0.145)</td>
</tr>
<tr>
<td>$c$</td>
<td></td>
<td></td>
<td>1.023 (0.172)</td>
<td>0.002 (0.040)</td>
</tr>
<tr>
<td>log $d$</td>
<td></td>
<td></td>
<td></td>
<td>-6.678 (24.817)</td>
</tr>
</tbody>
</table>

The letters A, B and C denote groupings with significant differences (between groupings) in average catches ($p<0.05$); letters that are the same indicate no significant difference. The symbols +, − and 0 respectively denote increasing, decreasing or non-significant effects on average catch. * indicates the model used to predict mean catches.
Table 4.6 List of large standardised residuals (>= 4) and the estimated probability of the observed catch or greater occurring for the fishing groups defined covariates.

<table>
<thead>
<tr>
<th>Species</th>
<th>Standardised Residual</th>
<th>Observed Catch</th>
<th>Pr(&gt;= Observed Catch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellowfin Bream</td>
<td>10.26</td>
<td>50</td>
<td>0.00004</td>
</tr>
<tr>
<td></td>
<td>8.52</td>
<td>27</td>
<td>0.00002</td>
</tr>
<tr>
<td></td>
<td>8.44</td>
<td>16</td>
<td>0.00025</td>
</tr>
<tr>
<td></td>
<td>7.87</td>
<td>37</td>
<td>0.00032</td>
</tr>
<tr>
<td></td>
<td>4.88</td>
<td>20</td>
<td>0.00428</td>
</tr>
<tr>
<td></td>
<td>4.65</td>
<td>20</td>
<td>0.00521</td>
</tr>
<tr>
<td></td>
<td>4.63</td>
<td>7</td>
<td>0.00719</td>
</tr>
<tr>
<td>Dusky Flathead</td>
<td>6.92</td>
<td>8</td>
<td>0.00033</td>
</tr>
<tr>
<td>Summer Whiting</td>
<td>6.25</td>
<td>40</td>
<td>0.0014</td>
</tr>
<tr>
<td></td>
<td>6.06</td>
<td>25</td>
<td>0.0017</td>
</tr>
<tr>
<td></td>
<td>6.04</td>
<td>21</td>
<td>0.0017</td>
</tr>
<tr>
<td></td>
<td>5.02</td>
<td>11</td>
<td>0.0047</td>
</tr>
<tr>
<td></td>
<td>4.60</td>
<td>30</td>
<td>0.0055</td>
</tr>
<tr>
<td></td>
<td>4.08</td>
<td>12</td>
<td>0.0097</td>
</tr>
<tr>
<td></td>
<td>4.00</td>
<td>12</td>
<td>0.0104</td>
</tr>
</tbody>
</table>
Figure 4.8 Predicted mean catch, with 95% confidence intervals (dashed lines), of boat fishing groups catching and keeping A) yellowfin bream during winter 1998, B) dusky flathead and C) summer whiting during spring 1997. Predictions represent the peak-fishing season for non-zero catches only.
Figure 4.9 Predicted mean catch, with 95% confidence intervals (dashed lines), of A) yellowfin bream, B) dusky flathead and C) summer whiting dependent on the number of anglers in a fishing group, for boat fishing and shore fishing. Predictions represent a two-hour fishing period and one fishing line per angler for the peak fishing seasons of winter 1998 for yellowfin bream and spring 1997 for dusky flathead and summer whiting.
Figure 4.10 Predicted mean catch, with 95% confidence intervals (dashed lines), of A) yellowfin bream, B) dusky flathead and C) summer whiting dependent on the number of fishing lines used by a two person fishing group, for boat fishing and shore fishing. Predictions represent a two-hour fishing period for the peak fishing seasons of Winter 1998 for yellowfin bream and Spring 1997 for dusky flathead and summer whiting.
Figure 4.11 Standardised residuals plotted against predicted average catches for A) yellowfin bream, B) dusky flathead and C) summer whiting. The standardised residuals were from the extended Poisson Process model fits.
Figure 4.12 Profile log-likelihood plots for a range of fixed values of the parameter “c” in the extended Poisson process models for A) yellowfin bream, B) dusky flathead and C) summer whiting.
Figure 4.13 Comparison of predicted mean catches from the fitted truncated regression models for (A) yellowfin bream, (B) dusky flathead and (C) summer whiting. Predictions represent a two-angler boat group during winter 1998 (A) and spring 1997 (B and C). Poisson process model 1 represents the first $\lambda_n$ form (equation 2.12) and model 2 represents the second $\lambda_n$ form (equation 2.13) in chapter 2.
Figure 4.14 Comparison of standard errors of the predicted mean catches (Figure 4.13) from the fitted truncated models for (A) yellowfin bream, (B) dusky flathead and (C) summer whiting.
4.4 DISCUSSION

In this chapter models as described by Faddy (1997a & b) and Welsh (1996) have been used to analyse data on recreational fishing catches. The modelling used binary (zero / greater than zero catches) and truncated (catches greater than zero) regressions to estimate the effects of a number of covariates. The methodology was particularly applicable to these data, which exhibited many zeros, as the models used more accurately reflected this property of the data than more standard modelling options available in most statistical packages. The truncated negative binomial and extended Poisson process models have adequately allowed for the considerable dispersion shown in the data (Figure 4.4), and the overall analysis facilitated critical assessment of important effects on recreational catches. Inferences from both the truncated negative binomial and extended Poisson modelling were comparable. The modelling has provided a useful means of predicting recreational catch rates and made more effective use of the survey data. Further more, consideration of how zero catches arise should contribute to model selection. Here factors affecting zero catches were thought to be different from those that influence non-zero catches, with zero catches being either structural (where there were no fish in the location where the angler was fishing) or non-structural (where there were fish in the location but none were caught due to the angler's skill level and/or social behaviour). Faddy (1998) and Welsh et al. (1996) highlighted the importance of structural and non-structural zeros, and appropriate modelling; in circumstances different from those behind the data analysed here, a mixture model (Lambert, 1992) might be more appropriate.

The analyses identified important factors affecting the recreational catch. Total catch for each fish species was estimated separately in each estuary, season and fishing
platform (Chapter 5). However, the catch data could be grouped across weekends and weekdays to estimate total catch. The models also indicated some interesting relationships between catch and fishing effort. As expected for both boat and shore fishing groups, the greater the time fished the larger the average catch. However, larger boat fishing groups were less likely to catch yellowfin bream and summer whiting than similar sized shore groups. This negative relationship probably indicated that the more serious and experienced boat anglers tended to fish by themselves or in small groups. Larger sized groups fishing from a boat may have fished more as a social activity and were therefore less likely to catch fish. Also, more fishing lines used by a given number of anglers tended to increase the likelihood of catching fish. This latter positive influence had a counteracting effect on the negative influence of larger numbers of boat anglers reducing the chances of catching fish. The negative covariate effects of the number of shore fishers which only applied to yellowfin bream were the least significant results in the analyses, and perhaps they represent only small effects. Overall, the results indicate that the number of hours fished per group was a fair representation of boat-fishing effort, while the number of hours fished per line or angler (since these will be correlated) represented shore-fishing effort.

Fishery dependent catch and effort data are commonly used in fisheries stock assessment. Usually the source of these data is the commercial fishery sector. However, such data have many problems, especially with estuarine fish species in Queensland (Hoyle et al., 2000). These include the different sized mesh nets used between fishing operations, inconsistent recording of sorted and unsorted catch, variable units of recorded fishing effort and lack of information about the fish species targeted. These problems probably invalidate the assumption that the commercial
catch rate is proportional to fish abundance. However, since the recreational catch of yellowfin bream, dusky flathead and summer whiting considered here is larger than that for the commercial sector (O’Neill, 2000), accurate on-the-water or boat ramp surveys of recreational catches may provide more precise catch information to monitor estuarine fisheries.

Power analysis of the catch data indicated that for these three estuaries, 200 interviews per month from each estuary would give about 80% confidence in detecting a 15% difference in catch rates between time periods (O’Neill, 2000). If a monitoring program of this size were developed for recreational fishing in the three estuaries, the data would be valuable in a number of ways. They would provide retained and released fish catch trends, accurate fishing locations and fishery representative fish size information. Catch trends could also be estimated using the binary and truncated negative binomial/extended Poisson process based modelling.
Chapter 5. RECREATIONAL FISHING EFFORT AND CATCH

Unlike the commercial fisheries which provide compulsory logbook catch returns, the total recreational catch in the Burnett River, Maroochy River and Pumicestone Passage was unknown and needed to be estimated. In this chapter the total daytime recreational catch and effort were estimated. Bootstrap methods, which have not yet been widely used to estimate total recreational catch and effort, provided an alternate method to compute non-symmetric confidence intervals compared to the standard normal based intervals. Annual recreational fishing effort was of the order of 13 000 angler visits to the Burnett River, 28 000 to the Maroochy River, and 41 000 to the Pumicestone Passage. Estimated daytime recreational catch of yellowfin bream, dusky flathead and summer whiting was greater in the Pumicestone Passage than in the Maroochy River or the Burnett River.

5.1 INTRODUCTION

In areas where the recreational fish catch is appreciable, a combination of commercial and recreational catch information is required to provide an adequate assessment of fish stocks. The existing level of knowledge on the status of fish stocks in coastal estuaries and the magnitude of recreational catch, limit the quality of management decisions. To address the lack of information, data are required on recreational fishing effort, catch rates and changes in size/age of fish caught over time. The product of recreational fishing effort and catch rate data will provide an estimate of the total recreational catch. This method is fundamentally different from Queensland
commercial fisheries, where data is collected through a compulsory catch logbook system.

Collection of recreational fishing data from coastal estuaries is usually done using a roving creel survey method (Pollock et al. 1994). This method is used to interview people while they fish. Roving creel surveys are conducted by boat to interview boat anglers and by foot to interview shore based anglers. The roving method is used when access points for estuary fishing are too numerous to utilise a traditional boat ramp survey. Catch rates (numbers of fish caught per hour) are derived from interviews. Anglers are asked what time they started fishing and the number of fish they had caught up to the time of the recorded interview. Effort (group or person hours) in a fishing area is based on counts of anglers extrapolated to the number of hours in a survey period. In Australia, this roving method has been used previously in Port Philip Bay, Victoria (MacDonald and Hall, 1987; Coutin et al., 1995); in the Leschenault (Malseed et al., 2000), Peel-Harvey and Swan-Canning (Sumner et al., 2000) estuaries in Western Australia, and in the Clarence and Richmond estuaries in New South Wales (West and Gordon, 1994).

Few comprehensive estimates of recreational catches from coastal estuaries have been made in Queensland, and the total landings taken by anglers are largely unknown. In 1998 a state wide phone survey of households determined that 33% (420 000) of households included a person of 15 years of age or older who had fished at least once in the previous twelve months in Queensland (QFMA, 1999). This result suggests that the total fish harvest from coastal estuaries could be substantial. Recreational catch has been estimated for the whole of Queensland using angler diaries (Higgs, 1999),
but these estimates did not identify where catches were taken and failed to
discriminate between some fish species. Of the estuaries surveyed in this study,
historical recreational fishing data were available only for the Pumicestone Passage.
The total estimated winter bream catch by recreational anglers in the northern end of
the Passage (Caloundra) in 1979 was estimated to be 60 tonnes (Pollock, 1980). The
Queensland Department of Environment and Heritage (QDEH) estimated a total of
48000 boat angler visits (24000 boats) per year to Pumicestone Passage (WBM
Oceanics Australia, 1993).

The objectives of this chapter were to estimate seasonal recreational fishing effort and
catches of key target fish species yellowfin bream (*Acanthopagrus australis*), dusky
flathead (*Platycephalus fuscus*) and summer whiting (*Sillago analis* and *S. ciliata*)
from three estuaries in south-east Queensland.

### 5.2 Estimation of Total Fishing Effort and Catch

Details of the survey data collection were previously outlined in chapter 4. Counts of
active boat fishing groups and shore anglers were summarised into averages for each
estuary zone and survey day (Pollock et al., 1994). Bootstrap methods were used to
resample, at random with replacement, these values to obtain 5000 sample estimates
of boat group and shore angler numbers. The sum of these estimates across all zones
produced 5000 estimates for each estuary, season, day-type and fishing platform. The
average of each of these 5000 values produced an estimate of boat group and shore
angler numbers fishing on each estuary, for each season, day-type and platform. The
2.5 and 97.5 percentiles of the 5000 values produced 95% bootstrap confidence
intervals (Efron and Tibshirani, 1993). The 5000 values multiplied by the total number of hours covered by the survey (the 12 hour period 6am to 6pm multiplied by the number of day-types in each season), produced 5000 sample estimates of total fishing effort ($E$).

Boat fishing (number per day per km$^2$) and shore angler (number per day per km of shoreline) densities were estimated by dividing the average daily boat and shore angler numbers by a measure of the total fishing region in each estuary. The boat fishing area and shoreline distance was measured by tracing an ArcView GIS (1998) computerised coverage of each estuary with the computer software Optimas™ (1996). The total area fishable from a boat was defined as the entire estuarine area of water covered by the survey. The shoreline distance was measured only for the sections where access to fish from the shore was possible, without the use of a boat.

Catch rates ($R$) were calculated as the number of each species caught per hour of fishing effort (including zero catches), where fishing effort was defined as boat group or shore angler hours in accord with the results of the statistical analysis described in chapter 4. To reduce the variability in catch rates, only fishing durations of half an hour or more were used, as recommended by Pollock et al. (1997).

Total catch ($C$) was estimated by direct expansion of catch rates ($R$) by species and total fishing effort ($E$) by season, day-type and fishing platform strata. The observed catch rates ($R$) over fishing groups were re-sampled, at random with replacement, using bootstrap methods to produce 5000 sample estimates for each fish species, season and fishing platform. These 5000 values were then paired at random with the
previous 5000 fishing effort values. The 5000 products \( C = R \times E \) when averaged produced the estimate of total catch, and also enabled percentile (95%) bootstrap confidence intervals to be obtained.

5.3 RESULTS

5.3.1 General

The survey data covered 149, 232 and 170 shift days where fishing effort was recorded, during which 1055, 1295 and 1342 fishing group interviews were collected from the Burnett River, Maroochy River and Pumicestone Passage respectively (Table 5.1). These fishing groups expended a total of 2427, 2526 and 3807 group hours respectively. This resulted in 3245, 2116 and 3964 fish kept and 6676, 4017 and 4201 fish released. Of the anglers interviewed, 73% were male, 16% female and 11% children under 15 years of age. There was no significant difference in these demographics between estuaries \( (\chi^2=4.489, df=4, p=0.34) \). The percentages of fishing groups from areas local to the estuary, Brisbane, other parts of Queensland and interstate were dependent on the estuary fished, with most anglers being local residents \( (\chi^2=754.6, df=6, p<0.001) \) (Figure 5.1). The most common response from fishing groups when questioned on target fish species was ‘anything’ (50%) for each estuary. Yellowfin bream, dusky flathead and summer whiting were the most sought after target species. The percent varied with estuary and season \( (\chi^2=1287.66, df=50, p<0.001) \). Ignoring estuaries, generally yellowfin bream were targeted by 40% of angler groups during the winter months. Dusky flathead (15%) and summer whiting (26%) were more sought after during the warmer months. There
were significant changes in the percent of fishing boats that crabbed with both estuary fished and season period ($\chi^2=15.98, df=6, p=0.014$). Of the fishing boats surveyed, 15% crabbed in the Burnett River, 5% in the Maroochy River and 23% in the Pumicestone Passage. The percent of fishing boats crabbing in all three estuaries was higher during the summer and spring months (27%) compared to autumn and winter months (12%).

**Table 5.1** Sample number of shift days where fishing effort counts were recorded and the number of fishing group interviews collected (* - survey commenced September 1997).

<table>
<thead>
<tr>
<th>Season</th>
<th>Burnett River</th>
<th>Maroochy River</th>
<th>Pumicestone Passage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shift Days</td>
<td>Interviews</td>
<td>Shift Days</td>
</tr>
<tr>
<td>Winter 1997</td>
<td>*</td>
<td>32</td>
<td>52</td>
</tr>
<tr>
<td>Spring 1997</td>
<td>32</td>
<td>202</td>
<td>51</td>
</tr>
<tr>
<td>Summer 1998</td>
<td>42</td>
<td>264</td>
<td>34</td>
</tr>
<tr>
<td>Autumn 1998</td>
<td>40</td>
<td>211</td>
<td>52</td>
</tr>
<tr>
<td>Winter 1998</td>
<td>35</td>
<td>346</td>
<td>43</td>
</tr>
<tr>
<td>Total</td>
<td>149</td>
<td>1055</td>
<td>232</td>
</tr>
</tbody>
</table>
Fish species composition in the recreational catch varied with estuary and season. A total of 32, 20 and 29 species were recorded as being retained in the Burnett River, Maroochy River and Pumicestone Passage respectively. More species (50 in the Burnett River, 23 in the Maroochy River and 48 in the Pumicestone Passage) were caught and released by anglers. Yellowfin bream and whiting species contributed most (in numbers) to kept and released catch (Table 5.2). In the Burnett River the northern whiting *Sillago sihama* made up 48% of the retained catch. Flathead and tailor represented less than 10% of the retained species in the Maroochy River and Pumicestone Passage.
Table 5.2 Fish species percent contribution (by number) to recreational catches where the percentage was one or greater. (* - not recorded, 1 – does not include the large mulloway species *Argyrosomus hololepidotus*).

**a) Kept catch.**

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Burnett River</th>
<th>Maroochy River</th>
<th>Pumicestone Passage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bream – yellowfin</td>
<td><em>Acanthopagrus australis</em></td>
<td>20.9</td>
<td>41.0</td>
<td>33.7</td>
</tr>
<tr>
<td>Crab – mud</td>
<td><em>Scylla serrata</em></td>
<td>3.9</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Crab – sand</td>
<td><em>Portunus pelagicus</em></td>
<td>*</td>
<td>&lt; 1</td>
<td>12.8</td>
</tr>
<tr>
<td>Flathead – dusky</td>
<td><em>Platycephalus fuscus</em></td>
<td>6.0</td>
<td>6.7</td>
<td>9.2</td>
</tr>
<tr>
<td>Grunter – unspecified</td>
<td><em>Pomadasyx spp.</em></td>
<td>1.4</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Luderick</td>
<td><em>Girella tricuspidata</em></td>
<td>*</td>
<td>1.4</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Tailor</td>
<td><em>Pomatomus saltatrix</em></td>
<td>*</td>
<td>6.3</td>
<td>4.0</td>
</tr>
<tr>
<td>Tarwhine</td>
<td><em>Rhabdosargus sarba</em></td>
<td>*</td>
<td>1.6</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Whiting – northern</td>
<td><em>Sillago sihama</em></td>
<td>48.0</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Whiting – summer</td>
<td><em>Sillago ciliata/analis</em></td>
<td>10.0</td>
<td>31.5</td>
<td>25.9</td>
</tr>
<tr>
<td>Whiting – winter</td>
<td><em>Sillago maculata</em></td>
<td>3.3</td>
<td>7.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>6.6</td>
<td>3.0</td>
<td>7.3</td>
</tr>
</tbody>
</table>

**b) Released catch.**

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Burnett River</th>
<th>Maroochy River</th>
<th>Pumicestone Passage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bream – yellowfin</td>
<td><em>Acanthopagrus australis</em></td>
<td>13.0</td>
<td>63.5</td>
<td>53.1</td>
</tr>
<tr>
<td>Catfish – forktail</td>
<td><em>Ariidae</em></td>
<td>10.1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Cod – unspecified</td>
<td>Serranidae</td>
<td>1.1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Crab – mud</td>
<td><em>Scylla serrata</em></td>
<td>8.7</td>
<td>&lt; 1</td>
<td>1.7</td>
</tr>
<tr>
<td>Crab – sand</td>
<td><em>Portunus pelagicus</em></td>
<td>*</td>
<td>&lt; 1</td>
<td>16.6</td>
</tr>
<tr>
<td>Flathead – dusky</td>
<td><em>Platycephalus fuscus</em></td>
<td>1.0</td>
<td>4.0</td>
<td>4.9</td>
</tr>
<tr>
<td>Flounder</td>
<td>Bothidae</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>1.1</td>
</tr>
<tr>
<td>Grunter – striped</td>
<td>Teraponidae</td>
<td>3.4</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Grunter – unspecified</td>
<td><em>Pomadasyx spp.</em></td>
<td>6.4</td>
<td>1.3</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Jewfish – unspecified</td>
<td><em>Sciseniidae</em></td>
<td>6.6</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Perch – moses</td>
<td><em>Lutjanus russelli</em></td>
<td>2.1</td>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Ray – unspecified</td>
<td>Dasyatidae</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>2.5</td>
</tr>
<tr>
<td>Tailor</td>
<td><em>Pomatomus saltatrix</em></td>
<td>*</td>
<td>&lt; 1</td>
<td>1.1</td>
</tr>
<tr>
<td>Whiting – northern</td>
<td><em>Sillago sihama</em></td>
<td>30.6</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Whiting – summer</td>
<td><em>Sillago ciliata/analis</em></td>
<td>3.9</td>
<td>26.1</td>
<td>10.1</td>
</tr>
<tr>
<td>Whiting – trumpetet/winter</td>
<td><em>Sillago maculata</em></td>
<td>1.1</td>
<td>0.4</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Whiting – unspecified</td>
<td><em>Sillago spp.</em></td>
<td>6.9</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Other</td>
<td>Other</td>
<td>5.1</td>
<td>2.7</td>
<td>7.2</td>
</tr>
</tbody>
</table>
5.3.2 Boat Fishing Effort

The average number of boats involved in fishing in the Pumicestone Passage was about five times higher than in the Burnett River and three times higher than in the Maroochy River. There were more fishing boats during winter and they concentrated in specific areas, generally towards the estuary entrances (Figure 5.2; Appendix 8.1 – Figure 8.1, Figure 8.2 and Figure 8.3). The average number of anglers was 1.98 per boat.

![Average daily fishing boat numbers](image)

**Figure 5.2** Average daily fishing boat numbers (± 95% bootstrap confidence intervals). Estimates were based on counts of fishing boats on 149 survey days on the Burnett River, 232 survey days on the Maroochy River and 170 survey days on the Pumicestone Passage.

The area available to fish from a boat was greater in Pumicestone Passage than in the Burnett and Maroochy Rivers. Allowing for this difference, the Maroochy River had
the highest density of boats fishing, followed by the Burnett River and then the Pumicestone Passage (Table 5.3).

Table 5.3 Average fishing boat density on the Burnett River, Maroochy River and Pumicestone Passage (95% bootstrap confidence interval in parentheses).

<table>
<thead>
<tr>
<th>Estuary</th>
<th>Area (km²)</th>
<th>Boat Fishing Density (boats / day / km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week Days</td>
<td>Weekend Days</td>
</tr>
<tr>
<td>Burnett River</td>
<td>7.9</td>
<td>0.9 (0.6-1.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.5 (1.2-1.8)</td>
</tr>
<tr>
<td>Maroochy River</td>
<td>5.6</td>
<td>2.0 (1.6-2.4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.4 (2.8-4.2)</td>
</tr>
<tr>
<td>Pumicestone Passage</td>
<td>51.0</td>
<td>0.5 (0.4-0.7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2 (1.0-1.3)</td>
</tr>
</tbody>
</table>

5.3.3 Shore Fishing Effort

The pattern in fishing effort differed between shore and boat fishing. Shore angler numbers on the Maroochy River were about 2 1/2 times greater than the number on the Burnett River and 1 1/2 times more than the number on the shore of the Pumicestone Passage. The number of shore anglers on weekdays was higher during winter (Figure 5.3). This was not always the case on weekends with more shore anglers observed during spring on the Maroochy River and autumn on Pumicestone Passage (Figure 5.3). In the Burnett and Maroochy Rivers, shore anglers were distributed evenly over a number of areas, while the number of shore anglers on Pumicestone Passage was highest in the northern end of the estuary (Appendix 8.1 – Figure 8.1, Figure 8.2 and Figure 8.3).
Figure 5.3 Average daily numbers of people fishing from the shore (± 95% bootstrap confidence intervals). Estimates were based on counts of shore anglers on 149 survey days on the Burnett River, 232 survey days on the Maroochy River and 170 survey days on the Pumicestone Passage.

The number of shore anglers was converted to a density to allow for the different size of each estuary. The amount of shoreline accessible to shore based anglers was greatest in the Pumicestone Passage, followed by the Burnett River and then the Maroochy River. Allowing for these differences, the density of shore based anglers was highest on the Maroochy River, while the Burnett River and Pumicestone Passage had similar densities (Table 5.4).
Table 5.4 Average shore angler density on the Burnett River, Maroochy River and Pumicestone Passage (95% bootstrap confidence interval in parentheses).

<table>
<thead>
<tr>
<th>Estuary</th>
<th>Total shoreline distance (km)</th>
<th>Accessible shoreline to fish (km)</th>
<th>Shore Angler Density (anglers / day / km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Week Days</td>
</tr>
<tr>
<td>Burnett River</td>
<td>54</td>
<td>27</td>
<td>0.4 (0.3-0.6)</td>
</tr>
<tr>
<td>Maroochy River</td>
<td>47</td>
<td>23</td>
<td>1.2 (1.0-1.4)</td>
</tr>
<tr>
<td>Pumicestone Passage</td>
<td>101</td>
<td>35</td>
<td>0.6 (0.4-0.8)</td>
</tr>
</tbody>
</table>

5.3.4 Total Catch

The total daytime catch of yellowfin bream, dusky flathead and summer whiting from the Pumicestone Passage was greater than that from the Burnett and Maroochy Rivers. Total catch was higher during winter than for the other seasons for yellowfin bream and dusky flathead, whereas the summer whiting catches were more uniformly distributed across seasons (Figure 5.4, Figure 5.5 and Figure 5.6). Boat fishing accounted for most of the catch (> 70%), with the exception of shore anglers taking more dusky flathead in the Maroochy River (55%). The estimated annual daytime catch, measured in tonnes, for the period from September 1997 to August 1998 was greatest for yellowfin bream (Table 5.5). A detailed break-up of total catch for retained and released fish is given in Appendix 8.1. Average fish weights were calculated using the fish length/weight keys in Appendix 8.1.
Table 5.5 Total daytime recreational catch and average fish weights for the annual period from September 1997 to August 1998 (95% bootstrap confidence intervals shown in parentheses).

<table>
<thead>
<tr>
<th></th>
<th>Burnett River</th>
<th>Maroochy River</th>
<th>Pumicestone Passage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yellowfin Bream</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Catch (tonnes)</td>
<td>5.5 (4.4-6.7)</td>
<td>12.9 (9.6-17.0)</td>
<td>22.7 (19.1-27.0)</td>
</tr>
<tr>
<td>Average fish weight (kg)</td>
<td>0.344</td>
<td>0.246</td>
<td>0.307</td>
</tr>
<tr>
<td><strong>Dusky Flathead</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Catch (tonnes)</td>
<td>2.6 (1.8-3.3)</td>
<td>2.3 (1.4-3.1)</td>
<td>10.6 (7.9-13.0)</td>
</tr>
<tr>
<td>Average fish weight (kg)</td>
<td>0.554</td>
<td>0.378</td>
<td>0.494</td>
</tr>
<tr>
<td><strong>Summer Whiting</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Catch (tonnes)</td>
<td>1.4 (1.19)</td>
<td>5.2 (4.2-6.2)</td>
<td>9.8 (8.1-11.7)</td>
</tr>
<tr>
<td>Average fish weight (kg)</td>
<td>0.151</td>
<td>0.162</td>
<td>0.199</td>
</tr>
</tbody>
</table>

Figure 5.4 Total number (± 95% bootstrap confidence interval) of yellowfin bream caught and retained in the Burnett River, Maroochy River and Pumicestone Passage.
Figure 5.5 Total number (± 95% bootstrap CI) of dusky flathead caught and retained in the Burnett River, Maroochy River and Pumicestone Passage.

Figure 5.6 Total number (± 95% bootstrap CI) of summer whiting caught and retained from the Burnett River, Maroochy River and Pumicestone Passage.
Accuracy of survey results can be indicated from confidence interval width. Relatively tight intervals were produced on estimates of recreational fishing effort. Intervals on total catch were wider and could be improved with more fishing group interviews. The percentile bootstrap method was applied to the catch and effort data to produce 95% confidence intervals. This method was dependent on the notion of a bootstrap sample where a random sample was drawn with replacement from the data. This procedure was repeated to produce 5000 averages. Efron and Tibshirani (1993) state that the percentile method was only first order accurate compared to the bias corrected and bootstrap-t methods, which were second order accurate. Hoyle et al (2000) compared six different bootstrap methods for computing confidence intervals for recreational diary catch data. They concluded that the bootstrap-t produced the best intervals because its average confidence interval width was greater and had coverage of the population mean 85% of the time. Their results for the bias corrected (standard and accelerated), hybrid and percentile methods all had reasonable and similar coverages of about 75%. Efron and Tibshirani (1993) also state that the bootstrap-t method can give somewhat erratic results, and can be heavily influenced by a few outlying data points, which was a concern given the highly skewed recreational fishing data. They recommended the percentile and bias corrected methods are more reliable for most applications than the bootstrap-t. For this reason the percentile method was used here as it had similar coverage to the bias corrected method (Hoyle et al, 2000). Even though the 95% percentile method possibly only covered the mean total catch only 75% of the time, no simple adjustments are available to correct for this possibility and extensive simulations of the data are required to test the actual confidence interval coverage.
The principal reason for using the bootstrap method was to produce confidence intervals that take account of non-normally distributed data. Confidence intervals calculated from standard variance estimators rely upon asymptotic normality and often require the sample size to be large depending on the variability of the data. The catch and effort data exhibited many zero values, resulting in low catch rates. Total catch estimates from the product of bootstrap catch rate and effort produced relatively symmetric confidence intervals. The distributions of bootstrap means were approximately normally distributed (the central limit theorem states that the sum of $n$ independent and identically distributed random variables is approximately normally distributed for large $n$ (Montgomery 1997)).

The Burnett River, Maroochy River and Pumicestone Passage estuaries have high human population levels in their immediate vicinities. The size and shape of each estuary influenced the estimated level of boat and shore fishing effort. The Pumicestone Passage, which was the largest estuary of the three and closest to the city of Brisbane, had higher numbers of fishing boats than the Burnett and Maroochy Rivers. In contrast, the smallest estuary, the Maroochy River, had the highest density of boats. The average fish size for yellowfin bream and dusky flathead was smallest in the Maroochy River. This smaller fish size may reflect the higher density of fishing effort. However, West and Gordon (1994) found no such pattern in the New South Wales estuaries of the Clarence and Richmond Rivers. In their study, larger fish size was associated with higher density of fishing effort, measured in angler hours, for yellowfin bream, dusky flathead and sand whiting.
At present, management of the recreational fish catches of yellowfin bream, dusky flathead and summer whiting in Queensland is by way of minimum legal size limits and some small spatial closures. Should the number of people participating in recreational fishing increase, the significance of this fishing sector’s catch may have to be addressed directly to reduce the risk of overfishing. A number of management options have been discussed in the past for recreational fishing. These include licence fees, fishing gear restrictions, bag limits, and closed seasons and areas (Lal et al. 1992). The results of this work indicate that bag limit restrictions might do little to reduce the overall total catch, given the large proportion of small or zero catches. However, the high number of boats fishing during the winter months in specific areas on the Burnett River, Maroochy River and Pumicestone Passage could be addressed. Some clustering of fishing effort would be common in many estuaries of south east Queensland. This pattern in boat fishing effort could be altered to control where people can fish through possible closed areas and seasons. Restricting boat-fishing effort from such areas for a period of time could provide a useful tool to manage angler effort if needed. However, closed areas would only be beneficial if fishing was displaced from areas of high catch rates causing less fish to be caught (Horwood et al., 1998). To achieve this, closed areas may have to be enforced in a number of estuaries. However, the effects on stock size of such closures would have to be investigated through fishery yield models such as those described by Attwood and Bennett (1995) and Horwood et al. (1998). The economic and social effects of such closures would also have to be recognised.
Chapter 6. CONCLUDING DISCUSSION

6.1 GENERAL AIMS OF THE THESIS

This study had the broad aims of investigating better techniques for analysing recreational fish catches and determining the level of recreational catch, and fishing effort directed at the key fish species yellowfin bream, dusky flathead and summer whiting. In Australia, especially Queensland, there is an obligation for government to conduct ongoing monitoring of the magnitude of recreational fishing to ensure sustainable use of the target fish species. The Department of Primary Industries, Queensland has funded the ongoing collection of diary logbooks of recreational fish catches from throughout the state. However, despite the obvious importance of collecting such data to monitor fishery resources, little is published on the appropriate techniques for analysing recreational fishing data. The methods used in this work can be incorporated into assessments of recreational fisheries, as well as any species abundance data collected that exhibit extra zero values.

6.2 REGRESSION MODELS FOR ANALYSING RECREATIONAL FISH CATCHES

Through the investigation of a number of regression models in Chapter 2, a general framework was developed for the two-stage analysis of recreational fish data that contain many zero catches. In particular, the second stage of the analysis provided a technique that allowed for over-dispersion relative to the truncated Poisson distribution. These second stage truncated regression models were applied to the non-
zero fish catches allowing for a range of dispersion properties. The models also allowed for various factor and covariate effects to be parameterised using a log linear function. The computation for the truncated Poisson and truncated negative binomial models was relatively straightforward and easily applied through the non-linear procedure in the statistical package Genstat. However, the computations required for the extended Poisson process models were more intensive due to the requirement of calculating matrix exponentials for Markov chain probabilities. These calculations were done using MATLAB software, as the ability to program these routines (ie calculate matrix exponentials) within Genstat via linking C++ or Fortran code was not possible. These extended Poisson process calculations have been programmed in S-plus (Podlich 1999). However, the ability to program them into a variety of statistical software is needed if they are to be used widely by statisticians, ecologists and biologists.

Chapter 3 outlined the methods required to compute the model goodness of fit, predicted mean catches and to conduct hypothesis testing. A number of statistics were suggested for determining the goodness of fit of a regression model. However, interpretation of the deviance and generalised Pearson $\chi^2$ statistics can be problematic due to the extra parameters required in the truncated negative binomial and extended Poisson Process models. The log-likelihood statistic provided the most reliable means of comparing different model fits to the data, enabling a range of models to be compared. The extended Poisson process models had the advantage that different model types can be compared easily within the one program by altering only certain parameters. An additional benefit of using the extended Poisson process model was
that it should provide more reliable standard errors for the parameter estimates given the model's extra parameter to control residual dispersion.

Derivatives of the means were provided in order to calculate the standard errors of estimated average catches via the "delta-technique". In this thesis prediction of average catches was only considered for the non-zero data. However, this technique could be applied to combine the probabilities of catching fish from the logistic regression and mean catches from the truncated regressions. Calculations of the derivatives for this technique however are cumbersome, but would be needed to provide estimates of the variances of mean catches. This leaves further work to be done.

### 6.3 Recreational Harvest of Fish

Knowledge of commercial and recreational catches is essential to fisheries stock assessment and for effective fisheries management. Despite this fact, the level of recreational catch in Queensland is not known with any certainty because of the difficulties in estimating catch for the state as a whole. Consequently, it is largely unknown if the level of fishing effort exerted on yellowfin bream, dusky flathead and summer whiting will cause recruitment overfishing (where the level of breeding stock cannot produce sufficient replacements to maintain the total population at an acceptable level). To date, management has not introduced any precautionary measures to limit or control the level of recreational fishing effort in Queensland. This thesis has now provided estimates, with confidence intervals, of the total recreational catch taken from three estuaries in southern Queensland (Chapter 5). If data collection
were to be continued, stock assessments could be conducted in each of these estuaries to provide more precise information for management than is currently available.

Some aspects of this study such as the effect of factors on the recreational catch and the suggested appropriate measures of fishing effort (Chapter 4) are likely to be applicable to other recreational fishery studies. The results here can be used as a guide for appropriate strata, and details to collect in future surveys. Application of the two-stage regression models to predict average fish catches may provide a more precise approach to estimate total catch than use of the raw means and variance. Further development from here could consider incorporating the logistic and truncated regression models and their residuals into a bootstrapping routine.
Chapter 7. Bibliography


Dredge, M., 1983. A study of the beam trawl fishery and its impact on other fisheries in the Bundaberg region. Fisheries Research Branch, Department of Primary Industries, Burnett Heads, Report to the Queensland Fish Management Authority.


Chapter 8.  APPENDICES

8.1  RECREATIONAL FISHING CATCH AND EFFORT ESTIMATES
Figure 8.1 Spatial distribution of average boat and shore fishing effort in the Burnett River.
Figure 8.2 Spatial distribution of average boat and shore fishing effort in the Maroochy River.
Figure 8.3 Spatial distribution of average boat and shore fishing effort in the Pumicestone Passage.
Table 8.1 Recreational harvest estimate (number of fish) of all fish caught in the Burnett River, Maroochy River and Pumicestone Passage (95% bootstrap confidence interval shown in parentheses).

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Burnett River</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harvest (numbers)</td>
<td>-</td>
<td>11492</td>
<td>10351</td>
<td>36029</td>
<td>39752</td>
</tr>
<tr>
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<td></td>
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<td>(7876-13152)</td>
<td>(26026-48479)</td>
<td>(27345-58359)</td>
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<td>-</td>
<td>34415</td>
<td>35005</td>
<td>91600</td>
<td>60765</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(24395-47680)</td>
<td>(27546-43313)</td>
<td>(71605-114269)</td>
<td>(49623-72957)</td>
</tr>
<tr>
<td>Ratio (released:kept fish)</td>
<td>-</td>
<td>3</td>
<td>3</td>
<td>2.5</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Maroochy River</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Harvest (numbers)</td>
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<td>55481</td>
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<tr>
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<td>(15169-28907)</td>
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<td>(58549-90921)</td>
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</tr>
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<td>Ratio (released:kept fish)</td>
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<td>3.5</td>
<td>3.6</td>
<td>3.4</td>
<td>1.8</td>
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<td></td>
<td></td>
</tr>
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<td>Harvest (numbers)</td>
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<td>47061</td>
<td>26820</td>
<td>42337</td>
<td>92823</td>
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<td>(38704-87601)</td>
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<tr>
<td>Ratio (released:kept fish)</td>
<td>1</td>
<td>0.9</td>
<td>1.5</td>
<td>1.5</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Table 8.2 Recreational harvest estimate of yellowfin bream caught in the Burnett River, Maroochy River and Pumicestone Passage (95% bootstrap confidence interval shown in parentheses).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Burnett River</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harvest (kgs)</td>
<td>-</td>
<td>506</td>
<td>674</td>
<td>544</td>
<td>3753</td>
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<tr>
<td></td>
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<td>(249-838)</td>
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<td>Harvest (numbers)</td>
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<td>1472</td>
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<td>1581</td>
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<td>(900-3358)</td>
<td>(638-2960)</td>
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<td>3.3</td>
<td>2.5</td>
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<td><strong>Maroochy River</strong></td>
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<td></td>
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<td></td>
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<tr>
<td>Harvest (kgs)</td>
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<td>1128</td>
<td>651</td>
<td>1355</td>
<td>9814</td>
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<td>(32931-48736)</td>
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<td>6.7</td>
<td>8.6</td>
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<td>2</td>
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<td><strong>Pumicestone Passage</strong></td>
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<tr>
<td>Harvest (kgs)</td>
<td>13819</td>
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<td>3.1</td>
<td>2.4</td>
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### Table 8.3 Recreational harvest estimate of dusky flathead caught in the Burnett River, Maroochy River and Pumicestone Passage (95% bootstrap confidence interval shown in parentheses).

<table>
<thead>
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</tr>
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<td>Harvest (kgs)</td>
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<td>297</td>
<td>693</td>
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<td>(101-555)</td>
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<td>(741-1919)</td>
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<td>(175-965)</td>
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<td>(547-2147)</td>
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### Table 8.4 Recreational harvest estimate of summer whiting caught in the Burnett River, Maroochy River and Pumicestone Passage (95% bootstrap confidence interval shown in parentheses).

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*The released fish estimate includes all whiting species (Sillago analis, S. ciliata, S. maculata and S. sihama). The percent break-up of each whiting species caught is reported in chapter 5.
Table 8.5 Average recreational effort counts in the Burnett River (maximum observed number shown in parentheses).

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<th>Non Fishing Boats</th>
<th>Shore Anglers</th>
<th>Yabby Pumping</th>
<th>Cast Netting</th>
<th>Wind Boats</th>
<th>Jet Skis</th>
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Table 8.7 Average recreational effort counts in the Pumicestone Passage (maximum observed number shown in parentheses).

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<th>Yabby Pumping</th>
<th>Cast Netting</th>
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Table 8.8 Size and length/weight keys used in total harvest calculations.

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<th>Size Range TL (cm)</th>
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</thead>
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<tr>
<td>Yellowfin Bream</td>
<td><em>Acanthopagrus australis</em></td>
<td>1817</td>
<td>19-44</td>
<td>TL=0.4201+1.10874*FL</td>
<td>99.1</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“</td>
<td>“</td>
<td>TL=1.3466+1.22172*SL</td>
<td>98.2</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“</td>
<td>“</td>
<td>FL=0.8676+1.10034*SL</td>
<td>98.8</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td></td>
<td>219</td>
<td>22-37</td>
<td>WT=0.0277*TL^{2.8385}</td>
<td>91.0</td>
<td>Hoyle et al 2000</td>
</tr>
<tr>
<td>Dusky Flathead</td>
<td><em>Platyccephalus fuscus</em></td>
<td>233</td>
<td>22-84</td>
<td>TL=1.269+1.10245*SL</td>
<td>99.8</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td></td>
<td>202</td>
<td>30-75</td>
<td>WT=0.0041*TL^{3.1262}</td>
<td>98.0</td>
<td>Hoyle et al 2000</td>
</tr>
<tr>
<td>Sand Whiting</td>
<td><em>Sillago ciliata</em></td>
<td>2954</td>
<td>19-43</td>
<td>TL=0.0589+1.06502*FL</td>
<td>99.5</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“</td>
<td>“</td>
<td>TL=1.1269+1.14604*SL</td>
<td>98.9</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“</td>
<td>“</td>
<td>FL=1.0123+1.07569*SL</td>
<td>99.3</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td></td>
<td>160</td>
<td>22-42</td>
<td>WT=0.0093*TL^{2.976}</td>
<td>97.0</td>
<td>Hoyle et al 2000</td>
</tr>
</tbody>
</table>

TL – total length (cm); FL – fork length (cm); SL – standard length (cm); WT – weight (grams)
8.2 Programs for the Truncated Regression Models

The purpose of this appendix was to document the programs that have been developed for fitting the truncated Poisson, truncated Negative Binomial and Poisson Process regression models to non-zero counts. Genstat 5 Release 4.1 (1999) and Matlab 5.3 (1999) were used as the programming interface. The programs outlined were for the log-linear function used for the analysis in chapter 4.

8.2.1 Truncated Poisson

(Genstat – fitnonlinear procedure)

"This model fits the Truncated Poisson for the platform.fishers and platform.lines effect"

"First fit a standard Poisson model to save the design matrix X"

MODEL [DISTRIBUTION=poisson; LINK=logarithm; DISPERSION=.*;] catch
FIT [PRINT=model,summary,estimates; CONSTANT=estimate; FPROM=yes; TPRB=yes;
FACT=9] area+season+daytype+platform+hours+fishers.platform+lines.platform
rkeep designmatrix=m
rkeep df=df

"Second separate the design matrix X into column variates"
"Note the factor effects of Pumicestone Passage, Autumn 1998 were set to zero"
"fb=boat fishers, fs=shore fishers, lb= boat lines, ls=shore lines"

calculate c=ncolumns(m)
calculate r=nrows(m)
variate [nvalues=r] const,mar,bur,spr97,sum98,win97,win98,day,plat,hour,fb,fs,lb,ls
calculate const,mar,bur,spr97,sum98,win97,win98,day,plat,hour,fb,fs,lb,ls=m[*;l,2,3,4,5,6,7,8,9,10,11,12,13,14]

"Third fit the Truncated Poisson code"
"e1 was the log-linear function"
"e2 was the log-likelihood function"
"e3 was the deviance function"
"e4 was the saturated log-likelihood function"
"a was the value to calculate the observed catches exactly under the saturated log-likelihood"
"logfact was the natural log of the factorial of catch"

expression e1; value=\le(pred=exp(const*constant+mar*maroochy+bur*burnett+\spr97*spring97+sum98*summer98+win97*winter97+win98*winter98+day*dayt+\plat*platf+hour*time+fb*fishboat+fs*fishshor+lb*lineboat+ls*lineshor))
expression e2; value=le(ll=-sum(-pred+catch*log(pred)-log(l-exp(-pred))-logfact))
expression e3; value=le(dev=-sum(2*((-pred+(catch*log(pred))-log(1-exp(-pred)))-\(a+(catch*log(a))-log(1-exp(-a))))))
expression e4; value=le(satll=-sum(-a+(catch*log(a))-log(1-exp(-a))-logfact))
model[function=dev]; fitted=pred
rcycle constant,maroochy,burnett,spring97,summer98,winter97,winter98,day,platf,time,\fishboat,fishshor,lineboat,lineshor; initial=0.02,-0.1,0.2,0.1,-0.06,-0.1,0.0,-0.3,0.2,0,0.0,0;
fitnonlinear[print=monitoring,model,deviance,summary,estimates,correlations;\calculation=e1,e2,e3,e4]
rkeep se=se
rkeep estimates=est
rkeep inverse=covm "covariance matrix"

"Calculate model statistics"
calculate adjses = se * sqrt(dev / df)
calculate ttest = est / se "or use the adjusted se"
print ll, dev, satll, df
print est, se, adjses, ttest

8.2.2 Truncated Negative Binomial

This model fits the Truncated Negative Binomial for the platform.fishers and platform.lines effect

"First fit a standard Negative Binomial model to save the design matrix X"

MODEL [DISTRIBUTION=negativebinomial; LINK=logarithm; DISPERSION=*; AGGREGATION=1] catch
FIT [PRINT=model, summary, estimates; CONSTANT=estimate; FPROB=yes; TPROB=yes; FACT=9]
area+season+daytype+platform+hours+fishers.platform+lines.platform
rkeep designmatrix=m
rkeep df=df

"Second separate the design matrix X into column variates"
"Note the factor effects of Pumicestone Passage, Autumn 1998 were set to zero"
"fb=boat fishers, fs=shore fishers, lb= boat lines, ls=shore lines"
calculate c = ncolumns(m)
calculate r = nrows(m)
variate [nvalues=r] const, mar, bur, spr97, sum98, win97, win98, day, plat, hour, fb, fs, lb, ls
calculate const, mar, bur, spr97, sum98, win97, win98, day, plat, hour, fb, fs, lb, ls = m[*; l, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14]
pi = 3.141592654

"Third fit the Truncated Negative Binomial code"
"e1 was the log-linear function"
"e2 and e3 were log-gamma functions for the log-likelihood"
"e4 was the saturated log-likelihood function"
expression e1;  value=\[pred=exp(const*constant+mar*maroochy+bur*burnett+\spr97*spring97+sum98*summer98+win97*winter97+win98*winter98+day*dayt+\plat*plat+hour*time+fb*fishboat+fs*fishshor+lb*lineboat+ls*lineshor))
expression e2;  value=\[lgmxt=-((catch+(l/k))-((catch-i-(l/k))-0.5)*log(catch-i-(l/k))-log((2*3.141592654)**0.5)-log(l+(l/(12*(l/k)))-l-(l/(288*((l/k)**2)))-(l/(51840*((l/k)**3)))-(l/(2488320*((l/k)**4)))))
expression e3;  value=\[lgt=-((k*pred)-logfact-log(1-(1+(k*pred)))-\[catch+(1/k)*log(1+(1*(k*pred))-logfact-log(1-(1+(k*pred)))-\[catch+(1/k)*log(1+(1*(k*pred)))-logfact-log(1-(1+(k*pred)))-\[catch+(1/k)*log(1+(1*(k*pred)))-logfact-log(1-(1+(k*pred)))-\[catch+(1/k)*log(1+(1*(k*pred)))-logfact-log(1-(1+(k*pred)))-\[catch+(1/k)*log(1+(1*(k*pred)))-logfact-log(1-(1+(k*pred)))]
expression e4;  value=\[lgmxt=-((catch+(1/k)))+(catch+(1/k)*k))\]
expression e4;  value=\[lgmxt=-((catch+(1/k)))+(catch+(1/k)*k))\]
model[function=ll];  fitted=pred
rcycle constant, maroochy, burnett, spring97, summer98, winter97, winter98, day, plat, time, 
fishboat, fishshor, lineboat, lineshor;  initial=0.1, 0.1, 0.2, 0.1, -0.6, -0.1, -0.3, 0.2, 0.0, 0.0, 0.5;
fitnonlinear[print=monitoring, model, deviance, summary, estimates, correlations;] 
calculation=e1, e2, e3, e4]
rkeep se=senb
rkeep estimates=estnb
rkeep inverse=covm "covariance matrix"

"Calculate model statistics"
calculate t=estnb / senb
print ll/2
print estnb, senb, t
8.2.3 Extended Poisson Process model 1

(Matlab function – loglikelihood=fmins('fit',param))

%"This model fits the Poisson Process regression for the platform.fishers and platform.lines effect"
%"This model used the first $\lambda_n$ form for variation of in-between truncated Poisson and truncated negative $\beta$-binomial (chapter 2, equation 2.13)"
%"The "fmins" command was used for the minimisation and required the input of the function name %"fit" for the program below and a vector "param" of initial parameter values"

function f=ll(param)
global SEASON AREA PLATFORM FISHERS HOURS LINES DAYTYPE CATCH res
f=0.0; g=0.0; res=[]; prob=[];
for i=1:length(CATCH)
    % "The if statements identify factor levels in the log-linear equation"
    if AREA(i)==1
        areaeffect=0.0;
    elseif AREA(i)==2
        areaeffect=param(2);
    else
        areaeffect=param(3);
    end
    if SEASON(i)==1
        seasoneffect=0.0;
    elseif SEASON(i)==2
        seasoneffect=param(4);
    elseif SEASON(i)==3
        seasoneffect=param(5);
    elseif SEASON(i)==4
        seasoneffect=param(6);
    else
        seasoneffect=param(7);
    end
    if PLATFORM(i)==0
        boatfishers(i)=FISHERS(i);
        boatlines(i)=LINES(i);
    else
        boatfishers(i)=0;
        boatlines(i)=0;
    end
    % $\mu$ was the log-linear equation
    mu=exp(param(1)+areaeffect+seasoneffect+param(8)*DAYTYPE(i)+param(9)*PLATFORM(i)+param(10)*HOURS(i)+param(11)*boatfishers(i)+param(12)*PLATFORM(i)*FISHERS(i)+param(13)*boatlines(i)+param(14)*PLATFORM(i)*LINES(i));
    b=exp(param(15));
    c=param(16);
    a=log(1+mu/b);
    n=[0:CATCH(i)];
    q=-a*(n+b).^c;
    q1=q(1:length(q)-1);
    if n==[0]
        Q=diag(q);
    else
        Q=diag(q)+diag(q1,1);
    end
    p=[1 zeros(1,length(n)-1)];
    pp=p*expm(Q);
    f=f-log(pp(CATCH(i)+1)/(1-pp(1)));
    prob=[prob pp(CATCH(i)+1)/(1-pp(1))];
end
f
8.2.4 Extended Poisson Process model 2

(Matlab function - loglikelihood=fmins('fit',param))

%"This model fits the Poisson Process regression for the platform.fishers and platform.lines effect"
%"This model used the second \( \lambda_n \) form for variation in excess of truncated negative %binomial (chapter 2, equation 2.14)"
%"The "fmins" command was used for the minimisation and required the input of the function name %"fit" for the program below and a vector "param" of initial parameter values"

function f=ll(param)
    global SEASON AREA PLATFORM FISHERS HOURS LINES DAYTYPE CATCH res
    f=0.0; g=0.0; res=[]; prob=[];
    for i=1:length(CATCH)
        if AREA(i)==1
            areaeffect=0.0;
        elseif AREA(i)==2
            areaeffect=param(2);
        else
            areaeffect=param(3);
        end
        if SEASON(i)==4
            seaseffect=0.0;
        elseif SEASON(i)==1
            seaseffect=param(4);
        elseif SEASON(i)==2
            seaseffect=param(5);
        elseif SEASON(i)==3
            seaseffect=param(6);
        else
            seaseffect=param(7);
        end
        if PLATFORM(i)==0
            boatfishers(i)=FISHERS(i);
            boatlines(i)=LINES(i);
        else
            boatfishers(i)=0;
            boatlines(i)=0;
        end
        mu=exp(param(1)-i-areaeffect-i-seaseffect-param(8)*DAYTYPE(i)-i-param(9)*PLATFORM(i)-i-param(10)*HOURS(i)+param(11)*boatfishers(i)-i-param(12)*PLATFORM(i)*FISHERS(i)-i-param(13)*boatlines(i)-i-param(14)*PLATFORM(i)*LINES(i));
        b=param(15);d=exp(param(16));c=param(17);
        a=log(1-hmu/b);
        n=[0:CATCH(i)];
        q=-max(a*(n-b+(c./(d-t-n))),10^-6);
        q1=-q(1:length(q)-1);
        if n==[0]
            Q=diag(q);
        else
            Q=diag(q)+diag(q1,1);
        end
        p=[1 zeros(1,length(n)-1)];
        pp=p*expm(Q);
        f=f-log(pp(CATCH(i)+1)/(1-pp(1)));
        prob=[prob pp(CATCH(i)+1)/(1-pp(1))];
    end
    f
    return
end
8.2.5 Extended Poisson Process Model - Standard Errors

(Matlab function)

%"This matlab function computes the matrix of first and second derivatives for the the Poisson Process
% regressions"
%"The matlab function requires the input of the solved "param" vector for the regression model"

%"The matlab function "deriv2'' is run and links to the function "deriv1''"
%deriv2
param=input('vector of estimates ?')
parinc=0.001*param;DD=[];
for jj=1:length(param)
    param(jj)=param(jj)+parinc(jj);
    deriv1;dd1=d
    param(jj)=param(jj)-2*parinc(jj);
    deriv1;dd2=d
    dd=(dd1-dd2)/2/parinc(jj);DD=[DD;dd]
    param(jj)=param(jj)-i-parinc(jj)
end
%deriv2
ff1=[];ff2=[]
for ii=1:length(param)
    param(ii)=param(ii)+parinc(ii);
    ff1=[ff1 f];
    param(ii)=param(ii)-2*parinc(ii);
    ff2=[ff2 f];
    param(ii)=param(ii)+parinc(ii);
end
d=(ff1-ff2)/2./parinc;d0=d;
8.2.6 Extended Poisson Process Model – Saturated log-likelihood calculation

(Matlab function)

"Note that the two different \( \lambda_n \) forms can be exchanged within these Matlab functions"

"Matlab function "satll" for solving the mean catch equal to the observed catch for the saturated LL"

function f=ll(param)
% use maximum likelihood estimates for b, c, and d
b=exp(0.069); c=0.672; mu=param(1); d=exp(-2.801);
a=log(1+mu/b);
n=[0:num];
% num here is a suitably large value, eg 250, required to predict the observed catch.
q=-a*(n-i-b).^c;
q2=(q(l:length(q)-l));
Q=diag(q)+diag(q1,1);
p=1 zeros(1,length(1)-1));
pp=p*expm(Q);
ppp=ppp(1:ppp(1));
ey=sum([1:ppp(2:2)])
f=(Y-ey).^2;

"Matlab function "loopsatll" for running the "satll" function above for a range of catch sizes"

global mean Y v f
v=
for Y=1:50
  mean=fmins('satll',param)
  Y,mean,f
v(Y,:)=mean;
end

"Matlab function "finalsatll" for computing the regression model saturated log-likelihood"

global CATCH Y b c ppp v
Y=CATCH;
% use maximum likelihood estimates for b, c, and d
b=0.019; c=0.121;
d=exp(-2.801);
for i=1:length(CATCH)
  mu=v(Y(i),2);
a=log(1+mu/b);
n=[0:Y(i)];
q=-a*(n+b).^c;
q2=(q(l:length(q)-l));
Q=diag(q)+diag(q1,1);
p=1 zeros(1:length(1)-1));
pp=p*expm(Q);
ppp(i)=ppp(1:ppp(1));
end
satll=sum(log(ppp))
**Extended Poisson Process Model – predicting mean catch**

(Matlab function – avgcatch=compute_means(param,CATCH))

%" This matlab function "compute_means" calculates the mean catch for a given list of variables"
%" The function requires the input of the solved "param" vector and the "CATCH" vector.
%" The function links to the meanfn matlab function"
function f=compute_means(param,y)
global mean var pearson res 
f=[];mean=[];var=[];
for i=1:length(y)
    cmean=meanfn(param,i);
    mean(i)=cmean(1);
    var(i)=cmean(2);
    f=[f;mean(i) var(i)];
end
pearson=sum((y'-mean).^2./var);
res=(y'-mean).^2./var;

%" This matlab function "meanfn" computes the predicted mean"

function f=meanfn(param,i)
global SEASON AREA PLATFORM RSHERS HOURS UNES DAYTYPE CATCH
if AREA(i)==1
    areaeffect=0.0;
elseif AREA(i)==2
    areaeffect=param(2);
else
    areaeffect=param(3);
end
if SEASON(i)==1
    seaseffect=0.0;
elseif SEASON(i)==2
    seaseffect=param(4);
elseif SEASON(i)==3
    seaseffect=param(5);
elseif SEASON(i)==4
    seaseffect=param(6);
else
    seaseffect=param(7);
end
if PLATFORM(i)==0
    boatfishers(i)=FISHERS(i);
    boatlines(i)=LINES(i);
else
    boatfishers(i)=0;
    boatlines(i)=0;
end
mu=exp(param(1)+areaeffect+seaseffect+param(8)*DAYTYPE(i)+param(9)*PLATFORM(i)+param(10)*HOURS(i)+param(11)*boatfishers(i)+param(12)*PLATFORM(i)*FISHERS(i)+param(13)*boatlines(i)+param(14)*PLATFORM(i)*LINES(i));
b=exp(param(15)); c=param(16);
a=log(1+mu/b);
% num here is a suitably large value, eg 250, required to predict the mean catch.
q=-max(a*(n+b+c),10^-6);
q1=-q(1:length(q)-1);
Q=diag(q)+diag(q1,1);
p=[1 zeros(1,length(n)-1)];
pp=p*expm(Q);
ppp=pp(1-pp(1));
mean=sum(n.*ppp);
\textbf{8.2.8 Extended Poisson Process Model – predicting standard errors of mean catch}

(Matlab – ses=compute_ses(param,CATCH,info))

\texttt{var=\text{sum(n.^2.*ppp)}-\text{mean}^2;}
\texttt{f=[\text{mean var}];}

\% This matlab function \texttt{compute_ses} calculates the standard errors for the predicted mean catch for a given list of variables
\% The function requires the input of the solved \texttt{param} vector, the \texttt{CATCH} vector and the inverse of the second derivative matrix \texttt{info}
\% This matlab function \texttt{dervimean} calculates the first derivative for the predicted mean catch for a given list of variables

\texttt{function f=compute_ses(param,y,info)}
\texttt{for i=1:length(y)}
\texttt{\hspace{1cm}derivmu=dervimean(param,i);}
\texttt{\hspace{1cm}se(i)=sqrt(derivmu*info*derivmu');}
\texttt{end}
\texttt{f=se}

\texttt{function d=dervimean(param,i)}
\texttt{\hspace{1cm}ff1=[];ff2=[];}
\texttt{\hspace{1cm}parinc=param*0.0001;}
\texttt{\hspace{1cm}for ii=1:length(param)}
\texttt{\hspace{2cm}param(ii)=param(ii)+parinc(ii);}
\texttt{\hspace{2cm}meanvar=meanfn(param,i);}
\texttt{\hspace{2cm}ff1=[ff1 meanvar(1)];}
\texttt{\hspace{2cm}param(ii)=param(ii)-2*parinc(ii);}
\texttt{\hspace{2cm}meanvar=meanfn(param,i);}
\texttt{\hspace{2cm}ff2=[ff2 meanvar(1)];}
\texttt{\hspace{2cm}param(ii)=param(ii)+parinc(ii);}
\texttt{end}
\texttt{d=(ff1-ff2)/2./parinc;}

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