OPTIMIZATION OF TRAWLNET CODEND MESH SIZE TO ALLOW FOR MAXIMAL UNDERSIZED FISH RELEASE AND A MODEL CONSIDERATION OF TOWING TIME TO THE EFFECTS OF THE SELECTION CURVE

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Optimization of Trawlnet Codend Mesh Size to Allow for Maximal Undersized Fish Release and a Model Consideration of Towing Time to the Effects of the Selection Curve

by

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Abstract

This dissertation consists of two research topics related to the fishing industry.

First, the problem of comparing several gears occurs frequently in the fishing industry. There is a desire to determine whether the response to one or more experimental gear(s) differs from the response of a traditional gear, and, if so, to further identify which experimental gear(s) is better than the traditional gear and which is the best under certain criteria. In many fishing experiments, one often has prior knowledge that the experimental gears are at least as effective as the traditional gear, and their responses are monotonically increasing or decreasing. It is well known that utilization of this ordering information increases the efficiency of statistical inference procedures. The aim of the first part of this thesis is to give a useful statistical inference procedure for the problems met in the fishing industry by utilizing this prior information.

Secondly, we introduce the towing time concept into the framework of gear selectivity studies. In the past, scientists have generally not considered the effects of the towing time. It is only considered since prolonged towing time may destroy the fish. Hardly any research had been done on the effects of gear selectivity and total catch by varying the towing time. In this dissertation, a new model is proposed, with its corresponding selection curve, considering the effect of towing time. This new model also generates a Sigmoid-shaped

selection curve, which is different from the one generated by the traditional selection model. Based on this new model, some adjustments can be proposed in towing time, the fishing process, and gear design. These changes may be of benefit to both fishing industry and fishery management.

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Chapter 1

Introduction

Fishing communities across Canada gain social and economic value from using natural ocean resources. How to maintain those economic and social benefits while protecting and restoring environmental health is a key challenge for both Canadian citizens and the government. However, this equilibrium is not always in balance. In 1973, the major cod stocks, and in 1974, all of the cod stocks in the Northwest Atlantic were placed under quota regulation. The rapid decline in cod in the early 1990s led to a reduced Total Allowable Catch and eventually to a moratorium on commercial fishing in 1992 (CRIC Focus Vol.1, No.6). The solution, not just for cod, but groundfish, invertebrates, and all other species at risk of over-exploitation, is the widespread adoption of selective fishing techniques. To ensure a sustainable fishery, all fishing activities must be regulated to operate at the lowest level possible to minimize the negative impacts on fish populations and fish habitat. Trawl gear selectivity is the focus of this dissertation.

Selective fishing is defined as the ability to avoid non-target fish, invertebrates, seabirds, and marine mammals or, if encountered, to release them alive and unharmed (Fisheries and Oceans Canada 2001). Research in fishing gear selectivity is a very important area for fisheries management. For commercial fishing activity carried out at sea, fishing gear should be designed to allow undersized fish to escape and large fish to be retained. Improving fishing selectivity may require modifications to existing gear and fishing methods. In this dissertation, the target species to be studied will be assumed as cod fish which is one of the major fishing resources in the province of Newfoundland and Labrador. For simplicity, we will not consider factors such as by-catch. To allow for the release of more undersized fish is the goal of this research.

One of the most widely used mobile gear is trawl, which consists of a conical-shaped net towed behind a vessel at a speed typically similar to walking pace (Millar, 1992). A typical trawl gear is shown in Figure 1.1. The forward part of the trawl consists "wings", followed by the upper and lower "bellies", and the end part is called the codend component. In a typical fishing process, the trawl is towed and fish are herded into the trawl by the trawl boards and bridles. Once exposed to the gear, most fish will be herded into the codend component.

There are many factors which may affect the selectivity of trawls. Mesh size and mesh shape in different gear components such as codend and forepart (composed of wings and bellies) are considered to be the main factors. Other factors, such as towing time environmental conditions, fishing area, harvest season and trawling method may also influence gear performance in commercial fishing (Fisheries and Oceans Canada 2001). This dissertation will focus on two main factors: mesh size of the codend component and the *towing time* (defined in Chapter 2). Interested readers are referred to our list of references for more comprehensive studies and reviews in this research area.

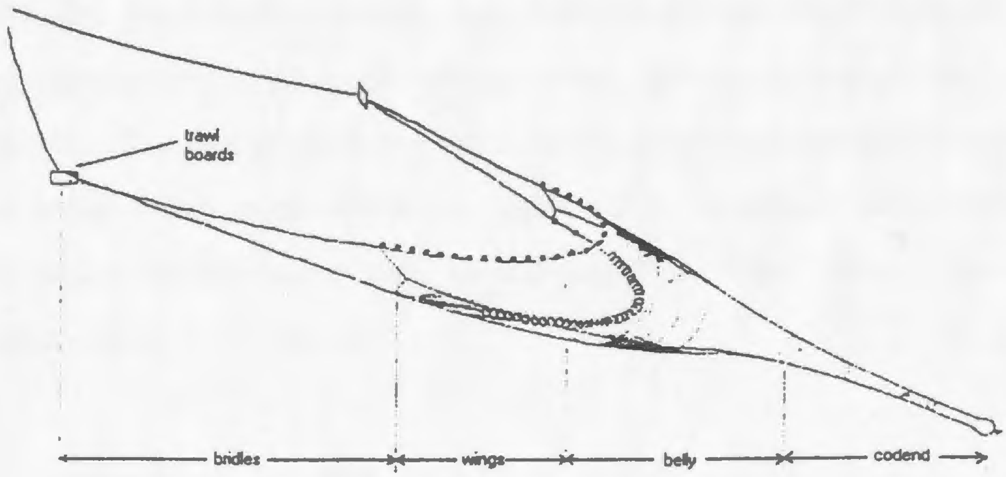

Figure 1.1: A Trawl Gear (Simplified)

The mesh size is defined as the distance between opposite corners of the mesh when it is fully stretched. Usually, for the same mesh shape, the larger the codend mesh size, the higher the probability of undersized fish escaping through the codend component of the gear (MacLennon, 1992). The problem of comparing more than two gears of different mesh size in the codend component occurs frequently in fisheries research. It is observed that increasing mesh size can release more undersized fish, while total fish production will be reduced. In practice, however, it is impossible to obtain maximum production while releasing most of the undersized fish. Therefore, a method to find the "ideal" codend mesh size, which can allows relatively high production while releasing most of the undersized fish, is extremely important for the fishing industry.

Traditionally, towing time is not of interest to either commercial fishing practices or fisheries research. Nonetheless, it should not be neglected, not only because prolonged towing time destroys the fish by splitting, tearing, etc., but also it alters the retention rate of the undersized fish. Prolonging the towing time gives the fish more time to escape from the codend of the trawl. Conversely, if the gear stays in the water for too long until nearly all the mesh in the codend component is blocked, there will be no chance for undersized fish to escape. In this dissertation, we will study the "ideal" towing time and suggest a means to identify it.

1.1 Literature Review

Enlarge the codend mesh size can increase the probability of undersized fish escaping through the gear (MacLennon, 1992). Comparing the selectivity of two gears, one is the traditional gear, one is a gear enlarged mesh size in codend component, is the one currently in use: (Livadas, 1969), (Koura, 1988), (Millar, 1992), (Suronen, 1992). This kind of comparison is not a problem for the researchers. The problem is that increasing mesh size can release more undersized fish, while reducing marketable product. To achieve both goals at the same time is not easy. Therefore, trawling several gears with different codend mesh sizes, and comparing them with the traditional gear, as well as the method to find the gear with the "ideal" mesh size of codend from more than one experimental gears, is extremely important for the fishing industry.

The selectivity curve is widely used to describe the capability of a gear to catch or release fish. It is shown in Figure 1.2. The selectivity curves produced by most mobile gears are S-shaped (Millar 1992). This is because small fish can escape through the gear while large fish cannot. As fish size increases, escape from the codend becomes more difficult. Very large and very small fish will be caught with a probability approximated to 1 and 0, respectively. When analyzing selectivity data, a researcher would mostly choose between one of the two variants of sigmoid curve to serve as a model: the logistic curve or Richard's curve. The general equation and parameters for Richard's curve are:

$$Prob.(Length) = \left(\frac{1}{1 + e^{-a-b \times length}} \right)^{1/s}$$

where a, b and s are the parameters. The logistic curve is a special case of a Richard's curve with $s = 1$. These parameters will only depend on the gear itself. When a gear is chosen, the selection curve will not change for the same species of fish. However, this dissertation shows that the towing time is one of the factors that may change the selection curve for the same gear. This consideration was neglected in the past.

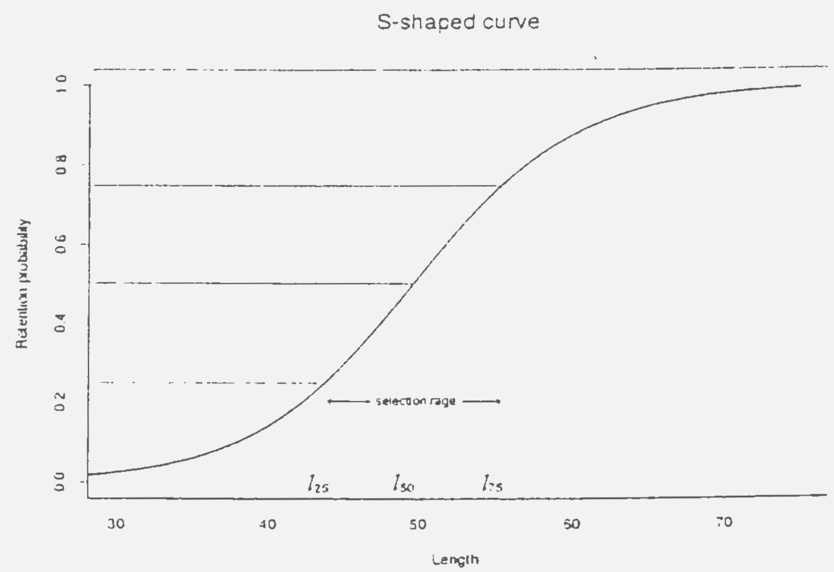

Figure 1.2: Sigmoid-shaped Selection Curve

1.2 Proposed Objectives

This dissertation has two objectives:

(1) To determine the "ideal" gear among several experimental gears.

Usually, we can have several experimental gears being studied with different codend mesh sizes (130mm, 145mm, 150mm, etc.). A gear with large codend mesh size will release more undersized fish. As a result, it will also reduce the commercial product of each haul. There are two main effects of altering codend mesh sizes that are of concern to researchers:

i). Increasing the mesh size will decrease the undersized fish retention rate, and the gear attempts to allow more undersized fish herded in the codend to escape.

ii). Increasing the mesh size will also decrease the total catch, which will considerably reduce the profit,which fishing companies may oppose.

To develop a sensible procedure, based on valid commercial fishing data, and sound statistical science, so that, among a group of experimental gears with a increasing codend mesh size, a fishing gear can be identified with a certain mesh size which will allow the undersized fish to escape at acceptable rate, and at the same time, to retain reasonable production. This gear is referred to as "best" or "ideal". This dissertation will attempt to utilize a procedure introduced in a Ph.D dissertation by Peng (2002) to establish a procedure to single out the "ideal" one among several experimental gears.

(2) To propose a model relating towing time to the effects of the selection curve.

Currently, towing time is not of concern in commercial fishing practices and fisheries research. Among existing selectivity studies, all experiments are conducted with almost no consideration of towing time. As a direct consequence, all selection curves are estimated with no consideration of the effect of towing time. In the literature, towing time is involved in a discussion only when large amounts of fish are destroyed in the gear.

By contraries, of interest to this field of fisheries research, we found that varying towing time can greatly affect the form of selection curve estimated. Intuitively, if we have a longer towing time, when a fish swims into the codend component, it has more time (and more chances) to escape, regardless the size of the fish. For example: if towing time is only 1 hour, a fish comes into the gear at the middle of the trail. Therefore, it only has half an hour to escape. If towing time is for 2 hours, the fish has 1 hour to escape, if it comes into the gear mid-way through the tow. Therefore, the fish with a towing time of 2 hours will have more time and more chances to escape, on average. Considering the *basic retention probability* (defined in Chapter 2) which is dependent on the fish length, the retention probability for different sizes of fish will be no longer a Richard's curve. The selection curve should be a function of towing time. Under this consideration, the longer towing time, the more chance a fish has to escape.

If the towing time affects the selection curve only in the way described, a longer towing time will significantly decrease fish retention rate, and it would seem that it is simple to determine the effect of towing time. However, this is a more complicated scenario than at first it may seem. Generally, with a longer a towing time, more fish will enter the gear, and more fish we will be in the codend component. Therefore, we will have a heavy crowd in the codend component, some fish will block the mesh. This crowding and blocking prevents fish from escaping.

Thus, the second objective of this dissertation includes building a new model, finding a reasonable towing time and illustrating how much difference the new model may make by comparing it with the traditional model.

1.3 Qualitative Overview of Results and Recommendations

The primary results are separated into two parts:

(1) Determining the "ideal" gear among several experimental gears.

Fishing selectivity should be optimized for the maximum of release undersized fish, while retaining commercial catch. In fishing studies, increasing the mesh size of the codend component is expected to release more undersized fish. The gear response, such as undersized fish retention probability, decreases monotonously for large codend mesh size gears. For this monotonous response, this dissertation gives a novel method to test whether there is indeed a experimental gear effect, compared with the traditional one. And furthermore, if at least one gear is found to be effective, a method is given to identify the smallest codend mesh size gear producing a desirable effect over that of the traditional. Two examples are given, one using the undersized fish retention rate as the response, and the other using l_{25} (defined in Chapter 2)as the response. To choose undersized fish retention probability as the response is based on its importance for gear selectivity. A reason to choose l_{25} as the main response is that l_{25} does not depend on the population, and it is more efficient than undersized fish retention probability. Both mean responses have their own advantages. Using the method shown in Chapter 3, we can find out the "ideal" gear, if it exists, directly from all the experimental gears, when a standard is given. For example, if we want to makes the undersized fish retention probability 0.5% smaller comparing to the traditional gear, using undersized fish retention rate as the response, we can find out the answer directly from a summery table (as in Table 3.4).

(2) Proposing a model relating towing time to the effects of the selection curve.

This dissertation proposes a new model which considers the towing time. In this model, the fish retention rate will be affected in the following ways by towing time:

i). the fish need time to escape. For example, if a fish meets the codend once every 10 minutes, and has a 50% probability to stay in the codend. If the fish stays in the gear for 20 minutes, it can meet the gear twice, and it will have a 50% × 50% = 25% probability to be trapped. This is equivalent to tossing a coin every 10 minutes until a "head" is obtained.

ii). the more crowded in the codend component, the harder it is for a fish to meet the gear, and thus harder for it to escape. After a certain period of time, the codend part will accumulate fish, and fish will have difficulty contacting the mesh and escaping. This is equivalent to an hourglass, where sand is funnelled though a narrow hole, which takes a definite amount of time.

iii). when fishing, some fish and other objects (like seaweed) may block the mesh. Prolonging the towing time will increase blocking, which makes it harder for the fish to escape. This is equivalent to standing in line at a supermarket, with 10 counters of 15 open to serve many people, where one must wait his/her turn to be served.

The above three assumptions show the differences caused by the towing time. A new S-Shape Selection Curve (no longer the Richard's Curve, nor even an expression function) is given under these assumptions. The new model clearly describes the effect of the towing time. Based on these assumptions and this model, we propose recommendations to help reduce the undersized fish retention rate:

1. Choose an ideal towing time;

2. Making modifications to the codend component design;

3. Prolonging the gathering time.

The towing time model provides a novel means to examine fishing research. The towing time should be of concern, not only because of fish behavior, but also for the fish product and the fish retention rate. Based on this towing time study, we propose changes to fishing behavior, and even changing the design of gear to release more undersized fish, while keeping the product yield high.

Chapter 2

Terms and Preliminaries

Some fishing selectivity terminology (Section 2.1), symbolic notations, definitions and assumptions (Section 2.2) are introduced in this Chapter. Some theoretical background (Section 2.3) for the development of the model designs is also provided.

2.1 Terms Used in Fishing Selectivity

The explanations of the following terms and definitions are taken from published materials and/or industry standards. The following definitions are useful for understanding model designs, adopted methods, and the analysis involved. More details are provided in the Methodology Manual (1995), Protocol for Conducting Selectivity Experiment with Trawls - Parallel Haul (1996) and Responsible Fisheries (1998).

Retention Probability: the probability that a fish, if contacting the gear component, will be retained. It is a function of fish length.

Selection Length or l_{50}: the fish length at which 50% of the fish of a given species exposed to a gear escapes and 50% is retained. It may be noted that this length is also the length at which the fish of the given species has a 50% probability of being caught by the gear or of escaping from the gear. l_{50} is a basic measure of the selectivity of a gear component.

l_{25}: the fish length at which 25% of the fish of a given species exposed to a gear is retained.

l_{75}: the fish length at which 75% of the fish of a given species exposed to a gear is retained.

Selection Factor: the ratio of l_{50} by the mesh size (the length of two sides of the mesh). Selection factor enables experimenters to compare the experimental results of gears of slightly different mesh sizes.

Selection Range: the difference in length between the fish that has a 75% probability of retention (l_{75}) and that with a 25% probability of retention (l_{25}) for a certain gear component. Selection range is a measure of sharpness of selection. A gear with a large selection range will retain some undersized fish and fail to catch some large fish.

Selection Curve: the graphical output of the retention probability for each length class of fish: the horizontal axis indicates fish length and the vertical axis indicates retention probability for a given length.

The most commonly used selection curves for mobile gears are sigmoid-shaped (S-shaped) curves. For the codend component of a trawl gear, the selection curve is usually found to be S-shaped, because undersized fish can escape through the gear while large fish cannot. The larger the length of a fish, the higher the probability it will be caught once it enters the codend component. With fixed mesh size, if a fish is longer than a certain length, it will be caught with an approximate probability of 1 once it enters the codend component. Very small fish will all escape (probability approximated to 0). Hence the codend component of trawl gears usually generates a sigmoid-shaped selection curve. Usually, a logistic curve is used to represent a symmetric curve derived from the data and the Richard's curve is used for asymmetric curves derived from the data. It seems that the logistic curve is the best fit when the data does not fit well with either symmetric or asymmetric curves (Methodology Manual, 1995). The general equation and mathematical parameters for the logistic curve are shown:

$$Prob.(Length) = \frac{1}{1 + e^{-a-b\times length}}$$

To make the connection between l_{50}, l_{25}, l_{75} and selection range, it can be shown that:

$$\begin{aligned} l_{50} &= -a/b \\ l_{25} &= (-ln(3) - a)/b \\ l_{75} &= (ln(3) - a)/b \\ S.R. &= (2 \times ln(3))b \end{aligned}$$

The general equation and mathematical parameters for the Richard's curve can be found in the Methodology Manual (1995).

After estimating the selection curve, we can easily locate the l_{50} and the selection range. The graphical output can be displayed as shown on Figure 1.2. A curve with larger l_{50} indicates a good selection, and releases more undersized fish. Note that the shorter the selection range, the steeper the selection curve. Hence, a codend with a large selection range will retain more undersized fish and fail to catch larger fish compared with a codend with the same l_{50} with a smaller selection range.

In Chapter 4, we will have a new S-sharped curve, which was developed from a logistic curve. This new curve is no longer a logistic curve, but looks similar.

Now, we will introduce some new definitions, which will be used in Chapter 4 to explain the model.

Fishing Time: the time that fish can enter. The fishing time begins at the time that the gear is shot into the water, because the gear immediately opens to catch fish. When we want to gather the gear at the end of trawl, the diameter of the gear opening will decrease, and only a few fish can come in. Thus, the fishing time ends after the fishers begin to gather the gear.

Gathering Time: the time period when no fish can enter the gear, but when fish can still escape. Gathering time begins shortly after beginning to gather the gear, when the opening of the gear decrease, and ends when the gear is completely out of the water.

Towing Time: generally refers to the whole fishing process. It refers to the time to shoot the gear, the time when beginning to gather the gear, and the time that the gear is out of the water. The towing time period includes fishing time and gathering time.

The relationship of towing time, fishing time and gathering time is shown in Figure 2.1.

Empty Gear: when the gear is not blocked, and no fish is in the codend component.

Basic Retention Probability: the probability that a fish, if contacting the gear component, will be retained after one hour in an empty gear. It is a function depending only on fish length.

Touch Probability: the probability that a fish will meet with the mesh

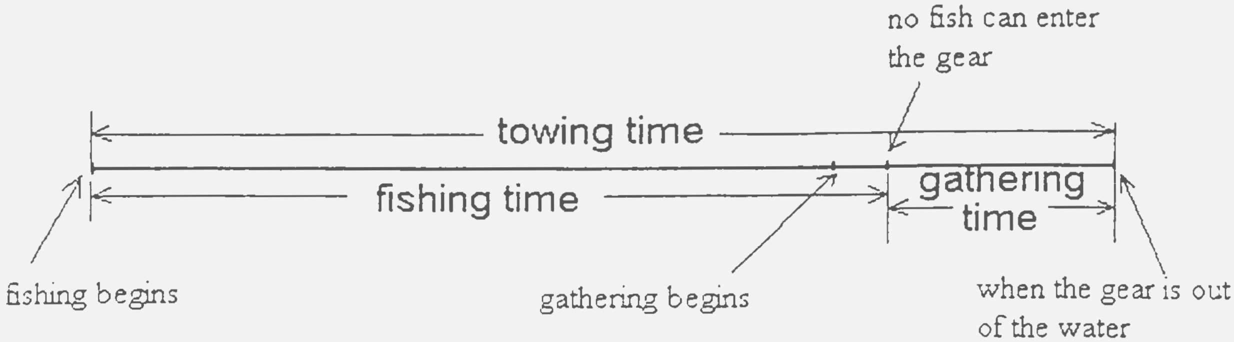

Figure 2.1: Relationship Between Fishing Time, Gathering Time and Towing Time

in the codend component. If there are many fish in the codend, not all the fish can meet with the mesh. We assume a fish can never escape, if it cannot meet with the mesh.

Block Probability: the percentage of mesh in the codend component blocked by the fish or seaweed etc. in the codend component. The fish cannot escape from the mesh that is blocked by fish.

Escape Rate: the fish releasing ability of a gear compared to the same gear when it is empty with neither crowded nor blocked.

2.2 Notations and Assumptions

Here, some notations and assumptions for the future use in this dissertation are introduced.

2.2.1 Notations and Abbreviations

Some notations and abbreviations are introduced in this section. The first set of terms is denoted for the Find The Best Mesh Size for Fish detailed in Chapter 3. And the remaining terms are used in Chapter 4.

Determining the "ideal" gear among several experimental gears:

$SECMSG$: the smallest effective codend mesh size gear, which is the gear among several experimental gears with the smallest codend component mesh size that gives a significantly better response, compared with the mean response of a standard gear.

r_{130mm} : the undersized fish retention probability of a 130mm diamond gear; and r_{135mm}, r_{140mm}, r_{145mm}, $r_{150mm}$for the 135mm, 140mm, 145mm, and 150mm diamond gears, respectively.

Y : the undersized fish retention probability;

C : the total product fish of all length caught by the control gear per hour;

E : the total product of all length fish caught by the experimental gear per hour;

Pc : the percentage of undersized fish caught by the control gear;

Pe : the percentage of undersized fish caught by the experimental gear;

r_1 : the undersized fish retention probability of the experimental gear;

r_0 : the large fish retention probability of the experimental gear;

p : the proportion that a fish enters the experimental compared with the control gear;

k : the total gears in the experimental group.

n_i : the total observations in ith group.

Subscript i**,** $i = 0..k$ is the ith experimental group. ($i = 0$ is the traditional or standard group.)

Subscript j is the jth observation in the ith group, $i = 1..n_i$.

Proposing a model relating towing time to the effects of the selection curve:

$\tau_1(t)$: the touch probability at time t;

$\tau_2(t)$: the block probability at time t;

$\tau(t)$: the escape rate at time t;

$\beta(l)$: the basic retention probability of a length l fish;

$r(l)$: the selection curve;

ft : the towing time;

b : the gathering time;

t_2 : the duration that the gear stays in ocean, $t_2 = ft + b$;

N_{ij} : the number of fish entering both (experimental and control) gears;

Y_{ij} : the number of fish caught by both (experimental and control) gears;

N_{ij+} : the number of fish entering experimental gear;

N_{ij-} : the number of fish entering control gear;

Y_{ij+} : the number of fish caught by experimental gear;

Y_{ij-} : the number of fish caught by control gear;

l_i : Partition the length scale into n length class with corresponding midpoints is as follows: l_i, $i = 1, 2, \ldots, n$.

Subscript i is the ith length class.

Subscript j is the jth trawl.

2.2.2 Assumptions

In this section, we shall introduce some necessary assumptions used in this dissertation.

Assumption 1: N_{ij+} and N_{ij-} are assumed to be a Poisson Process with parameters λ_{ij+} and λ_{ij-}, $(N_{ij+} \sim P(\lambda_{ij+}), N_{ij-} \sim P(\lambda_{ij-}))$ based on the following:

(a) when the experimental or control trawl is towed during the experiment, the probability of a length l_i fish coming in contact with the gear in any short time interval $[t, t + \Delta t]$ is approximately $\lambda_{ij+} \cdot \Delta t$ and $\lambda_{ij-} \cdot \Delta t$, which is approximately proportional to the length of the interval for all values of t;

(b) the probability of more than one length l_i fish coming in contact with the gear in interval $[t, t + \Delta t]$ is almost 0, when $\Delta t \to 0$;

(c) the number of length l_i fish coming in contact with the gear in any interval of time is independent of the number of length l_i fish coming in contact with the gear in any other non-overlapping interval of time.

Here, λ_{ij+}, λ_{ij-} are unknown constants for each $i, i = 1, 2, \cdots, n$. So N_{ij+}, N_{ij+} are identified as a Poisson Process (Hogg and Craig, 1995) and we can assume the total number of length l_i fish coming in contact with the experimental gear or control gear during this experiment N_{ij+}, N_{ij+} has a Poisson distribution with parameter λ_{ij+}, λ_{ij-}, respectively.

Assumption 2: It is assumed that no fish is able to escape the gear through the forepart component. That is, all fish enter the codend components, given that fish enter the gear.

Assumption 3: It is assumed that the small mesh size codend component (control codend component) retain all fish that enter it.

Assumption 4: It is assumed that the *Basic Retention Probability* is a logistic distribution with the independent l_i. That is

$$\beta(l_i) = \frac{exp(\alpha_1 + \alpha_2 l_i)}{1 + exp(\alpha_1 + \alpha_2 l_i)}.$$

Here, α_1, α_2 are parameters for the gear.

Assumption 5: The assumption for the twin trawl is: $N_{ij+} \sim P(\lambda_{ij})$ and $N_{ij-} \sim P(\lambda_{ij})$.

2.3 Theorems

The following theorems are relevant and assist the explanation of the models and analysis in this dissertation.

Definition 2.3.1 *(P.Bickel and A. Doksum, 1977, Page67) The family of distributions of a model $P_\theta : \theta \in \ominus$, is said to be a one parameter exponential family, if there exist real-valued functions $c(\theta)$, $d(\theta)$ on $\ominus$, real-valued functions T and S on R^n, and a set $A \subset R^n$ such that the density functions $p(x, \theta)$ of the P_θ may be written,*

$$p(x, \theta) = exp\{c(\theta)T(x) + d(\theta) + S(x)\}I_A(x)$$

where I_A is the indicator of the set A.

Lemma 2.3.2 *(Example(d), Page216, Feller 1968) Suppose that the number of trials is not fixed in advance but depends on the outcome of a chance experiment in such a way that the probability of having exactly N trials equals $e^{-\lambda}\lambda^n/n!$. In other words, the number of trials itself is now a random variable with the Poisson distribution $e^{-\lambda}\lambda^n/n!$. Given the number n of trials, the event $\{X_1 = k_1, X_2 = k_2, X_3 = k_3,\}$ has the (conditional) probability given by*

$$P(\{X_1 = k_1, X_2 = k_2, X_3 = k_3,\}) = \frac{n!p_1^{k_1}p_2^{k_2}p_3^{k_3}(1-p_1-p_2-p_3)^{n-k_1-k_2-k_3}}{k_1!k_2!k_3!(n-k_1-k_2-k_3)!},$$

here, k_1,k_2 and k_3 are non-negative integers such that $k_1+k_2+k_3 \leq n$. Then the three variables X_j are mutually independent, and each of them has a Poisson distribution.

The similar result can be obtained for binomial case which will be used frequently in this dissertation. That is

Theorem 2.3.3 *The number of trials N has Poisson distribution $e^{-\lambda}\lambda^n/n!$ with parameter λ. Given the number $N = n$ of trials, the conditional probability of X_1 is binomial with success probability p. That is, the conditional probability distribution of event $\{X_1 = k, X_2 = n-k | N = n\}$ is*

$$\frac{n!p^k(1-p)^{n-k}}{k!(n-k)!},$$

where, k is a non-negative integer such that $0 \leqslant k \leqslant n$. Then random variables X_1 and X_2 are all have Poisson distribution with parameters λp and $\lambda(1-p)$ respectively, and X_1 and X_2 are independent.

Proof.

N follows the Poisson distribution with parameter λ,

$$P(N = n) = e^{-\lambda}\lambda^n/n!.$$

Given $N = n$, the conditional probability distribution of $\{X_1 = k, X_2 = n-k\}$ is

$$P(X_1 = k, X_2 = n-k|N = n) = \frac{n!p^k(1-P)^{n-k}}{k!(n-k!)}.$$

The unconditional joint probability distribution of X_1, X_2 is

$$\begin{aligned}
P(X_1 = k, X_2 = n-k) &= P(X_1 = k, N = n) \\
&= P(X_1 = k, X_2 = n-k|N = n) \cdot P(N = n) \\
&= \frac{n!p^k(1-p)^{n-k}}{k!(n-k!)} \cdot \frac{e^{-\lambda}\lambda^n}{n!} \\
&= \frac{p^k(1-p)^{n-k}}{k!(n-k)!} \cdot e^{-\lambda}\lambda^n \\
&= \frac{(\lambda p)^k e^{-\lambda p}}{k!} \cdot \frac{(\lambda(1-p))^{n-k}e^{-\lambda(1-p)}}{(n-k)!}
\end{aligned}$$

From the equation above, $P(X_1 = k_1, X_2 = k_2) = f_1(X_1) \cdot f_2(X_2)$, we obtain that X_1 and X_2 are independent.

To find the marginal distribution of X_1, we sum the joint probability of $\{X_1 = k, N = n\}$ over all possible n, which is

$$\begin{aligned}
P(X_1 = k) &= \sum_{n=k}^{\infty} P(X_1 = k, N = n) \\
&= \sum_{n=k}^{\infty} \frac{p^k(1-p)^{n-k}}{k!(n-k)!} \cdot e^{-\lambda}\lambda^n \\
&= \frac{(\lambda p)^k e^{-\lambda p}}{k!} \cdot e^{-\lambda(1-p)} \cdot \sum_{n=k}^{\infty} \frac{(\lambda(1-p))^{n-k}}{(n-k)!} \\
&= \frac{(\lambda p)^k e^{-\lambda p}}{k!} \cdot e^{-\lambda(1-p)} \cdot e^{\lambda(1-p} \\
&= \frac{(\lambda p)^k e^{-\lambda p}}{k!}
\end{aligned}$$

Then, X_1 is a Poisson random variable. That is, $X_1 \sim P(\lambda p)$. Similarly, $X_2 \sim P(\lambda(1-p))$.

Theorem 2.3.4 *(P. Bickel and A. Doksum, 1977, Theorem 4.2.3) Let*

$\{P_\theta : \theta \in \Theta\}$ be a k parameter exponential family. Suppose that the range of $c = (c_1(\theta), \cdots, c_k(\theta))$ is complete as well as sufficient.

Corollary 2.3.5 *If $Y \sim P(\lambda\alpha)$, then for fixed α, Y is a sufficient and complete statistics for λ.*

Proof. If $Y \sim P(\lambda\alpha)$, then

$$\begin{aligned} P(Y = y) &= \frac{(\lambda\alpha)^y e^{(\lambda\alpha)}}{y!} \\ &= exp\{yln(\lambda) + \lambda\alpha + (yln(\alpha) - ln(y!))\} \end{aligned}$$

for $y = 0, 1, \ldots$. Hence, this family of distributions of Y for all possible values of λ is a one parameter exponential family by Definition 2.3.1 for fix α. From Theorem 2.3.4, we have $k = 1$ and $T(Y) = y$ is a sufficient and complete statistic for the parameter λ.

Theorem 2.3.6 If $X \sim P(\alpha)$, $Y \sim P(\beta)$, and X and Y are independent. Let $Z = X + Y$, then

1. $Z \sim P(\alpha + \beta)$;

2. Given $Z = z$, the conditional probability distribution of X is binomial with success probability $\alpha/(\alpha + \beta)$in z trials experiment.

Proof.

1. Because $X \sim P(\alpha)$, $Y \sim P(\beta)$, so the moment generation function (m.g.f) of X and Y are

$$M_X(t) = E(e^{tX}) = \sum_{i=0}^{\infty} \frac{(\alpha)^x e^{-\alpha}}{x!} \cdot e^{tx} = e^{\alpha(e^t - 1)}$$

and,

$$M_Y(t) = E(e^{tY}) = e^{\beta(e^t - 1)}$$

Because X and Y are independent, so the m.g.f for $Z = X + Y$ is

$$\begin{aligned} M_Z(t) &= E(e^{tZ}) = E(e^{t(X+Y)}) \\ &= E(e^{tX} \cdot e^{tY}) = E(e^{tX}) \cdot E(e^{tY}) = M_X(t) \cdot M_Y(t) \\ &= e^{(\alpha+\beta)\cdot(e^t-1)} \end{aligned}$$

which belongs to the Poisson family, hence,

$$Z \sim P(\alpha + \beta).$$

2. From above, $Z \sim P(\alpha+\beta)$. Then the conditional probability distribution of X given $Z = z$ will be:

$$\begin{aligned} P(X = x|Z = z) &= P(X = x, Y = z - x|Z = z) \\ &= \frac{P[(X = x, Y = z - x) \bigcap (Z = z)]}{P(Z = z)} \\ &= \frac{P(X = x, Y = z - x)}{P(Z = z)} \\ &= \frac{\alpha^x e^{\alpha}/x! \cdot \beta^{z-x} e^{\beta}/(z-x)!}{(\alpha+\beta)^z e^{\alpha+\beta}/z!} \\ &= \frac{z!}{x!(z-x)!} \cdot \left(\frac{\alpha}{\alpha+\beta}\right)^x \left(1 - \frac{\alpha}{\alpha+\beta}\right)^{z-x} \end{aligned}$$

which is just a probability mass function of a binomial distribution. Therefore, given $Z = z$, the conditional probability distribution of X is

$$X \sim Bin\left(z, \frac{\alpha}{\alpha+\beta}\right).$$

Theorem 2.3.7 *(Chatfield, 1975, P245-246)* Given

$$x_{ij} = \mu + b_i + t_j + \varepsilon_{ij} \quad (i = 1, \ldots r; j = 1, \ldots c)$$

where $\sum_{i=1}^{r} b_i = \sum_{j=1}^{c} t_j = 0$, and ε_{ij} are iid with cdf and pdf $F(x)$ and $f(t)$, and median 0. The best point estimates of the unknown parameters are:

$$
\begin{aligned}
\hat{\mu} &= \bar{x}, \\
\hat{b}_i &= \bar{x}_{i\cdot} - \bar{x} \quad (i = 1 \ldots r), \\
\hat{t}_j &= \bar{x}_{\cdot j} - \bar{x} \quad (j = 1 \ldots c)
\end{aligned}
$$

Chapter 3

Determining the Ideal Mesh Size

The problem of comparing several new gears with traditional ones occurs frequently in fishing trials and other experiments. For example, we expect that increasing the mesh size of the codend component would release more undersized fish. It is necessary that fisheries experiments attempt to show whether these experimental gears are significantly better than the traditional ones in releasing undersized fish, and to identify which codend mesh size is "ideal".

Formulating the statistical problem in terms of selection or multiple comparison seems particularly pertinent if the choice or if the experiment to be studied in a later trail depends upon which group turns out to be superior to the others in the initial trial. Traditionally, a common tool for analyzing data in these studies is a test of homogeneity of the experimental group means and the traditional group mean as in the *Analysis of Variance*. However, considering that their responses are monotonically increasing or decreasing, such homogeneity tests, whether or not they yield statistically significant results, usually do not supply concrete conclusions regarding the ideal mesh size of the sizes tested. Furthermore, should a significant result be obtained, the experimenter's problems have only just begun since the experimenter is seldom satisfied with terminating the analysis at this point; in particular, he or she may want to determine which gear is better than the traditional, or to see which gear can be considered ideal in some well-defined sense of the term ideal. Moreover, there may be a question as to whether testing a null hypothesis of homogeneity and estimating a parameter are appropriate formulations of the problem. A formulation such as a ranking and selection problem ought to be realistic in real world cases such as fishery studies.

In many fisheries experiments, the most important problem is to correctly identify the ideal fishing process or the ideal mesh size.

3.1 Approach and Expectations with Respect to Fishing

In fishery studies, increasing mesh size of the codend component is frequently expected to release more undersized fish or at least provide an equal response. Also, it is the most widely used method to reduce undersized fish retention probability. The main response decreases monotonically at larger codend mesh sizes. The response can also be monotonically increased with larger mesh size gears if one defines the response in another way. For example, if one defines the undersized fish retention probability for the response, it is monotonically decreased at larger mesh sizes, and it is increased if one denotes the response to undersized fish releasing probability. l_{50} and l_{25} are other very popular responses included in fishery studies.

In fisheries research, the primary goal is to assess whether there is indeed a mesh size effect, meaning that at least one gear's mean response is greater than that of the traditional. If a gear response effect is found, then there is a need to identify the gear with the lowest codend mesh size producing a desirable effect over that of the control. The smallest effective codend mesh size gear (SECMSG) is referred to as the smallest codend mesh size gear that gives a significantly better response, compared with the mean response of the traditional gear, such as allow more undersized fish to be released, among several experimental gears. Identifying an SECMSG is important, since larger mesh also reduces commercial product.

Actually, in fishery studies, there are many treatments. For example, larger codend components usually allow more fish to be released from the gear. Therefore, we can find the "ideal" codend component mesh size for commercial fishing. However, this dissertation is only concerned with the codend mesh size.

3.2 Method for Determining the Smallest Effective Codend Mesh Size Gear

A method to identify the ideal gear from several experimental gears with monotonically response was given in "Statistical Inference for Treatments versus a Control" (Peng, 2002). We will use the method in this dissertation.

We describe the necessary notation first. In fishing industry, to protect from overfishing, a typical study has a control/standard/traditional group indexed as 0 and k treatment groups indexed as $1, \cdots, k$ with increasing mesh size of the codend component, with n_i subjects randomly assigned to group i, $i = 0, \cdots, k$. For gear j at mesh size level i, let Y_{ij} be the response (for example, if we are interested in undersized fish retention probability, then Y_{ij} is the undersized fish retention probability will be the response). We assume that all observations Y_{ij} are mutually independent with Y_{ij} being approximately $N(\mu_i, \sigma^2)$, $i = 0, \cdots k$ and $j = 1, 2, \cdots, n_i$. The statistic $S^2 = \sum_{i=0}^{k} \sum_{j=1}^{n_i} (Y_{ij} - \bar{Y}_i)^2 / \nu$ is used as an estimator for σ^2 when it is unknown, and it is independent of the sample means $\bar{Y} = (\bar{Y}_0, \cdots, \bar{Y}_k)$, where $\nu S^2/\sigma^2 \sim \chi^2_\nu$ and $\nu = \sum_{i=0}^{k} n_i - (k+1) > 0$. Usually the response curve is expected to be continuous. Accordingly, SECMSG should be defined as the minimum mesh size such that the mean response of a certain kind of fish is significantly better than the mean response of the controls; that is

$$SECMSG = \min\{i : \mu_i > \mu_0 + \delta\} \tag{3.1}$$

where δ defines a significant difference preassigned by an experimenter. Suppose that the control group is the control group with a commercial fishing mesh size which is known to be reasonable, then the SECMSG can be defined by (3.1) with δ either positive or 0.

3.2.1 Test Statistic

The response effectiveness can be tested through the null hypothesis H_0 : $\mu_k - \mu_0 \leqslant \delta$ versus the alternative hypothesis $H_a : \mu_k - \mu_0 > \delta$, where δ defines a significant difference. By incorporating the assumption that $\mu_q \leqslant \mu_{q+1} \leqslant \cdots \leqslant \mu_k$, one rejects H_0 in favor of H_a for large values of

$$T_{q,k} = \max_{c \in C_{q,k}} \frac{\sum_{i=q}^{k} n_i c_i \bar{Y}_i - (\bar{Y}_0 + \delta)}{S\sqrt{\sum_{i=q}^{k} n_i c_i^2 + 1/n_0}} \tag{3.2}$$

where

$$C_{q,k} = \{c = (c_0, c_1, \cdots, c_k) : \sum_{i=q}^{k} n_i c_i = 1, c_1 = \cdots = c_{q-1} = 0, c_0 = -1/n_0, 0 \leqslant c_q \leqslant \cdots \leqslant c_k\}.$$

Without loss of generality, we assume $q = 1$ and $\delta = 0$. For simplicity we use T_k to denote $T_{1,k}$ and C_k to denote $C_{1,k}$. Let $t_{k,\alpha,\nu}$ be the critical value of T_k, then

$$P_\mu\{\sum_{i=0}^{k} n_i c_i \mu_i \geqslant \sum_{i=0}^{k} n_i c_i \bar{Y}_i - t_{k,\alpha,\nu} S(\sum_{i=0}^{k} n_i c_i^2)^{1/2}, \text{for all } c \in C\} = 1 - \alpha.$$

Let $\mathcal{L} = \{\mu : \mu_0 = \mu_1 = \cdots = \mu_k\}$ and $\Omega = \{\mu \in R^{k+1} : \mu_0 \leqslant \bar{\mu} \leqslant \mu_1 \leqslant \cdots \leqslant \mu_k\}$, where $\bar{\mu} = \frac{\sum_{i=0}^{k} n_j \mu_j}{\sum_{i=0}^{k} n_j}$. Then $\Omega = \mathcal{C} \oplus \mathcal{L}$. Let μ^* be the MLE of μ under Ω which will be discussed in the next subsection. Using the definition of isotonic regression, one may show that

$$\max_{c \in C} \left\{ \frac{\sum_{i=0}^{k} n_i c_i \bar{Y}_i}{\sqrt{\sum_{i=0}^{k} n_i c_i^2}} \right\} = \max_{c \in C} \left\{ \frac{\sum_{i=0}^{k} n_i c_i \mu_i^*}{\sqrt{\sum_{i=0}^{k} n_i c_i^2}} \right\} = \sqrt{\sum_{i=0}^{k} n_i (\mu^* - \bar{\bar{Y}})^2}$$

where $\bar{\bar{Y}} = \sum_{i=0}^{k} n_i \bar{Y}_i / \sum_{i=0}^{k} n_i$. From the above equation,

$$T_k^2 = \sum_{i=0}^{k} n_i (\mu_i^* - \bar{\bar{Y}})^2 / S^2. \tag{3.3}$$

When σ^2 is known, $\sum_{i=0}^{k} n_i (\mu_i^* - \bar{\bar{Y}})^2/\sigma^2$ is the likelihood ratio test statistic for testing $H_0' : \mu_0 = \cdots = \mu_k$ Versus $H_a' : \Omega - H_0'$. When σ^2 is unknown, we call $\sum_{i=0}^{k} n_i (\mu_i^* - \bar{\bar{Y}})^2/S^2$ the modified likelihood ratio test statistic for testing H_0' versus H_a'.

3.2.2 MLE μ^* in the Test Statistic

In this subsection, it will show how to find the MLE μ^* in the Test Statistic in (3.3), for a given response data $\bar{Y} = (\bar{Y}_0, \bar{Y}_1, \cdots, \bar{Y}_k)$.

Step i: For $(\bar{Y}_1, \cdots, \bar{Y}_k)$ (excluding the control), let the weight $\omega = (\omega_1 = n_i, \omega_2 = n_2, \cdots, \omega_k = n_k)$ at the beginning. If y is isotonic, then the isotonic adjusting of the data y' is y. Otherwise, these must exist an index i such that $\bar{Y}_{i-1} > \bar{Y}_i$. These two values are then replaced by their weighted average, namely $AV(i-1, i)$ and the two weights ω_{i-1} and ω_i are replaced by $\omega_{i-1} + \omega_i$. If this new set of $k-1$ values is isotonic, then $\bar{Y}_{i-1} = \bar{Y}_i = AV(i-1, i)$ and $y'_j = y_j$ otherwise. If this new set is not isotonic then this process is repeated using the new values and weights until an isotonic set of values is obtained. (This process is called pool adjacent violation algorithm. It is to obtain the isotonic regression with respect to $\mu_1 \leqslant \mu_2 \leqslant \cdots \leqslant \mu_k$.)

Step ii: For isotonic data $(\bar{Y}'_1, \cdots, \bar{Y}'_k)$, if $\bar{Y}_0 \geqslant \bar{Y}'_k$, then $\mu^*_i = \bar{\bar{Y}}$, $i = 0, 1, \cdots, k$. Otherwise, subtracting $\bar{\bar{Y}}$ from each component, ignoring those nonpositive treatments, go to the next step.

Step iii: The new data is $(\bar{Y}_0, \bar{Y}'_{i_1}, \cdots \bar{Y}'_k,)$. Computing the average of the updated data, denoted by av $= (\sum_{i=i_1}^{k} n_i \bar{Y}'_i + n_0 \bar{Y}_0)/(\sum_{i=i_1}^{k} n_i + n_0)$. Subtracting av from each component, then ignoring those nonpositive treatment components, if there are any. New data will have the following form

$$(\bar{Y}_0 - \text{av}, \bar{Y}'_{i_1} - \text{av}, \bar{Y}'_k - \text{av})$$

(the i_1 may change and $\bar{Y}'_{i_1} - \text{av} > 0$). Go to Step iv.

Step iv: Compute the new av, if av $= 0$, stop and μ^* is

$$\bar{\bar{Y}} + (\bar{Y}_0, 0, \cdots, 0, \bar{Y}'_{i_1}, \cdots, \bar{Y}'_k).$$

Otherwise, go to Step iii.

3.2.3 Proposed Method

We propose the following procedure to find the SECMSG. We denote $t_{\alpha,\nu}$ as the upper $100(1-\alpha)$ percentile of the t distribution with degrees of freedom ν. The value of $t_{k,\alpha,\nu}$ is showed in Table 3.1 on page 32.

Step 1: Only the treatment means $\bar{Y}_q, \cdots, \bar{Y}_k$ and the control mean $\bar{Y}_0$ will be used to compute T_{k-q+1}. If $T_{k-q+1} > t_{k-q+1,\alpha,\nu}$, then claim $\mu_k > (\mu_0+\delta)$ and go to Step 2; else claim that there is no non-zero size level which is significantly better than the control and

$$(\mu_k - \mu_0) > \max_{c \in C_{q,k}} \left\{ \sum_{i=q}^{k} n_i c_i \mu_i^* - \mu_0^* - t_{k-q+1,\alpha,\nu} S \sqrt{1/n_0 + \sum_{i=q}^{k} n_i c_i^2} \right\},$$

then stop.

Step 2: Treatment means $\bar{Y}_q, \cdots, \bar{Y}_{k-1}$ and the control mean $\bar{Y}_0$ will be used to compute T_{k-q}. (We need to find the new μ^* again.) If $T_{k-q} > t_{k-q,\alpha,\nu}$, then claim $\mu_{k-1} > (\mu_0 + \delta)$ and go to Step 3; else claim $SEC\hat{M}SG = k$ and

$$(\mu_{k-1} - \mu_0) > \max_{c \in C_{q,k-1}} \left\{ \sum_{i=q}^{k-1} n_i c_i \mu_i^* - \mu_0^* - t_{k-q,\alpha,\nu} S \sqrt{1/n_0 + \sum_{i=q}^{k-1} n_i c_i^2} \right\},$$

then stop.

$\vdots$

Step $(k-q)$: Treatment means $\bar{Y}_q$ and the control mean $\bar{Y}_0$ will be used to compute T_2. If $T_2 > t_{2,\alpha,\nu}$, then claim $\mu_{q+1} > (\mu_0 + \delta)$ and go to Step $(k-q+1)$; else claim $SEC\hat{M}SG = (q+2)$ and

$$(\mu_{q+1} - \mu_0) > \max_{c \in C_{q,q+1}} \left\{ \sum_{i=q}^{q+1} n_i c_i \mu_i^* - \mu_0^* - t_{2,\alpha,\nu} S \sqrt{1/n_0 + \sum_{i=q}^{q+1} n_i c_i^2} \right\},$$

then stop.

Step $(k-q+1)$: If $\bar{Y}_q - (\bar{Y}_0 + \delta) - t_{\alpha,\nu} S \sqrt{1/n_0 + 1/n_q} > 0$, then claim $\mu_q > (\mu_0 + \delta)$ and go to Step $(k-q+2)$; else claim that $SEC\hat{M}SG = (q+1)$

ν	α	k=treatment groups								
		2	3	4	5	6	7	8	9	10
5	.10	1.712	1.814	1.871	1.908	1.936	1.952	1.972	1.980	1.987
	.05	2.273	2.396	2.454	2.494	2.534	2.548	2.565	2.577	2.588
	.01	3.701	3.878	3.947	3.999	4.032	4.068	4.100	4.106	4.120
10	.10	1.581	1.670	1.720	1.749	1.772	1.792	1.800	1.814	1.819
	.05	2.027	2.121	2.275	2.202	2.227	2.249	2.258	2.269	2.280
	.01	3.005	3.114	3.172	3.305	3.223	3.256	3.265	3.279	3.292
15	.10	1.539	1.622	1.670	1.703	1.723	1.741	1.752	1.761	1.772
	.05	1.957	2.040	2.088	2.119	2.142	2.159	2.173	2.184	2.193
	.01	2.816	2.902	2.958	2.990	3.010	3.035	3.053	3.055	3.0711
20	.10	1.523	1.603	1.649	1.676	1.700	1.718	1.729	1.735	1.744
	.05	1.821	2.005	2.052	2.078	2.100	2.119	2.133	2.138	2.145
	.01	2.731	2.818	2.862	2.902	2.919	2.936	2.943	2.953	2.960
25	.10	1.507	1.587	1.634	1.667	1.688	1.703	1.709	1.723	1.729
	.05	1.897	1.977	2.027	2.057	2.078	2.093	2.102	2.114	2.119
	.01	2.676	2.762	2.804	2.839	2.865	2.872	2.884	2.898	2.909
30	.10	1.500	1.581	1.628	1.658	1.676	1.691	1.700	1.712	1.723
	.05	1.884	1.970	2.012	2.045	2.063	2.078	2.086	2.098	2.110
	.01	2.642	2.733	2.777	2.807	2.825	2.839	2.848	2.858	2.872
40	.10	1.493	1.575	1.616	1.643	1.667	1.685	1.691	1.703	1.706
	.05	1.871	1.952	1.995	2.022	2.045	2.059	2.069	2.081	2.086
	.01	2.610	2.694	2.733	2.759	2.782	2.796	2.805	2.812	2.821
50	.10	1.487	1.568	1.609	1.640	1.658	1.676	1.685	1.697	1.700
	.05	1.860	1.942	1.982	2.012	2.030	2.047	2.059	2.071	2.071
	.01	2.579	2.661	2.702	2.735	2.750	2.767	2.872	2.798	2.793
60	.10	1.483	1.565	1.606	1.637	1.655	1.667	1.682	1.691	1.697
	.05	1.857	1.934	1.975	2.005	2.022	2.037	2.052	2.057	2.066
	.01	2.571	2.644	2.687	2.718	2.735	2.750	2.764	2.768	2.775
∞	.10	1.459	1.543	1.584	1.612	1.634	1.646	1.655	1.667	1.673
	.05	1.822	1.897	1.942	1.970	1.985	2.002	2.010	2.025	2.027
	.01	2.492	2.565	2.608	2.633	2.655	2.666	2.680	2.683	2.694

Table 3.1: Upper Percentage Points for $t_{k,\alpha,\nu}$

and

$$(\mu_q - \mu_0) > \bar{Y}_q - \bar{Y}_0 - t_{\alpha,\nu} S\sqrt{1/n_0 + 1/n_q},$$

then stop.

$\vdots$

Step k**:** If $\bar{Y}_1 - (\bar{Y}_0 + \delta) - t_{\alpha,\nu} S\sqrt{1/n_0 + 1/n_1} > 0$, then claim $\mu_1 > (\mu_0 + \delta)$ and go to Step $(k+1)$; else claim that $SEC\hat{M}SG = 2$ and

$$(\mu_1 - \mu_0) > \bar{Y}_1 - \bar{Y}_0 - t_{\alpha,\nu} S\sqrt{1/n_0 + 1/n_1},$$

then stop.

Step $(k+1)$**:** If $\bar{Y}_1 - (\bar{Y}_0 + \delta) - t_{\alpha,\nu} S\sqrt{1/n_0 + 1/n_1} > 0$, then claim $\mu_1 > (\mu_0 + \delta)$ with $SEC\hat{M}SG = 1$ and $\min_{1 \leqslant i \leqslant k} \mu_i - \mu_0 = \min_{1 \leqslant i \leqslant q} \mu_i - \mu_0 > \min_{1 \leqslant i \leqslant q} \{\bar{Y}_i - \bar{Y}_0 - t_{\alpha,\nu} S\sqrt{1/n_0 + 1/n_i},\}$, then stop.

Let step M $(1 \leqslant M \leqslant k+1)$ be the step at which the stepwise method stops. If $M > 1$, then the stepwise method declares mesh sizes $(k - M + 2), \cdots, k$ to be efficacious. If $M < k + 1$, then the stepwise method fails to declare mesh sizes $1, \cdots, (k - M + 1)$ to be efficacious. If $M = (k+1)$, then the stepwise method gives a lower bound on how efficacious every mesh is.

3.3 Application I - Using Undersized Fish Retention Probability as the Response

In this section, the model is applied to simulated data, which has the product per hour and the percentage of undersized fish for all experimental gears with different mesh sizes and their control gear. We test whether the gears with larger mesh sizes are significantly effective for the undersized fish retention probability and identify which gear is ideal.

The mesh sizes of the gears' codend component are given: 130mm, 135mm,140mm, 145mm, 150mm. The gear with 130mm codend mesh size is treated as the traditional gear. All of the codend mesh are diamond in shape. It is obvious that smaller mesh sizes will retain more undersized fish. r_{130mm} is denoted for the undersized fish retention probability of 130mm diamond gear, and r_{135mm}, r_{140mm}, r_{145mm}, r_{150mm} for the 135mm, 140mm, 145mm, and 150mm diamond gears, respectively. We believe that:

$$r_{130mm} \geq r_{135mm} \geq r_{140mm} \geq r_{145mm} \geq r_{150mm}. \tag{3.4}$$

The data are given in five groups in Table 3.2 on page 35. Each group has six trawls, although this number is arbitrary. Each trawl (observation) has 4 results: they are product per hour of the control gear(C_{ij}), product per hour of the experimental(E_{ij}), percentage of undersized fish in the control(Pc_{ij}) and percentage of undersized fish in the experimental gear(Pe_{ij}). Usually, we are interested in the undersized fish retention probability (UFRP).

To begin, we will find the UFRP. In the data set, we have the total catch per hour, and the percentage of undersized fish caught. However, it is not desirable to estimate the UFRP from only the average of the percentage of undersized fish. It also highly depends on the population, and the fish populations of the experimental gear and of the control gear are not always the same. Therefore, between these paired gears, there exists a split proportion p $(0 \leq p)$ which is the proportion that a fish enters the experimental compared to the control gear.

Thus, we estimate from the following relations.

$$\begin{cases} (r_1) = \frac{E\times Pe}{C\times Pc} \cdot p \\ (r_0) = \frac{E\times(1-Pe)}{C\times(1-Pc)} \cdot p \end{cases} \tag{3.5}$$

mesh size of the codend part	product per hour of control	product per hour of experimental	Percentage of undersized fish of control	Percentage of undersized fish of experimental
130cm Diamond	534.25	201.00	30.03	13.10
	130.00	222.22	33.33	10.65
	771.45	333.33	16.15	5.84
	326.00	147.00	43.54	14.79
	550.00	250.00	51.91	21.18
	457.30	180.00	23.74	9.94
135cm Diamond	357.00	143.33	39.07	13.40
	420.00	200.00	47.61	14.39
	385.00	204.50	23.04	9.12
	632.25	273.33	29.07	8.75
	231.00	179.00	38.56	15.21
	473.00	315.50	17.80	5.03
140cm Diamond	347.00	210.00	47.23	16.77
	418.00	197.00	15.46	5.02
	489.00	257.00	29.07	10.38
	273.00	159.00	27.37	9.64
	395.00	222.22	9.67	3.16
	603.00	295.00	34.39	9.59
145cm Diamond	262.00	222.22	26.57	9.42
	389.00	300.00	7.71	2.04
	693.00	266.66	42.11	13.12
	421.66	234.00	34.78	9.90
	460.00	247.33	36.47	9.28
	200.00	105.00	13.50	3.77
150cm Diamond	430.50	240.00	34.11	9.73
	143.00	255.00	26.34	7.90
	511.00	196.25	47.35	15.07
	451.00	311.11	21.64	4.35
	236.66	144.00	30.01	10.21
	289.00	201.00	24.90	6.90

Table 3.2: Simulated Data Set of Application I - Using UFRP as the Response

Because it is easier to find the relation in a linear model, we will take the logarithm of both sides.

$$\begin{cases} log(r_1) = partA + log(p) \\ log(r_0) = partB + log(p) \end{cases} \tag{3.6}$$

where

$$partA = log\left(\frac{E \times Pe}{C \times Pc}\right) \quad \text{and} \quad partB = log\left(\frac{E \times (1 - Pe)}{c \times (1 - Pc)}\right).$$

Using the following model:

$$x_{ij} = \mu + b_i + t_j + \varepsilon_{ij} \quad (i = 1, \ldots r; j = 1, \ldots c)$$

where $\sum_{i=1}^{r} b_i = \sum_{j=1}^{c} t_j = 0$, and ε_{ij} are iid with cdf and pdf $F(x)$ and $f(t)$, and median 0. The best point estimates of the unknown parameters are:

$$\begin{aligned} \hat{\mu} &= \bar{x}, \\ \hat{b}_i &= \bar{x}_{i\cdot} - \bar{x} \quad (i = 1 \ldots r), \\ \hat{t}_j &= \bar{x}_{\cdot j} - \bar{x} \quad (j = 1 \ldots c) \end{aligned}$$

Rewrite the equation 3.6:

$$\begin{cases} partA = log(r_1) + (-log(p)) \\ partB = log(r_0) + (-log(p)) \end{cases} \tag{3.7}$$

The expected value of $log(p)$ is assumed to be 0, because, the experimental method is twin trawl. Therefore, we can calculate $log(r_1)$ as $\mu + b_1$ and find the estimates of UFRP r_1 for the different gears:

$$\begin{cases} r_1 = e^{E(partA)} \\ \varepsilon_{1j} = e^{partA_j + \frac{1}{2}(partA_j + partB_j) - \frac{1}{2n}\Sigma_{j=1}^{n}(partA_j + partB_j) - E(partA)} \end{cases} \tag{3.8}$$

Based on the above, we find the UFRP for the different gears in Table 3.3.

Group	Mesh size	Sample size	Mean	Std. Dev.
0	130mm	6	.201700	2.07229E-02
1	135mm	6	.178210	1.78618E-02
2	140mm	6	.178435	1.41866E-02
3	145mm	6	.169543	1.46760E-02
4	150mm	6	.156687	1.27952E-02

Table 3.3: Descriptive Statistics of UFRP for Different Mesh Size Gears

Based on fishing knowledge, we believe that larger mesh size gears will decrease the UFRP. However, the method illustrated here requires the response to be monotonically increasing as mesh size increases. Therefore, we shall consider the negative value of the retention probability (-UFRP) to be the response. (Or 1-UFRP can be another choice, which is the undersized fish releasing probability).

We let $\alpha = 0.05$. We find that $S^2 = 0.0002656$.

Using the method in Section 3.2, we first find the MLE of μ^*.

Step i: The response is $\bar{Y} = (Y_0 = -.201700, Y_1 = -.178210, Y_2 = -.178435, Y_3 = -.169543, Y_4 = -.156687)$ and the wight $\omega = (\omega_1 = 6, \omega_2 = 6, \omega_3 = 6, \omega_4 = 6)$. The $\bar{Y}$ is not isotonic. The isotonic regression of $\bar{Y}$ is $(-.201700, -.1783225, -.1783225, -.169543, -.156687)$.

Step ii: We have $\bar{Y}_0 < \bar{Y}_k'$. Compute the $\bar{\bar{Y}} = -.176915$, and subtract av from each component and get$(-.02479, -.00141, -.00141, .00737, .02023)$.

Step iii: Ignore those nonpositive treatment(except $\bar{Y}_0$), the updated data is $(-.02479, .00737, .02023)$

Step iv: Compute the av=0.000938, go to Step iii.

Step iii: subtract av from each component, and the updated data is

$(-.025723, .006434, .019290)$

Step iv: We get μ^* is

$$(-.20264, -.17692, -.17692, -.17048, -.15762)$$

Then we use the method in Section 3.2 to find the SECMSG.

Step 1: Compute $T_5 = 4.92 > t_{5,0.05,25} = 2.057$, and when $\delta \in [0, .01564]$, we still have $T_5 > t_{5,0.05,25}$.

Step 2: Only using the first four groups to compute, find the $\mu*$ again and we get $T_4 = 3.58 > t_{4,0.05,20} = 2.052$, and when $\delta \in [0, .00937]$, we still have $T_4 > t_{4,0.05,20}$.

Step 3: Only using the first three groups to compute, $T_3 = 2.61 > t_{3,0.05,15} = 2.04$, and when $\delta \in [0, .00344]$, we still have $T_3 > t_{3,0.05,15}$.

Table 3.4 shows a summary of the results.

δ	(0,0.344%]	(0.344%,0.937%]	(0.937%, 1.564%]	> 1.564%
$SEC\hat{M}SG$	1 or 2	3	4	NA

Table 3.4: Choosing an Ideal Gear for Different δ Values Using UFRP as the Response

This shows that: if you want to have significant difference in undersized fish retention probability, you could choose the 135mm or 140mm gear. These gears decrease the UFRP by 0.344%. To further significantly reduce the UFRP, between 0.344% and 0.937%, the 145mm mesh size gear should be chosen. If you choose the 150mm gear, it can make the retention probability 1.564% smaller. No gear can make a significant difference more than 1.564% in UFRP. (The confidence level of all the above conclusion is: 95%.)

3.4 Application II - Using l_{25} as the Response

In Application I, the response is strongly dependent on the population, and the data set only gives the amount of large/small size fish caught by the trawl/control gear. Thus, this data only provides information regarding the undersized fish caught, not of specific length frequencies. For example, two gears both have 20% UFRP. One hundred 40 cm fish have entered one gear, and twenty of them have been caught, while fifty 30 cm fish, forty 35 cm fish, ten 40 cm fish have entered the other gear. That gear caught no 30 cm fish, ten out of forty 35 cm fish, and ten of ten 40 cm fish. From the UFRP, the two gears are the same, but when the percent caught in each length division is considered, they are different. In this section, the model is applied to data of l_{25}. Traditionally, it is preferable to use l_{25}, l_{50}, l_{75} to describe the gears' capability. Here, the reason to choose l_{25} from these three is because l_{25} is closer to the undersized fish size. To describe the ability to release undersized fish, l_{25} is preferred. Whether the larger codend mesh size gears will have significantly larger l_{25} or not will be tested. Furthermore, the ideal mesh size can be found.

Let us consider the simulated data set given in Table 3.5. Five different mesh sizes are given. They are 130mm, 135mm,140mm, 145mm, 150mm; all are diamond shaped. It is reasonable to believe that smaller codend mesh size gears will retain more fish. We want to test whether an increase in the mesh size will significantly increase l_{25}. We use L_{130mm} to denote the l_{25} of the gear with 130mm diamond mesh in codend, and L_{135mm}, L_{140mm}, L_{145mm}, L_{150mm} for the 135mm, 140mm, 145mm, and 150mm gears respectively. We believe that:

$$L_{130mm} \leq L_{135mm} \leq L_{140mm} \leq L_{145mm} \leq L_{150mm}. \tag{3.9}$$

We have five groups of data. Each group has six trawls, but this number is again arbitrary.

Different Mesh Size	l_{25} of trawls					
130mm Gear	42.65	42.74	42.35	42.18	42.67	42.20
135mm Gear	43.07	42.39	42.88	42.80	43.07	43.67
140mm Gear	43.58	43.31	43.20	43.56	42.87	43.68
145mm Gear	43.97	43.88	43.61	44.07	43.73	43.62
150mm Gear	44.61	43.84	44.36	44.69	43.97	44.18

Table 3.5: Simulated Data Set of Application II - Using l_{25} as the Response

The l_{25} of all the gears is assumed to follow normal distribution. The means and standard deviations are displayed in Table 3.6.

Group	Mesh size	Sample size	Mean of l_{25}	Std. Dev.
0	130mm	6	42.4650	.2516
1	135mm	6	42.9800	.4202
2	140mm	6	43.3667	.3029
3	145mm	6	43.8133	.1900
4	150mm	6	44.2750	.3415

Table 3.6: Descriptive Statistics of l_{25} for Different Mesh Sizes Gears

Based on fishing knowledge, we believe that larger mesh sizes will increase the l_{25}. We assume that the distributions of l_{25} for different gears are normal. The method introduced in section 3.2 can be used.

Let $\alpha = 0.05$. We find that $S^2 = 0.097034$. Then, the MLE of μ^* can be found.

Step i: The response is $\bar{Y} = (Y_0 = 42.47, Y_1 = 42.98, Y_2 = 43.36, Y_3 = 43.81, Y_4 = 44.27)$ and the wight $\omega = (\omega_1 = 6, \omega_2 = 6, \omega_3 = 6, \omega_4 = 6)$. $\bar{Y}$ is isotonic.

Step ii: We have $\bar{Y}_0 < \bar{Y}_k'$. Compute the $\bar{\bar{Y}} = 43.38$, and subtract av from each component and get$(-.92, -.40, -.01, .43.89)$.

Step iii: Ignoring those nonpositive treatment(except $\bar{Y}_0$), the updated data is $(-.92, .43, .89)$

Step iv: Compute the av=0.13, go to Step 2.

Step iii: subtract av from each component, and the updated data is $(-1.053, .296, .756)$

Step iv: We get μ^* is

$$(-42.73, -41.68, -41.68, -41.38, -40.92)$$

Next, the SECMSG can be find.

Step 1: Compute $T_5 = 10.46 > t_{5,0.05,25} = 2.057$, and when $\delta \in [0, .72]$, we still have $T_5 > t_{5,0.05,25}$.

Step 2: Only using the first four groups to compute, find the $\mu*$ again and we get $T_4 = 7.644 > t_{4,0.05,20} = 2.052$, when $\delta \in [0, .49]$, we still have $T_4 > t_{4,0.05,20}$.

Step 3: Using the first three groups to compute, $T_3 = 5.13 > t_{3,0.05,15} = 2.04$, and when $\delta \in [0, .28]$, we still have $T_3 > t_{3,0.05,15}$.

Step 4: Using the first two groups to compute, $T_3 = 2.89 > t_{2,0.05,10} = 2.027$, and when $\delta \in [0, .10]$, we still have $T_2 > t_{2,0.05,10}$.

Table 3.7 shows the summary of the result.

This shows that: if you want to have a significant difference in undersized fish retention probability compared to the 130mm gear, the 135mm gear is satisfactory. This experimental gear can also make l_{25} 0.10 cm larger than the

δ	(0,0.10]	(0.10,0.28]	(0.28, 0.49]	(0.49, 0.72]	> 0.72
$SEC\hat{M}SG$	1	2	3	4	NA

Table 3.7: Choosing an Ideal Gear for Different δ Values Using l_{25} as the Response

130mm gear. To further significantly increase the l_{25}, for example, between 0.28 cm and 0.49 cm, the 145mm mesh size gear should be chosen. If you choose the 150mm gear, it can make the l_{25} 0.72 cm larger. No experimental gear can make a significant difference in l_{25} of more than 0.72 cm. (The confidence level of the above conclusions is 95%.)

Chapter 4

Proposed Model Relating Towing Time to the Selection Curve

Traditionally, fisheries and researchers are not interested in *towing time* (defined in Chapter 2). When the selection curve is estimated, its effect is neglected. In the past, researchers and fisherpeople were concerned with the towing time only because a too long towing time destroys some fish. No research has been done on the effect of towing time on the selection curve. This study shows that there is some difference when the effect of towing time is considered. An hourglass is an example of the difference in the effects of time. Every grain of the sand can get through the hole, but it takes a definite amount of time. The fishing process is more complicated and the effects of towing time can be seen in the selection curve.

4.1 Towing Time Affects the Selection Curve

In this section, how towing time affects the fish retention rate will be shown.

i) A fish trapped in the codend component needs time to escape.

This situation is equivalent to, for example, tossing a coin every hour until a "head" is obtained, where the fish attempts to escape before succeeding. Suppose, a coin is tossed every hour. and is tossed for a total of 2 hours, there will be a probability of $50\% \times 50\% = (50\%)^2$ to get a "head".

It is the same in fishing. Suppose a fish meets the codend of an empty gear once every hour. There is a 50% probability that it will be trapped. If the fish stays in the gear for 2 hours, it can meet the gear twice, and the probability of being trapped will be $50\% \times 50\% = (50\%)^2$. If the fish stays in the gear for half an hour, it will have a $(50\%)^{0.5}$ probability of being trapped, as long as it continues to meet the gear. Therefore, we assume that one hour after the fish has entered the gear, there is a probability p of that fish being trapped. After 2 hours, there is a probability p^2 of the fish being trapped. If the gear trawls for half an hour, the fish will have a probability of $p^{0.5}$ being trapped. After z hours, the probability of a fish being trapped will be p^z.

ii) As fish crowd the codend, it becomes more difficult for fish to escape.

The following two examples show that the effects of fish crowding are equivalent to what occurs to sand in an hourglass, or to people waiting in a check out line. Firstly, every grain of sand can go through the hole in an hourglass, but, it takes a definite amount of time, as regularly as a clock. Secondly, if, for example, 10 people are waiting in the checkout lines at the supermarket, and there are 15 cash registers open, everyone has a choice of which counter to line up at. However, if there are 15 checkouts for 20 people, only 75% can be served at one time; the other 5 must wait their turns. The crowd may make it more difficult for customers to line up and be served efficiently.

These preceding examples mirror almost exactly what is encountered when fishing. The codend component of the gear, similar to the checkout lines of a supermarket, only allows a limited amount of fish to meet the gear at one time. Generally, the longer towing time we have, the more fish that enter the gear, and the more fish that crowd in the codend, making it harder to meet the mesh. Thus, a new definition is introduced, called *touch probability* (defined in Chapter 2). In the beginning of the trawl, there are very few fish in the codend, and these fish have no trouble meeting the mesh. In this case, the touch probability is 1. As the towing time increases, it is expected that more fish accumulated in the codend, and it becomes harder to meet the codend mesh, and then to escape. Therefore, the touch probability will decrease with increasing towing time. If the towing time goes to infinity, theoretically, there will be infinity fish in the codend, and the touch probability will be 0.

Based on this concept, it is assumed that the touch probability:

$$\tau_1(t) = \frac{1}{(1 + t/\alpha_1)} \tag{4.1}$$

which is a function of towing time t. $\alpha_1 > 0$ is an unknown parameter, and is referred to, in this dissertation, as *accumulation rate*, used to describe how fast the fish accumulate in the codend component. This rate will be affected by other factors such as the population of fish, the shape and size of mesh, etc. For all sizes of fish, the touch probability function is the same.

iii) The blockage will stop fish from escaping.

When fishing, some fish and other objects may block the mesh. This situation is equivalent to checkout lines, in which there are many more people waiting to be served than there are checkout lines open. For example, if 100 people are waiting to be served. and only 10 out of 15 possible checkouts are open, many people will be prevented from being served immediately. It would take much less time for the people to pass through if the maximum number of checkout lines were open.

The preceding example mirrors what is encountered when fishing. In the beginning of the fishing process, there is no fish in the codend. and thus no block. As fish enter, slight blockages may occur, but as towing time increases, blockages become more substantial. The block probability changes from 0 to very close to 1 as towing time increases.

Based on this concept, another new definition, called *block probability* must be introduced:

$$\tau_2(t) = t/\alpha_2, \quad (t < \alpha_2) \tag{4.2}$$

where towing time t is the dependant on this function. $\alpha_2 > 0$ is an unknown parameter. and is referred to, in this dissertation, as *blocking rate* (defined in Chapter 2). used to describe how fast the fish will block the mesh. This rate will change with the shape and size of mesh, the population of fish, etc. For all sizes of fish, the block probability function is the same. When fishing, we want to stop before the mesh is totally blocked. Therefore, it is assumed that the towing time be $< 2/3\alpha_2$.

iv) Considering the touch probability and block probability together, the *escape rate* is obtained.

Both the crowd and the blockage are caused by fish. They are functions of towing time t. Thus, these two can be put together and the *escape rate* (defined in Chapter 2) can be obtained.

The crowding and blocking situation is again equivalent to checkout lines, in which there are many more people waiting to be served than there are checkouts open. If 15 checkouts are open to serve very few people, everyone has a probability of 1 to be served. If 15 checkouts are open to serve 30 people, only half of them can be served at one time. If 10 out of 15 checkouts are open to serve 30 people, only 1/3 of them can be served. The crowding and blocking may make it it more difficult for customers to line up and be served efficiently.

These examples mirror what is encountered when fishing. When fish enter an empty gear, meaning that it is neither crowded nor blocked, it will have a probability of 1 to meet the mesh. As fish enter, crowding and blockage may occur, and as towing time increases, these become more substantial.

Based on this concept, along with touch probability and block probability, the escape rate $\tau(t)$ can be written:

$$\tau(t) = \tau_1(t) \cdot (1 - \tau_2(t)) = \frac{1 - t/\alpha_2}{1 + t/\alpha_1} \tag{4.3}$$

which is a function of towing time t. $\alpha_1 > 0$ is the accumulation rate, $\alpha_2 > 0$ is blocking rate.

v) A new selection curve is produced.

Under Assumption 4 in Chapter 2, it is assumed that a l_i length fish stays in empty gear for one hour, where the retention probability is $\beta(l_i)$, which is a function of l_i, the length of fish, and it is assumed that $\beta(l_i)$ is a logistic curve:

$$\beta(l_i) = \frac{exp(\alpha_3 + \alpha_4 \cdot l_i)}{1 + exp(\alpha_3 + \alpha_4 \cdot l_i)} \tag{4.4}$$

The only difference between having an empty gear for one hour and what occurs in commercial fishing is that there is neither crowd nor blockage in the codend component at all times.

If we have an empty gear, and an l_i length fish comes into the codend, one hour later, the probability that the fish is still in the codend is $\beta(l_i)$. If it is towed for another hour, the probability that the fish is still in the codend component is $\beta(l_i)^2$. After two and half hours of towing, the probability that the fish will stay in the gear is $\beta(l_i)^{2.5}$, assuming that there is never fish or a block in the codend component during the trawl.

Suppose a fish stay in an empty gear for one hour. It will try x times to escape the gear. After two and half hours, it will try $2.5x$ times to escape. Assuming that the codend of the gear is always half blocked (unlike in commercial fishing), the fish stay for two hours, and can try x times to escape. The probability that the fish will stay in the codend will be the same as the fish stay in an empty gear for one hour, $(\beta(l_i))^1$. Experimentally, if we have a gear, the touch probability is always 0.5, and the codend is always half blocked, one fish stays in the codend for 2 hours, it has $0.5 \times 0.5 \times 2x = 0.5x$ times to try to escape. Then, if a fish comes to the codend at time t_1 and stays there until time t_2, the fish has $x \cdot \int_{t_1}^{t_2} \tau(t)dt$ times to escape the gear. The probability that the fish will stay in the gear until time t_2, if it is known the fish comes to the codend at time t_1 is:

$$\beta(l_i)^{\int_{t_1}^{t_2} \tau(t)dt}$$

If we already know a fish came in the codend before the fishing has finished, the distribution of the fish comes at time point t ($0 < t < ft$, ft is the fishing time) is a uniform. That is, the probability of the fish came into the codend between $(t, t + \triangle t)$ is $\triangle t / ft$.

The probability that l_i length fish will enter between $(t_1, t_1 + \triangle t)$ and remain in the codend until time t_2 is:

$$\triangle t \cdot \beta(l_i)^{\int_{t_1}^{t_2} \tau(t)dt} / ft \qquad .$$

For the fish process, t_2 is the time that the fish cannot escape. It is also, the time that a gear is totally out of ocean. Therefore, $t_2 = ft + b$. The probability that l_i length fish will be caught by the codend, under the condition that the fish has already entered the gear, is $r(l_i, ft, b)$:

$$r(l_i) = \int_0^{ft} \beta(l_i)^{\int_{t_1}^{t_2} \tau(t)dt} dt_1 \tag{4.5}$$

where $\beta(l_i) = \frac{exp(\alpha_3+\alpha_4 \cdot l_i)}{1+exp(\alpha_3+\alpha_4 \cdot l_i)}$, $\tau(t) = \frac{1-t/\alpha_2}{1+t/\alpha_1}$ and $t_2 = ft + b$. $r(l_i, ft, b)$ is the formula for the novel selection curve. An example is shown in Figure 4.1 on page 58.

4.2 Model Definition

In this section, the twin trawl experiment method is used to generate data. The towing time model provides a method to estimate the ideal towing time for releasing undersized fish.

Under Assumption 5 in Chapter 2, the number of length l_i fish in contact with these gears during fishing time ft_j, has a Poisson distribution with rate λ_{ij}. That is, $N_{ij+} \sim P(\lambda_{ij})$ and $N_{ij-} \sim P(\lambda_{ij})$. It is clear that N_{ij+} and N_{ij-} are independent.

For the fish that enter the experimental gear, we make the following observations:

1. Each fish entering the gear may be either retained or escape;

2. The status of one fish (retained or escaped) is independent of others;

3. The probability of a fish being retained after entering the gear is constant $r_j(l_i)$ for each length class l_i, $i = 1, 2, \ldots n$ and fishing time ft_j, $j = 1, 2, \ldots m$;

Therefore, for the experimental gear, and given N_{ij-}, the number of length l_i fish retained in towing time t_j, Y_{ij-} is a binomial random variable with success probability $r_j(l_i)$. That is:

$$Y_{ij-}|N_{ij-} \sim Bin(N_{ij-}, r_j(l_i))$$

According to Theorem 2.3.3, $N_{ij-} \sim P(\lambda_{ij})$, we have

$$Y_{ij-} \sim P(\lambda_{ij} \cdot r_j(l_i))$$

For the control gear, all fish will be retained. Therefore $N_{ij+} = Y_{ij+}$.

$$Y_{ij+} \sim P(\lambda_{ij})$$

Note that the actual total catch Y_{ij} of length l_i fish with towing time t_j of both the control and the experimental gears can be observed $y_{ij} = y_{ij+} + y_{ij-}$. By theorem 2.3.6, given the y_{ij}, the conditional probability distribution of the number of fish caught by experimental gear Y_{ij} is Binomial with:

$$Y_{ij\_}|Y_{ij} \sim Bin\left(Y_{ij}, \frac{r_j(l_i)}{1 + r_j(l_i)}\right)$$

Hence the total number of fish caught by both the experimental gear and the control gear can be modelled as observations from a Binomial experimental with Y_{ij} trails.

The corresponding log-likelihood function is given by

$$\sum_j \sum_i (y_{ij-} \cdot log(\phi_j(l_i)) + y_{ij+} \cdot (1 - \phi_j(l_i))) \tag{4.6}$$

where

$$\phi_j(l_i) = \frac{r_j(l_i)}{1 - r_j(l_i)}$$

is the probability that a fish will be retained by the experimental gear, providing that it enters the gear.

Maximizing the log-likelihood function of all possible values of parameters $\alpha = (\alpha_1, \alpha_2, \alpha_3, \alpha_4)$, the MLE of these parameters can be obtained, and also the estimated selection curve.

4.3 Application

In this section, the model is applied in a simulated data set and the ideal towing time is found.

The model was fitted to a simulated data set. Each l_i class varies by a length of 1 cm with midpoint l_i. For example, the length class 30 represents the class of fish with length range from 29.5cm to 30.5cm.

This data set has 41 length classes with midpoints from 30cm to 70cm. The data set is only sample data, and the sample weight and total weight are also collected. A weighted factor (the fraction of the total weight to the sample weight of each length class) is used to scale the data set from length frequency of sample data to length frequency of the total catch in the control codend, the experimental codend. We have the fishing time, the length of fish, and the gathering time $b = 2/3$. The scaled data set "Data Set I" is attached in appendix A and the following is the partial data set:

```
len ft nfine nwide
30  1    1    0
31  1    1    0
32  1    2    0
33  1    4    1
34  1    6    0
..
42  1    49   7
43  1    60   7
44  1    54   10
45  1    53   9
46  1    46   12
..
69  1    0    0
70  1    0    0
```

```
30  3  0  0
31  3  5  0
..
70  3  0  1
30  8  7  0
..
70  8  3  1
```

where `len` denotes the midpoint of each length class, `nfine` denotes the number of fish of each length class entering the control codend component, `nwide` denotes the number of fish of each length class retained by the experimental codend component, and `ft` denotes the fishing time for each trail.

4.3.1 Results

The MLE of selection curve parameters is obtained, which is shown in Table 4.1.

parameter	α_1	α_2	α_3	α_4
estimator	3.161	13.35	-16.80	0.3372

Table 4.1: Estimated Selection Curve Parameters

The estimated selection curves of the experimental codend component are shown in Figure 4.1A on page 58 for different towing times. The plot shows that the probability of catching fish will increase after several hours towing while catching fish of length class of approximately 40 cm. The Figure 4.1B on the same page obviously shows the difference. For example, with 40 cm fish and 8 hours fishing time, the retention probability will be about 10% higher than the retention probability of one hour fishing time, and also about 2% higher than the retention probability of 7 hours fishing time. Thus, it makes a great difference if we reduce the fishing time of a trawl from 8 hours and

7 hours. Figure 4.2 on page 59 and Figure 4.3 on page 60 shows that for longer fishing times (after 1 or 2 hours), the retention probability will become larger. This is not desirable for the release of undersized fish. For example, the retention probability of a 44 cm fish is about 20% when fishing time is 2-4 hours. However, when the fishing time becomes longer, for example 8 hours, the retention probability will increase to 27%. If the fishing time is even longer, for example 10 hours, the retention probability will increase to 32%. This is not acceptable for commercial fishing, where it is not permitted to retain such undersized fish.

Population of fish of varying lengths, the ideal fishing time will also be different. Figure 4.3 on page 60 shows the result. For 40 cm fish, less than 4 hours is an ideal fishing time, and for 44 cm fish, less than 5 hours is acceptable. If we prolong the fishing time from 4 hours to 7 hours, the retention probability will increase for different size fish: 5% for 40 cm fish, 4% for 44 cm fish, 1% for 48 cm fish. Then, the decision is whether to prolonging the towing time from 4 hours to 7 hours, since it will increase the undersized fish retention probability drastically, to about 5%, and at the same time, the large fish retention probability does not change much, only 1%.

Therefore, we can choose a reasonable towing time for commercial fishing and release as many undersized fish as possible. From this data set, we can conclude that a reasonable fishing time is 2 to 5 hours.

4.4 Comparison with the Traditional Model

This model is novel. The difference between the new model and the traditional model, which is using logistic curve, will be discussed in this section.

Using the traditional model on the same data set for different fishing times, Figure 4.4 on page 61 shows a logistic curve along with three other curves representing different fishing times to show the difference. The selection curve shows that the l_{50} is almost the same for each condition. However, in the new model, the retention probability is larger than that of the traditional model for fish larger than l_{50}. Also, the traditional model gives a larger selection range.

In the analysis, the deviance residual plots of the curve (in Figure 4.4B) are given by individual deviance residuals defined as:

$$r_D = sign(y - \mu)\left\{2\left(y \cdot log\frac{y}{\mu} + (n - y) \cdot log\frac{n - y}{n - \mu}\right)\right\}^{1/2} \tag{4.7}$$

which is used to generate the deviance statistic, is noted by $\sum r_D^2$ (McCullagh and Nelder, 1989).

The log-likelihood value can be compared. For this data set, the traditional model gives a log-likelihood value of -4054.39, and the new model gives a log-likelihood value of -4039.10. Therefore, the new model describes this data set better than the traditional model, even though the new model has two additional parameters compared the traditional.

The different effects on responses with variable fishing times can also be seen by fitting the same data set using the traditional model separately for different towing times (Table 4.2).

4.5 Parameter Effects on the Selection Curve

The effects of the parameters $(\alpha_1, \alpha_2, \alpha_3, \alpha_4)$, particularly for the new parameters α_1 and α_2, will be discussed in this section.

towing time	l_{25}	l_{50}	l_{75}	sr
1 hour	48.06(0.76)	55.90(1.57)	63.75(2.65)	15.69(2.31)
3 hours	48.39(0.50)	57.27(1.03)	66.15(1.74)	17.76(1.52)
8 hours	46.08(0.35)	57.76(0.82)	69.44(1.51)	23.36(1.46)

Table 4.2: Data Set Arranged According Different Fishing Times Using the Traditional Method (Values in Parentheses Indicate Standard Error)

4.5.1 Accumulation Rate α_1 Effects

In the beginning of this chapter, it was stated that parameter α_1 represents the speed that the fish accumulated in the codend.

A small α_1 indicates that the fish will accumulate rapidly, and the fish may find that it is difficult to touch the gear and escape for the same period of time. A large α_1 indicates that the fish will accumulate slowly, and the fish may wait for their turn to meet with the gear and to escape.

Figure 4.5A on page 62 shows the effects of α_1. If α_1 is increased slightly, by 20% for example, the selection curve will change. Figure 4.5B on the same page shows this the difference. It will make the retention probability 2-3% smaller (for some length classes). If the α_1 is 20% smaller, the retention probability will increase 2-3%.

4.5.2 Blocking Rate α_2 Effects

It was stated that α_2 represents the speed that the fish block the codend component.

A small α_2 indicates that the fish will block the mesh rapidly, and the fish may find that it is difficult to touch the gear and escape. A large α_2 indicates that the fish will block the gear slowly, and the fish may wait for its turn to meet with the gear and attempt to escape.

Figure 4.6A on page 63 shows the effects of α_2. If α_2 is increased by 20%, for example, the selection curve will also change. Figure 4.6B on the same page shows that this will make the retention probability 1-2% smaller (for some length classes). If the α_2 is 20% smaller, the retention probability will increase 2-3%.

4.6 Gathering Time b Effects on Selection Curve

In Chapter 2, gathering time was defined as follows: when we finish towing, the gear is gathered and the catch is brought onto the ship. In this process, the opening of the gear becomes smaller and smaller. Therefore, we have fewer, or even no fish, coming into the gear, but at the same time, the fish will not stop escaping from the codend component. Actually, in this model, the gathering time obviously affects the retention probability.

Figure 4.7 on page 64 shows that with a gathering time is from 0.3 hours to 2 hours, the selection curve will shift downwards by about 10% for undersized fish.

4.7 Fishing Modifications to Control the Undersized Fish Retention Probability

Based on these assumption and the model, some suggestions can be written to control the undersized fish retention probability:

i). Choose an ideal towing time.

If the towing time is too short, fish never get a chance to meet the gear and to escape. If the towing time is too long, the mesh will be heavily blocked and there is a large crowd in the codend part, and fish will find it more difficult to escape. Then there exists an ideal time for releasing fish. For different lengths of fish, the ideal fishing time will be different. For most undersized fish, however, 2-5 hours is adequate. If the towing time is too long, for example, more than 8 hours, most of the fish, no matter large or small, will be caught, because of blocking and crowding.

ii). Making slight modifications to the codend design if possible.

It is desirable to work towards both prolonging the blocking time and diluting the crowd in the codend in order to optimize the fishing process by releasing the undersized fish. If possible, a larger codend component should be included as part of the gear. For example, if the diameter of the codend is increased by 10%, the crowding will, in general, improve by 20%, and also the blockage will, in general improve by 20%. Decrease in either crowding or blocking will generally decrease the UFRP by 2-5%. Therefore, modifying the gear only a little can makes an obvious difference in the fish retention probability. (Note: these effects will depend on the fish population.)

iii). Prolonging the gathering time.

If the gathering time can be increased a little, for example, 10 or 20 minutes longer, this will give all sizes of fish more time to escape. For the large fish, it can meet the gear, but it is still difficult to escape, even with the longer gathering time. In contrast, for undersized fish, the longer gathering time gives them more chance to meet the gear, it will make it easier to escape. It is necessary to prolong the gathering time, because these small fish need more time to meet the gear and attempt to escape.

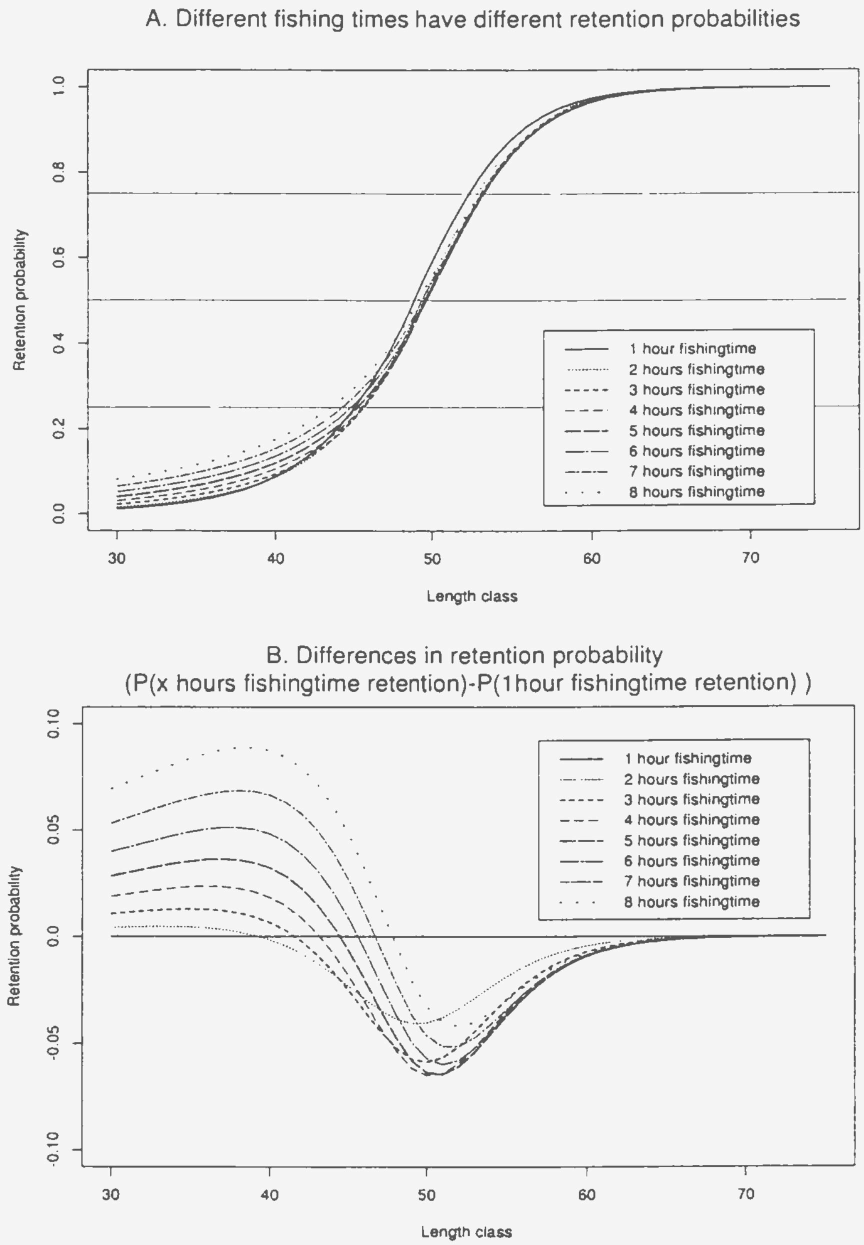

Figure 4.1: The (Cumulative) Effects of Fishing Time on the Selection Curve

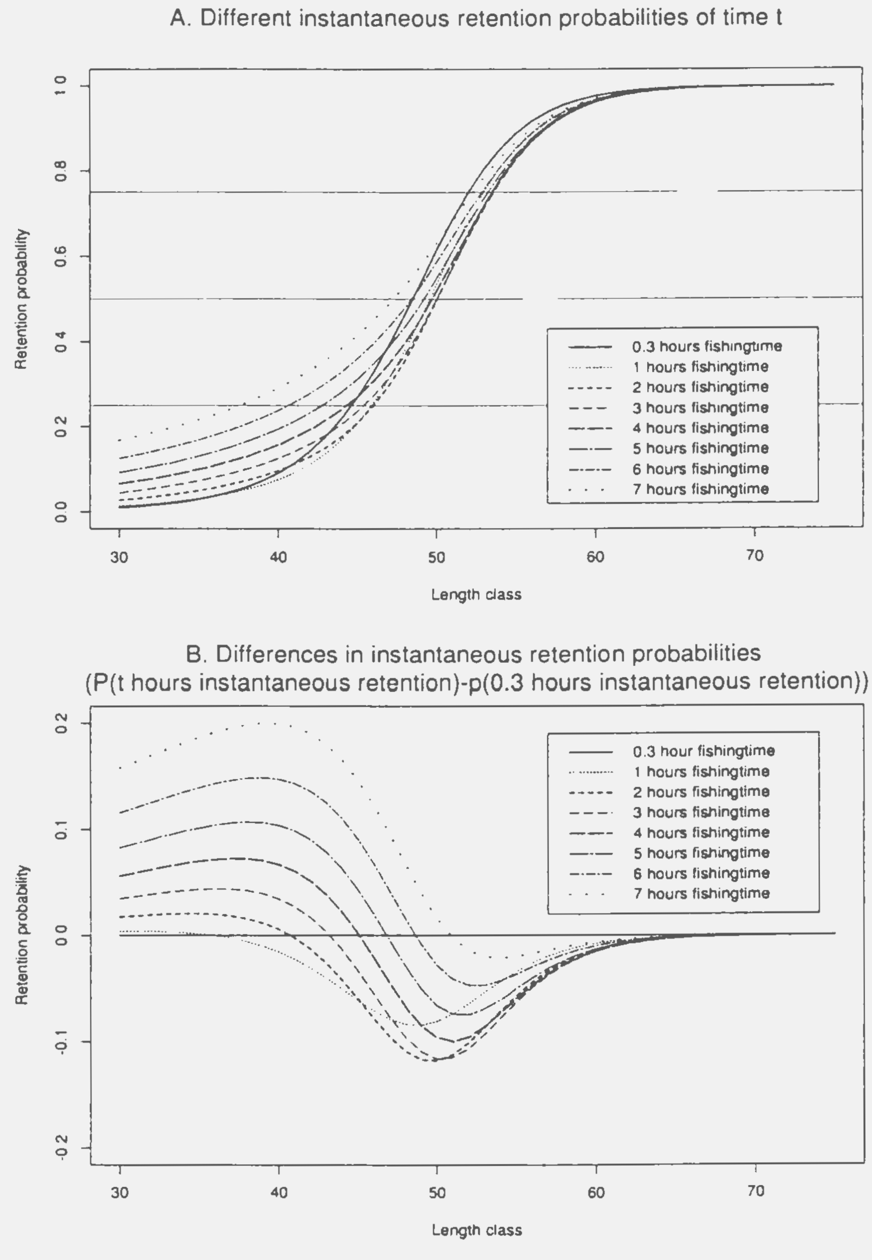

Figure 4.2: The Instantaneous Effects of Time t on Retention Probability

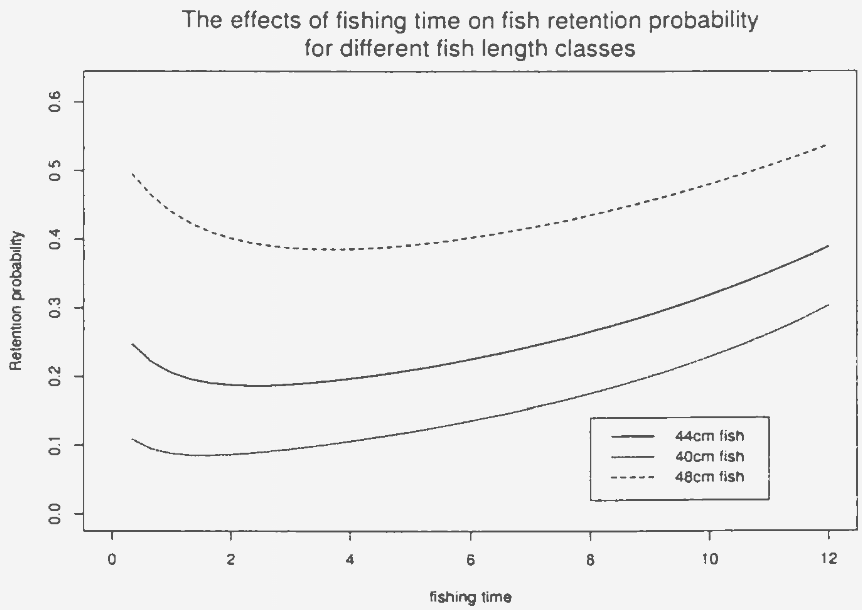

Figure 4.3: Retention Probability Affected by Increasing Fishing Time for Different Length Classes of Fish

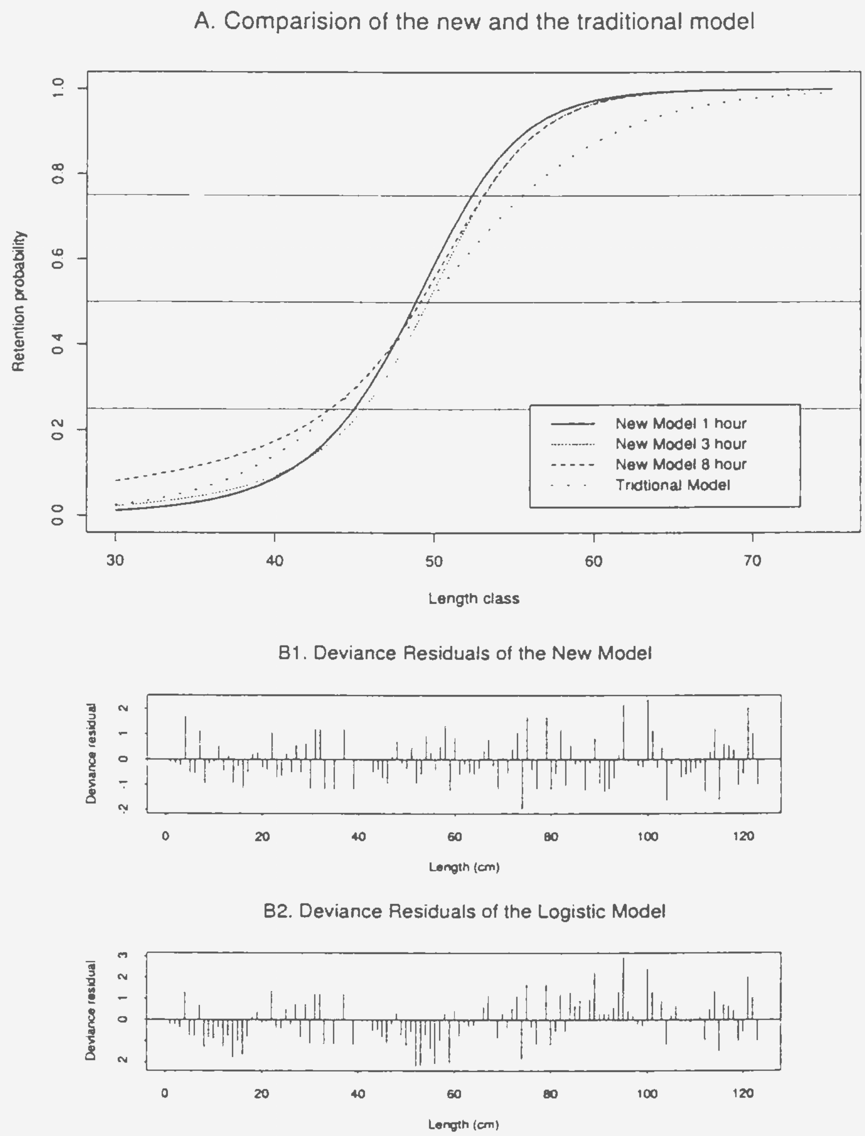

Figure 4.4: Selection Curve and Deviation Comparisons of the New and the Traditional Models

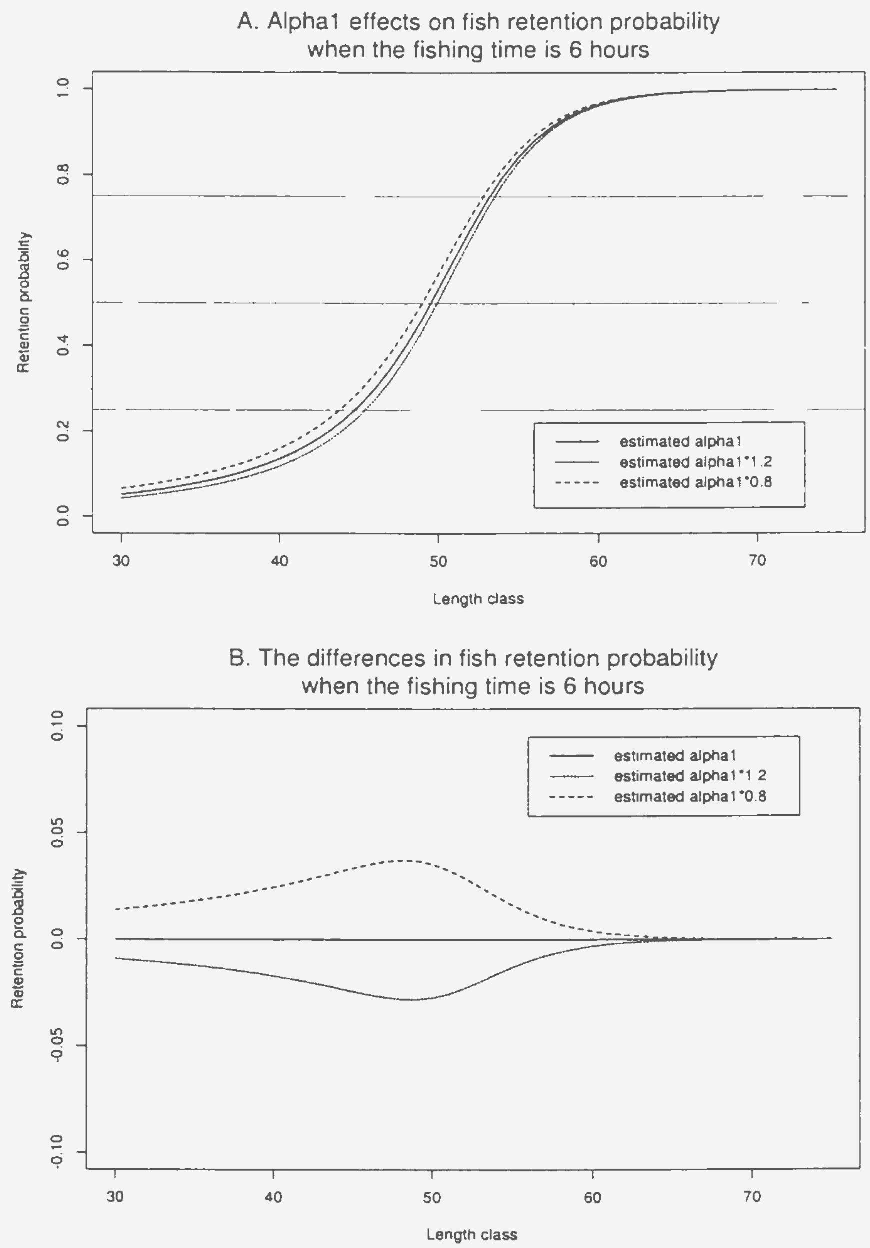

Figure 4.5: Accumulation Rate α_1 Effects on Fish Retention Probability in the Proposed Model

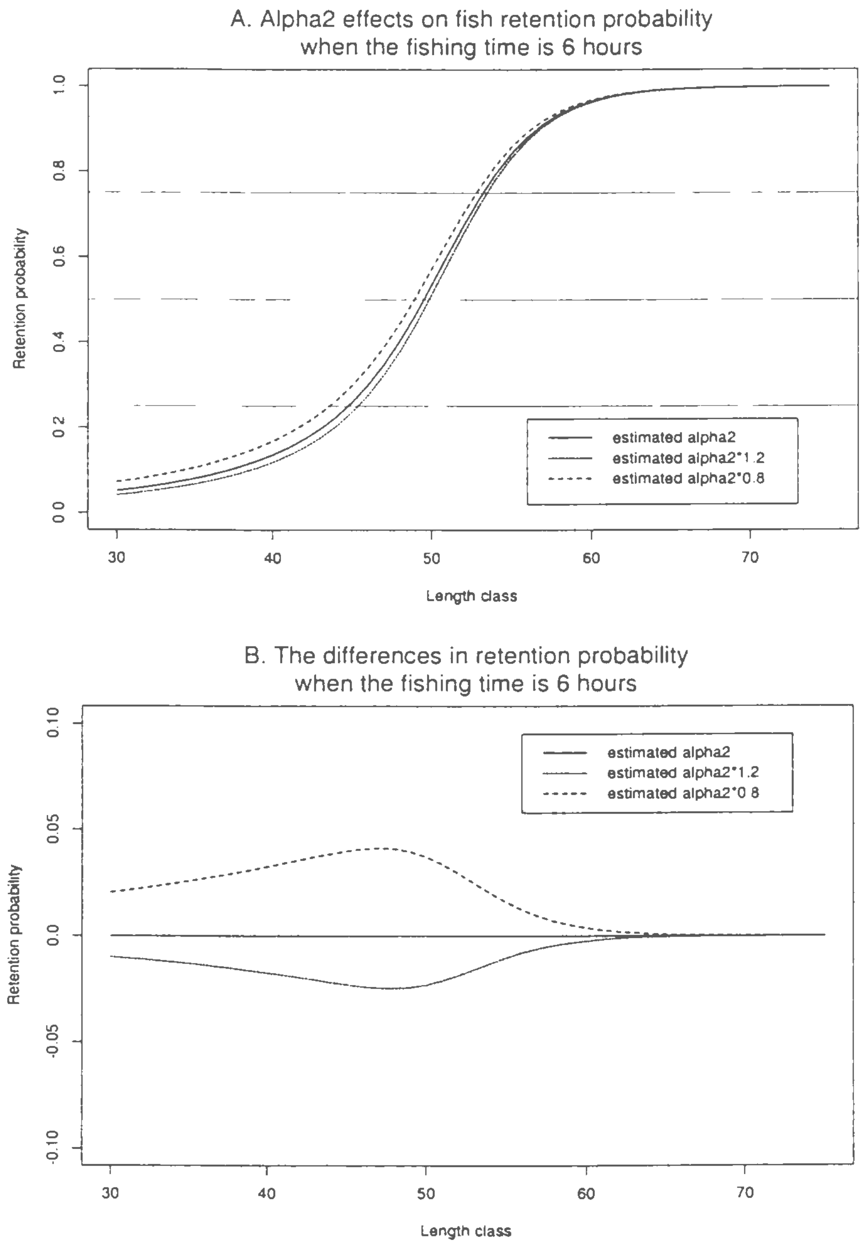

Figure 4.6: Blocking Rate α_2 Effects on Fish Retention Probability in the Proposed Model

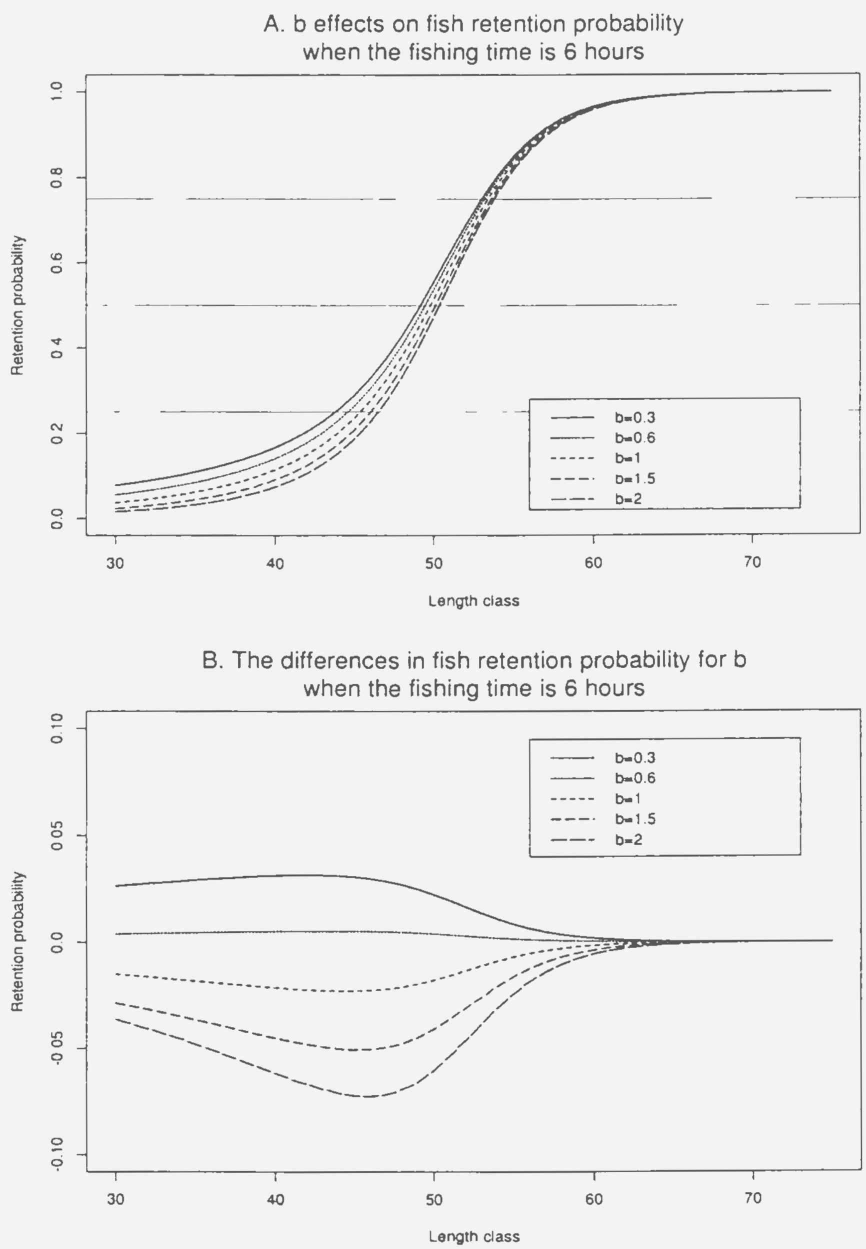

Figure 4.7: The Gathering Time b Effects on Retention Probability in the Proposed Model

Chapter 5

Discussion

All data in this dissertation were simulated. In Chapter 3, the way the method works was shown, using simulated data as an example. The data used to find the ideal mesh size was simulated, and whether this data is real or not does not matter in showing how the method works. In Chapter 4, however, because this is a totally novel model considering the towing time, real data is desirable, but no real data was found to use to apply the model. Therefore, we relied on simulated data. Without real data, we can only compare these two models and show the rationale of the new model. We cannot compare the traditional and the new models to declare which model is better, and it is not even possible to say that the towing time affects the selection curve without a real data. Therefore, before further studies are carried out, real data must be obtained experimentally before the model may be applied to obtain real-world conclusions regarding the effects of towing time.

In Chapter 4, it is assumed that the basic retention probability is a logistic curve, and the unit time is defined as one hour. This assumption is vital, and it may even be said that the whole model is built on this assumption. Whether the assumption is true or not, however, has never been tested. Also, the basic retention probability may be more similar to a Richard's curve, and the unit time may be 10 minutes, a half hour, 2 hours, etc. In future studies, using real data, the assumption may be adjusted, and made to resemble the real situation more closely.

In Chapter 4, it is assumed that for all trawls, fish coming into the codend part is a Poisson processe with the same parameter. Therefore, the accumulation rate and the blocking rate will be the same for all the trawls. When the parameters in the new model were estimated, and used in other trawls, those trawls are also assumed to be a Poisson process with the same parameter. Sometimes, the fish population may change, and the model may no longer be useful. Therefore, it is necessary to develop a model considering the different parameter Poisson process. Using product per hour to describe the Poisson process parameter may be one choice to solve this issue.

While it is already commonplace to study the codend mesh size as a means to examine undersized fish escape, the method for finding the ideal mesh size elucidated in this study is novel. The new method allows for multiple mesh sizes to be examined and compared to the standard, in contrast to the current method, which only allows one mesh size to be examined and compared to a standard. Because the results of the method will vary according to what fish are desired to be caught and/or released, there is no one ideal mesh size, and the method should be applied on a case-by-case basis. The strength of the method is its versatility.

Large fish will be caught according to their size, no matter how many attempts they have to escape. In contrast, undersized fish will be caught as a result of the crowding and blocking in the gear with prolonged towing. If a fish of any size never meets the mesh, it will never escape. This is especially true for undersized fish because they can escape though mesh while the desired catch cannot. Some modifications can be made to the gear and the towing time to reduce the crowding and blocking that would give the undersized fish more chance to meet the mesh and thus escape. The ideal towing time model was found to be effective using the simulated data, and it is recommended that fishing time be shortened from 8 hours to 4 hours, and the gathering time be prolonged by 20 minutes so that 3-6% more of the retained undersized fish may be allowed to escape. Thus, the probability of retention undersized fish can be decreased from the current 20% (using the traditional method) to approximately 15% (using the proposed method). Redesigning the gear to reduce the crowding and blocking in the codend component will also release many more undersized fish. By simply increasing the diameter of the codend component by 10%, there will be an approximately 20% decrease in both blocking and crowding, corresponding to a 3-5% decrease in the UFRP. Thus, the UFRP is reduced from approximately 20% to 15%. If both recommendations are followed, that is, a change in both codend mesh size and towing time as long as the gathering time, the UFRP may be reduced by as much as 5-10%. The merit for these modifications is that, if adopted, they would result in the release of more undersized fish, while retaining the total desired catch.

Chapter 6

Conclusion

Increasing codend mesh size is believed to release more undersized fish, and is also one of the mostly widely used methods to reduce the UFRP. However, increased codend mesh size gear will also reduce total catch. To find a balance is always the goal of fisheries and researchers. In Chapter 3, a method to correctly identify the ideal gear, among several increasing codend mesh size gears, is introduced. This method can be used not only on the UFRP, but also on selection length or l_{25}, etc. Also, if increasing gear mesh size gives homogenous responses, as in the example of UFRP as the response, it will yield more information, and for the same confidence level, fewer experimental trawls are needed. This will reduce the costs of experimentation, shorten the experimental period, and reduce the waste. Using this method to find the ideal codend mesh size gear is much more economical, efficient and environmentally friendly than all of the other methods currently used in similar fishing experiments. This method would be useful and efficient for governments and fishery organizations in defining mesh size regulations because it allows for multiple mesh sizes to be compared with a standard at the same time.

The proposed towing time model gives novel insight for fishing research that shows the importance of towing time when trawling. Not only fish habitat, but also the fish product itself, is affected by towing time. From the studies of towing time, we may change our fishing behavior, and even change the design of the gear. These fishing modifications can reduce the undersized fish retention probability by 5-10%, while not decreasing the total product, if the proposed model is further tested and proved to be more efficient. These results may also inspire further research of a similar vein that examines fish retention as functions of both size and time. Researchers may find it useful to study fish escape as a stochastic process. The impotence of this study for the fishery and fish stocks in general is evident. It is suggested to governments and fishery organizations to examine and test the model using real data. The method to find the ideal gear mesh size and the model relating the towing time may be solutions for optimizing commercial fishing and protecting the fish stocks.

Appendix A: Data Sets

Length frequency distribution of turbot fish of the codend for twin trawl.

In this data set, `len` denotes the midpoint of each length class, `tt` denotes the towing time, `nfine` denotes the number of fish of each length class entering the control codend, `nwide` means the number of fish of each length class retained by the experimental codend. The gathering time `b` is 2/3 hour.

len	tt	nfine	nwide	len	tt	nfine	nwide	len	tt	nfine	nwide
30	1	1	0	30	3	0	0	30	8	7	0
31	1	1	0	31	3	5	0	31	8	6	1
32	1	2	0	32	3	3	0	32	8	13	1
33	1	4	1	33	3	8	0	33	8	22	2
34	1	6	0	34	3	12	0	34	8	41	2
35	1	5	0	35	3	20	1	35	8	38	4
36	1	6	1	36	3	22	2	36	8	69	10
37	1	10	0	37	3	38	2	37	8	95	9
38	1	21	1	38	3	70	4	38	8	174	19
39	1	30	2	39	3	72	7	39	8	221	28
40	1	34	4	40	3	106	7	40	8	290	45
41	1	36	3	41	3	148	14	41	8	343	68
42	1	49	7	42	3	134	22	42	8	332	92
43	1	60	7	43	3	138	23	43	8	391	92
44	1	54	10	43	3	162	28	44	8	374	99
45	1	53	9	45	3	145	36	45	8	383	111
46	1	46	12	46	3	92	33	46	8	334	109
47	1	30	12	47	3	111	28	47	8	199	102
48	1	27	13	48	3	64	30	48	8	174	88
49	1	18	8	49	3	70	28	49	8	147	69
50	1	18	9	50	3	42	21	50	8	98	59
51	1	7	8	51	3	33	17	51	8	74	33
52	1	10	5	52	3	25	14	52	8	62	41
53	1	6	3	53	3	17	11	53	8	42	32
54	1	4	4	54	3	13	12	54	8	44	30
55	1	5	3	55	3	10	12	55	8	37	27
56	1	2	3	56	3	9	7	56	8	19	14
57	1	3	1	57	3	13	7	57	8	21	17
58	1	1	2	58	3	5	5	58	8	17	15
59	1	1	0	59	3	6	4	59	8	20	12
60	1	0	1	60	3	3	4	60	8	9	10
61	1	0	1	61	3	1	3	61	8	7	12
62	1	1	0	62	3	6	1	62	8	10	4
63	1	0	0	63	3	0	2	63	8	5	7
64	1	1	0	64	3	3	2	64	8	6	8
65	1	0	0	65	3	1	0	65	8	3	4
66	1	0	1	66	3	1	1	66	8	3	1
67	1	0	0	67	3	0	2	67	8	2	1
68	1	1	0	68	3	1	0	68	8	0	3
69	1	0	0	69	3	2	1	69	8	1	3
70	1	0	0	70	3	0	1	70	8	3	1

Appendix B: S-Plus Implementation for the Towing Time Model

B.1: Functions and Subfunctions

The function `fish.q` is used for the towing time model to estimate the parameters needed to obtain selection curves of the towing time model.

In `fish.q`, eight functions are used to find the estimator and to compare with the traditional model. `loglikefunc`, `cchood` are the log-likelihood functions for the towing time model and the traditional logistic model. `fit`, `fitper` are the towing time model selection curve for different towing time. `lselect` is the selection curve for traditional logistic model. `devres` computes the Pearson and deviance residuals. `cccov` computes the covariance of parameters for traditional model. `ccfit` computes the l_{25}, l_{50}, l_{75} and selection range.

B.2: Using the Functions

The data set to be analyzed by these function should be contain four columns with names `len`, `tt`, `nfine` and `nwide`. Where `len` is from 30 to 70, and denotes the midpoint of each length class; `tt` gives the towing time of each experimental trail; `nfine` denotes the number of fish of each length class entering the control codend, `nwide` means the number of fish of each length class retained by the experimental codend.

Before recalling the function `fish.q`, read the data set into S-Plus library (command `read.table` can do this task). The data set must be put into `maa`. Then the selection curves can be estimated by executing `fish.q`. For example:

```
> maa<-read.table('data.txt',header=T)
> source('fish.q')
```

B.3: Pseudo Code

Use command 'nlminb' to find the maximum log-likelihood estimate of parameters $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ in the selection curve of the experimental codend. loglikefunc is the log-likelihood function. Vector x0 is the initial value of parameters. Also, use 'nlminb' to find the maximum log-likelihood estimate of parameters for traditional model.

```
aa<-nlminb(start=x0,objective=loglikefunc)
```

`devres` computes the Pearson and deviance residuals for the towing time model (`Ndevres`) and the traditional logistic model (`Ldevres`).

```
Ndevres_devres(nwide,(nwide+nfine)*(1-1/(1+fit(ealpha1,
          ealpha2,ebeta,len,tt,2/3))),nwide+nfine)
Ldevres_devres(nwide,(nwide+nfine)*llselect(x00),nwide+nfine)
```

`cccov` is used here to estimate the covariance matrix of the estimated α_1, α_2 of traditional logistic model.

```
Tcov<-cccov(Tfit$x)
```

ccfit gives the estimated l_{25}, l_{50}, l_{75} and selection range and the corresponding standard errors of the traditional logistic model for different towing time trails.

```
out2<-ccfit()
```

Draw the estimated selection curves and the difference between different towing time, including the instant selection curve plots.

```
plot(x,y,main="Different towing times have different retention
    probability",xlab="Length class", ylab="Retention
    probability",type='n',xlim=c(30,75),ylim=c(0,1))
plot(x,y,main="Difference of retention probability(P(x hours'
    towing time)-P(1hour towing time) )" ,xlab="Length class",
    ylab="Retention probability",type='n',xlim=c(30,75),ylim=
    c(-0.1,0.1))
plot(x,y,main="Different retention probability in every
    hour(instant)",xlab="Length class",ylab="Retention
    probability",type='n',xlim=c(30,75),ylim=c(0,1))
plot(x,y,main="Different retention probability in every
    hour(instant)",xlab="Length class",ylab="Retention
    probability",type='n',xlim=c(30,75),ylim=c(-0.2,0.2))
```

Draw the effect of towing time for different length fish plots.

```
plot(x,y,main="The effect of towing time on fish retention
    probability for different length",xlab="Towing
    time",ylab="Retention
    probability",type='n',xlim=c(0,12),ylim=c(0,0.62))
plot(x,y,main="The effect of towing time on fish retention
    probability for different length(instant)",xlab="Towing
    time",ylab="Retention probability",type='n',xlim=
    c(0,12),ylim=c(0,0.9))
```

Draw the effect of parameters plots.

```
plot(x,y,main="The effect of alpha1 on fish retention probability
    when towing time is 6 hours",xlab="Length class", ylab="Retention
    probability",type='n',xlim=c(30,75),ylim=c(0,1))
plot(x,y,main="The difference in fish retention probability when
```

```
    towing time is 6 hours",xlab="Length class", ylab="Retention
    probability",type='n',xlim=c(30,75),ylim=c(-0.1,0.1))
plot(x,y,main="The effect of alpha2 on fish retention probability
    when towing time is 6 hours",xlab="Length class", ylab="Retention
    probability",type='n',xlim=c(30,75),ylim=c(0,1))
plot(x,y,main="The difference in retention probability when towing
    time is 6 hours",xlab="Length class", ylab="Retention
    probability",type='n',xlim=c(30,75),ylim=c(-0.1,0.1))
```

Draw the effect of gathering time plots.

```
plot(x,y,main="The effect of b on fish retention probability when
    towing time is 6 hours",xlab="Length class", ylab="Retention
    probability",type='n',xlim=c(30,75),ylim=c(0,1))
plot(x,y,main="The difference in fish retention probability for b
    when towing time is 6 hours",xlab="Length class", ylab="Retention
    probability",type='n',xlim=c(30,75),ylim=c(-0.1,0.1))
```

Draw the corresponding deviance residual for new and traditional models plots.

```
plot(Num0,Ndevres$devres,type="h",xlab="",xlim=c(1,123),ylab="")
plot(Num0,Ldevres$devres,type="h",xlab="",xlim=c(1,123),ylab="")
```

B.4: Output Result

The first part is to get the parameter for the towing time model, and get the graphic outputs using the estimated parameters. The graphics are:

`ret1.ps` contains the selection curve for different towing times;

`ret1b.ps` shows the difference in selection curve for different towing times;

`ret2.ps`, `ret2b.ps` contain the instant selection curve and the difference between different towing times;

`towing1.ps`, `towing2.ps` shows the different in towing time for different length fish;

`alpha1.ps`, `alpha1b.ps`, `alpha2.ps`, `alpha2b.ps` shows the effect of parameters;

`b0.ps`, `b0b.ps` shows the effect of gathering time;

The second part is to compare with the traditional logistic model. The log-likelihood value for both model is contained. The l_{25},l_{50},l_{75} and selection range are given for different towing time trails.

`comp.ps`, displays the selection curves for both traditional logistic model and the new towing time model in the same plot.

`compdev.ps` contains the corresponding deviance residual for both models.

B.5: An Example

```
> maa<-read.table('data.txt',header=T)
> source('fish.q')
Generated postscript file "ret1.ps".
Generated postscript file "ret1b.ps".
Generated postscript file "ret2.ps".
Generated postscript file "ret2b.ps".
Line segments out of bounds X= 14 Y=0.02 Line segments out of
bounds X= 9 Y= 0.02 Line segments out of bounds X= 9 Y= 0.14
Generated postscript file "towing1.ps".
Line segments out of bounds X= 14 Y= 0.02 Line segments out of
bounds X= 9 Y= 0.02 Line segments out of bounds X= 9 Y= 0.14
Generated postscript file "towing2.ps".
Generated postscript file "alpha1.ps".
Generated postscript file "alpha1b.ps".
Generated postscript file "alpha2.ps".
Generated postscript file "alpha2b.ps".
Generated postscript file "b0.ps".
Generated postscript file "b0b.ps".
Generated postscript file "comp.ps".
Generated postscript file "compdev.ps".

 The estimators of the parameters:
```

```
[1]   3.1609807  13.3528704 -16.7961962   0.3372453

 Comparing the modified log-likelihood value for two model:

The towing time model: 4039.10384007566 The logistic model:
4054.39798070905

Using logistic model on different towing time trail:

 The 1 th trail
$lens:
         [,1]      [,2]
[1,] 48.06010 0.7651549
[2,] 55.90622 1.5774553
[3,] 63.75233 2.6576037

$sr: [1] 15.692224  2.311532


 The 2 th trail
$lens:
         [,1]      [,2]
[1,] 48.39061 0.4991827
[2,] 57.27194 1.0287496
[3,] 66.15328 1.7391033

$sr: [1] 17.762677  1.521192


 The 3 th trail
$lens:
         [,1]      [,2]
[1,] 46.08460 0.3492888
[2,] 57.76421 0.8197081
[3,] 69.44381 1.5118961

$sr: [1] 23.35921  1.45876

Warning messages:
```

```
1: NAs generated in: gamma(x)
2: singularity encountered in: nlminb.0(temp, p, liv, lv,
        objective, bounds, scale)
3: singularity encountered in: nlminb.0(temp, p, liv, lv,
        objective, bounds, scale)
```

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