A STUDY OF THE BIOLOGY OF THE

SAND FLOUNDER RHOMBOSOLEA PLEBEIA

(RICHARDSON) OFF THE CANTERBURY COAST

A thesis presented for the degree of Ph.D. in
Zoology, in the University of Canterbury,
Christchurch, New Zealand.

by

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1968
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The Sand Flounder *Rhombosolea plebeia* (after Waite).
The Biology of the Sand Flounder *Rhomboselea plebeia* (Richardson) off Canterbury, New Zealand.

1.a. General introduction.

1.1. A method of age determination of the sand flounder *Rhomboselea plebeia* (Richardson) by the use of stained otoliths.

1.a. Abstract

The sand flounder *Rhomboselea plebeia* (Richardson) is found throughout the shallow coastal regions and inlets of New Zealand. The object of this study was to determine the relationship, if any, between the sand flounders inhabiting the bays and inlets of Banks Peninsula and those fish subject to exploitation by trawlers operating in the offshore deeper waters. The aspects studied were as follows.

Age determination was based on the interpretation of otoliths. Several methods of treatment were tried, staining providing the most successful.

Length frequency distributions were analysed for samples taken between January 1964 and February 1967.

The apparent shrinkage of fish after death was investigated, and a correction factor calculated for growth rate studies from tag returns.

A trial of four varieties of tags was run concurrently
Figure 1a. New Zealand landings of *Rh. plebeia* for the years 1944-1966.
with a tagging programme designed to investigate movement, 
growth and population dynamics. Spaghetti tags were shown 
to be superior to Petersen discs.

Growth data from tag returns was combined with that from 
otolith and length frequency interpretations, and seasonal and 
annual growth rates calculated.

A close relationship between inshore and offshore fish was 
proved, and evidence presented which indicated that two separate 
populations may be present.

Feeding habits were investigated, and the results related 
to age and locality.

Population estimations, survival, recruitment and 
emigration rates were calculated, and the importance of certain 
inshore regions to the offshore grounds discussed.

1.4. Introduction

This thesis is based on a research programme commenced in 
January 1964 by the writer in the capacity of a biologist with 
the New Zealand Marine Department. The original intention was 
to conduct an investigation of the sand flounder in the Banks 
Peninsula region, with a view to obtaining information to 
facilitate the planning of a major long-term programme. The 
main topics covered during this period were investigations into 
methods of age determination, and a trial of tag types. The 
particular regions studied were the Heathcote - Avon Estuary,
Figure 1b. Port landings of *Rh. plebeia* for the Canterbury area for the years 1944-1966.
Lyttelton Harbour and Akaroa Harbour.

When the writer joined the University of Canterbury in 1965, the project was increased in scope, particularly in the fields of otolith staining techniques, length frequency distribution analyses, and detailed movement studies to include the offshore trawling grounds.

1.c. **Systematic position**

For the purposes of this study, the writer has used Norman's "Monograph of the Flatfishes" (1934), which is widely accepted. No attempt has been made to investigate the systematic position occupied by *Rhombosolea plebeia* (Richardson), but Norman's classification will be quoted.

(Quoted by Norman 1934).

Norman, following Regan (1929) considers that the flatfishes constitute a homogeneous group derived from a generalised percoid stock. He divides the Heterosomata into five families: Pseicotidae, Soleidae, Cynoglossidae, Bothidae and Pleuronectidae.

It is to the family Pleuronectidae that *Rhombosolea* belongs.

This genus contains four species, all of which inhabit the shallow coastal regions of New Zealand. *Rhombosolea retiaria* (Hutton) inhabits marine, brackish and fresh water regions throughout the country; *Rh. tapirina* (Gunther) inhabits marine and brackish regions, and is found mainly south of Banks Peninsula, but may also occur in parts of Australia; *Rh. millari* (Waite) inhabits marine and brackish regions throughout New Zealand and possibly Australia; and *Rh. plebeia* (Richardson)
Figure 1c. Total and percentage values of the sand flounder catch for the years 1960-1966.

(Taken from Marine Dept. N.Z. Annual Reports 1960-66).
inhabits marine and brackish regions throughout New Zealand, the Auckland Islands, and possibly Australia.

*Rh. plebeia* has many common names given to it by commercial and amateur fishermen. As well as sand flounder, it is also known as the white, common, square or New Zealand flounder, dab, tinplate, three-corner and patiki.

1.d. **The Commercial Fishery**

Figure 1.a. shows the annual New Zealand landings for the sand flounder since 1944. Two conclusions are obvious: the six yearly cycle of landings, with peaks in 1947-48, 1953-54, and 1960, and the basically static state of the fishery taken overall, until the increased catches for 1965 and 1966.

Figure 1.b. shows the annual landings for each of the Canterbury ports and Lake Ellesmere. The cycle of landings is not very pronounced for Lyttelton, although the highest landings are during 1947, 1953-55 and 1961. Akaroa shows highest landings in 1948, 1953 and 1960. Timaru shows peaks for 1947-48, 1953 and 1960. Furthermore, all three regions show an extremely heavy catch for the year 1965.

The highest landings and widest fluctuations in catch occur at Timaru and Lake Ellesmere. There is a marked similarity in the pattern of landings for these two areas, with the highest Lake Ellesmere catches tending to follow one year behind the Timaru peak landings.
Figure 1d. Prohibited trawling zones in the vicinity of Banks Peninsula.
The value of the sand flounder for the country as a whole is shown in figure 1.c. A comparison is made with the total wet fish catch.

1.e. Distribution

The sand flounder is a shallow water species, found within 30 fathoms off Canterbury, but reported caught to 60 fathoms off Otago (Thompson and Anderton 1921). It inhabits most, if not all of the estuaries, bays and harbours of Banks Peninsula, and is taken offshore, largely on specified grounds - figure 1.d.

The catches are largely seasonal, fish being taken within Banks Peninsula Bays from March until August. The heaviest catches taken offshore are August to December at the Akaroa Heads, August to October on the Winter Ground, and November to March on the Flounder Patch.

The stock of flounders around Banks Peninsula is protected from the activity of trawlers, due to the prohibited trawling zones laid down by the Marine Department (figure 1.d.). Sand flounders within the Estuary are subject to a considerable degree of amateur fishing by beach seine; furthermore, because of the generally small size of fish captured, it is known to the writer that many undersized fish are taken from the area. Lyttelton Harbour and Akaroa Harbour are subject to limited amounts of commercial and amateur beach seining. With the delicensing of fishing boats in 1964, the rate of exploitation on these confined waters has risen rapidly.
Methods of Capture

Samples were taken at two monthly intervals for purposes of tagging, length frequency analysis, otolith, gut and gonad examination.

Inshore Waters

The Estuary was sampled by means of a 2½ inch (stretched mesh) beach seine, 30 yards in length. The lead line was cut parallel to the selvage, the cork line being shaped continuously to give 20 meshes at the start of the wings to 80 meshes at the centre of the bunt. Fishing was done at low tide, when the fish were concentrated in the main channels, the mud-flats being exposed, and the current greatly reduced or absent. Captured fish were held in the live cage shown in plate 1.a. This comprised three half inch mesh galvanized steel trays 43 x 18 x 4 inches deep, mounted one on top of the other in a half inch wire netting covered frame. Floats were attached to give enough buoyancy to hold the cage at the water line. By this means, up to 1,000 fish were held for purposes of sampling and tagging. Such a capacity was necessary as numbers of this magnitude were frequently taken in one haul.

Sampling in Lyttelton and Akaroa Harbours was carried out with an otter trawl. After experiments with mesh sizes, a 2½ inch trawl was constructed, modified from a pattern given by Rupp and DeRoche (1960).
Plate 1.a. Floating holding cage used for tagging in the Estuary.
The net was modified to the extent of having twelve foot wings attached to each side panel, bringing the overall ground- 
rope to 50 feet, and headrope to 48 feet. The otter boards 
measure 43 x 27 inches, being attached by thirty foot double 
extensions to the trawl. Thirty yard warps of S.F. 120 
braided rope were found suitable for depths up to 35 feet. 
In water deeper than this it was found necessary to use steel 
warps to attain sufficient weight to keep the gear fishing.

Fishing in both Akaroa and Lyttelton Harbours was carried 
out from chartered local commercial fishing vessels, ranging 
from 20 to 28 feet in length. Towing was normally done for 
periods of between \( \frac{1}{2} \) and \( \frac{3}{4} \) of an hour, depending upon the 
amount of debris and other species of fish being taken.

On capture, fish were retained alive by means of a live 
tank on board the vessel. This tank comprised a plywood box, 
42 x 24 x 12 inches, with a lip to reduce spillage. A \( \frac{1}{4} \) inch 
metal stainless steel screen kept slopping, and the associated 
physical injury to the fish, to a minimum. The water supply 
was simply a deck hose, with an overflow to keep the water 
depth at about eight inches. The numbers of fish captured in 
the short tows undertaken did not necessitate the use of trays 
to keep the fish separate and facilitate water circulation. 
On emptying the cod end into the live tank, it was found 
better to clean out all unwanted fish and debris immediately 
before filling with water. This prevented accumulation of 
mucous-laden water, a condition proving fatal to fish in a
Plate 1.b. Large live tank used for offshore tagging.
few minutes in warm weather.

1.2. Offshore Waters

Sampling on these grounds was done from chartered vessels between 38 and 50 feet in length. Commercial-sized trawls of 60 and 80 feet respectively were used, with a 4½ inch body mesh and 2½ inch cod end mesh.

The fishing procedure on these grounds was identical to that carried out inshore, except that sorting took place in the deck pond, and a somewhat more elaborate live tank was used. The main difference was an increase in size (60 x 36 x 12 inches) with more screens to counteract the action of a normally rougher sea - plate 1b. Water was again supplied by means of the boat's deck hose.

Tagged fish were retained in the live tank until the end of the tow, and released once the gear had been retrieved. Releasing the fish immediately was avoided because of the danger of damage from the vessel's propeller, and the possibility of a second recapture in the trawl.

1.4. Presentation of Thesis

This thesis has been presented as a series of associated papers, each dealing with one aspect of the biology of the sand flounder.

The papers, in order of sequence, are:
(1) A method of age determination of the sand flounder *Rhomboselea plebeia* (Richardson) by the use of stained otoliths.

(2) Length frequency distributions of the sand flounder *Rhomboselea plebeia* (Richardson) inhabiting the Banks Peninsula region.

(3) Errors encountered in growth rate calculations due to length shrinkage after capture for the sand flounder *Rhomboselea plebeia* (Richardson).

(4) A comparison of Petersen and spaghetti tags used in a study of the sand flounder *Rhomboselea plebeia* (Richardson).

(5) Movements of the sand flounder *Rhomboselea plebeia* (Richardson) in Canterbury waters.

(6) Growth rate of sand flounder *Rhomboselea plebeia* (Richardson) off Banks Peninsula.

(7) Feeding habits of the sand flounder *Rhomboselea plebeia* (Richardson) in Canterbury waters.

(8) Some estimates of the population of the sand flounder *Rhomboselea plebeia* (Richardson) inhabiting three localities around Banks Peninsula.

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1.1. A method of age determination of the sand flounder *Rhombopterus plebeia* (Richardson) by the use of stained otoliths.

**1.1.1. Summary**

Various standard techniques for improving the reading qualities of otoliths were investigated and found unsuitable. A method of staining the protein matrix of the winter ring is described, and evidence presented which shows this method of age determination to be valid for the sand flounder. The interpretation of the otolith is based on the nucleus depicting the first twelve months of life, followed by alternate translucent summer and opaque winter rings. A suggestion is made that spawning checks may be present in the otoliths of many fish above two years of age.

**1.1.2. Introduction**

Some method of age determination is essential for any study concerning the growth of fish, and furthermore, is necessary for all studies leading to the appraisal of population dynamics.

**1.1.2.1. Basic methods of age determination**

Three main techniques have been adopted by workers in this field. The first involves the recognition of periodic markings
on certain skeletal structures, the most frequently used
being scales, otoliths, vertebral bones, fin rays and
operculae. The second, known as "Petersen's method", after
his pioneer work on the growth of plaice (Petersen 1894),
makes use of the polynodal nature of the length frequency
distributions of samples containing fish of more than one age
group. The third method involves the marking and recovery of
tagged individuals. These latter two methods will be dealt
with in subsequent chapters.

1.1.2.2. Age determination using skeletal structures

Scales and otoliths are generally the most convenient
methods for age determination. The use of both these methods
is acceptable provided the results can be subjected to
empirical proof.

With the sand flounder, it was found that scales proved
difficult or impossible to read. Work was therefore concen-
trated on otoliths, these being readily obtainable, and
generally easier to work on than other skeletal structures.

1.1.3. Spawning time and sexual maturity.

For purposes of age determination, the approximate time
of spawning must be known. Samples taken for otolith examin-
ation were also inspected for the state of maturity of the
gonads. This showed the breeding season to be prolonged,
ripe fish being taken between June and December. The peak period as regards the occurrence of ripe fish was August and September, so that for purposes of age determination, the 1st of September has been taken as the theoretical "birthday" for *Pleuronectes plebeia*. This agrees with the findings of Thompson and Anderton (1921) for flounders off the Otago coast.

The size at which sexual maturity was reached differed in males and females. From 785 fish examined, it was known that 70% of males were mature at between 18 and 25 cm., whereas only 21% of females were mature within this range, 70% of females reaching maturity at between 25 and 30 cm.

1.1.4. CTOLITHS

1.1.4.1. Introduction

Héibisch (1899 - cited by Moore 1947) was the first to point out the use of otoliths in the study of plaice. The otolith - for purposes of age determination this refers to the sagitta - shows alternate light (translucent) and dense (opaque) rings in reflected light. In transmitted light the translucent rings become the dark rings. Héibisch maintained that the dense, opaque rings were deposited at low temperatures. Cunningham (1905) refuted this, maintaining that an increase in calcification of a ring would occur during summer in warm water when growth was at its height, and that the rings in winter, when growth was at a standstill, would be translucent. This
theory was apparently based on the assumption that the opaque nature of the ring was due to calcification.

1.1.4.2. Method of sampling

To enable a selection of otoliths covering a cross-section of the population size range to be collected, stratified sub-samples were taken at two monthly or monthly intervals. These collections were made concurrently with length frequency sampling. Fish were selected so that a sample of ten fish for each five centimetre length group was obtained. This gave each sample a theoretical maximum of 100 fish, but sufficient numbers of fish at each end of the scale were never obtained.

After capture, fish were measured on board the vessel, and deep frozen on return to the laboratory. This avoided any possible error due to shrinkage after death.

1.1.4.3. Storage of Otoliths

As freezing caused no apparent deterioration of the structure of the otolith, material was normally stored in this manner for two to three months. Samples were then handled in bulk amounts for removal of the otolith and storage prior to reading.

Various standard storage methods were investigated, comprising the use of glycerin, clove oil, cedarwood oil, and xylol. Such agents generally appeared to impair the reading qualities of the otolith, resulting, finally, in all samples
being cleaned in detergent after removal from the fish, rinsed and stored dry.

1.1.4.4. Methods of Reading

Initial attempts comprised reading the whole otolith in its normal state, either immersed in water, ethyl alcohol or xylol, using transmitted or reflected light. The choice of the type of light sources is of great importance in this method, and is chosen to suit the individual otolith under examination.

This method is apparently satisfactory as regards reading of otoliths showing four rings – presumably two year old fish. Fish with more than four rings gave cause for concern as to the reliability of the method, particularly with regard to the interpretation of the outer rings.

Other standard methods of otolith preparation, found satisfactory by other workers and covering a wide range of fish species, were therefore investigated in an attempt to find a method which would result in the satisfactory age determination of older sand flounders.

1.1.4.5. Sectioning and Grinding

Sectioning and grinding techniques have been widely used with varying degrees of success. Campbell and Messeroff (1965) describe a technique of longitudinal and axial fracture for the otoliths of the whiting (Merlangius merlangus). Taning
Plate 1.1.1. Otolith grinding machine.
(1938) embedded cod otoliths in gypsum, and ground the otolith from both sides to obtain best results. Campbell and Neustorff found, however, that the unpolished surface of the fracture was easier to read.

In order to facilitate the grinding of otoliths a machine designed by Witt (1961) was constructed for this purpose. Plate 1.1.1. shows a photograph of this machine. Otoliths were attached with a clear epoxy resin glue to \( \frac{1}{4} \) inch long strips of \( \frac{1}{2} \) inch diameter perspex rod.

Grinding was done in two ways. Firstly, otoliths were glued to the rod so that the sulcus acousticus lay uppermost, and were then ground as far as the nucleus. Secondly, otoliths were glued into a slot in the top of the rod, and ground longitudinally, again only as far as the nucleus. The otoliths could then be viewed in reflected light, or by transmitted light via the length of the perspex rod.

The first method was generally more satisfactory than the second and while it had definite advantages over direct reading, many otoliths were still encountered in which the outer rings were difficult to interpret. Frequently, this difficulty was caused by what can only be described as secondary opaque rings forming within the translucent zone.

1.1.4.6. **Burning**

The heating or burning of otoliths is a technique found successful with some species of fish, e.g. Chuganova (1963).
and Christensen (1964). The method involved usually consists of placing the otolith on a hot plate, or holding it in an alcohol flame. Neither method was found to be practical for flounder otoliths, largely because of fracturing and charring.

1.1.4.7. Staining

An investigation of the microstructure of the otolith by Irie (1960), with the aid of an electron microscope, has yielded much information on the difference in structure between summer and winter rings. He has shown that the summer rings comprise relatively large crystals of calcium carbonate, in the form of aragonite, each crystal apparently surrounded by a groove. Winter rings show the crystals to be smaller in size, and having this groove completely filled with an organic material, later shown to be protein. It is this protein, laid down during the winter months, which causes this ring to be opaque in reflected light.

Assuming, therefore, that Irie's interpretation of the ring structure was correct, it was felt that it should be possible to devise a technique for staining the protein in the winter ring.

No reference to any previous use of this method could be found, excepting one by Hagerman (1952), who stated that "decalcifying, sectioning and staining otoliths proved to be of no use".
Initial investigations were directed along the lines of staining the protein with a fluorescent "tagging" stain, the stained material then being viewed under ultra violet light for fluorescence.

1.1.4.8. Method

Experiments were conducted with locally available fluorescent stains — notably fluorescein, auramine, rhodamine B and fluorite.

Solutions of the stains in water were prepared at 25%, 50% and saturated strengths. After dissolving, the solution was brought to as near a neutral pH as possible, using 5% sodium hydroxide, to prevent any possible corrosion of the otolith. Otoliths left in these solutions took up the stain after two to four weeks with the saturated solutions, and two to six weeks with the 50% solution. Little take-up of stain was achieved by using a 25% solution.

As solutions stronger than 50% tended to crystallise out into the otolith, making cleaning very difficult, all future staining was done with the 50% strength.

For reading, otoliths were removed from the stain, brushed clean, dipped in 5% hydrochloric acid for 2-3 seconds to complete cleaning, rinsed in a calcium bicarbonate solution to neutralise the acid, and viewed under ultra-violet light.

Some success was immediately apparent with fluorescein. This success depended largely upon the correct choice of primary
Plate 1.1.2. A comparison between a stained and an unstained otolith from the same sand flounder, (length 21.0 cm), showing two broad stained (black) winter rings in the top photograph.
and secondary filters. An exciting wavelength of 450-490A was required, but there was some doubt as to the exact value of the achieved wavelength.

Of more interest, however, was the fact that otoliths stained with an auramine/rhodamine B mixture or with plain rhodamine B, after cleaning in acid and viewed under transmitted light, showed the opaque rings to be stained red, the translucent rings remaining colourless.

A series of comparisons was made between stained and unstained otoliths. Selected pairs, both of which were easily read in the natural state, had one of each pair stained, and the results then compared. In all cases the stained ring of one otolith corresponded to the opaque ring of the other.

Plate 1.1.2 shows such a comparison.

Material, comprising 785 otoliths, and covering the period September, 1965 to February, 1967 was examined by this method. Transmitted light was used at all times, and a green filter in front of the light source was found to reduce glare and improve contrast between stained and unstained areas. Any overstaining was remedied by further brief dipping in 5% hydrochloric acid. Further washing in a calcium bicarbonate solution then followed as before.

1.1.4.9. Results

One major difficulty in reading otoliths is to determine the significance of the nucleus. With the sand flounder, this
Plate 1.1.3. The otolith of a 26.5 cm sand flounder showing details of the nucleus.
interpretation was made in conjunction with three known facts. The rate of growth for the first year was known from length frequency curves and tag returns; the time of spawning had been observed, and otoliths from a small number of two to three centimetre fish had been examined.

The nucleus of the sand flounder otolith has therefore been interpreted as depicting the first twelve months of life. It can be seen (Plate I, Fig. 1) to comprise a central dark papilla, surrounded in turn by a translucent and an opaque ring. It is suggested that the papilla represents the period between hatching and metamorphosis, the translucent ring the first summer as a fully metamorphosed fish, and the opaque ring as the first winter - at the end of which the fish will be one year old.

Other workers have described the nucleus, e.g. Wallace (1947) (1907) and Moore, but considerable variation would appear to exist with different species of fish, and the interpretation of them.

Once the rings in the otoliths can be read with a satisfactory degree of uniformity, it is essential to produce evidence that will show that the rings are, in fact, a standard by which the fish can be aged.

This is most conveniently done following the methods of Matsuura, Mio and Yunokawa (1961).

Firstly, it must be shown that there is a basic relation-
Figure 1.1. The relationship between total fish length and otolith size.

Figure 1.2. The relationship between total otolith size and individual ring size.
ship between otolith size and total length of fish. Secondly, any variation in growth rate within a single year class should not be reflected in the number of rings in the otolith, although its overall size may vary. Thirdly, after compensating for variation in otolith size and growth rate within a year class, that in fact the rings are laid down in the otolith in a position which corresponds to the length of fish, enabling back calculations of length at each age to be made; and lastly, only one summer and one winter ring is laid down each year.

All the following measurements of ring size relate to the maximum diameter of opaque rings taken to the exterior edge.

Figure 1.1. shows the relationship between otolith size and total length of fish. The relationship has been taken as a linear one, and at the 1% level, \( p = 0.537 \), showing a positive correlation between the variables.

Figure 1.2. shows the result of plotting total otolith size \( (N) \) against individual ring size \( (r) \) for fish in the range 25-31 cm, from one year class. This shows that the distance between rings increases linearly with size of fish, providing that the same number of rings occurs in fish of one age class irrespective of the length of that fish.

Figure 1.3. shows the relationship between standardized ring diameter and total length of fish. Therefore, compensating for irregularities in growth of individual fish within a year class, rings are laid down on a regular basis with
Figure 1.3. The relationship between total fish length and standardised ring size.

Figure 1.4. The percentage number of fish possessing a partially or fully formed outer winter band.
respect to the length of the fish, and the position of corresponding rings in the otolith is independent of the number of rings in that otolith.

Figure 1.4 shows the relationship between time of year and percentage of the fish sampled having a partially or fully formed winter ring. This would indicate the period of winter ring formation to be between April and September. The period of summer ring formation is between October and December.

This analysis of ring formation and size gives sufficient evidence to support the method of ageing fish by the examination of their otoliths.

### 1.1.4.9.1. Ring formation as a guide to past life history

Certain characteristic types of ring formation may be connected with past life history.

It has already been shown that the rate of growth of individual fish of any year class is reflected in their otolith size. The structure of the nucleus shows large differences in the width of the innermost translucent and first opaque ring. It is suggested that this could be connected with the time of hatching. Fish hatched early in the season (July), would have a longer summer growth period than fish hatched later (November). A wide variation in width shown by the first winter ring is puzzling, although the size variation of both rings may be simply explained by variations in growth rate.
Plate 1.1.4. Variation in ring diameters found in the nucleus.
Plate 1.1.4. shows typical examples of the types of nucleus found.

Another frequently observed characteristic is the narrowness of the winter ring from the third winter onwards. The majority of female fish exhibit this characteristic in the otolith. The ring, averaging 0.1 to 0.2 mm in width for the first and second winter, then narrows to no more than 0.01 to 0.02 mm in width. These narrow rings never occur in young fish, and never alternate with the larger bands. Bearing in mind the fact that the flounder spawns during the winter months, it is possible that the narrow ring could represent a growth check associated with spawning. Hollemann (1935) reached a similar conclusion on observing similar rings in the otoliths of adult cod.

The interpretation of the otolith as shown in plate 1.1.5. would be as follows. The nucleus N, covers the pelagic stage, metamorphosis and ensuing summer and winter. A year of fast growth follows, shown by large summer (S) and winter (W) rings. The third and following winter rings show the typical narrowness which may be associated with spawning. The summer rings decrease in width with age, as does growth (paper 6).

1.1.5. Discussion

Much of the published work on the age determination of fish by otoliths is based on the fact that the white, opaque ring is the summer ring. Many workers apparently accept that
Plate 1.1.5. The otolith from a 47.5 cm sand flounder, stained with an auramine - rhodamine B mixture, showing 5 winter rings.
it is the summer ring because it is white and appears calcified (Cunningham). The work of Irie has disproved this, showing the whiteness to be due to protein around the calcium carbonate crystals. The staining technique developed for ageing flounders substantiates this - at least for the sand flounder. Aquarium tests by Molander (1947) using plaice show that fish held in cool tanks had wide opaque, and narrow translucent zones and those in warm tanks had wide translucent and narrow opaque zones. As the temperature of the tanks was kept constant, he suggests some inherent annual rhythm must be present. His findings are still in agreement with Irie’s interpretation of the structure.

1.1.6. Conclusions

The above tests applied to otolith readings have shown that this method of age determination for the sand flounder is permissible. It has been shown that one winter ring (opaque) and one summer ring is formed each year irrespective of the growth rate of the fish. The nucleus has been shown to represent the first complete year of life. Many female fish exhibit narrow winter rings from the third winter on. These may be spawning checks.
1.1.8. Bibliography


Chugunova, N.I. 1963: "Age and Growth Studies in Fish." Israel Program for Scientific Translations, Jerusalem. 132 pp. (Translated from Russian.)


Molander, A.R. 1947: Observations on the growth of plaice and on the formation of annual rings in its otoliths. 
_Svenska hydrogr. - Bk. Komm Skr._


2. Length frequency distributions of the sand flounder
Rhombochias plebeia (Richardson) inhabiting the
Banks Peninsula region.

2.1. Summary

The most representative sample of sand flounders was
shown to be taken with a 2½ inch stretched mesh net. Direct
comparisons with commercial gear showed a 50% retention level
at 17.7 cm for a 4½ inch net. Fish were shown to enter the
sample taken by 2½ inch gear when one year old, and enter the
commercially exploited phase of the population during their
second winter. The majority of harbour fish were shown to
be under three years of age, and evidence was found of a
marked movement from the harbours of two year old fish during
each spring, leaving a resident population of younger fish.

2.2. Introduction

Paper 1 was concerned with the determination of age by
means of the interpretation of seasonal markings on otoliths.

Results obtained by this method, while valuable in
themselves, are more fully justified if presented with support­
ing evidence.

Petersen's (1894) method of age determination is based on
the fact that the lengths of fish of one age tend to form a
normal distribution. The method is usually limited to the
Figure 2.1. Length frequency samples for *Rh. plebeia* with otter trawls of A) 4\(\frac{1}{2}\), B) 2\(\frac{1}{2}\) and C) 1\(\frac{1}{4}\) inch stretched mesh.
first two to four years of life, due to an increasing overlap in length distributions, and a lessening distance between the modes of older fish.

Length frequency distributions may also provide information on growth rate, and the relative abundance of year classes (survival rate).

2.3. Mesh Size

Worthwhile results from length frequency data are dependent upon capturing as representative a sample of the population as is possible. An investigation of the efficiency of various mesh sizes was undertaken in an attempt to ascertain the true value of the resultant data.

The catch obtained from standard commercial trawl gear is shown in figure 2.1.a. This graph indicates that escapement may occur with fish of less than \( \frac{25}{100} \) cm.

To check the size range sampled, a smaller trawl was constructed from a design by Mupp and De Hoche (1960). This had a mesh size of \( \frac{1}{2} \) inches, and was modified to the extent of having six foot wings attached to each side. A sample of the fish captured, figure 2.1.b. shows that a considerable escapement of young fish does occur with the commercial gear. However, it is quite obvious that a representative sample of fish above \( \frac{1}{4} \) cm was not captured. The reason for this is uncertain. One major disadvantage of a mesh of this size was the large numbers
Figure 2.2. Length frequency distributions for *Rh. plebeia* using parallel tows.
of blowfish (*Spheroidees richei*) and young dogfish (*Squalus acanthias* blown into) retained. Frequently these were caught in such large quantities as to render the gear unusable.

A compromise was sought by constructing a net from the original plan, but using $2\frac{1}{2}$ inch mesh, thus doubling the size. Figure 2.1.c. shows the sample taken. An escapement level of $\frac{1}{2}$ cm is indicated, but overall it provided the best representative sample, although there still appeared a tendency to undersample older fish. Davis (North Shields experiment, 1934), found that while a larger mesh allows more small fish to escape, it also catches proportionately more large fish. He suggested the reason for this was the freer flow of water through the gear.

All future sampling was undertaken with this $2\frac{1}{2}$ inch trawl, excepting the *Estuary*, which was fished by beach seine, of similar mesh size.

In order to obtain additional evidence as regards the value of the samples taken by the $2\frac{1}{2}$ inch trawl, a programme of experimental parallel towing was undertaken in Akaroa Harbour. Parallel tows were made using two vessels, one equipped with a $4\frac{1}{2}$ inch commercial trawl, and one with $2\frac{1}{2}$ and $1\frac{1}{2}$ inch trawls. Tows of equal duration were made, and the results compared.

Figure 2.2. shows the resulting sample from three hours trawling, together with the sample obtained from five days fishing with the $2\frac{1}{2}$ inch trawl. The results show that the
Figure 2.3. The selection ogive for *Rh. plebeia* taken by a 4½ inch mesh otter trawl.
1\frac{1}{2} inch net definitely undersamples larger fish, and the
2\frac{1}{2} inch net shows a limited tendency to do likewise.

A comparison of the catches made by these nets indicates
the level of escapement obtained by the 4\frac{1}{2} inch commercial
gear. A plot of the ratio of the catch per centimetre size
group for the 4\frac{1}{2} and 2\frac{1}{2} inch nets enables a selection ogive
to be compiled, as shown by figure 2.3. A 50% retention
level is given as 17.9 cm, and a 100% retention level as
22.0 cm.

According to Beverton and Holt's (1957) definition, the
age of entry to the exploited phase is determined by the size
at which 50% of the individuals are retained by the fishing
gear. It will therefore be of interest for purposes of future
administration to determine the levels of escapement for
various mesh sizes. This is done by means of the selection
factor, which is defined as

\[
\frac{\text{50\% retention length (cm)}}{\text{mesh size (cm)}}
\]

In this particular instance this is \(\frac{17.9}{11.4} = 1.57\).

Using this selection factor, the 50\% retention level for
other cod end mesh sizes can be calculated.
Figure 2.4. Banks Peninsula inshore tagging grounds.
Table 2.1. 50% retention sizes for commercial trawls

<table>
<thead>
<tr>
<th>Cod end mesh</th>
<th>50% retention level</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches</td>
<td>cm</td>
</tr>
<tr>
<td>3.5</td>
<td>8.9</td>
</tr>
<tr>
<td>4.0</td>
<td>10.2</td>
</tr>
<tr>
<td>4.5</td>
<td>11.4</td>
</tr>
<tr>
<td>5.0</td>
<td>12.7</td>
</tr>
<tr>
<td>5.5</td>
<td>14.0</td>
</tr>
</tbody>
</table>

2.4. Method

Sampling was undertaken at two monthly intervals between January 1964 and July 1965 in both harbours, followed by monthly samples up to February 1967. The Estuary was sampled at two monthly intervals between March 1965 and July 1966, and then monthly as above. Figure 2.4 shows the tagging localities in question.

Sample periods comprised five days fishing (consecutive when possible) for two monthly samples, and two day periods for monthly samples.

Trawling comprised three-quarter hour tows; Estuary beach seining was conducted at low tide. All fish were held in live tanks prior to measuring. The measurement taken was the overall length of the fish, and was taken to the nearest millimetre.
2.5. Results

All length frequency samples have been analysed into year classes, and mean length for each year class. Analysis was done by combining the form of the length frequency curve with the results of otolith readings for each particular month. Final selection of year class position and mean length was done by Cassie's (1950) probability paper method.

The results obtained for Akaroa Harbour, Lyttelton Harbour and the Estuary are shown on the following pages.
Figure 2.5. Length frequency distributions for *Rh. plebeia* for Akaroa Harbour for the period May 1965 to February 1967.
2.5.1. Akaroa Harbour

Figure 2.5. shows the samples taken between May 1965 and February 1967.

Table 2.2. gives the mean length of each year class:

Table 2.2. Mean length of each year class from Akaroa Harbour.

<table>
<thead>
<tr>
<th>Year Class</th>
<th>0+</th>
<th>1+</th>
<th>2+</th>
<th>3+</th>
<th>Year Class</th>
<th>0+</th>
<th>1+</th>
<th>2+</th>
<th>3+</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965 March</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1966 March</td>
<td>12.5</td>
<td>18.0</td>
<td>28.0</td>
<td>36.5</td>
</tr>
<tr>
<td>April</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>April</td>
<td>13.0</td>
<td>19.0</td>
<td>29.6</td>
<td>35.5</td>
</tr>
<tr>
<td>May</td>
<td>12.4</td>
<td>18.0</td>
<td>28.3</td>
<td>35.0</td>
<td>May</td>
<td>13.8</td>
<td>20.7</td>
<td>31.3</td>
<td>37.0</td>
</tr>
<tr>
<td>June</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>June</td>
<td>13.1</td>
<td>20.7</td>
<td>30.9</td>
<td>36.5</td>
</tr>
<tr>
<td>July</td>
<td>14.1</td>
<td>20.4</td>
<td>29.5</td>
<td>36.5</td>
<td>July</td>
<td>14.3</td>
<td>22.5</td>
<td>31.5</td>
<td></td>
</tr>
<tr>
<td>Aug</td>
<td>14.9</td>
<td>21.5</td>
<td>30.0</td>
<td></td>
<td>Aug</td>
<td>14.4</td>
<td>21.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sept</td>
<td>9.5</td>
<td>15.1</td>
<td>22.7</td>
<td>32.8</td>
<td>Sept</td>
<td>15.8</td>
<td>24.4</td>
<td>32.1</td>
<td>37.0</td>
</tr>
<tr>
<td>Oct</td>
<td>12.9</td>
<td>20.0</td>
<td>24.5</td>
<td>33.5</td>
<td>Oct</td>
<td>12.1</td>
<td>18.8</td>
<td>27.7</td>
<td>35.0</td>
</tr>
<tr>
<td>Nov</td>
<td>11.6</td>
<td>19.8</td>
<td>26.0</td>
<td>35.0</td>
<td>Nov</td>
<td>11.6</td>
<td>21.5</td>
<td>29.6</td>
<td>37.7</td>
</tr>
<tr>
<td>Dec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dec</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1966 Jan</td>
<td>12.2</td>
<td>19.0</td>
<td>26.8</td>
<td>35.5</td>
<td>1967 Jan</td>
<td>12.2</td>
<td>22.6</td>
<td>30.4</td>
<td>37.0</td>
</tr>
<tr>
<td>Feb</td>
<td>13.0</td>
<td>19.8</td>
<td>27.5</td>
<td>36.0</td>
<td>Feb</td>
<td>12.7</td>
<td>24.8</td>
<td>31.1</td>
<td></td>
</tr>
</tbody>
</table>

From table 2.2. The rate of growth per year for each year class can be calculated by taking the mean of the length differences between year classes for each monthly sample.
Hatching to 0+ & 1965 & 6.6 cm & 1966 & 8.1 cm  
0+ to 1+ & 8.1 cm & 8.9 cm  
1+ to 2+ & 8.2 cm & 6.5 cm  

A factor had been added to the 1965 value to compensate for the unsampled period March to May.

The entry of the new year class into the sample can be seen in September 1965 and October 1966. These fish would be the product of the previous winter/spring spawning, and therefore are one year old at this stage.

The extended period of entry of young fish into the sample - September to January - is probably related to a similarly prolonged spawning season.
Figure 2.6. Length frequency distributions for *Rh. plebeia* for Lyttelton Harbour for the period July 1965 - January 1967.
2.5.2. Lyttelton Harbour

Figure 2.6 shows samples taken between July 1965 and January 1967.

Table 2.3 gives the mean length of each year class for the areas February 1966 to January 1967. No reliable breakdown of the distribution into year classes prior to February 1966 was obtainable.

Table 2.3. Mean length of each year class from Lyttelton Harbour.

<table>
<thead>
<tr>
<th>Year Class</th>
<th>0+</th>
<th>1+</th>
<th>2+</th>
<th>3+</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966 Feb.</td>
<td>12.5</td>
<td>19.6</td>
<td>25.8</td>
<td>31.5</td>
</tr>
<tr>
<td>March</td>
<td>13.1</td>
<td>20.3</td>
<td>26.3</td>
<td>32.5</td>
</tr>
<tr>
<td>April</td>
<td>13.5</td>
<td>22.3</td>
<td>29.0</td>
<td>36.0</td>
</tr>
<tr>
<td>May</td>
<td>14.3</td>
<td>22.3</td>
<td>28.4</td>
<td>-</td>
</tr>
<tr>
<td>June</td>
<td>15.2</td>
<td>23.0</td>
<td>29.1</td>
<td>-</td>
</tr>
<tr>
<td>July</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aug</td>
<td>11.0</td>
<td>16.5</td>
<td>23.0</td>
<td>29.0</td>
</tr>
<tr>
<td>Sept</td>
<td>11.0</td>
<td>17.0</td>
<td>26.9</td>
<td>36.5</td>
</tr>
<tr>
<td>Oct</td>
<td>10.5</td>
<td>17.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nov</td>
<td>11.6</td>
<td>18.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dec</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jan</td>
<td>12.8</td>
<td>21.3</td>
<td>28.5</td>
<td>-</td>
</tr>
</tbody>
</table>

From Table 2.3, the rate of growth per year for each year class can be calculated as below:

- Hatching to 0+ (September) 7.3 cm
- 0+ to 1+ 6.8 cm
- 1+ to 2+ 6.9 cm
The samples obtained from Lyttelton generally contained fewer fish than those from Akaroa, and those from October onwards must be regarded as inadequate for purpose of age and growth determination.

The entry of one year fish into the sample can be seen in October of each year, and appears to continue at least until December.

One important aspect of the commercial fishery in Akaroa and Lyttelton Harbours is the seasonal fluctuation in catch. In both harbours the fishing season is primarily an autumn and winter one. The length frequency curves shows a marked decline in numbers of fish over 25 cm during August and September, followed by an increase commencing during January and February. Such a decline in numbers is presumably due in part both to fishing and natural mortalities, but the decline is sharp enough in the spring to suggest that migration may play an important part in this.

Fish of year class 0+ do not show as great a decline in numbers, and the length frequency curves indicate that a considerable number remain in the harbours until the following winter. The relative importance of natural mortality and migration as a cause in the decline of numbers of 0+ fish is unknown. It has been observed that large numbers of red cod (Physiculus bacchus) are frequently caught in these harbours,
especially Akaroa, and young flounders have been observed in quantities in the stomachs of these fish.
Figure 2.7. Length frequency distributions for *Rh. plebeia* for the Estuary for the period March 1965 to January 1967.
2.5.3. The Estuary

Figure 2.7. shows samples taken between March 1965 and January 1967.

Table 2.4. gives the mean lengths.

Table 2.4. Mean length frequencies of Estuary flounders.

<table>
<thead>
<tr>
<th></th>
<th>1965</th>
<th>1966</th>
<th>1967</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>-</td>
<td>-</td>
<td>16.8</td>
</tr>
<tr>
<td>Feb.</td>
<td>-</td>
<td>16.2</td>
<td></td>
</tr>
<tr>
<td>March</td>
<td>11.0 19.0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>-</td>
<td>17.2</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>17.0</td>
<td>16.3</td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Aug.</td>
<td>17.4</td>
<td>14.3</td>
<td></td>
</tr>
<tr>
<td>Sept.</td>
<td>-</td>
<td>17.4</td>
<td></td>
</tr>
<tr>
<td>Oct.</td>
<td>17.1</td>
<td>17.1</td>
<td></td>
</tr>
<tr>
<td>Nov.</td>
<td>-</td>
<td>19.0</td>
<td></td>
</tr>
<tr>
<td>Dec.</td>
<td>19.0</td>
<td>17.1</td>
<td></td>
</tr>
</tbody>
</table>

Two factors are immediately obvious. Firstly, the majority of the fish in each sample comprise one year class (1+), and secondly, the mean lengths vary erratically month by month, and indicate a slow annual rate of growth. As estuarine localities of this nature normally provide very rich feeding grounds, it
is unlikely that the growth rate would be exceptionally slow in this case. A more likely explanation for the slow mode movement would be the entry of young fish into the sample, and the migration of larger fish from the area. Of the fish leaving, most appear to do so before reaching 25 cm in length.

Figure 2.7. does give some general indications of fish movement. Young fish enter the sample between December and January in both the years sampled. The numbers of older fish migrating from the area increases during this period.

The low mean of the August 1966 sample is difficult to explain, but may well be caused by rather localised sampling.

2.6. Discussion

Sampling for length frequency data as described has yielded information in respect of the age structure of the population and the growth rate.

The prolonged entry of young fish into the sample in both Lyttelton and Akaroa is evidence of an extended spawning period. This in turn makes length frequency analysis difficult. Many of the distributions shown would have been very difficult to break down without information yielded by otolith readings. This problem is aggravated by gear which does not catch a representative sample. An alternative method would have been to undertake parallel trawls with different nets. Figure 2.2. shows the result of such trawling in Akaroa Harbour. The break-
down of the 2¾ inch catch by otolith data and Cassie's method agrees well with the distributions obtained by these parallel tows.

2.7. Conclusion

Sampling by means of a 2¾ inch net has shown that fish enter the catch when one year old, and enter the commercially exploited phase of the population during their second winter.

Analysis of the length frequency distributions obtained has shown that the harbour population is comprised of fish up to the age of four years (3+), the majority being one and two year olds. There is evidence of an annual spring movement of 1+ and older fish away from the sampling areas, a resident population of 0+ fish remaining until the end of the following winter.

The use of parallel tows to assist in length frequency analysis has enabled estimations to be made of the length at which fish enter the post-recruit phase. For a 4¾ inch mesh cod end net this is 17.9 cm, and for the minimum legal size limit of 4 inches, the level is 15.8 cm. With a minimum legal fish length of 22.8 cm (9 inches), the present regulations can only be regarded as being highly unsatisfactory for this particular species. Furthermore, it was stated in paper 1 that only 21% of female sand flounders were sexually mature between the sizes of 21 and 25 cm. In order to allow the essential escapement of young sand flounders prior to
reaching sexual maturity, a cod end mesh of 5\(\frac{1}{2}\) inches would be necessary.

2.8. Bibliography


3. Errors encountered in growth rate calculations due to length shrinkage after capture for the sand flounder 
*Rhombosolea plebeia* (Richardson).

### 3.1. Summary

Tagged fish returned to the laboratory shortly after release frequently showed some decrease in length. This decrease was not found with live material. Further investigation showed an average shrinking of 2.3% during storage. A linear relationship \( Y = 0.023x + 0.004 \) was shown to exist between the length of fish and the amount of shrinking, a minimum legal size fish shrinking an average of 5.3 mm, with the probability of 2\% of the fish shrinking 6.95 mm, and 1\% shrinking 7.82 mm.

### 3.2. Introduction

The experiences of earlier workers engaged in tagging fish have shown that for accurate determination of growth rates, an allowance must frequently be made for shrinkage occurring after capture and death. Johansen (1907), working on plaice, found that an average shrinkage of 2.2% occurred after ten hours on deck. Lux (1960), found an average shrinkage of 1.47% for yellowtail flounder.

During the course of a tagging programme on the sand flounder (*Rhombosolea plebeia*) (paper 6), it was observed that
Figure 3.1. A comparison of growth rates for *Rh.plebeia* obtained from A) live, and, B) frozen material.
the majority of tagged fish returned to the laboratory after capture by commercial trawlers within three to four weeks of liberation showed some shrinkage. For the purpose of determination of growth rate, it was therefore necessary to determine to what extent this shrinkage occurred, and to make the necessary corrections to allow for it.

3.3. The Return of Tagged Fish to the Laboratory

After capture by trawlers, tagged fish were placed in specially provided polythene bags on board the vessel, and frozen upon return to the wharf. The time spent on deck varied for periods of up to 24 hours, and averaged two weeks in the freezer. On subsequent thawing, the fish were measured, sexed and weighed.

3.4. Growth Rates

Figure 3.1. shows the comparison between growth rates of fish as recorded by measuring frozen material as against that recorded by measuring live material. Measurements were taken by the same personnel in all cases. The live material measured comprised flounders caught on board chartered vessels. Both curves have been drawn to show a linear relationship. This is felt justified in view of the short time period from which the data has been taken. Furthermore, any variations of growth rate between the various year classes of fish have been ignored.
However, figure 3.1. shows clearly that a true growth rate is not indicated by the measurement of frozen material, unless some factor is taken into account to compensate for shrinkage. While some small shrinkage may occur as a direct result of the tagging process itself, it is regarded as being of no consequence within the framework of this study.

3.5. Method

This problem was investigated in such a manner as to try to show whether shrinkage occurred during deck storage, during subsequent freezing, or both.

3.5.1. Storage on Deck

A random selection of 100 fish was taken from one trawl shot. The fish were held alive until they could be measured, tagged and stored on deck in a standard fish case. Remeasuring was undertaken at two hourly intervals for six hours, the same person measuring throughout.

3.5.2. Frozen Storage

A selection of 100 fish was taken as above, measured, tagged and stored in a covered fish case until the return to port. Freezing took place immediately on return to the laboratory. The period between capture and freezing varied as these fish had to be collected from several trawl shots.
Figure 3.2. The relationship between total length and shrinkage for *Rh. plebeia*. 
3.6. Results

3.6.1. Storage on Deck

Table 3.1. shows the average shrinkage occurring at two hourly intervals. This is given as the percentage of the original length of the fish.

Table 3.1. Shrinkage occurring with deck stored fish.

<table>
<thead>
<tr>
<th>Time</th>
<th>Two Hours</th>
<th>Four Hours</th>
<th>Six Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Shrinkage</td>
<td>1.1%</td>
<td>1.5%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Range of Shrinkage</td>
<td>0.0-2.0%</td>
<td>0.5-3.0%</td>
<td>0.9-3.9%</td>
</tr>
</tbody>
</table>

3.6.2. Frozen Storage

The material measured was allowed to thaw overnight. In both (w) and (%) remeasuring was done by the original operator.

The shrinkage occurring with frozen material covered a range of 0.7 to 3.9%, with an average of 2.3%.

3.7. Relationship of Original Length to Shrinkage

The data shown in figure 3.2. is that taken from the measurements made from frozen fish.

A linear relationship can be seen to exist (Y = 0.023 X + 0.004). With 21 degrees of freedom and r = 0.614, a positive correlation between the variables exists at the 1% level.
Figure 3.2. shows that the average value for the shrinkage occurring with a legal sized fish (9 inches or 22.8 centimetres) is 0.52 cm. The standard deviation for the data presented in figure 3.2. is 0.087.

From the standard deviations shown, the amount of shrinkage at different probability levels can be predicted. These are given in table 3.2.

Table 3.2. Predicted shrinkages at different probability levels.

<table>
<thead>
<tr>
<th>Legal Size Limit</th>
<th>Average Shrinkage</th>
<th>Probability of Shrinkage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>68% level</td>
</tr>
<tr>
<td>9 inches 22.8 cm</td>
<td>5.3 mm</td>
<td>6.08 mm</td>
</tr>
<tr>
<td>10 inches 25.4 cm</td>
<td>5.8 mm</td>
<td>6.67 mm</td>
</tr>
</tbody>
</table>

3.8. Discussion

The two methods described for the investigation of shrinkage indicate little difference between methods of storage. Although the fish examined after freezing are likely to have shrunk to some extent before freezing, the close agreement between results would indicate that this was relatively unimportant. The problem could, perhaps, be more fully investigated with regard to existing weather conditions, and different frozen storage times.
The level of shrinkage found by the methods used here agree well to the figures given by other workers.

It is obvious, therefore, that in any study involving the estimation of growth rate from stored material, some compensating factor must be added.

3.9. Conclusion

An average shrinkage of 2.3% has been shown to occur with sand flounders on storage. A legal size fish of nine inches (22.8 cm) is therefore subject to a shrinkage of 5.3 mm, with a probability of 23% of the fish of this length shrinking 6.95 mm, and 1% shrinking 7.82 mm.

3.10. Bibliography


4. A comparison of Petersen and spaghetti tags used in a study of the sand flounder *Rhombocephalus plebeia* (Richardson).

4.1. **Summary**

An analysis of the returns from Petersen tags showed an average recapture rate of 17.3%, compared with 20.3% for spaghetti tags. Double Petersen tags gave a return of 20.6% and single Petersen 14.0%. Clipped spaghetti tags gave a return of 22.3%, and tied 18.3%. Spaghetti tags proved easier to attach to the fish, caused less wound formation, and were easier to recognise when recaptured.

4.2. **Introduction**

Marking members of a natural population so that they can be identified later provides a direct and convenient method of studying long and short-term movements at different life history stages, delineating geographical ranges, measuring the rate and pattern of growth, providing information on the validity of skeletal markings as indicators of age, and for population studies to obtain estimates of mortality rates and population size.
Plate 4.1. Method of holding fish and tagging for inshore work.
4.3. Tagging Techniques

The majority of length frequency samples described in paper 2 were taken from samples of fish caught for purposes of tagging. Fishing methods were therefore, those described in that paper. Trawl shots in Lyttelton and Akaroa Harbours were normally of ¾ to ½ of an hour’s duration, depending upon the numbers of other fish and amount of weed present. Such material tends to injure flounders during long tows. Even during relatively clean hauls, the loss of scales becomes noticeable when tows exceed about an hour’s duration.

On the completion of each haul, the contents of the cod end were emptied directly into the live tanks, plate 4.1. The gear was reset immediately, and towing continued during the ensuing tagging operation. It was found more practical to sort the fish before filling the tank, thus preventing the accumulation of mucus laden water, a condition which proved fatal to fish in a few minutes, especially under warm conditions.

Tagging was restricted to fish of 17 cm and over. It was felt that fish below this size were too small to carry some of the tags used in this study. Sickly, injured or badly scaled fish were not tagged. After tagging, all fish were retained in the live tanks until the gear had been retrieved. This avoided any chance of their being damaged by the propeller or caught a second time. The most satisfactory method of releasing
Figure 4.1. Banks Peninsula inshore tagging grounds.
fish was simply to return them in a bucket of water, tipping the bucket once below the surface of the sea. This overcame any danger of stunning by being thrown overboard, and kept predation by gulls to a minimum.

Tagging was done in the estuary at the water's edge. A cage (plate 4.2.) enabled fish to be held for any required length of time provided adequate tidal flow was available. After tagging, each fish was returned directly to the estuary. From experience received on board the trawlers, no advantage was gained by holding fish after tagging as a check on their condition.

Tagging localities are shown in figure 4.1.

4.4. Tag Varieties

Whatever tag types are used for the marking of fish, they must fulfil certain properties to as great a degree as possible. The main criteria are that they must not affect the mortality rate, the fish's vulnerability to fishing gear, they must not be shed, must be easily recognisable when caught, and should be as simple as possible to apply.

As part of the requirement of this study was to provide information on the most suitable method of setting up a major research programme, a trial of tag types was run concurrently with the marking programme.

Tags used for flatfish research have remained virtually
Plate 4.2. Floating cage used for Estuary tagging.
the same since Petersen began marking in 1887, using two bone
discs joined by a wire passed through the musculature below
the dorsal fin. In recent years these tags have usually been
of plastic, with platinum, silver or stainless steel wire
joining them. Evidence exists however, that these tags may
have a marked effect on the rate of mortality. Aquarium tests
carried out by Manzer (1952) showed a difference in mortality
rates of 34.4% between marked fish and controls.

Best (1963) reported encouraging results with "spaghetti"
tags. This tag is simply a length of hollow, soft, vinyl
tubing, with the legend printed along its length, and the whole
coated with a resin to prevent abrasion of the lettering.
(Manufactured by Floy Tag and Mfg. Inc. 2909 N.E. Blakeley St.,
Seattle, Washington, 98105.)

The basis of the tag trial was a comparison between the
Petersen and spaghetti tags. Petersen tags, comprising
yellow plastic discs 13 mm in diameter, were attached by means
of a 20 gauge stainless steel wire staple. These tags were
attached to the fish either as a "single" Petersen (Ps) or a
"double" Petersen (Pd) tag. The single Petersen comprised
the staple, pushed through the musculature below the dorsal fin,
with the disc threaded onto it from the upper surface. The
protruding wires were then bent over, and the excess cut off.
The double Petersen tag was attached in the same manner, but a
blank disc was threaded onto the staple before pushing it
Plate 4.3. Tag types used in this study.
through the fish. By this means it was hoped to determine whether the presence or absence of the blank disc had any long-term effect, especially regarding the growth in thickness of the fish, and the loss of tags because of excessive wound formation or physical snagging with objects in the environment.

Spaghetti tags were attached to the fish with the aid of a stainless steel needle. The hollow tag was pushed over the barbed end of the needle, and the whole pushed through the fish in the same position as the Petersen tags. The end of the tag was then removed from the needle, and the ends either tied (SpK), or joined by crimping with a soft copper ring (SpC). The ring consisted of a section of copper pipe, with external and internal diameters of 6.0 and 4.0 mm respectively. These two methods were compared to determine whether the copper ring would reduce marine growth on the tags, and thus reduce drag, and to overcome any danger of hardening of the plastic and breakage at the knot. Chadwick (1963) reported such breakages occurring in trials with striped bass. Any danger of cutting the plastic by the overtightening of the clip was overcome by modifying the pliers used for this by means of a stop.

Plate 4.3 shows the four types of tags used in this trial.

4.5. **Tags of Application**

The greater the ease and speed of application of tags, the less likelihood there is of injury to the fish during the holding
period, thus minimising possible effects on the mortality rate. Furthermore, although it is usually of little significance in relatively sheltered inshore waters, ease of attachment becomes very important in off-shore areas, where working conditions are frequently more adverse.

Considerably less time and handling procedure is required for the attachment of spaghetti than for Petersen tags. One difficulty experienced with the Petersen tags was making the staple sharp enough to pass easily through the flesh without lifting the upper skin. Furthermore, the subsequent series of actions, namely, threading on the disc and bending and cutting the wires, were also lengthy when compared with the simple procedure of threading the spaghetti tag through the fish and tying a knot. The use of the copper slip lengthened the process, but in turn was quicker than Petersen tags.

Using two personnel, one tagging and one recording data, the rate at which fish could be tagged varied from 200 per hour for tied spaghetti tags to 75 per hour for Petersen tags.

4.6. Subsequent Identification

It has been shown many times that yellow tags are more easily noticed by fishermen and thus give higher returns. Observations made during the course of this study indicate that the importance of colour decreases in proportion to the time the fish is at liberty. This is due to the various forms
Plate 4.4. Petersen tag returned after 23 months at liberty.
of marine growth which rapidly cover the tags. Plate 4.4.
shows a typical example. The green colour of this growth
causes the Petersen discs to blend with the skin tones of the
fish. Spaghetti tags, because of their larger size, are seen
more easily even if discoloured. This is backed up by the not
infrequent return of Petersen tagged fish from fish shops.

Plate 4.5. shows an example of heavy growth covering a
spaghetti tag.

4.7. Wounding

The subsequent healing or wound formation around a tag
must have a direct bearing on the rate of tag loss. A high
rate of tag loss leads to serious errors in any calculations
based on tag returns.

The only information available at present is based on
observations on wound formation in fish returned to the
laboratory. It was noted that fish marked with Petersen tags
showed conditions ranging from a perfect heal to raw sores
almost large enough for the tag to drop through. Spaghetti
tags invariably showed a very clean heal, leaving a hole some
\(\frac{1}{2}\) inch in diameter, with the tag fitting loosely in it.

Reports from commercial fishermen of their catching fish with
large holes at the usual point of tag attachment suggests that
festered causes a higher degree of tag loss with Petersen tags
than with spaghetti tags.
Plate 4.5. Spaghetti tags after 23 months at liberty.
4.8. Rate of Tag Loss

A programme of double tagging was undertaken to furnish data for rate of tag loss. Unfortunately, circumstances beyond the control of the writer forced this to be abandoned, after 250 of a proposed 1,000 fish had been marked. To date no adequate returns from these are at hand.

4.9. Tag Returns

The trial of Petersen and spaghetti tags was run between January 1964 and June 1965. Where possible, the four varieties of tags were applied in rotation, but delays in delivery prevented this on occasions. As tagging took place in restricted waters, heavy local fishing could give rise to a biased return, especially when all tag varieties were not available. The percentage returns are therefore divided into those caught in the harbour or estuary where tagging occurred, and those caught outside the harbour or estuary limits.

Table 4.1. shows the numbers tagged and percentage returns for fish tagged between January 1964 and June 1965, as at December 31st, 1965.

Tag varieties are as follows:

1. Single Petersen  Ps
2. Double Petersen  Pd
3. Clipped spaghetti  SpC
4. Tied spaghetti  SpK
Table 4.1. Percentage returns related to tag type and locality, as at 31.12.65.

<table>
<thead>
<tr>
<th>Tag Type</th>
<th>Locality</th>
<th>Number Tagged</th>
<th>Percentage Returns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Within Limits</td>
</tr>
<tr>
<td>Pa</td>
<td>Akaroa</td>
<td>662</td>
<td>0.9</td>
</tr>
<tr>
<td>Pd</td>
<td></td>
<td>673</td>
<td>1.6</td>
</tr>
<tr>
<td>SpC</td>
<td></td>
<td>589</td>
<td>0.5</td>
</tr>
<tr>
<td>SpK</td>
<td></td>
<td>147</td>
<td>1.4</td>
</tr>
<tr>
<td>Pa</td>
<td>Lyttelton</td>
<td>127</td>
<td>0.0</td>
</tr>
<tr>
<td>Pd</td>
<td></td>
<td>124</td>
<td>0.0</td>
</tr>
<tr>
<td>SpC</td>
<td></td>
<td>218</td>
<td>0.0</td>
</tr>
<tr>
<td>SpK</td>
<td></td>
<td>35</td>
<td>0.0</td>
</tr>
<tr>
<td>Pa</td>
<td>Estuary</td>
<td>M11</td>
<td></td>
</tr>
<tr>
<td>Pd</td>
<td></td>
<td>M11</td>
<td></td>
</tr>
<tr>
<td>SpC</td>
<td></td>
<td>886</td>
<td>0.0</td>
</tr>
<tr>
<td>SpK</td>
<td></td>
<td>1660</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 4.2. Average total returns to 31.12.65.

<table>
<thead>
<tr>
<th></th>
<th>Within Limits</th>
<th>Outside Limits</th>
<th>Total</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Petersen Pa</td>
<td>8.1</td>
<td>5.2</td>
<td>13.3</td>
<td>16.1</td>
</tr>
<tr>
<td>Double Petersen Pd</td>
<td>8.9</td>
<td>10.0</td>
<td>18.9</td>
<td></td>
</tr>
<tr>
<td>Clipped spaghetti SpC</td>
<td>11.8</td>
<td>5.7</td>
<td>17.5</td>
<td>15.3</td>
</tr>
<tr>
<td>Tied spaghetti SpK</td>
<td>4.6</td>
<td>8.6</td>
<td>13.2</td>
<td></td>
</tr>
</tbody>
</table>
"Within limits" means within the harbour or estuary where fish were tagged. "Outside limits" means any other area.

Table 4.2. shows a higher return for double as for single Petersen tags. The significance of the difference in return for each type of spaghetti tag is unknown. The total average returns for both tag groups show little difference. Since the spaghetti tags were quicker and easier to apply, they were used for the remainder of the tagging programme.

At this stage there were no long term returns to indicate any significant difference between clipped and tied tags. This trial was therefore continued until March of 1966.

Table 4.3. gives the numbers of spaghetti tags used as at March 1966, and an analysis of returns as at 31 June, 1966.

Table 4.3. Percentage returns for spaghetti tags to 31.6.66.

<table>
<thead>
<tr>
<th>Tag Type</th>
<th>Locality</th>
<th>Number Tagged</th>
<th>Percentage Returns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Within Limits</td>
</tr>
<tr>
<td>SpC</td>
<td>Akaroa</td>
<td>1358</td>
<td>11.4</td>
</tr>
<tr>
<td>SpK</td>
<td></td>
<td>1744</td>
<td>10.3</td>
</tr>
<tr>
<td>SpC</td>
<td>Lyttelton</td>
<td>655</td>
<td>12.2</td>
</tr>
<tr>
<td>SpK</td>
<td></td>
<td>1302</td>
<td>4.5</td>
</tr>
<tr>
<td>SpC</td>
<td>Estuary</td>
<td>1915</td>
<td>4.3</td>
</tr>
<tr>
<td>SpK</td>
<td></td>
<td>3406</td>
<td>3.2</td>
</tr>
</tbody>
</table>
Total average returns are therefore:

Table 4.4. **Average spaghetti returns to 31.6.66.**

<table>
<thead>
<tr>
<th></th>
<th>Within</th>
<th>Outside</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clipped SpC</td>
<td>9.3</td>
<td>6.7</td>
<td>16.0</td>
</tr>
<tr>
<td>Tied SpK</td>
<td>6.0</td>
<td>5.9</td>
<td>11.9</td>
</tr>
<tr>
<td><strong>Difference</strong></td>
<td>3.3</td>
<td>0.8</td>
<td>4.1</td>
</tr>
</tbody>
</table>

The returns from spaghetti tags when compared over a period of between 3 and 30 months indicate a higher return for the clipped variety by a value of 4.1% of the original number tagged, for all returns. The returns for those fish caught outside the tagging area show a difference of only 0.8%. This latter figure is probably a more realistic return as it allows for any bias which may have arisen by heavy local fishing after tagging operations.

Tagging between March 1966 and February 1967 was carried out with knotted tags only, due to difficulties in the supply of clips. The returns from these tags cannot be compared with any others because of the relatively short period since release.

4.10. **Rate of Tag Return**

Table 4.3. showed the returns for spaghetti tags as at June 31st, 1966.
Table 4.5. shows the returns for these tags as at 1st August, 1967:

Table 4.5. **Percentage returns for spaghetti tags as at 1st August, 1967.**

<table>
<thead>
<tr>
<th>Tag Type</th>
<th>Locality</th>
<th>Number Tagged</th>
<th>Percentage Returns</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Within Limits</td>
</tr>
<tr>
<td>SpC</td>
<td>Akaroa</td>
<td>1358</td>
<td>13.0</td>
</tr>
<tr>
<td>SpK</td>
<td></td>
<td>1744</td>
<td>11.3</td>
</tr>
<tr>
<td>SpC</td>
<td>Lyttelton</td>
<td>695</td>
<td>12.7</td>
</tr>
<tr>
<td>SpK</td>
<td></td>
<td>1302</td>
<td>4.8</td>
</tr>
<tr>
<td>SpC</td>
<td>Estuary</td>
<td>1915</td>
<td>5.3</td>
</tr>
<tr>
<td>SpK</td>
<td></td>
<td>3406</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Table 4.6. shows an analysis of spaghetti tag returns from fish tagged prior to March, 1966.

Table 4.6.1. **Percentage returns for spaghetti tags, 1) to 31.6.66 and 2) to 1.8.67.**

<table>
<thead>
<tr>
<th>Tag Type</th>
<th>To June 1966</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Within</td>
</tr>
<tr>
<td>SpC</td>
<td>9.3</td>
</tr>
<tr>
<td>SpK</td>
<td>6.0</td>
</tr>
<tr>
<td>Diff.</td>
<td>3.3</td>
</tr>
</tbody>
</table>
Table 4.6.2.

<table>
<thead>
<tr>
<th>Tag Type</th>
<th>Within</th>
<th>Outside</th>
<th>Total</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>SpC</td>
<td>10.3</td>
<td>12.0</td>
<td>22.3</td>
<td></td>
</tr>
<tr>
<td>SpK</td>
<td>6.7</td>
<td>11.6</td>
<td>18.3</td>
<td>20.3</td>
</tr>
<tr>
<td>Diff.</td>
<td>3.6</td>
<td>0.4</td>
<td>4.0</td>
<td></td>
</tr>
</tbody>
</table>

These returns indicate little change in rate of return during the period shown, except for a slight shift in favour of the tied tags.

Table 4.7. shows an analysis of Peterson tag returns from fish tagged prior to June 1965.

Table 4.7.1. Percentage returns for Peterson tags 1) to 31.12.65, 2) to 1.8.67.

<table>
<thead>
<tr>
<th>Tag Type</th>
<th>Within</th>
<th>Outside</th>
<th>Total</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ps</td>
<td>8.1</td>
<td>5.2</td>
<td>13.3</td>
<td></td>
</tr>
<tr>
<td>Pd</td>
<td>8.9</td>
<td>10.0</td>
<td>18.9</td>
<td>16.1</td>
</tr>
<tr>
<td>Diff.</td>
<td>0.8</td>
<td>4.8</td>
<td>5.6</td>
<td></td>
</tr>
</tbody>
</table>
Figure 4.2. Rate of tag return for each tag type.
To August 1967

<table>
<thead>
<tr>
<th>Tag Type</th>
<th>Within</th>
<th>Outside</th>
<th>Total</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pa</td>
<td>8.1</td>
<td>5.9</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>Pd</td>
<td>8.9</td>
<td>11.7</td>
<td>20.6</td>
<td>17.3</td>
</tr>
<tr>
<td>Diff.</td>
<td>0.8</td>
<td>5.8</td>
<td>6.6</td>
<td></td>
</tr>
</tbody>
</table>

This table shows little difference between the returns from fish caught within the area of tagging operations, but the considerably higher return for double tags from those fish which have moved outside of the limits has been largely maintained.

Both tables 4.6 and 4.7 show that very few returns come from the locality of tagging after the first twelve months. The pattern of rate of tag return in figure 4.2 shows that the return of tags from within the harbours falls off rapidly, indicating a probable movement of marked fish away from the area. The individual rates of tag returns are given in table 4.8.

Table 4.8 Individual rates of tag returns

<table>
<thead>
<tr>
<th>Tag Type</th>
<th>Within harbour</th>
<th>Outside harbour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pa</td>
<td>100.0</td>
<td>60.5</td>
</tr>
<tr>
<td>Pd</td>
<td>70.3</td>
<td>67.5</td>
</tr>
<tr>
<td>SpC</td>
<td>90.5</td>
<td>65.5</td>
</tr>
<tr>
<td>SpK</td>
<td>77.5</td>
<td>77.5</td>
</tr>
</tbody>
</table>
Figure 4.3. Percentage tag return related to size at tagging - a) inshore recaptures, b) offshore recaptures.
These returns are based on the results of the 1965-1967 period. An allowance has been made for the period 1st August - 31st December, 1967.

A contingency table test indicates a significant difference in the rate of return of tags from the harbour areas as compared with offshore areas (chi square = 29.77, 14\(^0\) of freedom) at the 2\% level.

There is no significant difference between the rate of return of tags from offshore areas (chi square = 3.95, 8\(^0\) of freedom).

4.11. Tag Returns Related to Size at Tagging

Figure 4.3. shows the percentage return of tagged fish for each two cm size group at the time of tagging. Those fish caught within the harbour limits show a tendency to decline in return with an increase in the size at the time of tagging, but those caught offshore by commercial fishermen show a marked increase.

The explanation is unlikely to be due to a high mortality rate amongst smaller fish. Should this occur, a high initial rate of return followed by a fall would be expected in both graphs. The movement of fish within a certain size group out of the harbours could account for both the fall in the return of larger fish from the harbours, and the increase from offshore. While migration no doubt plays a part in this, selection of the
Figure 4.4. The monthly return of tagged fish for each fishing ground.
larger marketable fish by commercial fishermen is also likely.

4.12. The Seasonal Variation in Tag Return

Figs. 4.4.1, 4.4.2, and 4.4.3 show the numbers of marked flounders returned each month for the three tagging localities.

In all three cases, offshore returns are taken mainly between August/September and February/March of each year. Lyttelton and the Estuary show inshore peaks between April/May and July/September. The inshore catch from Akaroa shows no definite seasonal pattern.

The peaks shown correspond to the activities of the fishing fleet. During December to March the Lyttelton boats fish for flounders in Pegasus Bay. The Akaroa boats pursue them off the Akaroa Heads between August and Christmas, while the Timaru boats fish for them between August and October. The inshore fishing is confined to the autumn and winter months in Lyttelton Harbour, and is more successful during this period in the Estuary. Akaroa Harbour provides fishing for most of the year.

The large seasonal variation in figure 4.4 may, therefore, be due as much to the activity of the fishing boats as that of the flounders, thus creating difficulties in the analysis of fish movements and seasonal growth rates.

4.13. Discussion

The four varieties of tags compared all give relatively high rates of tag return. The final choice of tied spaghetti
tags was made because of the simplicity and speed with which this tag could be applied. This aspect becomes of great importance during tagging operations in rough sea conditions.

The rate of tag loss, important for population estimates, is at present unknown. Observations of marked fish returned to the laboratory indicate that Petersen tags are more likely to cause severe wounding than spaghetti tags.

The ensuing tightness of double Petersen tags with growth of fish is also of probable importance. In aquarium tests Manser (1952) found the lowest mortality rate for lemon sole was with loose Petersen tags below the dorsal fin. The use of spaghetti tags obviously avoids this particular problem.

4.14. Conclusion

The tag trial conducted between January 1964 and March 1965 gave returns of 16.1% and 15.3% for Petersen and spaghetti tags respectively. Because the attachment of spaghetti tags was much quicker and easier than Petersen tags, these were chosen in preference for the remainder of the programme. A further trial of clipped and tied spaghetti tags showed a higher return for clipped tags by a factor of 0.8% to 0.4% for offshore returns, and 3.3% to 3.6% for inshore returns respectively.

Insufficient data is available to show any significant difference in the long-term rates of return. Tables 4.6. and 4.7. do show, however, that the final combined return at
August 1967 for tags released between January 1964 and March 1966 was 20.3% for spaghetti and 17.3% for Petersen tags.

The analysis of these tag returns is made difficult by variations in percentage returns of the original tagging size, and the seasonal activities of the fishing fleet.

While the highest percentage return was obtained with the clipped spaghetti tag, it is considerably easier to apply the tied variety. Offshore recaptures show a maximum fall of 0.8% in the return when using this tag compared to the clipped. It would seem unlikely that the slightly higher return with clipped tags justifies the extra handling time required.

4.3 Bibliography

Best, L.A. 1963: Movements of Petrale Sole, 

C. monte irs (Lockington) tagged off California. 


Can. 8: 479-90.
5. The movements of the sand flounder *Amadobagrus plebeia* (Richardson) in Canterbury waters.

5.1. Summary

Regular tagging in three Banks Peninsula bays was conducted at intervals between January 1964 and February 1967. This programme was later extended to the offshore Flounder Patch and Winter Ground for the period July 1966 to February 1967. The broad patterns of movement detected showed an annual migration of year class 2+ fish from the Estuary and Lyttelton Harbour northward to the Flounder Patch, and southward to the Winter Ground. The majority of Akaroa Harbour tagged fish showed a movement to the Winter Ground. These migrations occurred largely in August and September. No significant movement was detected from tag releases on the Flounder Patch, but a marked movement of year class 3+ and older fish from the Winter Ground to the Flounder Patch was shown.

A seasonal variation in sex ratio ranged from 2 females per male during the peak spawning period to 12.5 females per male at mid off-season periods. To explain the pattern of movements shown, a theory is put forward that the Flounder Patch and Winter Ground represent the spawning grounds of separate populations. The existing water currents would account for the distribution of young fish and their subsequent migration routes.
Figure 5.1. Main areas of capture for *Rh. plebeia* off the Canterbury Coast.
5.2. Introduction

The sand flounder inhabits most if not all of the bays and harbours of Banks Peninsula, and is subject to varying degrees of commercial and amateur fishing. Both the inshore and offshore areas exhibit large seasonal variations in catch.

Figure 5.1 shows the fishing grounds under investigation. The offshore grounds consist of the Flounder Patch, covering some 30 square miles, situated between 9 and 20 fathoms off the Waimakariri and Ashley Rivers; the Akaroa Head (Peraki Bay) area, where fishing is close inshore within 25 fathoms; and the 'Winter Ground', an area of some 25 square miles situated approximately 20 miles S.S.W. of Timaru, in 18–25 fathoms.

Fishing is seasonal on all grounds. Those around Banks Peninsula are largely an autumn and early winter fishery, whereas the Flounder Patch is fished largely between November and February and both the Akaroa - Peraki Bay and Winter Grounds yield the majority of their catch between August and January.

The catch for these offshore grounds is usually taken in large numbers over a relatively short period. The seasonal nature of the landings may be due to one of two reasons, or a combination of both. It may be due to definite seasonal patterns of movement, or migrations, of the population at certain stages in its life history; or it may be a reflection
on the seasonal distribution of the fishing effort by the commercial fleet.

Tagging was undertaken in two major phases. Regular sampling and tagging of the inshore areas was conducted between January 1964 and June 1966. The results from this indicated the need for similar tagging offshore. This was done on the Winter Ground and Flounder Patch, and was scheduled to take place between July 1966 and July 1967. A scaled-down sampling and tagging programme was continued in each inshore area. The second stage of the programme was terminated in February of 1967, the circumstances responsible being beyond the control of the writer.

5.3. The pattern of tagging

Tagging methods have already been described in paper 1. Tagging was commenced in Akaroa Harbour in January 1964, and conducted at two-monthly intervals until July 1965, followed by monthly intervals until February 1967. Lyttelton Harbour was sampled for four weeks during April 1964, 289 fish being tagged and released. Thereafter two-monthly tagging was carried out between March 1965 and July 1965, followed by monthly tagging until January 1967. The Estuary was sampled regularly on a two-monthly basis between March 1965 and July 1966, and monthly until January 1967.

As a result of movements detected by this programme, an
extension of tagging localities was undertaken to include the Flounder Patch and Winter Ground, as described above. Although this programme was terminated at an early stage, some valuable information resulted from it.

5.4. The return of tagged fish

Most of the tagged fish recaptures were made by commercial fishermen. To impress upon them the importance of the return of all tagged fish caught, a reward of ten shillings (one dollar) was paid for each one, provided all the required information accompanied it. The return of tags alone, or fish without information concerning their capture, and the returns from amateur fishermen were paid a reward of four shillings. To facilitate the return, both from the commercial fishermen’s and the laboratory’s points of view, trawlers were supplied with draw-string polythene bags containing pencils and waterproof instruction/data sheets. Upon return to port these bags were placed in wharf freezers, and subsequently collected by laboratory staff. The increase in the reward payment from four to ten shillings, coupled with the supply of polythene bags, resulted in a virtual 100 per cent return of all tagged fish caught and the relevant information required.

5.5. Plotting of returns

The position of recapture accompanying tagged fish returns was usually given as a number of miles or hours steaming along
Figure 5.2. The basic patterns of movement for *Rh. plebeia* shown by Banks Peninsula tagged fish.
a given course from the port of origin. Most of the catches were taken in sight of land, but the given localities of a few recaptures were unlikely or quite impossible. An example is the number of fish reported caught between 20 and 60 miles north of Timaru, placing them up to 40 miles inland. In the main, however, the capture positions appear to be sufficiently accurate for the purposes of the present study.

The position of recapture given by the vessel was plotted on a five mile square grid pattern. Thus, although each area contained 25 square miles of surface area, this was as accurate as could be expected, and gave enough detailed information for the relative broad movements of fish populations to be detected.

5.6. General patterns of movement from inshore grounds

Figure 5.2. shows the basic patterns of movement as shown from all tagging conducted at the Estuary, Lyttelton and Akaroa Harbours, and indicates that there is a movement of fish from the three inshore areas to all the major offshore fishing grounds. The data from which this basic movement pattern has been drawn up is dealt with later.

5.7. Seasonal variations in the recapture of tagged fish

Figure 5.3. shows the number of tagged fish caught on each of the main offshore grounds on a two-monthly basis. The numbers of fish tagged, and the time interval between tagging and recapture have not been included since neither factor is
Figure 5.3. The seasonal capture of tagged fish for the offshore grounds.
constant. The seasonal nature of the catch is, however, clearly evident. Although this probably indicated the main movements of the fish population, it should be noted that the seasonal variation in fishing effort may play some part in producing this pattern.

5.8. The Estuary

Tagging was undertaken in this locality in three phases. An initial 486 fish were tagged in June 1964 to ascertain whether or not a long term programme was warranted. Returns over the ensuing six months were received from all the Canterbury Fishing grounds, indicating that a long term programme was highly desirable. Accordingly, two-monthly tagging was carried out between March 1965 and July 1966; this was followed by monthly tagging until January 1967. Two-monthly tagging comprised five days fishing, and monthly tagging two days. All fishing days were consecutive when possible.

The dates of tagging and numbers of fish tagged are given in table 5.1.
Table 3.1. Estuary Tagging Programme

<table>
<thead>
<tr>
<th>Date</th>
<th>No. tagged</th>
<th>Date</th>
<th>No. tagged</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 1964</td>
<td>486</td>
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<td>359</td>
</tr>
<tr>
<td>March 1965</td>
<td>886</td>
<td>July 1966</td>
<td>60</td>
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<tr>
<td>June 1965</td>
<td>1266</td>
<td>August 1966</td>
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<tr>
<td>August 1965</td>
<td>955</td>
<td>Sept. 1966</td>
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<td>379</td>
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<td>381</td>
</tr>
<tr>
<td>Feb. 1966</td>
<td>509</td>
<td>Dec. 1966</td>
<td>273</td>
</tr>
<tr>
<td>April 1966</td>
<td>307</td>
<td>Jan. 1967</td>
<td>369</td>
</tr>
</tbody>
</table>

As figure 5.2. shows, sand flounders leave the estuary at some stage during the year and travel northwards to the Flounder Patch, or else in a south-westerly direction, passing close to the Akaroa Heads and on to the Timaru Winter Ground.

Table 5.2. comprises an analysis of the movements of fish from each tagging operation, and this analysis is aimed at giving some indication of the minimum time intervals between tagging in the estuary and capture on each offshore ground.
Figure 5.4.1.

Figure 5.4.2. Approximate period of migration from the Estuary for Rh. plebeia.
Table 5.2. Minimum Recovery Times for Estuary Tagging Programme

<table>
<thead>
<tr>
<th>Tagging Date</th>
<th>Akaroa Heads</th>
<th>Winter Ground</th>
<th>Flounder Patch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interval (Months)</td>
<td>Recapture Date</td>
<td>Interval (Months)</td>
</tr>
<tr>
<td>6.64</td>
<td>2 - 3</td>
<td>Aug 64</td>
<td>14 - 15</td>
</tr>
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<td>3.65</td>
<td>7 - 8</td>
<td>Oct 65</td>
<td>5 - 6</td>
</tr>
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<td>6.65</td>
<td>4 - 5</td>
<td>Oct 65</td>
<td>14 - 15</td>
</tr>
<tr>
<td>8.65</td>
<td>2 - 3</td>
<td>Dec 65</td>
<td>12 - 13</td>
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<td>Aug 66</td>
<td>10 - 11</td>
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<td>8 - 9</td>
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<td>1.67</td>
<td>-</td>
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<td>-</td>
</tr>
</tbody>
</table>

The minimum times recorded were 40 days to the Akaroa Heads, 70 days to the Winter Ground, and 40 days to the Flounder Patch.

Figure 5.4.1. gives a further analysis of the individual tagging operations to assist in determining the time of year when flounders leave the Estuary. In figure 5.4.1. each line represents the period between date of tagging on the left, and
date of recapture on the right. The date of recapture is
taken as the time the first fish is caught in each offshore
locality from that particular tagging operation, and is there-
fore a graphical presentation of the data given in table 5.2.

The seasonal nature of the catch, especially as made by
the Akaroa and Tinaru fleets during August 1966, is particularly
evident. Although this figure does not show the actual time
when the fish leave the Estuary, it does suggest that the re-
captures made at the Winter Ground in August 1966 left the
Estuary at some period between March/April and August 1966.
As the fish tagged at monthly intervals prior to April 1966
are at liberty for a correspondingly longer period of time,
it would seem reasonable to suggest that this was spent in the
Estuary rather than on the Winter Ground, where no recaptures
were recorded prior to August, in spite of fishing activity in
the area. Similarly, fish tagged in March 1965 were recaptured
at the Winter Ground in August 1965, but fish tagged in June
1965 and later were not caught there until August 1966.

The tagged fish recaptured at the Akaroa Heads suggest
that fish left the Estuary between June and October. From
recaptures taken on the Flounder Patch, the majority of fish
movement seems to occur between July and November.

Figure 5.4.2. shows the same method of analysis for
multiple recaptures. The broken lines indicate the period
between the last capture within the Estuary and recapture offshore. Fish recaptured at the Akaroa Heads probably left the Estuary between July and October 1965, and June and November 1966. Those caught on the Flounder Patch left the Estuary between September and December 1965, and October 1966 and January 1967. Fish tagged between June and October 1965 show evidence of remaining within the Estuary for approximately one year.

The length frequency distributions for samples from this area (paper 2) indicate a movement of larger fish from the Estuary between August and October of each year.

5.9. Lyttelton Harbour

Tagging was again undertaken in three phases. During April 1964, 289 flounders were tagged. Twelve months later, in March 1965, tagging on a regular basis was commenced; twice-monthly until July 1965, and monthly until June 1966. Tagging operations between these dates comprised five days fishing, consecutive when possible. Between July 1966 and January 1967, tagging was restricted to two day periods at monthly intervals.

The dates and numbers of fish tagged are shown in Table 5.3.
Table 5.3. **Lyttelton Harbour Tagging Programme**

<table>
<thead>
<tr>
<th>Date</th>
<th>Number Tagged</th>
<th>Date</th>
<th>Number Tagged</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 1964</td>
<td>289</td>
<td>March 1966</td>
<td>159</td>
</tr>
<tr>
<td>March 1965</td>
<td>135</td>
<td>April 1966</td>
<td>180</td>
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<tr>
<td>May 1965</td>
<td>84</td>
<td>May 1966</td>
<td>292</td>
</tr>
<tr>
<td>July 1965</td>
<td>477</td>
<td>June 1966</td>
<td>348</td>
</tr>
<tr>
<td>August 1965</td>
<td>73</td>
<td>July 1966</td>
<td>453</td>
</tr>
<tr>
<td>Sept. 1965</td>
<td>37</td>
<td>August 1966</td>
<td>58</td>
</tr>
<tr>
<td>Oct. 1965</td>
<td>123</td>
<td>Sept. 1966</td>
<td>37</td>
</tr>
<tr>
<td>Nov. 1965</td>
<td>307</td>
<td>Oct. 1966</td>
<td>40</td>
</tr>
<tr>
<td>Dec. 1965</td>
<td>16</td>
<td>Nov. 1966</td>
<td>33</td>
</tr>
<tr>
<td>Jan. 1966</td>
<td>325</td>
<td>Dec. 1966</td>
<td>34</td>
</tr>
</tbody>
</table>

The broad movements of tagged flounders, shown in figure 5.2, show a movement of fish from Lyttelton Harbour to the three offshore trawling grounds.

Table 5.4 gives the approximate minimum time of travel to each offshore ground for fish tagged in each operation.
Table 5.4. Minimum Recovery Times for Lyttelton Tagging Programme

<table>
<thead>
<tr>
<th>Tagging Date</th>
<th>Akaroa Heads</th>
<th>Winter</th>
<th>Ground</th>
<th>Flounder Patch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Interval (Months))</td>
<td>(Recapture Date)</td>
<td>(Interval (Months))</td>
<td>(Recapture Date)</td>
</tr>
<tr>
<td>Apr 64</td>
<td>6 - 7</td>
<td>Nov 64</td>
<td>4 - 5</td>
<td>Sep 64</td>
</tr>
<tr>
<td>May 65</td>
<td>7 - 8</td>
<td>Nov 65</td>
<td>5 - 6</td>
<td>Sep 65</td>
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<td>Jun 65</td>
<td>4 - 5</td>
<td>Nov 65</td>
<td>14 - 15</td>
<td>Sep 66</td>
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<td>Jul 65</td>
<td>1 - 2</td>
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<td>3 - 4</td>
<td>Nov 65</td>
</tr>
<tr>
<td>Aug 65</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Sep 65</td>
<td>17 - 18</td>
<td>Mar 67</td>
<td>17 - 18</td>
<td>Mar 67</td>
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<td>Jan 67</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

There is a seasonal variation in the time lapse between tagging and recapture, being generally longest during November to March, and shortest between June and September.
Figure 5.5.1. Figure 5.5.2. Approximate period of migration from Lyttelton Harbour for *Rhatridia plebeia*. 

RECAPTURE POSITION 1965 1966 1967
AKAROA HEADS 1 2 3 4 5 6 7 8 9 10 11 12
WINTER GROUND 1 2 3 4 5 6 7 8 9 10 11 12
FLOUNDER PATCH 1 2 3 4 5 6 7 8 9 10 11 12
The fastest rates of travel for individual fish represented in this table are 60 days to the Akaroa Heads (45 miles), 55 days to the Winter Grounds (125 miles) and 84 days to the Flounder Patch (20 miles).

Figure 5.5.1 is a graphical representation of the data shown in table 5.4. The seasonal nature of the catch is apparent, as in figure 5.4. Apparently fish leave Lyttelton Harbour from June to January as confirmed by the analysis of multiple recapture returns shown in figure 5.5.2.

Length frequency distributions for Lyttelton Harbour for this period (paper 2) indicate a sharp decrease in the numbers of fish present during August and September. This applies particularly to fish of 25 cm and over.

2.10. Akaroa Harbour

Tagging in this locality was conducted on a two-monthly basis between January 1964 and May 1965; followed by monthly tagging until June 1966. Fishing for these operations was carried out over a five day period. Monthly tagging, covering a two-day period, was undertaken between July 1966 and February 1967.

The dates and numbers of fish tagged are shown in Table 5.5.
Table 5.5. Akaroa Tagging Programme

<table>
<thead>
<tr>
<th>Date</th>
<th>Number Tagged</th>
<th>Date</th>
<th>Number Tagged</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 1964</td>
<td>428</td>
<td>February 1966</td>
<td>447</td>
</tr>
<tr>
<td>March 1964</td>
<td>135</td>
<td>March 1966</td>
<td>327</td>
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<tr>
<td>May 1964</td>
<td>294</td>
<td>April 1966</td>
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<tr>
<td>August 1964</td>
<td>428</td>
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<td>October 1964</td>
<td>437</td>
<td>June 1966</td>
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<td>January 1965</td>
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<td>July 1966</td>
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<tr>
<td>May 1965</td>
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<td>July 1965</td>
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<td>August 1965</td>
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<td>September 1965</td>
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<td>October 1965</td>
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<tr>
<td>January 1966</td>
<td>251</td>
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<td></td>
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</tbody>
</table>

As shown in figure 5.2, there is a general movement of fish out of Akaroa Harbour southwards to the Akaroa Heads and the Winter Ground, and a lesser movement northwards to the Flounder Patch. Table 5.6 gives the approximate minimum times of travel to the offshore grounds for fish tagged in each operation.
Table 3.6. Minimum Recovery Times for Akaroa Ticking Program

<table>
<thead>
<tr>
<th>Tagging Date</th>
<th>Akaroa Heads</th>
<th>Winter Ground</th>
<th>Fleamond Patch</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>Interval (Months)</td>
<td>Recapture Date</td>
<td>Interval (Months)</td>
</tr>
<tr>
<td>Jan 64</td>
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<td>-</td>
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<tr>
<td>Mar 64</td>
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<td>Nov 65</td>
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<td>May 64</td>
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</tr>
<tr>
<td>Sep 66</td>
<td>3 - 4</td>
<td>Dec 66</td>
<td>-</td>
</tr>
<tr>
<td>Oct 66</td>
<td>2 - 3</td>
<td>Oct 66</td>
<td>4 - 5</td>
</tr>
<tr>
<td>Nov 66</td>
<td>4 - 5</td>
<td>Apr 67</td>
<td>-</td>
</tr>
<tr>
<td>Jan 67</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Feb 67</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 5.6.1. RECAPTURE POSITION 1965 1966 1967
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6
AKAROA HEADS

WINTER GROUND

FLOUNDER PATCH

Figure 5.6.2. Approximate period of migration from Akaroa Harbour for Rh. plebeia.
The seasonal capture of fish, evident in this table, agrees closely with that shown in tables 5.2. and 5.4. The fastest rates of travel for individual fish (in Table 19) are 21 days to the Akaroa Heads (10 miles), 70 days to the Winter Ground (70 miles), and 59 days to the Flounder Patch (45 miles).

Figure 5.6.1. shows a graphical representation of table 5.6., and indicates the seasonal nature of fish captures from August to December for Akaroa and the Winter Ground, and December to March for the Flounder Patch. Figs. 5.6.1. and 5.6.2. both indicate that flounders leave the harbour between the months of August and February.

Length frequency distributions for Akaroa Harbour for the period 1965 - 1966 show a marked decline in the numbers of fish over 25 cm present during August and September.

Table 5.7. shows a summary of the estimated dates of leaving inshore grounds for all areas.
Table 5.7. Inshore to Offshore Movement Periods

<table>
<thead>
<tr>
<th>Year</th>
<th>To</th>
<th>From Estuary</th>
<th>From Lyttelton Harbour</th>
<th>From Akaroa Harbour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>Flounder Patch</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Akaroa</td>
<td>-</td>
<td>-</td>
<td>Oct - Jan</td>
</tr>
<tr>
<td></td>
<td>Winter Ground</td>
<td>-</td>
<td>-</td>
<td>Oct - Jan</td>
</tr>
<tr>
<td>1965</td>
<td>Flounder Patch</td>
<td>Aug - Oct</td>
<td>Oct - Jan</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Akaroa</td>
<td>Aug - Oct</td>
<td>Jul - Dec</td>
<td>Sep - Dec</td>
</tr>
<tr>
<td></td>
<td>Winter Ground</td>
<td>Jun - Aug</td>
<td>Aug - Nov</td>
<td>Jul - Sep</td>
</tr>
<tr>
<td>1966</td>
<td>Flounder Patch</td>
<td>Aug - Dec</td>
<td>Jul - Nov</td>
<td>Sep - Feb</td>
</tr>
<tr>
<td></td>
<td>Akaroa</td>
<td>Jun - Aug</td>
<td>Jun - Oct</td>
<td>Aug - Dec</td>
</tr>
<tr>
<td></td>
<td>Winter Ground</td>
<td>Jun - Aug</td>
<td>Jun - Nov</td>
<td>Aug - Dec</td>
</tr>
</tbody>
</table>

In all cases the exit of flounders from inshore areas takes place between the months of June and February.

It is unlikely that fish leave any particular locality immediately after tagging, and are recaptured immediately they arrive on the fishing grounds. Consequently the majority of the sum total of fish movements probably occurred over a shorter period than this. Length frequency analysis of the sample used for tagging indicates that the greatest change in the inshore
population occurs between August and October.

III. The Relationship Between Movement and Size

An estimation of the size of fish when they leave inshore areas can only be given in broad terms at this stage. Probably the most reliable method is the use of data from multiple recaptures; that is, those fish which have been recaptured after tagging, measured, released alive, and subsequently recaptured a second time. With tag returns of this nature, the size of the fish is known at the time of tagging; the size is known at some later date (still within the area of tagging); and finally, the size is known when the fish is caught and returned from an offshore area at a known and still later date.

For this calculation, only multiple recaptures from year class 1 fish have been used. No account has been taken of the time interval between the first, second or third capture. Instead, the mean lengths of all fish at each recapture period have been calculated for each tagging operation. This is shown in tables 3.8., 3.9., and 3.10.
Table 5.8. Mean Lengths of Recaptures, Estuary

<table>
<thead>
<tr>
<th>Date of Tagging</th>
<th>Length cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>When Tagged</td>
</tr>
<tr>
<td>March 1965</td>
<td>20.1</td>
</tr>
<tr>
<td>April 1965</td>
<td>19.1</td>
</tr>
<tr>
<td>June 1965</td>
<td>18.3</td>
</tr>
<tr>
<td>August 1965</td>
<td>18.4</td>
</tr>
<tr>
<td>October 1965</td>
<td>18.6</td>
</tr>
<tr>
<td>December 1965</td>
<td>21.5</td>
</tr>
<tr>
<td>February 1966</td>
<td>17.3</td>
</tr>
<tr>
<td>June 1966</td>
<td>22.7</td>
</tr>
<tr>
<td>July 1966</td>
<td>19.1</td>
</tr>
<tr>
<td>August 1966</td>
<td>21.2</td>
</tr>
<tr>
<td>October 1966</td>
<td>21.4</td>
</tr>
<tr>
<td>November 1966</td>
<td>24.5</td>
</tr>
<tr>
<td>Weighted Mean</td>
<td>20.1</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>2.6</td>
</tr>
</tbody>
</table>
Table 5.9. Mean Lengths of Recaptures, Lyttelton Harbour

<table>
<thead>
<tr>
<th>Date of Tagging</th>
<th>Length cm</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>When Tagged</td>
<td>Second (Inshore) Capture</td>
<td>Third (Offshore) Capture</td>
<td></td>
</tr>
<tr>
<td>April 1964</td>
<td>23.1</td>
<td>24.0</td>
<td>31.0</td>
<td></td>
</tr>
<tr>
<td>March 1965</td>
<td>23.7</td>
<td>25.6</td>
<td>30.0</td>
<td></td>
</tr>
<tr>
<td>July 1965</td>
<td>19.2</td>
<td>21.4</td>
<td>22.8</td>
<td></td>
</tr>
<tr>
<td>August 1965</td>
<td>20.8</td>
<td>20.9</td>
<td>32.5</td>
<td></td>
</tr>
<tr>
<td>October 1965</td>
<td>19.6</td>
<td>29.8</td>
<td>31.6</td>
<td></td>
</tr>
<tr>
<td>January 1966</td>
<td>24.2</td>
<td>26.7</td>
<td>28.8</td>
<td></td>
</tr>
<tr>
<td>March 1966</td>
<td>26.6</td>
<td>27.4</td>
<td>29.6</td>
<td></td>
</tr>
<tr>
<td>April 1966</td>
<td>26.7</td>
<td>27.3</td>
<td>30.5</td>
<td></td>
</tr>
<tr>
<td>May 1966</td>
<td>29.0</td>
<td>29.5</td>
<td>33.5</td>
<td></td>
</tr>
<tr>
<td>Weighted Mean</td>
<td>23.6</td>
<td>25.9</td>
<td>30.0</td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>-</td>
<td>3.2</td>
<td>3.1</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.10. Mean Lengths of Recaptures, Akaroa Harbour

<table>
<thead>
<tr>
<th>Date of Tagging</th>
<th>Length cm</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>When Tagged</td>
<td>Second (Inshore) Capture</td>
<td>Third (Offshore) Capture</td>
<td></td>
</tr>
<tr>
<td>October 1964</td>
<td>20.7</td>
<td>29.8</td>
<td>33.9</td>
<td></td>
</tr>
<tr>
<td>May 1965</td>
<td>19.9</td>
<td>26.8</td>
<td>31.9</td>
<td></td>
</tr>
<tr>
<td>July 1965</td>
<td>19.0</td>
<td>19.6</td>
<td>34.3</td>
<td></td>
</tr>
<tr>
<td>September 1965</td>
<td>21.1</td>
<td>28.3</td>
<td>35.4</td>
<td></td>
</tr>
<tr>
<td>October 1965</td>
<td>21.7</td>
<td>28.0</td>
<td>33.1</td>
<td></td>
</tr>
<tr>
<td>November 1965</td>
<td>23.4</td>
<td>28.3</td>
<td>31.9</td>
<td></td>
</tr>
<tr>
<td>January 1966</td>
<td>20.5</td>
<td>24.0</td>
<td>33.0</td>
<td></td>
</tr>
<tr>
<td>March 1966</td>
<td>19.4</td>
<td>22.9</td>
<td>25.0</td>
<td></td>
</tr>
<tr>
<td>Weighted Mean</td>
<td>20.7</td>
<td>27.1</td>
<td>32.1</td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>-</td>
<td>3.5</td>
<td>3.2</td>
<td></td>
</tr>
</tbody>
</table>
Figure 5.7. Length frequency distributions of Rh. plebeia for the Flounder Patch and Winter Ground.
These tables indicate that flounders leave the Estuary between 23.1 and 28.7 cm; Lyttelton Harbour between 25.9 and 30.0 cm; and Akaroa Harbour between 27.1 and 32.1 cm in length, within the range of the calculated standard deviations. Otolith readings (paper 1) and length frequency analysis (paper 2) indicate that sand flounders of the above size are two or three years old.

5.12. The Off-Shore Grounds

The Flounder Patch and Winter Ground were sampled on a monthly basis between July 1966 and February 1967. Fishing was undertaken for three days per month, consecutive whenever possible.

5.13. Length Frequency Distribution

Figure 5.7. shows the length frequency distributions for both grounds for the period sampled. The samples were taken with a commercial otter trawl, the body being of 4½ inch mesh, fitted with a 2½ inch cod end. Since escapement takes place largely from the cod end (Davis 1934) and a 2½ inch end was also used on the shallow water gear for the Estuary and harbours, the samples obtained by both methods are considered comparable.

The Flounder Patch contained representatives of all year classes detected in the present study. The entry of year class 0+ fish is seen to commence in September, and terminate in December.
The Winter Ground samples contained few fish under 20 cm in length, consisting largely of fish between 30 and 50 cm in length. The smaller fish taken in September 1966 were taken just off Timaru rather than on the true offshore ground.

Evidently the stocks on the two grounds differ in age class representation. The low number of fish in many of the samples, and the restricted period of sampling prevented detailed analysis of the distributions.

5.14. The Movement of Fish from the Flounder Patch

Tagging on the Flounder Patch was carried out between July 1966 and January 1967 for a three-day period each month. The dates of tagging and numbers of fish tagged are given in Table 5.11.

Table 5.11. Flounder Patch Tagging Programme

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Tagged</td>
<td>32</td>
<td>38</td>
<td>53</td>
<td>124</td>
<td>286</td>
<td>126</td>
<td>90</td>
<td>368</td>
<td>1,119</td>
</tr>
</tbody>
</table>

To date there have been few returns from the Flounder Patch giving any indication of regular movements from that area. Four fish were recaptured in the Estuary and four in Lyttelton Harbour. These fish were between 20 and 25 cm in length, and their movements are as likely to be due to random dispersion as due to migration. One female was recaptured at
Figure 5.8. Recaptures of *Rh. plebeia* tagged on the Flounder Patch.
Peraki Bay, and another female on the Winter Ground. These fish were 35 and 42 cm respectively at the time of tagging. The significance of these recaptures is also difficult to assess. The fact that both were considerably older than the fish moving into the estuary or Lyttelton Harbour may be of importance.

Figure 5.8. shows the movements previously described.

5.15. The Movement of Fish from the Winter Ground

Tagging on the Winter Ground followed the same pattern as that for the Flounder Patch (Table 5.12.).

Table 5.12. Winter Ground Tagging Programme

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Tagged</td>
<td>163</td>
<td>353</td>
<td>418</td>
<td>80</td>
<td>165</td>
<td>135</td>
<td>70</td>
<td>1,386</td>
</tr>
</tbody>
</table>

Figure 5.9. marks the points of recapture for flounders tagged in the programme in table 5.12. An northerly movement of fish up the Canterbury coast is evident, the Flounder Patch marking the northernmost recaptures.

Table 5.13. is an analysis of the recaptures from each tagging operation, designed to show the minimum time period for travelling between the Winter Ground and the Akaroa Heads, and the Flounder Patch.
Figure 5.9. Recaptures of Rh. plebeia tagged on the Winter Ground.
### Table 5.13. *Winter Ground Tag Returns*

<table>
<thead>
<tr>
<th>Tagging Date</th>
<th>Akaroa Heads</th>
<th></th>
<th>Flounder Patch</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interval (Months)</td>
<td>Recapture Date</td>
<td>Interval (Months)</td>
<td>Recapture Date</td>
</tr>
<tr>
<td>Aug. 66</td>
<td>2 - 3</td>
<td>Sept 65</td>
<td>4 - 5</td>
<td>Nov. 66</td>
</tr>
<tr>
<td>Sept 66</td>
<td>1 - 2</td>
<td>Oct. 66</td>
<td>1 - 2</td>
<td>Oct. 66</td>
</tr>
<tr>
<td>Oct. 66</td>
<td>2 - 3</td>
<td>Dec. 66</td>
<td>2 - 3</td>
<td>Dec. 66</td>
</tr>
<tr>
<td>Nov. 66</td>
<td>1 - 2</td>
<td>Dec. 66</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dec. 66</td>
<td>2 - 3</td>
<td>Feb. 67</td>
<td>2 - 3</td>
<td>Feb. 67</td>
</tr>
<tr>
<td>Jan. 67</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Feb. 67</td>
<td>2 - 3</td>
<td>Apr. 67</td>
<td>2 - 3</td>
<td>Apr. 67</td>
</tr>
</tbody>
</table>

The data in Table 5.13 indicates that flounders do not remain for any length of time in the Akaroa Heads, Feraki Bay region, as no significant difference in the average minimum times of travel between the Winter Ground and Akaroa or the Flounder Patch is apparent.

As would be expected, the majority of these fish were taken on the Flounder Patch between October and February. It would therefore seem reasonable to suggest that the majority of fish leaving the Winter Ground do so between August and October, the minimum times of travel being two to three months.

### 5.16. Seasonal Variation in Sex Ratio

The ratio of female to male flounders for fish tagged in the Banks Peninsula region and recaptured offshore is shown in
Figure 5.10. The sex ratio of *Rh. plebeia* tagged inshore and recaptured on the offshore grounds.

Figure 5.11. The sex ratio of *Rh. plebeia* tagged and recaptured on the Winter Ground.
figure 5.10. Both the Winter Ground and the Akaroa Heads ground show marked seasonal changes in the ratio. Fish caught on the Winter Ground varied from 9.75 females per male in January to 2.25 per male in July and August. Those caught at the Akaroa Heads showed a variation of 12.5 females per male in March to 2.0 per male in September and October. The Flounder Patch reflects this variation to a far lesser degree, varying from 2.25 per male in January and February to 0.9 per male in November and December.

Spawning takes place in August and September (Thompson and Anderton 1921, and paper 1). Evidently the ratio of females to males is lowest during the spawning season, and highest mid way between spawnings.

Figure 5.11. shows the seasonal variation in the sex ratio of fish tagged and recaptured on the Winter Ground. The pattern of variation follows very closely that of those fish originating from Banks Peninsula.

Insufficient returns were made from those fish tagged on the Flounder Patch to allow an analysis of this nature.
Figure 5.12. The sex ratio of *Rh. plebeia* captured offshore related to specific inshore release areas.

Figure 5.13. The sex ratio of *Rh. plebeia* tagged and recaptured each inshore ground.
## Table 5.14. Numbers of Male and Female Fish Caught on the Offshore Grounds.

<table>
<thead>
<tr>
<th></th>
<th>Fish Caught Recaptured</th>
<th>Estuary</th>
<th>Lyttelton Harbour</th>
<th>Akaroa Harbour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Channel</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fleurieu Patch</td>
<td>Akaroa</td>
<td>Winter Grounds</td>
<td>Fleurieu Patch</td>
</tr>
<tr>
<td>1965/66</td>
<td>Male</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>68</td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>102</td>
<td>103</td>
<td>46</td>
</tr>
<tr>
<td>1966/67</td>
<td>Male</td>
<td>132</td>
<td>155</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>174</td>
<td>65</td>
<td>11</td>
</tr>
<tr>
<td>1967/68</td>
<td>Total Male</td>
<td>257</td>
<td>123</td>
<td>53</td>
</tr>
<tr>
<td>1967/68</td>
<td>Total Female</td>
<td>276</td>
<td>168</td>
<td>57</td>
</tr>
<tr>
<td>1967/68</td>
<td>Ratio</td>
<td>1.07</td>
<td>1.36</td>
<td>0.78</td>
</tr>
</tbody>
</table>
5.17. The Dispersion of Male and Female Fish

Figure 5.10. showed the seasonal variation in the sex ratio of all inshore tagged fish caught on the offshore grounds. Figure 5.12. shows this same ratio subdivided to give the sex ratio on the offshore grounds for each original tagging area. As with figure 5.10, the general tendency is one of the highest proportion of females to males between March and August, and lowest between September and February.

Table 5.14. gives a summary of the data from which figure 5.12. was drawn.

Table 5.14. shows a higher percentage of male fish originate from the Estuary and Lyttelton Harbour than from Akaroa Harbour. Figs. 5.10 and 5.12 show a marked seasonal sex ratio variation both on the grounds and also between the grounds. Both the Akaroa Heads and the Winter Grounds show a wide variation, the maximum ratio being between March and August. The Flounder Patch shows considerably less variation, the peak ratio being May to June.

Figure 5.13 shows the seasonal variation of the sex ratio for the Estuary and both Harbours. Akaroa Harbour shows a peak between February and May. Both Lyttelton and the Estuary show evidence of a later peak. The peak for Akaroa coincides approximately with that for the Akaroa Heads and Winter Ground, and the peak for the Estuary and Lyttelton coincides with the Flounder Patch peak.
From table 5.14 it can be seen that the ratio of tagged fish recaptured on these offshore grounds varied with the locality of tagging; fish tagged in Akaroa Harbour have a ratio between 2.00 and 3.08 females per male; Lyttelton Harbour shows a wide range of variation which is difficult to explain, while the estuary ratio varies between 1.36 and 0.76 females per male.

No significant difference can be detected concerning the time of migration from inshore waters for any particular sex. While it is quite possible that some difference exists, as indicated by the changing patterns of sex ratio, the method used for the determination of the time of movement is too broad to detect these differences should they occur. Similarly the ratio of female to male fish migrating from the Winter Ground shows no significant difference in the time of movement.

5.18. Discussion

The analysis of fish movements from tag returns must allow for the effect the distribution of fishing effort has on the apparent dispersion of tagged fish. It has already been pointed out that there is a marked seasonal variation in fishing effort in both Pegasus Bay and the Canterbury Bight, but this effort is geared to work the various grounds at those times when the fish are present. From discussions with commercial fishermen, and from experiences received when tagging on these
grounds out of season, it seems fairly definite that the seasonal concentrations of tagg returned from the three major offshore grounds are due almost entirely to seasonal concentrations of fish.

Discussions with commercial fishermen indicate that the Canterbury fishery operates within the 30 fathom contour, and flounders are rarely caught in water deeper than this. Thomson and Anderton (1921), however, state that off the Otago coast sand flounders are caught at depths of up to 60 fathoms. The fact that these fish apparently stay within the thirty fathom mark in the Canterbury area is confirmed by the existence of the fishery along the southern coastline of Banks Peninsula. The thirty fathom depth contour is only two to three miles offshore along parts of the coast and it appears that this fishery operates on a migration route which is necessarily narrow, the steeply increasing depth contour acting as a physiological barrier a relatively short distance offshore.

The returns of tagged fish from all grounds have revealed complex seasonal movements, related to stages in the life cycle of the fish. Flounders migrate from the inshore, shallow water regions to deeper water between August and October. The pattern of movement for Banks Peninsula tagged fish is either northwards to the Flounder Patch, or else in a south-western direction to the Akaroa Heads and the Timaru Winter Ground.
Although the Flounder Patch tagging programme could not be carried out on the scale originally planned, the few returns from it indicated southerly movements. One was recaptured at Peraki, another on the Winter Ground, four in the Estuary and four in Lyttelton Harbour.

Flounders tagged on the Winter Ground showed a marked northerly movement to Akaroa and the Flounder Patch. This movement appears to be seasonal but further data would be desirable.

Certain returns from Akaroa Harbour are of interest here. Table 5.6. shows four instances where flounders took nearly two years to travel from Akaroa Harbour to the Flounder Patch. These fish could have remained in the Harbour for two years, but an alternative explanation is possible. A movement of fish from the inshore grounds to the Winter Ground occurs during the spring months. The majority of fish comprising this movement would be at the end of their third winter. Spawning takes place on the Winter Ground, and this could be followed by a subsequent movement to the Flounder Patch, possibly the same season, or twelve months later. Both the fish recaptured to the south of Banks Peninsula after release on the Flounder Patch were large females. These recaptures could indicate a twice yearly movement of larger fish between these two grounds.

Otolith studies show that sand flounders live to at least six years of age (paper 6), and, noting that they are only caught
in large numbers on any ground on a seasonal basis, this movement would account for their relative scarcity during the off periods, when widespread, generally small, catches are made throughout the whole region.

Sand flounders tagged off the Otago coast (Street 1959-63), showed a similar south-westerly movement. Further work should be undertaken to determine the relationship of sand flounders in these two areas.

Although spawning fish are taken on all offshore grounds, and to a limited extent in Lyttelton and Akaroa Harbours, the numbers of fish landed from the Winter Ground showed this to be the most important spawning area. The eggs are pelagic (Thompson and Anderton 1921) and could be carried northward from this region by the Southward Drift. Allowing a rate of movement between 4 and 10 miles per day (Brodie 1966), eggs or larvae spawned on the Winter Ground would therefore cover the 70 miles to Banks Peninsula within 7 to 18 days. They would therefore form a source of recruitment for the flounder population of Lake Ellesmere and Akaroa Harbour. By virtue of the fact that this current passes to the north of Banks Peninsula, striking the coastline at Amberley, and sending a branch southwards into Pegasus Bay, eggs or larvae would also be carried into the Estuary and Lyttelton Harbour.

The presence of separate northern and southern spawning grounds, and therefore separate populations, could be an
explanation for the fact that some fish from the Estuary and Lyttelton Harbour, in particular, move both to the north and south, supplementing the stocks on both grounds. The two grounds certainly show very different length frequency distributions, those on the Winter Ground being largely 3 year old and upwards, and those on the Flounder Patch containing all year classes. The observed differences in sex ratios, and time differences of seasonal variations in sex ratio may also be attributed to separate populations.

5.19. Conclusion

The inshore areas of Banks Peninsula contain a population of young flounders of year classes 0+, 1+ and 2+. These fish leave the inshore regions mainly between August and October of each year. Movements are either northwards to the Flounder Patch, or southwards to Akaroa and the Winter Ground. Spawning takes place between June and December, reaching a peak between August and September. Few or no spawning fish are taken in the Estuary. Thompson and Anderton (1921) and German (1960) postulate that sand flounders cannot breed in shallow water. It would therefore seem likely that both the Estuary and Lake Ellesmere are dependent upon pelagic eggs or larvae or young metamorphosed fish from the offshore grounds for their population recruitment. The wide fluctuations in the Lake Ellesmere catch suggest that the times of opening the Lake are
crucial. From the present investigation, it would appear most appropriate to open the Lake between August and December in order to reap the full benefit of that fishery.

Further investigation would be required to determine the stage in the life cycle at which flounders enter the lake.

The proposed erection of a barrier across the mouth of the Estuary must have a detriorious effect on the commercial fishery on all three commercial grounds. Such an effect could be more than a simple reduction in the yield of fish originating from the Estuary. It is possible that the large numbers of male fish migrating from there may be of considerable importance in offshore spawning areas. It has been shown that a ratio of 2.5 females per male exists on the grounds during the spawning period, and a considerable percentage of these males originate from the Estuary.

Accurate estimations of the population of fish in the Estuary, and of the seasonal movements of the sexes between the offshore grounds, should be obtained before any permanent barrier is constructed.

2.20. Bibliography


Thompson, G.M.; Anderton, T. 1921: History of the Portobello Fish Hatchery and Biological Station.

6. The growth rate of the sand flounder *Pseudoceros plebsia* (Richardson) off Banks Peninsula.

6.1. Summary

Age determination was made from otoliths, the maximum age found being six years. A growth curve for female sand flounders was derived, fitting the equation \( l_t = 59.9 \) \( (1-0.791 t + 0.083) \), with parameters of \( l_0 = 59.9 \) cm, \( t_0 = 0.083 \) years and \( k = 0.235 \). The length-weight relationship for Akaroa Harbour fish was found to have the equation \( \log W = 3.13 \) \( \log L = 2.05 \) for females and \( \log W = 2.89 \log L - 1.76 \) for males. This relationship varied in other localities and this variation is taken as evidence supporting the presence of two populations of this species off the Canterbury Coast. The period of maximum growth for estuary fish occurred between December and March, and minimum growth between May and September.

6.2. Introduction

The determination of growth rate is dependent upon successful age determination. In paper 1 it was shown that the interpretation of otoliths provided the most reliable method for the sand flounder, and the basic growth rate calculations are made from these data.

Comparative growth rate calculations have been made from tag returns on an area basis. These are subject to error
Figure 6.1a. The relationship between \( \log_{10} \) weight and \( \log_{10} \) length of *Rh. plebeia*.

6.1b. Length-weight relationship for *Rh. plebeia*, points observed, curves calculated from Figure 6.1a.
because of the effects of the tagging process upon the growth rate of the fish, and shrinkage following death.

6.3. The relationship between length and weight

With fish, weight varies as some power of length

\[ W = aL^b \]

When growth is isometric, that is, having an unchanging body form and an unchanging specific gravity, then \( b \) will have a value of 3.

Figure 6.1. shows the linear regression of log weight on log length for both female and male fish from Akaroa Harbour. The calculated relationships are:

- **Females** \( \log W = 3.13 \log L - 2.05 \)
- **Males** \( \log W = 2.89 \log L - 1.76 \)

The extent to which the \( b \) value varies from 3 is estimated from the \( b \) coefficient.

Where \( s_b \) = standard error of \( b \)

and \( B \) = hypothetical \( b \) value,

the significance (t) of the variation of the observed \( b \) to the hypothetical \( b \) is given by:

\[ t = \frac{b - B}{s_b} \]

For females, with a \( b \) coefficient of 2.166 and 12 degrees of freedom, the probability level of a variation from 3 is 0.10, showing no really significant variation from isometric growth.
Figure 6.2. The relationship between weight and age for *Rh. plebeia*.
A similar result is found with males, having a b coefficient of 1.39 and 8 degrees of freedom. However, with a d value of 2.497, there is a probability at the 0.02 level of a difference in growth rate between males and females.

The observed difference in growth pattern between the sexes may, in some part, be due to the difference in net mean-gain selection which must be present with two groups growing at different rates.

6.4. Mathematical description of growth

Typically, growth follows a sigmoid curve, which approaches an asymptotic value as age increases. Figure 6.2. shows the observed relationship between weight and age, a typical example of the relationship normally found. The observed relationship between length and age frequently shows only that part of the curve which is past the point of inflexion, the earlier portion representing the very early stages of the life-history of the species.

The mathematical treatment of length at age data can be based on the regression of \( l(t+1) \) on \( l_t \), where \( l_t \) represents the length at each age \( t \). The regression equation, as used by Walford (1946), is

\[
l(t+1) = m_t l_t + c
\]

The slope of the line, \( m_t \), is that proportion of the previous length added to the constant \( c \), which is the mean length of the
fish after one year. Since it always has a value less than 1, the growth is of an exponential form, tending to an asymptotic value \( l_\infty \), which can be derived as

\[
l = \frac{a}{1 - c}
\]

Bertalanffy's (1938) exponential formula is

\[
l_t = l \left(1 - e^{-kt}\right)
\]

where

- \( l_t \) = length at any time \( t \)
- \( k \) = constant

This will be equivalent to Salford's regression equation of

\[
l = \frac{a}{1 - c}
\]

and

\[e^{-k} = a, \quad C \text{ being the length at one year old. This last condition is necessary because the exponential equation}
\]

\[
l_t = l \left(1 - a^{k+t}\right)
\]

passes through the origin, whereas the regression allows for an \( l_0 \), the length when age is theoretically zero.

*Figure 6.3.* shows the regression of \( l^{(t+1)} \) on \( l_t \). The data is based on the mean annual increments for each year class as shown by otolith examination, and is for female fish, there being insufficient data for male fish to provide reliable means. The relationship between \( l^{(t+1)} \) and \( l_t \) is given by

\[
l^{(t+1)} = 0.791 l_t + 12.52.
\]
Figure 6.3. The Walford graph for Rh. plebeia, giving parameters of $k = 0.234$, $l = 59.9$ cm.

Figure 6.4. The plot of $\log (1 - l_t)$ against age, giving parameters of $k = 0.235$, $t_0 = 0.083$ years.
Therefore, from the Walford line,
\[
\frac{L}{O} = \frac{e}{1 - m} = \frac{12.52}{1 - 0.791} = 59.9 \text{ cm}
\]
\[e^{-k} = m \text{ (the slope)}\]
\[= 0.791\]
so that \(K = 0.234\)

A check on the fit of the Walford line to the original data is afforded by substituting the obtained value of \(L_{O}\) in the modified Bertalanffy equation.

\[
\log_e \left( L_{O} - L_{t} \right) = \log_e L_{O} + K t_0 - K_t
\]

Thus a plot of \(\log_e \left( L_{O} - L_{t} \right)\) against \(t\) should be straight.

This condition is shown to hold true in figure 6.4. From this figure, the slope of the line gives an estimate of \(K\), and the value of \(t\) where it has an ordinate of \(L\) is an estimate of \(t_0\).

The relationship between \(\log_e (L - L_t)\) and \(t\) is given by
\[
\log_e \left( L_{O} - L_{t} \right) = 0.2351 t + 1.792
\]

Therefore
\[K = 0.2351\]

From \(\log \frac{L}{O} + K t_0 = 1.792\)
\[t_0 = \frac{1.792 - 1.790}{-0.2351} = 0.083\]

An analysis of the above data by the Applied Mathematics Division of D.S.I.R., using the Forest Research Institute
Figure 6.5. The growth rate of *Rh. plebeia*. Points are the average annual increments from otolith readings. The curve drawn is calculated from the Walford line, figure 6.3., with parameters (computer) of \( t_0 = 0.0733 \) years, \( k = 0.2365 \), and \( l_\infty = 59.6059 \) cm.
programme FRI 022, gave parameter values as follows:

\[ K = 0.2365 \]
\[ L = 59.6 \text{ cm} \]
\[ t_0 = 0.08102 \]

Taking an average \( t_0 \) value, and using the exponential equation \( l_t = 59.9 (1 - 0.791 \ t + 0.083) \) calculated values for \( l_t \) can be found.

Table 6.1. Observed and Calculated Values for \( l_t \) from the Modified Bertalanffy Equation.

<table>
<thead>
<tr>
<th>( l_t )</th>
<th>Observed</th>
<th>Increment</th>
<th>( l_t )</th>
<th>Calculated</th>
<th>Increment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.0</td>
<td>12.0</td>
<td>1.083</td>
<td>13.4</td>
<td>13.4</td>
</tr>
<tr>
<td>2</td>
<td>21.5</td>
<td>9.5</td>
<td>2.083</td>
<td>23.1</td>
<td>9.7</td>
</tr>
<tr>
<td>3</td>
<td>29.5</td>
<td>8.0</td>
<td>3.083</td>
<td>30.8</td>
<td>7.7</td>
</tr>
<tr>
<td>4</td>
<td>37.5</td>
<td>8.0</td>
<td>4.083</td>
<td>36.9</td>
<td>6.1</td>
</tr>
<tr>
<td>5</td>
<td>41.2</td>
<td>3.7</td>
<td>5.083</td>
<td>41.7</td>
<td>4.8</td>
</tr>
<tr>
<td>6</td>
<td>45.0</td>
<td>3.8</td>
<td>6.083</td>
<td>45.5</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Assuming that the growth of the sand flounder is adequately described by the Bertalanffy equation, the calculated curve should fit the observed data. As shown in Table 6.1, this is not exactly the case. The reasons for this are difficult to pinpoint, but may well be due to size selection by the type of gear used (Javis 1934), or some undetected fault in the method.
Figure 6.6. Main areas of capture for *Rh. plebeia* off the Canterbury Coast.
of age determination used.

Having based the mathematical treatment of the data on the regression of \( l_{t+1} \) on \( l_t \), the growth of the sand flounder is shown in the calculated curve of figure 6.5. This curve has the parameters of \( l_\infty = 59.9 \text{ cm} \), \( t_0 = 0.083 \text{ years} \) and \( K = 0.235 \).

6.5. The comparison of off-shore length-weight relationships

In paper 5 it was suggested that two populations of sand flounders could be present off the Canterbury coast, one population spawning on the Winter Ground, the second on the Flounder Patch, figure 6.6. It was further shown that the currents prevalent in these regions would result in the pelagic egg and larval stages from each spawning ground being carried into both the Estuary and Lyttelton Harbour. The tagging of fish in these regions showed a subsequent movement after two years in both a northerly and a southerly direction.

The length-weight relationships of Estuary tagged fish were therefore compared on the basis of whether subsequent capture had been on the Flounder Patch or to the south of Banks Peninsula.

The regressions of log length on log weight, calculated by the method of least squares, are shown in figure 6.7. The curves are described by:

- Northern males: \( \log_{10} W = 3.119 \log_{10} L - 2.029 \)
- Southern males: \( \log_{10} W = 2.929 \log_{10} L - 1.775 \)
- Northern females: \( \log_{10} W = 3.087 \log_{10} L - 1.963 \)
- Southern females: \( \log_{10} W = 3.074 \log_{10} L - 1.948 \).
Figure 6.7. The comparison of length-weight relationships for north and south migrating Estuary tagged *Rh. plebeia*.
Using the b coefficients shown, the b values for both male curves show a significant variation from isometric growth. Similarly, northern area females show a significant variation, but southern females show no significant variation. A comparison of the two regression coefficients obtained for male fish show a significant difference between them (d = 2.283, with p = 0.05), whereas no significant difference is apparent between the female regression coefficients. Overall, however, it does seem that there is a general significant difference in the length-weight relationship between fish in these two areas, which in turn supports the view that two separate populations may exist. A similar analysis of the fish tagged in Lyttelton Harbour proved to be impractical due to the relatively low number of returns from fish taken south of Banks Peninsula.

6.6. The comparison of offshore growth rates

Although of doubtful significance for the purpose of separating populations, a comparison of the growth rate of north and south-migrating Estuary fish was made. The growth data was taken from the tag returns used in section 6.5.

Figure 6.6 shows the monthly increments for both sexes from each area. Slightly higher growth rates for south-moving fish are shown for each sex, but the differences are not significant, with d values of 0.808 for females and 0.922 for males.

Any differences in growth rate which may occur seem likely to be due either to population characteristics, or to variations
Figure 6.8. The comparison of growth rates for north and south migrating Estuary tagged *Rh. plebeia*. 
in feeding habits. This topic is further discussed in paper 7. The difference in water temperature between the two regions is negligible, both lying in the Southland current. The material from which the data was obtained had all been processed in an identical manner. Thus errors due to shrinkage will be similar for each curve.

6.7. The comparison of inshore growth rates

The growth rates of fish tagged and recaptured within the tagging locality are shown in figure 6.9. for the Estuary, Lyttelton Harbour and Akaroa Harbour. The fish were recaptured by chartered vessels, enabling the growth curves to be compiled only from measurements made by Marine Department personnel on live material. The curves shown are for female fish, insufficient numbers of males being taken to allow a comparative study. The observed increases in length showed a wide variation amongst individual fish, resulting in no significant differences in growth rate being detected. However, as with the offshore fish, the highest rate of growth was shown by fish from Akaroa Harbour, these later migrating to the southern winter Ground.

For both section 6.6. and 6.7. the data was taken from fish tagged between 17.0 and 25.0 cm in length. These fish were tagged between March 1965 and February 1967.

6.8. Seasonal variation in growth

The seasonal growth pattern for Estuary tagged fish is shown
Figure 6.9. The growth rates of *Rh. plebeia* tagged and recaptured within each inshore region.
in figure 6.10. The curves were obtained by plotting the mean monthly increments for each tagging operation for the period March 1965 until June 1966. The Estuary samples were chosen for this purpose because of the large number of returns available, and because the fish sampled were within the narrow size range of 17 to 25 cm, thereby largely avoiding variations in growth rate related to size.

The period of maximum growth was December to March, and of minimum growth May to September. Figure 1.4, a plot of the percentage of fish with an outer winter otolith band for each month, showed that the period of summer band formation commenced in September/October, with all fish having summer rings by January. The period of winter band formation is largely April to July, confirming the expected relationship between rate of growth and type of ring formation.

The measurements used to compile these curves were taken from fish captured by commercial fishermen, and are therefore subject to the shrinkage described in chapter 2. For this reason, the rate of growth shown is low by a factor of about 2.3%. Taking this into account, the annual growth shown by these curves is as follows:-

**Females** 20.8 to 33.5 = 22.7 cm + 2.3% = 12.99 cm

**Males** 19.0 to 29.5 = 20.5 cm + 2.3% = 10.79 cm

The results obtained from otolith and length frequency data should be taken as being more reliable because of the far greater number of measurements taken. However, it is difficult to see
Figure 6.10. Seasonal growth rates of male and female Estuary tagged *Rh. plebeia*.
why the tag results should generally be so high compared with otolith or length frequency results. That some undetected source of error in the samples taken due to net selection may be present should not be overlooked.

6.9. Discussion

The use of the Bertalanffy growth equation is apparently justified for describing the growth of the sand flounder, the calculated sample means being acceptably close to the observed means for female fish. The presence of a difference between the calculated and observed sample means indicates that the sampling technique may have an inherent bias. The most usual cause of a bias of this nature is mesh-size selection, resulting in the sample means being higher than the population means. The calculated means in Table 6.1 indicate, however, that the reverse is more probably the case. This may be explained by the type of net selection described by Davis (1954). He showed that large-meshed nets caught a higher percentage of the available large fish than small-meshed nets. If this occurred with the small-meshed nets used in this study, this would explain why the calculated sample means were higher than the observed sample means, and also why the annual increments shown by tag returns (fig. 6.8, 6.9, and 6.10) tended to be higher than those shown from otolith examination. Any bias of this nature must be the same for both $l_t$ and $l_{(t+1)}$ and are cancelled out in the Walford line, which depends upon the ratio of the two variables.
The calculated sample means, therefore, are more likely to be correct than the observed means.

The reason for the difference between the growth rates shown by otolith studies and tag returns is obscure. The wide variation in growth shown by individual fish makes any statistical comparison difficult. As, however, there was evidence in paper 2 of net mesh selection whereby larger fish were not sampled properly, it is possible that the observed and calculated \( l_t \) values could be low for all year classes that are completely recruited to the sample.

The comparison of length-weight relationships from fish from each locality, shows sufficient significant variations to allow them to be used to support the theory put forward in paper 5 that two populations of sand flounders exist in this area; one spawning on the Flounder Patch, and one on the Winter Ground.

6.10. Conclusion

The length-weight relationship for female sand flounders can be taken as isometric, although a significant variation does occur for males.

By plotting \( l_{t+1} \) against \( l_t \), the growth of the female sand flounder is described by the equations:

\[
l_{t+1} = 0.791 \, l_t - 12.52 \text{ (Walford)} \quad \text{and} \quad \]
\[
l_t = 59.9 \, (1 - 0.791 \, t + 0.083) \text{ (Bertalanffy)}
\]

with parameters of
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\[ l = 59.9 \text{ cm} \]
\[ t_0 = 0.083 \text{ years} \]
\[ K = 0.235 \]

Seasonal variations in growth rate occur, the period of maximum growth being December to March, and of minimum growth May to September. Data from tag returns shows females to have a higher rate of growth than males, with average increments in the third year of 12.0 cm for females and 9.7 cm for males.

6.13. Bibliography


Figure 7.1. Main areas of capture for \textit{Rh. plebeia} off the Canterbury Coast.
7. The feeding habits of the sand flounder *Rombosolea plebeia* (Richardson) in Canterbury waters.

7.1. Summary

The gut contents of sand flounders from four localities were sampled monthly for a period of between six and twelve months. The analysis was made in terms of the number of species present, and the percentage estimate of volume for the main items present. It was shown that juvenile fish in all areas fed largely on amphipods, with decapods, sedentary polychaetes or cymaceans forming the bulk of the diet for older fish, depending upon the area of capture.

7.2. Introduction

Monthly sampling of gut contents was undertaken in Lyttelton and Akaroa Harbours between July 1965 and June 1966. Between July 1966 and January 1967, further monthly samples were obtained from the Flounder Patch and Winter Ground (figure 7.1.). Otolith and gonad examinations were carried out with the same samples (paper 1). The selection of fish for gut analysis was done by means of stratified subsampling. The total size range of fish captured was divided into ten five centimetre groups, ten fish being chosen at random for each group.

To avoid duplication, gut samples were not analysed from the Estuary. Work in this locality was undertaken in co-operation with Mr B.J. Webb of the University of Canterbury. The sampling
of the gut contents of *Rh. plebeia* was undertaken by Mr. Webb as part of an M.Sc. thesis. The results obtained will be compared with those from the other localities sampled (Webb, in preparation).

7.3. Method

The entire intestinal tract was removed as soon as possible after capture, and preserved in 4% formalin, thus avoiding any prolonged continuation of digestion.

The contents were analysed according to the different species present, and the percentage estimate by volume of the main food groups found. This gave a more realistic result than recording the actual numbers of each species present.

7.4. Results

The gut contents, analysed into the major components, were related firstly to the area of capture and secondly to the age of the fish, using length-age data from paper 6. Figs. 7.2, 7.3, 7.4, and 7.5 show this analysis.
Figure 7.2. Percentage volume of the main food types for each year class of *Rh. plebeia* taken from Lyttelton Harbour.
7.4.1. Lyttelton Harbour

Figure 7.2. shows the analysis by volume of the main groups found. Amphipods, especially gammarids, formed 30% of the diet for year class 0+ fish, falling to 5% for year class 4+ fish. Decapods, notably Helice crassa, increased in amount from 5% in year class 0+ to 65% in year class 4+. Sedentary polychaetes averaged 20% presence in all size groups, with Logan sp. dominating. Other groups taken in the diet included isopods, Isocladus sp., megalepa larvae; cumaceans; bivalves; especially Amphicrenus australis, and Cyclomena ovata; gastropods, especially Notosetia sp., Micrelphusa dilatatus and Zadiloma sp.; errant polychaetes (doniada sp.); holothurians, probably Cucumaria sp.; and finally "siphons". These were provisionally identified as the tips of siphon tubes from Chione stutchburyi.
Figure 7.3. Percentage volume of the main food types of each year class of *Rh. plebeia* taken from Akaroa Harbour.
7.4.2. Akaroa Harbour

The feeding pattern (Figure 7.3.) was similar to that for Lyttelton Harbour. Amphipods formed 90% of the gut content in year class 0+ fish, dropping to 5% in year class 4+ fish. No decapods were found in year class 0+ fish, but formed 45% of the food in year class 3+ and 4+ fish; these were mainly *Helice grasse.* Sedentary polychaetes formed an important part of the diet for year classes 1+, 2+ and 3+ fish, but were not taken at all by year class 0+ fish, and only to a small extent by year class 4+ fish; (*Ladis* sp. being the dominant genus taken).

Other groups identified included isopods, *Isocladus armatus*, *Isocladus magellanicus*, and *Notidotea lacustris*; bivalves, *Cyclomastrea ovata*; and siphons from *Chione stutchburyi.*
Figure 7.4. Percentage volume of the main food types for each year class of *Rh. plebeia* taken from the Flounder Patch.
7.4.3. The Flounder Patch

Amphipods and cumaceans were the major food items for flounders in this region, amphipods being the main food of year classes 2+ and 3+ fish, and cumaceans were particularly important for year class 5+ fish (figure 7.4.). Sedentary polychaetes formed a staple percentage of the diet in all the age groups sampled. The individual items of importance were amphipods; isopods (*Aegida* sp. particularly); decapods, especially *Ommatocarcinus maccullivrayi* and *Cylindrus bipustulatus*; cumaceans, bivalves, especially *Cythomastus ovata*; sedentary polychaetes, including the families *Amphipontidae*, *Mephistiidae*, *Sebellidae* and *Ctenidae*; errant polychaetes, particularly *Lambrineria* sp., and from year class 2+ fish *Cnideria* (*Leuerinia olivacea*).
Figure 7.5. Percentage volume of the main food types for each year class of *Rh. plebeia* taken from the Winter Ground.
7.4.4. The Winter Ground

As figure 7.5. shows, amphipods and sedentary polychaetes formed the major items of diet for flounders in this region. While amphipods formed 70% of the food intake of year class 1+ fish, year classes 2+ to 5+ showed little variation, with amphipods forming 20 - 25% and sedentary polychaetes 65 - 70% of the diet. Of the sedentary polychaetes, Ampharetidae (Amphinectes sp.) was taken in the greatest numbers. Other items found in these samples were decapods (Halicarcinus sp.), Natantia (Pentophilus australis), cumaceans, ostracods, bivalves (Amphidana australis), gastropods (Noteoctia ?) and errant polychaetes (Goniida sp.).

7.5. Species List

AMPHIPODA - Callioipiidae, Gammaridae, Codicerotidae.
CUMACEA indet.
DECAPODA -
 Helice crassa (Dana), Halicarcinus sp.,
 Petrolithes elongatus (Milne Edwards),
Cammocarcinus macrostigmatus (White), Ovalipes bipustulatus (Chilton and Bennett), megalopa larvae.
ISCOPODA -
 Leocladus armatus (Milne Edwards), Leocladus magellancus (Richardson), Notidotea lacunaria (Thompson), Austridea spp.
MYSIDAE indet.
NATANTIA -
Pentophilus sp., Alpheus sp., and possible Fam. Alpheocida and Hippolytidae.
Ostracoda indet.

Bivalvia - *Amphidiena australis* (Gmelin), *Cyclonastra ovata* (Gray), *Protothaca eremocytes* (Deshayes), *Panopec selandica* (Quoy and Gaimard), *Perna* sp., *Mytilus edulis* (Linnaeus), *Spisula acutilateralis* (Deshayes), *Nastra discors* (Gray).


*Crenotria* sp., *Zedoloma subrostrata* (Gray), *Amyse* sp., *Zedoloma* sp., *Lecomplua* sp., *Philipia aurifera* (Suter).

Cnidaria - *Leiopenia* sp.

Ophiurida - *Amphipholia* sp.

Holothuria indet.

Holothuria - *Cucumaria* sp.

Polychaeta - Family *Amphistenidae* - *Logia* sp.

" " *Amphinectes* sp.

" " *Aphroditidae* - *Aphrodite* sp.

" " *Nephtyidae* - *Aclephanthus* sp. 1

" " - *Aclephanthus* sp. 2

" " *Ouandia* - *Oueria* sp.

" " *Oueridae indet.*

" " *Phyllophocidae* - *Steene* sp.

" " *Sebellidae* - *Dayshane* sp.
Family Sebellidae indet. (2 species)

- Sebellariidae indet.
- Terebellidae - Polyosiris sp.
- Lumbrineridae - Lumbrineris sp.
- Goniadidae - Goniada sp. 1
  - Goniada sp. 2
- Ounicidae indet.
7.6. Discussion

The main problem encountered in the food analysis was the lack of a definite stomach; this necessitated identifying the entire contents of the intestinal tract and probably produced a bias in favour of decapods and other group with persistent exoskeletons.

Some instances of food preference by individuals was noted in all areas. This tended to apply particularly to older fish.

The majority of the specimens analysed contained various quantities of detritus, mud and small stones in the gut. This was particularly noticeable in year class 0+ fish. This may be due to these juveniles forms taking in mud and detritus as a direct source of food supply. The food items taken by all the age groups sampled showed that the sand flounder is almost an exclusive bottom feeder, as would be expected.

7.7. Conclusions

A distinct pattern has been shown to exist in the feeding habits of flounders with respect to age and locality. In all the areas sampled, amphipods rated high in the diet of juvenile fish, falling to about 5% of the total food intake for older fish. Fish of year classes 3+ to 5+ taken from Lyttelton and Akaroa Harbours tended to have a diet consisting largely of decapods, while those from the Flounder Patch mainly contained crusaceans, and those from the Winter Ground sedentary polychaetes. Little
seasonal variation was noticed, except for the presence of megalopa larvae during the summer.

Webb (in preparation) reached similar conclusions for sand flounders inhabiting the Estuary. He found that sedentary polychaetes and amphipods formed the bulk of the diet, with bivalves and decapods following in that order. Polychaetes formed a higher proportion of the diet in this region than in any other. Owing to the restricted size range of fish taken in this region, no marked relationship between food habits, and length could be detected.

7.8. References

8. Some estimates of the populations of sand flounders


Shovelnosea picaria (Richardson) inhabiting three
localities around Banks Peninsula.

8.1. Summary

Population estimates by a Petersen type census gave maximum
peaks of 70,000 for the Heathcote - Avon Estuary, 24,000 for
Lyttelton Harbour, and 81,000 for Akaroa Harbour for May 1966.
The corresponding minimum peaks were 11,000, 17,000, and 8,000,
all for September 1966. For Akaroa Harbour there was sufficient
data to enable a catch effort analysis to be made in addition to
the Petersen method for the months of June and November 1966.
The catch effort analysis gave a value of 53,000 for the June
population and 29,000 for the November population; emigrants for
the period June to November were estimated at 76,000. The values
obtained by the Petersen analysis were 60,000 for June and 20,000
for November, with a minimum of 70,000 emigrants during the
intervening period.

8.2. Introduction

The analysis of the tag returns from tagging operations in
the Estuary, Lyttelton and Akaroa Harbours (paper 5), shows a
direct relationship between these stocks of fish and those subject
to exploitation by trawlers offshore.

Being restricted in area, sheltered, and relatively shallow,
Figure 8.1. Main areas of capture for Rh. plebeia off the Canterbury Coast.
the fish in those particular waters can be considered to be
highly vulnerable to commercial fishermen (especially since the
industry was delicensed in 1964), amateur fishermen, commercial
development, and perhaps, to pollution. It has also been stated
in paper 5 that these regions, along with other shallow water
areas off the Canterbury coast, act as nursery grounds, with two
and three-year-old fish moving from them to the offshore trawling
grounds, namely the Flounder Patch, Akaroa Heads and the Winter
Ground (figure 8.1.). Further analysis of these tag returns
has, therefore, been undertaken in an attempt to obtain data
relating to the importance of these inshore grounds as a source
of recruits for offshore regions.

8.3. Population Estimates - Methods Used

Two basic methods of estimating populations were used,
namely the "Petersen" or mark and recapture method, and Ricker's
(1958) method using declining catch effort data.

8.4. Petersen Census

This method is based on a single tagging experiment, with
subsequent sampling to examine the ratio of tagged to untagged
fish. The estimations made from data of this nature are depend-
ent upon the factors of an unchanged mortality rate between
tagged and untagged fish, no loss of tags, the random distribution
of tagged fish amongst the original stock, and no recruitment.
In order to obtain some balance between allowing random distrib-
ution to occur, minimising any possible loss of tags and recruitment, population estimations were made four weeks after tagging. Further tagging at each four weekly period enabled a series of estimations to be made.

Using $M = \text{number of fish tagged in month } t$

$R = \text{number of tagged fish recaptured in month } t+1$

and $C = \text{total number of fish sampled in month } t+1$

Bailey (1951) estimates the total population ($N$) as

$$N = \frac{M \cdot (C + 1)}{R + 1}$$

and the variance for the estimation as

$$V(N) = \frac{N^2 \cdot (C - R)}{(C + 1) \cdot (R + 2)}$$

5.4.1. The Weymouth - Avon Estuary

This region comprises an area of tidal mudflats of some 1,770 acres in area, of which about 75% are exposed at low tide.

The region is subject to considerable fishing activity by amateur fishermen for most of the year, with a considerable number of undersized fish being taken at times, owing to the generally small size of the catch.

Regular tagging was conducted at two monthly intervals between March 1965 and June 1966, and at monthly intervals from July 1966 until January 1967. The analysis of returns from this tagging showed the existence of an extensive movement of fish from the Estuary to each of the offshore grounds. The greater
part of this movement took place from July to November, a fact
which was reflected in the length frequency distributions for
this period (paper 2).

8.4.2. Population Estimations

These are calculated for the period July 1966 to January
1967 in table 8.1, when monthly sampling was undertaken.
Estimations are based on the recapture of tagged fish one month
after tagging. The capture of fish tagged prior to that period
is ignored for this exercise.

Table 8.1: Population Estimations for the Heathcote - Avon
Estuary, using Bailey's formula.

<table>
<thead>
<tr>
<th>Date</th>
<th>R</th>
<th>C</th>
<th>M</th>
<th>N</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 66</td>
<td>3</td>
<td>209</td>
<td>338</td>
<td>19,000</td>
<td>8,324</td>
</tr>
<tr>
<td>Aug. 66</td>
<td>2</td>
<td>523</td>
<td>60</td>
<td>11,000</td>
<td>5,285</td>
</tr>
<tr>
<td>Sep. 66</td>
<td>4</td>
<td>596</td>
<td>156</td>
<td>19,000</td>
<td>7,602</td>
</tr>
<tr>
<td>Oct. 66</td>
<td>9</td>
<td>1,331</td>
<td>344</td>
<td>53,000</td>
<td>5,083</td>
</tr>
<tr>
<td>Nov. 66</td>
<td>10</td>
<td>672</td>
<td>425</td>
<td>26,000</td>
<td>7,444</td>
</tr>
<tr>
<td>Dec. 66</td>
<td>13</td>
<td>1,114</td>
<td>381</td>
<td>30,000</td>
<td>7,835</td>
</tr>
<tr>
<td>Jan. 67</td>
<td>6</td>
<td>804</td>
<td>273</td>
<td>31,000</td>
<td>11,045</td>
</tr>
</tbody>
</table>

The high result of the October estimation is puzzling, but
is perhaps due to non-uniform distribution. Although the July,
August and September samples have large standard deviations, the population estimates show a general rise from a low point in July to September to a high level in December and January. The low estimates reflect the period of maximum migration from the Estuary, and the high estimates reflect the entry of year class 1+ fish into the sample, as shown by the length frequency distributions in paper 2 for this period.

Although the population just prior to migration is unknown, the level is likely to be considerably higher than the 31,000 estimated in January. This would mean the number of fish leaving the estuary is likely to be well in excess of 20,000 fish - the difference between the calculated estimates for August and January.

6.4.3. Lyttelton Harbour

This area, comprising 16 square miles in area, provides at present a seasonal fishery for up to four commercial fishing vessels, and numerous amateur parties. Fishing is largely carried out between April and August.

Tagging on a regular basis was undertaken at monthly intervals between June 1965 and January 1967. Movements indicated by tagged fish returns showed that large numbers of flounders moved from the harbour between July and November to each of the offshore grounds.
8.4.4. Population Estimations

Using Bailey's formula, these are calculated for the period February 1966 to August 1966.

Table 8.2. Population Estimations for Lyttelton Harbour

<table>
<thead>
<tr>
<th>Date</th>
<th>H</th>
<th>C</th>
<th>M</th>
<th>N</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb. 1966</td>
<td>1</td>
<td>768</td>
<td>825</td>
<td>125,000</td>
<td>72,050</td>
</tr>
<tr>
<td>Mar. 1966</td>
<td>1</td>
<td>777</td>
<td>182</td>
<td>71,000</td>
<td>40,820</td>
</tr>
<tr>
<td>Apr. 1966</td>
<td>6</td>
<td>758</td>
<td>159</td>
<td>17,000</td>
<td>6,043</td>
</tr>
<tr>
<td>May 1966</td>
<td>3</td>
<td>805</td>
<td>180</td>
<td>24,000</td>
<td>9,100</td>
</tr>
<tr>
<td>June 1966</td>
<td>12</td>
<td>734</td>
<td>292</td>
<td>17,000</td>
<td>4,371</td>
</tr>
<tr>
<td>July/Aug 66</td>
<td>10</td>
<td>612</td>
<td>348</td>
<td>19,000</td>
<td>5,548</td>
</tr>
</tbody>
</table>

No tagged fish were taken for the period September 1966 to January 1967, or for intermittent periods prior to February 1966. The lack of data and correspondingly high standard deviations for February and March 1966 render these estimations highly suspect. Little indication is given by the remaining estimations for evidence of migration, although migration on a large scale may be the major reason for no tagged fish being recaptured in August 1966.

8.4.5. Akaroa Harbour

This harbour also covers an area of about 16 square miles, and supports a similar rate of exploitation to Lyttelton Harbour,
although amateur fishing tends to be carried on throughout the year.

Tagging, at monthly intervals, between April 1966 and February 1967 provides the basis for Bailey's population estimates, given in Table 8.3.

Table 8.3. Population Estimates for Akaroa Harbour

<table>
<thead>
<tr>
<th>Date</th>
<th>R</th>
<th>C</th>
<th>M</th>
<th>N</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 66</td>
<td>11</td>
<td>1,343</td>
<td>327</td>
<td>37,000</td>
<td>10,220</td>
</tr>
<tr>
<td>May</td>
<td>7</td>
<td>1,274</td>
<td>508</td>
<td>81,000</td>
<td>26,910</td>
</tr>
<tr>
<td>June</td>
<td>9</td>
<td>1,140</td>
<td>579</td>
<td>66,000</td>
<td>19,810</td>
</tr>
<tr>
<td>July</td>
<td>4</td>
<td>429</td>
<td>448</td>
<td>39,000</td>
<td>15,830</td>
</tr>
<tr>
<td>Aug</td>
<td>2</td>
<td>414</td>
<td>137</td>
<td>19,000</td>
<td>9,466</td>
</tr>
<tr>
<td>Sept</td>
<td>6</td>
<td>337</td>
<td>164</td>
<td>8,000</td>
<td>2,799</td>
</tr>
<tr>
<td>Oct</td>
<td>1</td>
<td>235</td>
<td>150</td>
<td>19,000</td>
<td>10,930</td>
</tr>
<tr>
<td>Nov</td>
<td>2</td>
<td>559</td>
<td>168</td>
<td>20,000</td>
<td>9,958</td>
</tr>
<tr>
<td>Dec</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jan 67</td>
<td>2</td>
<td>444</td>
<td>169</td>
<td>25,000</td>
<td>12,460</td>
</tr>
<tr>
<td>Feb</td>
<td>2</td>
<td>405</td>
<td>216</td>
<td>29,000</td>
<td>14,450</td>
</tr>
</tbody>
</table>

The analysis of tag returns showed a movement from the Harbour between July and February, while length frequency analysis showed it to be between August and October. The population estimates in Table 8.3. indicate a movement between July and September for 1966, showing a general pattern of
minimum population in September to maximum in May, just prior
to the commencement of migration

Based on the estimations given in table 5.3, a minimum of
70,000 flounders migrate from Akaroa Harbour to the offshore
grounds each spring.

\section*{Discussion of Petersen Population Estimations}

This method of population estimation is suitable when sampling
for tagged fish takes place relatively quickly after the original
release of the fish. This must be so in order to minimise the
effects of recruitment, emigration, tag loss and mortality.
Periods of sampling undertaken at two monthly intervals are not
suitable for estimations of this type, giving grossly high
estimates. It has therefore only been possible to calculate
populations for the estuary for the period July 1966 to January
1967, for Lyttelton Harbour from February 1966 to July 1966, and
for Akaroa Harbour from April 1966 to February 1967. Not all
monthly samples were suitable for population estimates because
of insufficient or no data.

In all three localities, the trend is for populations to
decrease during the spring, which is in agreement with the
times of movements shown by tag returns in paper 9.

The largest population is probably that in Akaroa Harbour,
although the estuary appears to be of a similar order of mag-
nitude, but with a smaller average size of individual fish.
The population of sand flounders in Lyttelton Harbour is con-
siderably lower, as the estimates shown are for the peak periods of the year.

As noted earlier the approximate number of fish leaving Akaroa Harbour is at least 70,000. Because of the effects of recruitment, this figure will be lower than the real value, as the rate of entry of young fish into the sample is rapid between August and December. The data available for the Estuary shows that a similar population level is maintained during the spring and early summer. Allowing for similar rates of recruitment and growth, the May/June estimate should be of the same order of magnitude as for Akaroa. The autumn and winter population of sand flounders in Lyttelton Harbour appears to be approximately half to one third that of Akaroa Harbour for the same period. This ties in with the fact that these fish are largely restricted by depth to areas seaward of the Teddington side of Quail Island, very few being caught in the shallow upper regions of the harbour.

8.3. Population Estimation from Catch-Effort and Tagging Data

The method of population estimation based on the use of both catch-effort and tagging data enables an unbiased estimate of the population to be made, allowing for both recruitment and emigration.

DeLury (1947, 1951) developed procedures to obtain estimates of population size from the trend of catch per unit effort; thus enabling a check to be made on tagging estimates.

DeLury's method is dependent upon a declining catch-effort
ratio. Thus, if the catch-effort decreases to zero, the entire population has theoretically been captured, and the accumulated catch during that time will represent the population. Using DeLury's symbols, the catch during a given time \( t \) is denoted as \( C(t) \) and the effort expended in making the catch is denoted as \( E(t) \). The catch per unit of effort for internal \( t \) is then:

\[
C(t) = k N(o) - k K(t),
\]

where \( K(t) \) represents the catch up to, but not including, time \( t \). \( N(o) \) represents the number of individuals in the initial population. If the line relating \( C(t) \) to \( K(t) \) is reasonably straight, then values may be computed for \( k \) and \( N(o) \).

A graphical estimate of \( N(o) \) may be obtained by extrapolating the line to the \( K(t) \) axis. Assuming no recruitment or emigration, and that the catchability, \( k \) (that fraction of the population captured by one unit of effort) is constant, the slope of the line relating \( C(t) \) to \( K(t) \) will be a measure of \( k \). Should recruitment or emigration, or both occur, the slope of the line will yield \( k_a \), the apparent catchability, unless recruitment exactly equals emigration.

It is known that recruitment and emigration are present in the populations estimated here. To obtain a value for the difference between the true and apparent catchabilities, a tagging experiment must be conducted during the same period as covered the analysis of the catch-effort data (Ketchen 1953).
As DeLury (1951) points out, the trend in catch per unit of effort of tagged fish is related to the accumulated catch of tagged fish in the same way that catch per unit of effort from the whole population is related to the accumulated catch from the whole population, namely

\[ C'(t) = k'N'(o) - k'K'(t), \]

where \( C'(t) \) is the catch of tags per unit of effort, \( K'(t) \) is the accumulated catch of tags, \( k' \) is the apparent catchability of tagged fish, and \( N'(o) \) is the population of tagged fish when \( t = 0 \). The value of \( N'(o) \) may be equated with the number of tagged fish at large at the beginning of the experiment. Thus there is provided a means of testing the rate of emigration provided that tagging mortality is negligible.

Assuming that the tagged fish are evenly distributed throughout the population, and are equally as vulnerable to capture as untagged fish, the only factor which could make the slope of \( C'(t) \) to \( K'(t) \) different from that of \( C(t) \) to \( K(t) \) is emigration, as there can be no recruitment of tagged fish. The true catchability \( (k) \) of the population may then be calculated from the apparent catchability of the tagged fish \( (k') \) and the ratio of the estimated to actual number of tagged fish

\[ k = \frac{k'N'(o)}{\text{number tagged}} \]

Similarly, the slope of the relationship \( C(t) \) to \( K(t) \) measures an instantaneous rate of decrease or catchability \( K'' \), which includes the rates of fishing, recruitment and emigration. The equation relating \( C(t) \) to \( K(t) \) under the original assumptions,
namely

\[ C(t) = k N(t) - k K(t) \]

may now be written to include the rates of fishing, recruitment
and emigration:

\[ C(t) = k''N''(t) - k''K(t) \]

Hence \[ N(t) = \frac{k''N''(t)}{k} \]

Since the instantaneous rate \( k' \) includes the effects of
emigration and fishing, and \( k \) measures fishing only, the
instantaneous rate of emigration is represented by \( k' - k \).

Similarly, recruitment is the difference between \( k'' \) and \( k' \).
Allowing for the fact that recruitment adds to the population,
it must be represented by \( k' - k'' \).

\[ \text{5.5.1. A Population Estimation from Catch-Effort Data for} \]

\[ \text{Akaroa Harbour} \]

The data required for this estimation is given in
Table 5.4.
Table 8.4. Daily Catch per 5 hours Fishing (number of fish), c(t), catch per unit effort C(t), and accumulated catch K(t) for Akaroa Harbour.

<table>
<thead>
<tr>
<th>Date</th>
<th>c(t)</th>
<th>C(t)</th>
<th>K(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5.66</td>
<td>223</td>
<td>44.6</td>
<td>0</td>
</tr>
<tr>
<td>10.5.66</td>
<td>202</td>
<td>40.9</td>
<td>223</td>
</tr>
<tr>
<td>11.5.66</td>
<td>263</td>
<td>52.6</td>
<td>425</td>
</tr>
<tr>
<td>12.5.66</td>
<td>281</td>
<td>56.2</td>
<td>688</td>
</tr>
<tr>
<td>13.5.66</td>
<td>262</td>
<td>52.6</td>
<td>969</td>
</tr>
<tr>
<td>7.6.66</td>
<td>361</td>
<td>62.2</td>
<td>1231</td>
</tr>
<tr>
<td>8.6.66</td>
<td>351</td>
<td>70.2</td>
<td>1592</td>
</tr>
<tr>
<td>9.6.66</td>
<td>131</td>
<td>26.2</td>
<td>1943</td>
</tr>
<tr>
<td>10.6.66</td>
<td>294</td>
<td>58.8</td>
<td>2074</td>
</tr>
<tr>
<td>25.7.66</td>
<td>213</td>
<td>42.6</td>
<td>2368</td>
</tr>
<tr>
<td>26.7.66</td>
<td>215</td>
<td>45.0</td>
<td>2561</td>
</tr>
<tr>
<td>26.8.66</td>
<td>259</td>
<td>52.8</td>
<td>2796</td>
</tr>
<tr>
<td>23.8.66</td>
<td>151</td>
<td>30.2</td>
<td>3055</td>
</tr>
<tr>
<td>22.9.66</td>
<td>223</td>
<td>44.6</td>
<td>3206</td>
</tr>
<tr>
<td>23.9.66</td>
<td>120</td>
<td>24.0</td>
<td>3429</td>
</tr>
<tr>
<td>27.10.66</td>
<td>208</td>
<td>41.8</td>
<td>3549</td>
</tr>
<tr>
<td>28.10.66</td>
<td>49</td>
<td>9.8</td>
<td>3797</td>
</tr>
<tr>
<td>24.11.66</td>
<td>125</td>
<td>25.0</td>
<td>3806</td>
</tr>
<tr>
<td>25.11.66</td>
<td>235</td>
<td>47.0</td>
<td>3931</td>
</tr>
<tr>
<td>17.12.66</td>
<td>239</td>
<td>47.8</td>
<td>4166</td>
</tr>
<tr>
<td>18.1.67</td>
<td>231</td>
<td>46.2</td>
<td>4405</td>
</tr>
</tbody>
</table>

As this method of population estimation is dependent upon a declining catch effort, the analysis has been restricted to the period 7.6.66 to 24.11.66.
Figure 8.2. The relationship between daily catch, $C(t)$, and accumulated catch, $K(t)$ for *Rh. plebeia* from Akaroa Harbour.
Figure 8.2. shows $C(t)$ plotted against $K(t)$. The straight line fitted to the points by least squares has the equation

$$C(t) = 87.3 - 0.0168 \cdot K(t).$$

From the equation

$$C(t) = k''N''(O) - k'' K(t)$$

$$k'' = 0.0168$$

$$k''N''(O) = 87.3$$

Therefore

$$N''(O) = \frac{87.3}{0.0168}$$

$$= 5,196.$$  

This figure is an estimate of the fish present in Akaroa Harbour at June 1966. The extremely wide difference between this result and the 66,000 fish obtained by Bailey's method suggests that the rate of emigration is far in excess of the rate of recruitment for this period. This has been examined by means of a tagged fish catch-effort analysis given below.

8.6. Estimation of the Tagged Fish Population by Catch-Effort Analysis.

The data for this analysis covers the same period as for the initial catch-effort analysis. Owing to the restricted amount of data available, table 8.5, shows the combined results for each monthly sampling.
Figure 8.3. The relationship between monthly catch, $C'(t)$ and accumulated catch, $K'(t)$, for tagged *Rh. plebeia* from Akaroa Harbour.
Table 8.5. Catch per Sampling Period $c' (t)$, Effort in Boat Hours $e' (t)$, Catch per Unit of Effort $C' (t)$, and Accumulated Catch of Tagged Fish $K' (t)$ for Akaroa Harbour.

<table>
<thead>
<tr>
<th>Date</th>
<th>$c' (t)$</th>
<th>$e' (t)$</th>
<th>$C' (t)$</th>
<th>$K' (t)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 1966</td>
<td>5</td>
<td>3</td>
<td>1.0</td>
<td>0</td>
</tr>
<tr>
<td>June 1966</td>
<td>3</td>
<td>5</td>
<td>0.6</td>
<td>5</td>
</tr>
<tr>
<td>July</td>
<td>6</td>
<td>10</td>
<td>0.6</td>
<td>8</td>
</tr>
<tr>
<td>August</td>
<td>3</td>
<td>10</td>
<td>0.3</td>
<td>14</td>
</tr>
<tr>
<td>September</td>
<td>1</td>
<td>10</td>
<td>0.1</td>
<td>17</td>
</tr>
<tr>
<td>October</td>
<td>0</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>November</td>
<td>0</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>January 1967</td>
<td>1</td>
<td>10</td>
<td>0.1</td>
<td>18</td>
</tr>
<tr>
<td>February</td>
<td>0</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 8.3. shows $C' (t)$ plotted against $K' (t)$.

The straight line fitted to the points by least squares has the equation

$$C' (t) = 0.95 - 0.048 K' (t).$$

Therefore the original number of tagged fish released in May 1966 by this estimation is

$$N' (0) = \frac{0.95}{0.048} = 20$$

In fact, 579 fish were released at that time. This result shows that factors are present which cause a heavy removal of tagged fish from Akaroa Harbour during this period. From evidence presented in papers 2 and 5, the main cause is probably emigration,
with tagging and natural mortalities playing a less important role.

To obtain an estimation of the population of tagged fish uninfluenced by recruitment or emigration, a value for the true catchability must be obtained. This may be calculated from the apparent catchability of the tagged fish \( (k') \) and the ratio of the estimated to actual number of tagged fish.

\[
k = \frac{k' N' (o)}{\text{number tagged}} = \frac{0.25}{579} = 0.00164
\]

Therefore as \( N(o) = \frac{k'' N''(o)}{k} \)

the initial population as at the beginning of June 1966 must be

\[
\frac{579 \times 0.00164}{0.00164} = 53,231
\]

This figure agrees tolerably well with the result of 66,000 obtained by the Petersen census for this month.

This data can further be used to give estimations of emigration and recruitment. As no recruitment can take place with tagged fish, the instantaneous rate of emigration must be the difference between \( k' \), the apparent catchability of tagged fish, and \( k \), the true catchability.

\[
k' - k = 0.048 - 0.00164 = 0.0464
\]

Similarly, the instantaneous rate of recruitment must be the difference between \( k' \) and \( k'' \),

\[
k' - k'' = 0.048 - 0.0168 = 0.0312
\]

The total effort used during the period June to November 1966 was 5,650 boat hours. The \( k \) values for the whole of this
period are, therefore, as follows:-

rate of fishing = \( P = \delta k = 65 \times 0.00164 = 0.1066 \)

rate of emigration = \( e = E(k' - k) = 65 \times 0.0466 = 3.0106 \)

rate of recruitment = \( k = E(k' - k'') = 65 \times 0.0312 = 2.028 \)

As the average stock of fish throughout the fishing period (June to November 1966) \( \bar{N} \) is given as

\[
\bar{N} = \frac{\text{Total number of fish caught}}{0.1066} = \frac{2,700}{0.1066} = 25,328
\]

then the actual number of emigrants during that period is given by

\[
ge = 3.016 \times 25,328 = 76,389
\]

and the actual number of recruits

\[
kN = 2.028 \times 25,328 = 51,363
\]

Therefore, an excess 25,000 emigrants occurs over the number of recruits for this period, meaning that the population in June 1966 is 53,000 and the population in November is

\[
53,000 + 51,000 = 76,000 = 29,000.
\]

Again this is comparable with the Bailey estimate of 20,000 for the same month.

6.2 - Summary of Results

The results obtained by the Petersen and catch effort methods for Akaroa Harbour show a close resemblance. Table 6.6. summarizes this.
Table 8.6. Population Estimations Obtained by the Peterson Census and Catch-Effort Analysis Methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>Population at June 1966</th>
<th>Population at November 1966</th>
<th>Emigration</th>
<th>Recruitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peterson</td>
<td>66,000</td>
<td>20,000</td>
<td>Minimum of 70,000</td>
<td>Unknown</td>
</tr>
<tr>
<td>Catch-effort</td>
<td>53,000</td>
<td>29,000</td>
<td>76,000</td>
<td>51,000</td>
</tr>
</tbody>
</table>

The close agreement reached by these two methods shows that the results obtained can be taken as reliable. The lack of data from the other two areas prevents a detailed investigation of the seasonal fluctuation of their populations. Certain assumptions would seem justified with regard to estimating the populations of the Estuary and Lyttelton Harbour. The estimate of 24,000 fish for May for Lyttelton Harbour would be the maximum for that year, as it has already been shown that fish leave this region during the following spring. The Estuary figures are comparable with Akaroa for the winter and spring. The July figure seems low, but does have a large standard deviation and could be unreliable. Assuming similar rates of recruitment, the May peak population is likely to be 70,000, as with Akaroa.

8.3. The Value of the Inshore Regions and Nursery Grounds

The analysis of tag returns in paper 3 indicated that
recruitment for the offshore grounds was from fish originating in inshore Canterbury waters. There are insufficient statistics of the commercial catch to allow estimations to be made of the relative importance of each nursery ground to the total catch on each ground.

Moreover, using the length-weight relationship in figure 8.4, estimations of the weight of flounders migrating from each area can be made. The average length of fish leaving each of the harbours is given in tables 5.9, 5.10, 5.11 of paper 5.

The weight of fish leaving the Estuary, based on 70,000 individuals, is therefore 289 cwt. For Lyttelton Harbour it is 118 cwt, and for Akaroa Harbour 413 cwt. These values would be slightly high because of the limited commercial and amateur fishing that is carried on in each region. These values correspond to about one fifth of the average annual Canterbury catch of sand flounders, without allowing for continuing growth and mortality.

From studies on the movements of fish, it has been shown that two populations of sand flounders exist off the Canterbury coast. One, spawning on the Flounder Patch, inhabits the Estuary and Lyttelton Harbour, and the second, spawning on the Winter Ground, inhabits these areas together with Akaroa Harbour. From this it would seem likely that the proposed closing of the Estuary by means of an artificial barrier across the mouth would have an immediate effect on the productivity of all the offshore
traveling grounds.

While it has been shown that juvenile fish inhabit Pegasus Bay, more work would be required to determine whether or not this region could hold an increase in the numbers of juvenile fish to compensate for the closing of the estuary. As estuaries in general are richer feeding grounds than off-shore areas, it would seem unlikely that sufficient compensation would be made.

Another factor shown in paper 3 was the relatively large numbers of male flounders which migrate from both the estuary and Lyttelton Harbour to the winter ground. The significance of this is not known at the present stage, but it must be remembered that Lake Ellesmere, Akaroa Harbour, and to some extent the estuary and Lyttelton Harbour are dependent on the winter ground as a spawning area. The fact that the stock of sandflounders inhabiting the estuary is approximately 95% below the legal size limit indicates without doubt that this region should be closed to all fishing.

8.2. Conclusions

Akaroa Harbour had a population of flounders of 80,000 to 50,000 for May to June 1966. It is probable that a similar population is supported by the estuary and some 24,000 by Lyttelton Harbour for the same period. Of the peak annual population, some 80% has been shown to migrate each spring to the offshore commercial grounds, forming an important source of recruitment for these grounds.
Commercial development involving barriers, land reclamation or pollution could have a serious effect on the productivity of the offshore grounds.

8.10. Bibliography


8.1d. General Discussion and Conclusion

This study of the sand flounder fishery in the Pegasus Bay, Canterbury Bight region of the South Island, New Zealand, has been prepared as a series of eight papers. The title and summary from each is given below.

Paper 1. A method of age determination of the sand flounder *Pseudopleuronectes pleuronectes* (Richardson) by the use of stained otoliths.

Various standard techniques for improving the reading qualities of otoliths were investigated and found unsuitable. A method of staining the protein matrix of the winter ring is described, and evidence presented which shows this method of age determination to be valid for the sand flounder. The interpretation of the otolith is based on the nucleus depicting the first twelve months of life, followed by alternate translucent summer and opaque winter rings. A suggestion is made that spawning checks may be present in the otoliths of many fish above two years of age.
Paper 2. Length frequency distributions of the sand flounder *Bemboscoea plebeia* (Richardson) inhabiting the Banks Peninsula region.

The most representative sample of sand flounders was shown to be taken with a 2½ inch stretched mesh net. Direct comparisons with commercial gear showed a 50% retention level at 17.7 cm for a 4½ inch net. Fish were shown to enter the sample taken by 2½ inch gear when one year old, and enter the commercially exploited phase of the population during their second winter. The majority of harbour fish were shown to be under three years of age, and evidence was found of a marked movement from the harbours of two year old fish during each spring, leaving a resident population of younger fish.

Paper 3. Errors encountered in growth rate calculations due to length shrinkage after capture for the sand flounder *Bemboscoea plebeia* (Richardson).

Tagged fish returned to the laboratory shortly after release frequently showed some decrease in length. This decrease was not found with live material. Further investigation showed an average shrinkage of 2.3% during storage. A linear relationship \( Y = 0.023X + 0.004 \) was shown to exist between the length of the fish and the amount of shrinkage, a minimum legal size fish shrinking an average of 5.3 mm, with the probability of 2½% of the fish shrinking 6.95 mm, and 1% shrinking 7.62 mm.

An analysis of the returns from Petersen tags showed an average recapture rate of 17.3%, compared with 20.3% for spaghetti tags. Double Petersen tags gave a return of 20.6%, and single Petersen 14.0%. Clipped spaghetti tags gave a return of 22.3%, and tied 18.3%. Spaghetti tags proved easier to attach to the fish, caused less wound formation, and were easier to recognise when recaptured.

Paper 5. The movements of the sand flounder *Rhabdopleura plebsia* (Richardson) in Canterbury waters.

Regular tagging in three Banks Peninsula bays was conducted at intervals between January 1964 and February 1967. This programme was later extended to the offshore Flounder Patch and Winter Ground for the period July 1966 to February 1967. The broad patterns of movement detected show an annual migration of year class 2+ fish from the Estuary and Lyttelton Harbour northward to the Flounder Patch, and southward to the Winter Ground. These migrations occurred largely in August and September. No significant movement was detected from tag releases on the Flounder Patch, but a marked movement of year class 3+ and older fish from the Winter Ground to the Flounder Patch was shown. A seasonal variation in sex ratio...
from 2 females per male during the peak spawning period, to
12.5 females per male at mid off-season periods. To explain
the pattern of movements shown, a theory is put forward that
the Flounder Patch and Winter Ground represent the spawning
grounds of separate populations. The existing water currents
would account for the distribution of young fish and their
subsequent migration routes.

Paper 6. The growth rate of the sand flounder *Plebejus* plenus (Richardson) off Banks Peninsula.

Age determination was made from otoliths, the maximum age
found being six years. A growth curve for female sand flounders
was derived, fitting the equation \( l_t = 59.9 (1 - 0.791t + 0.083) \),
with parameters of \( l_\infty = 59.9 \text{ cm} \), \( t_0 = 0.083 \text{ years} \), and \( k = 0.235 \).
The length weight relationship for Akaroa Harbour fish was found
to have the equation \( \log W = 3.13 \log L - 2.05 \) for females and
\( \log W = 2.89 \log L - 1.76 \) for males. This relationship varied
in other localities and this variation is taken as evidence
supporting the presence of two populations of this species off
the Canterbury Coast. The period of maximum growth for all
Astuary fish occurred between December and March, and minimum
growth between May and September.
Paper 7. The feeding habits of the sand flounder *Rhomboseles plebeia* (Richardson) in Canterbury waters.

The gut contents of the sand flounders from four localities were sampled monthly for a period of between six and twelve months. The analysis was made in terms of the number of species present, and the percentage estimate of volume for the main items present. It was shown that juvenile fish in all areas fed largely on amphipods, with decapods, sedentary polychaetes or cumaceans forming the bulk of the diet for older fish, depending upon the area of capture.

Paper 8. Some estimates of the populations of sand flounders *Rhomboseles plebeia* (Richardson) inhabiting three localities around Banks Peninsula.

Population estimates by a Petersen type census gave maximum peaks of 70,000 for the Heathcote - Avon Estuary, 24,000 for Lyttelton Harbour and 81,000 for Akaroa Harbour for May 1966. The corresponding minimum peaks were 11,000, 17,000, and 8,000, all for September 1966. For Akaroa Harbour there was sufficient data to enable a catch effort analysis to be made in addition to the Petersen census for the period June to November 1966. The catch-effort analysis gave a value of 53,000 for the June population, and 29,000 for the November population; emigrants for this period were estimated at 76,000. The values obtained by the Petersen analysis were 60,000 for June and 20,000 for November with a minimum of 70,000 emigrants during the intervening period.
The overall picture obtained is of a seasonal commercial fishery based on relatively small numbers of fast growing fish. Two separate populations have been shown to exist, with the Flounder Patch (Pegasus Bay) and Winter Ground (Canterbury Bight) as the respective spawning grounds.

Water currents from the spawning grounds carry pelagic egg and larval stages into inshore, shallow regions, and juvenile forms are to be found along most of the Canterbury coastline. A migration to the spawning grounds takes place during the second or third winter. On the evidence used to support the theory that two populations exist off Canterbury, it is possible that all juvenile forms along this coastline return to their original hatching area.

Lack of data prevents an estimate of the numbers of fish congregating on the offshore grounds during the breeding season. Seasonal population estimations could be made by a catch-effort analysis and a concurrent tagging programme.

The relationship between the fish taken on the Winter Ground and those comprising the Otago fishery is a further aspect requiring attention. The release of tagged sand flounder off the Otago Heads showed a general south-westerly movement. A limited number of recaptures of Akaroa tagged fish were made off the Otago Heads. There is a distinct possibility that further populations of sand flounders exist to the south-east of the South Island.
The inshore period in the life history of this species results in the fishery being particularly vulnerable to the commercial development and pollution of bays and harbours. The relatively short life-span of this fish would result in the early decline of stocks from such interference.

Two areas which particularly require careful evaluation are the Heathcote-Avon Estuary and Lake Illesmere. The Estuary supports a large population of predominantly undersized fish, and because of this, is somewhat open to abuse from amateur fishermen, which can only be successfully overcome by total closure to fishing. This could be of no significance, however, should the proposed barrier across the mouth be constructed. Some practical investigation of the possible effects of such a barrier should be made with regards to the total fauna of the region. Any decrease in stock must surely result in a decrease of recruits entering all commercial grounds.

Although outside the scope of this study, the sand flounder fishery based on Lake Illesmere can only be regarded as unsatisfactory, due to the annual intake of eggs and larvae being dependent upon the lake being open to the sea at the correct time. If the lake was opened to the sea during October or November, flounder larvae would be expected to migrate in as in the Estuary; closure during the rest of the year could possibly conserve the stock by preventing the egress of two and three year old fish migrating to the Winter Ground during July and August. Control
of the opening could, therefore, overcome the problem of widely fluctuating annual catches, and the low price associated with the small size of fish comprising the present catch.