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THE ECOLOGY OF TROUT IN SOUTH AUSTRALIA

by

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March 1967

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FRONTISPIECE

Brown trout (*Salmo trutta* Linnaeus)

Rainbow trout (*S. gairdnerii* Richardson)



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SUMMARY

The ecology of Brown trout (*Salmo trutta* L.) and Rainbow trout (*S. gairdnerii* Richardson) was studied in South Australia.

The distribution of these "cold-water" fish is restricted to streams and man-made still-waters of the Mt. Lofty Ranges by the summer heat and aridity of the warm temperate (Mediterranean) climate. Even within this cooler, higher rainfall region the survival of trout was surprising. Maximum summer air temperatures often exceed 90°F (32°C) and even 100°F (38°C) and the flow of water down streams is very small during the summer.

The survival times of the offspring of wild trout were determined during the summers of two years at constant water temperatures of 28°, 29° and 30°C. These trout were not more resistant to high water temperatures than trout in cooler climates.

Recordings were made of hourly water temperatures during two years for one small trout-stream, Sixth Creek, in the coolest part of the Ranges near Adelaide. There was insufficient time during the summer days for the water to heat up to lethal levels. And the minimum water temperature of the early morning was independent of the heating of the previous day, due to the long period of overnight cooling. The minimum air temperature during the early morning was considerably lower in the valley of this stream than on the plains near Adelaide and the difference became larger when the daytime air temperatures increased.

While the trout lived in most places along Sixth Creek their distribution within more distant streams, in the directions of increasing heat and aridity to the north and east, was increasingly patchy. The fish in these streams were found to survive the summer in deep pools where they could avoid the surface water during the daytime heat.

Measurements of water temperature where trout actually survived revealed that the water at the bottom of deep pools was very much cooler than at the surface during the mid-afternoon of very hot days. The thermal stratification of pools in streams was recognized as an important feature of the ecology of trout since it allows them to extend their distribution into warmer climates.

Deep pools usually occur at bends in streams. Most of the rainfall in S.A. occurs during the winter. The small flow during the summer allows temperature stratification of the pools. Even where there was no surface flow of water in streams during the summer trout were found to survive in pools for as long as there was a sufficient depth of water to insulate them from the heat. The inimical influence of summer floods was described.

The small flow down streams during the spring, summer, and autumn results in narrowing of stream channels, due to the encroachment of bank vegetation, which does not favour the deposition of spawning gravel by winter floods. However Brown trout introduced during the late 19th and early 20th century in very small numbers apparently survived and were self-supporting for many years.

Only the growth component of the abundance of the trout was estimated for streams other than Sixth Creek, a tributary of the Torrens River. Sampling by electro-fishing in this creek revealed that the numbers of trout were high, they grew poorly after their first year, and moved extensively. The stream had been heavily fished and stocked with trout, especially Rainbow trout, during the last fifteen years and trout from the Torrens River spawned in it every winter.

The trout were almost continuously distributed along the section of Sixth Creek which was studied. In terms of the length of water-types of different classes the fish were much more crowded in the longest, deepest places (deep pools). This crowding was related to the linear distribution along the stream of fish when feeding. However in terms of living space the numbers and biomass of fish per unit volume of water were similar in different classes of water-types. The amount of food accessible to the fish was greatest in the fast running water of the shallowest water-types. But the deep pools provided more cover and cooler water for the fish during the summer period of heat and low flow.

Recaptures of tagged fish showed that the fish retreated to deeper water-types as the summer approached. Most of the tagged fish were recaptured in the subsection where they were released and most of these were fish which either stayed in deep pools or moved to them from shallower places. However at least 50% of the fish caught were untagged and had moved into a subsection during the 3 months between fishing and refishing it. The conclusion was reached that

the fish moved downstream extensively due to jostling for limited resources of food and cover. Brown trout were more successful than Rainbow trout in defending a site for a long time.

A large number of scale samples from Sixth Creek trout and trout captured by angling in other places (including fish of known age) were examined. Criteria for aging and backcalculating lengths are described for trout in S.A. There was a wide range of growth rates from high values for trout in a newly-filled reservoir to the low rates of Sixth Creek trout.

A growth model for fish was proposed. Use was made of the idea that an increment of growth in length is a measure of the expansion of the skeleton necessary to accommodate a preceding increment in the major bulk of the fish, the muscle, when this results in the weight of the fish exceeding a certain value for a given length of fish. An attempt was made to find the weights for trout of different lengths which when exceeded result in further growth in length. A condition factor, using these weights, was successfully employed as a variable in multiple regression analyses to provide descriptions of variations in the weights and energy contents of fat, muscle, and gonads of trout of different condition. Female trout were found to divert much more matter and energy into the production of ovaries than male trout do for testes. And this was put forward as one explanation for the smaller size of female trout of the same age. The growth model was also used to calculate the lengths above which trout in Sixth Creek were not growing further in length at different times of the year.

The food supply of the trout in Sixth Creek was described using two new methods, which sampled the animals actually accessible to the fish, as well as the customary Bottom Fauna method.

In running water the drift of aquatic invertebrates was sampled using nets and in the "still-water" of pools the number of animals in the open water was found by pumping water through a filter. The number of animals in the samples were expressed as densities using the volume of water filtered by the nets, or pumped through the filter. A more illuminating picture of the food supply was built up than is usual because the sizes of animals of different species in the catches were measured. A number of experiments were performed to show how the density of accessible food varied at different points along the stream and at different flows. The amount of accessible food increased during the late winter to a maximum in the spring. Another, smaller, increase occurred during the late summer-early autumn which was correlated with a summer bloom of algae in the stream.

Food sampling was also undertaken in other places where the trout grew better than in Sixth Creek. The phenomenon of an increase in the movements of invertebrates out from cover after sunset into the current of streams occurs in S.A. Also in true still-waters (a dam and a reservoir), as opposed to the "still" pools in Sixth Creek, there is a similar movement after sunset of animals larger than plankton.

The density of accessible animals was as high, or higher, in Sixth Creek as in the other places. But most of the animals accessible to the trout in Sixth Creek were very small. A comparison with the Bottom Fauna showed that the species present were inaccessible to the

trout except when small, or while emerging (insects) from the water. It was pointed out that the Sixth Creek trout therefore suffer from a rel ative shortage of food. Most of the available food was inaccessible to the trout during a day. More food became accessible to them for a time in the growing darkness after sunset. But while the density of items was high, the animals were too small for the trout (except while small when they grew very well) to get enough during this period of heightened accessibility.

The high numbers and almost continuous distribution of the trout along Sixth Creek was inferred to have resulted in the near elimination of species of larger food animals which in other places, where the trout grew better, were found to be highly accessible and frequently eaten by the fish.

Most trout in freshwater around the world grow at much lesser rates than they are inherently capable of growing. Where they have been known to grow very rapidly their food supply has been characterized by at least one large and highly accessible food animal. It is possible, therefore, to infer that most trout around the world suffer from a similar relative shortage of food to a lesser or greater degree.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and, to the best of my knowledge and belief, the thesis contains no material previously published or written by another person, except when due reference is made in the text of the thesis.

ACKNOWLEDGEMENTS

I am grateful to Professor H.G. Andrewartha for allowing me to study the trout in S.A., and for reading and criticizing the text of the thesis.

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Mr. K.V. Morris explained the iterative method of solving complex equations to me and Professor H. James verified the interpretation of the analysis in section 2.2.2.2.

Messrs P. Cudmore, C. Malpas, A. Wark, and R.O. Wilson gave me details of historical interest.

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1. INTRODUCTION

In Australia the Brown trout (Salmo trutta L.) and Rainbow trout (S. gairdnerii Richardson) have been successfully introduced into the streams and stillwaters of the one large and two much smaller mountainous regions enjoying relatively higher rainfalls (in the south only during the winter) and lower air temperatures (due to their southerly latitude, coastal proximity and altitude) than the greater part of the continent (Map 1).

In South Australia these "cold-water" fish would appear to be restricted in their overall distribution to the streams of the Mount Lofty Ranges by the increasing degrees of intense summer heat and aridity to the north and east (Section 2).

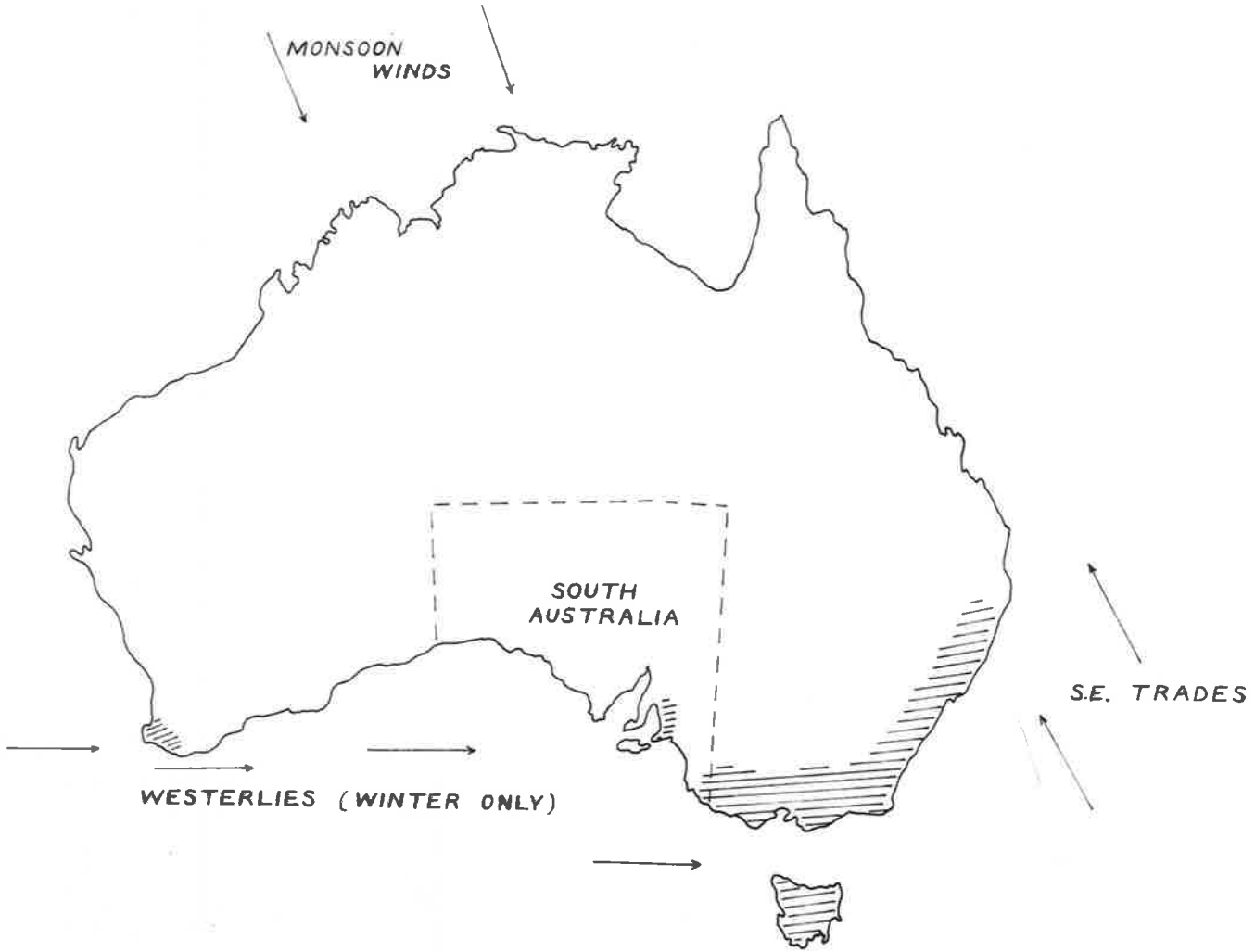
The high summer and mild winter temperatures of the Adelaide Region suggest that the seasonal cycle of growth of the trout (and hence the criteria needed for the aging of fish from their scales) would be different from that of fish in colder climates (part of Section 3).

Although trout have been established in the major streams of this region for at least fifty years, heavier stocking and their introduction into some places since 1950 give an opportunity for noting the changes in their food brought about by such a voracious fish predator previously absent, and the influence of these changes on their growth (part of Section 4).

The physiology, behaviour and genetics of trout, and other members of the Family Salmonidae, have been investigated for many years and a vast amount of literature has accumulated. However less work has been done on their ecology. Many components of their environment which

MAP 1

THE DISTRIBUTION OF TROUT IN AUSTRALIA



are known to be important are not recorded, or are inadequately (water temperatures, stream flow), or unrealistically (food), recorded. The long and distinguished literature on trout angling, as a source of observations of the fish in nature, is most often ignored by researchers.

1.1 Theoretical considerations

According to a recent review (Bakker, 1964) "one of the outstanding characteristics of ecology in general is the lack of agreement as to what the subject is really concerned with."

For this study in "population ecology" I have found that the following sequence of questions is useful.

(1) What characteristic of the animals is of interest and why? (The statistical estimation of parameters of a population of animals is usually called "population dynamics").

(2) How is this characteristic related to the environment? (The environment should be classified into various components on the basis of how they are causally related to the characteristic from a knowledge of the behaviour, physiology and morphology of the species).

(3) How has the species acquired the inherent properties (of behaviour, physiology and morphology) which produce this relationship?

(4) How do these properties, and changes in them, give the species a high probability of remaining extant? ("Population regulation").

Question (3) is usually given over to evolutionists but it is included as a necessary part of the sequence to (4) (aspects of which are also studied by geneticists).

Why particular measurements are made is, in part, usually influenced by the nature of the problem which initiates the study of a particular animal and also by the desired level for the solution of the

problem. How the particular measurements are to be made, as a problem of time and effort, usually has an important influence on the decision as well.

The animals themselves (1) above may be characterized by their distribution and abundance as Andrewartha and Birch (1954) have proposed for the solution of the problems of:- Why the animals are abundant, or absent, at one place but not at another - why they are abundant, or absent, at some times but not at others at one place. Ideally the abundance of the animals should be represented by distributions in time and space.

Theoretically "production" is an ideal measure of abundance. For trout, production has been estimated by Allen (1951) as the weight represented by the area under the curve found by plotting the number of survivors of a year- class at succeeding dates against their corresponding average weights, Figure 1.1. A value for the population over any interval of time can then be found by summing the estimates for each of the age- groups present.

Components of environment which kill, such as lethal extremes of weather and predators, can be causally related to production since it depends in part on the decrease in numbers due to deaths over an interval of time. Production also describes the change in numbers from egglaying to hatching before which the production of the parents conveniently includes the potential offspring. An amount of food can be causally related to production which describes the incorporation of food as growth. The production also includes the biomass produced by individuals which die, or move into or out of the space where it is

measured, during an interval of time.

The production of a year-class from the time of egg laying until they are all dead, Figure 1.2, or differences in the production of different populations over the same period, or the changes in the production of one population through successive periods of the year may, therefore, be explained.

The use of production as a measure of abundance in population ecology can be of considerable value when the animal studied is a fish of commercial, or sporting value. When the rate of production of an exploited fish population is low the sustained catch of saleable, or takeable, fish is also small. Many populations of trout have low rates of production despite high numbers (or because of high numbers, in most cases, when these are considered as a component of the environment of an individual) because the rate of growth of the individuals is low.

Elton (1927) has said: "Food is the factor which plays the biggest part in the lives of animals ..., but generally it is not a limiting factor." When numbers alone are used as a measure of abundance a shortage of food can be related to a decrease in numbers caused by death from starvation. If however production, or growth, is used a shortage of food may be found to be limiting abundance in many more instances. In Figure 1.3 a scheme is given which places particular emphasis on food and is the basis of Sections 3, 4 and 5.

Figure 1.1 Graph of the data needed for the estimation of the production of a year-class in the population. (After Allen, 1951).

Figure 1.2 Smoothed curves representing the production of a year-class. Curve A depicts the theoretical maximum for a given initial number where the environment is always entirely favourable: Curve B (after Allen, 1951) is for a realistic environment: and Curve C that for one set of offspring where the hatched area is included in the production of the parents. Curve A is equivalent to the maximum growth in weight with time of which an individual of the species is, on the average, inherently capable.

Fig.1.1

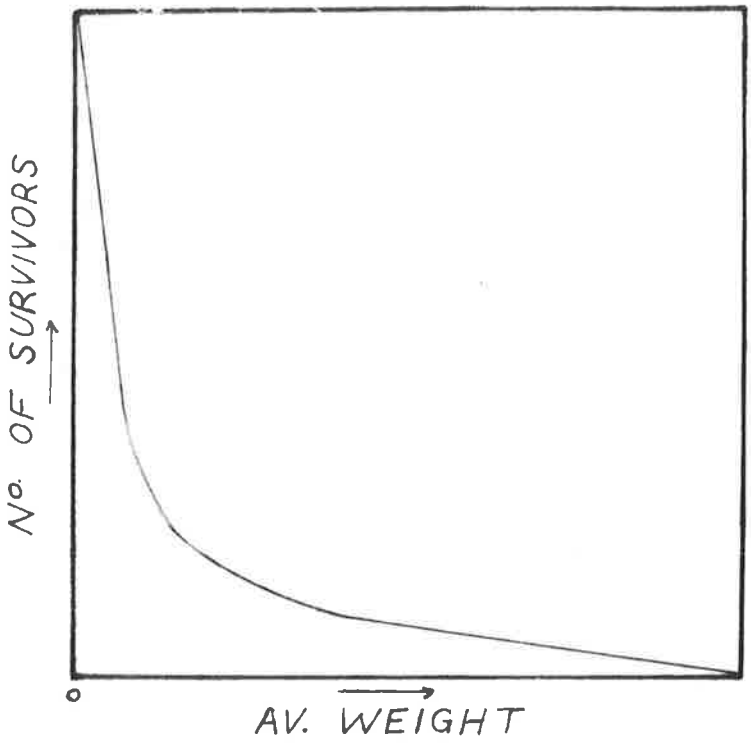

No. OF SURVIVORS
0
AV. WEIGHT

Fig.1.2

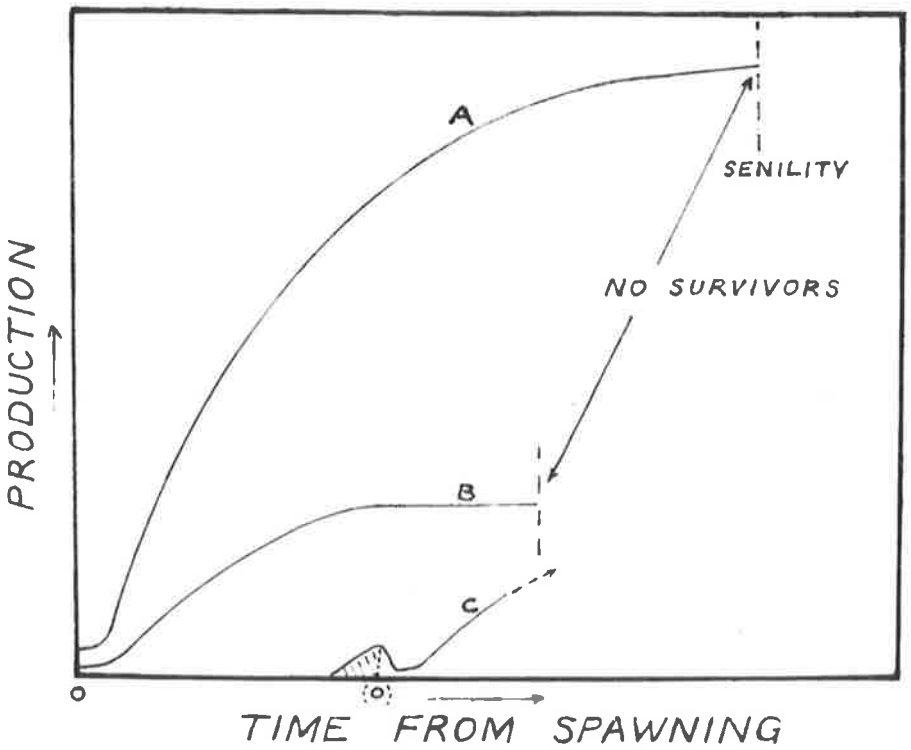
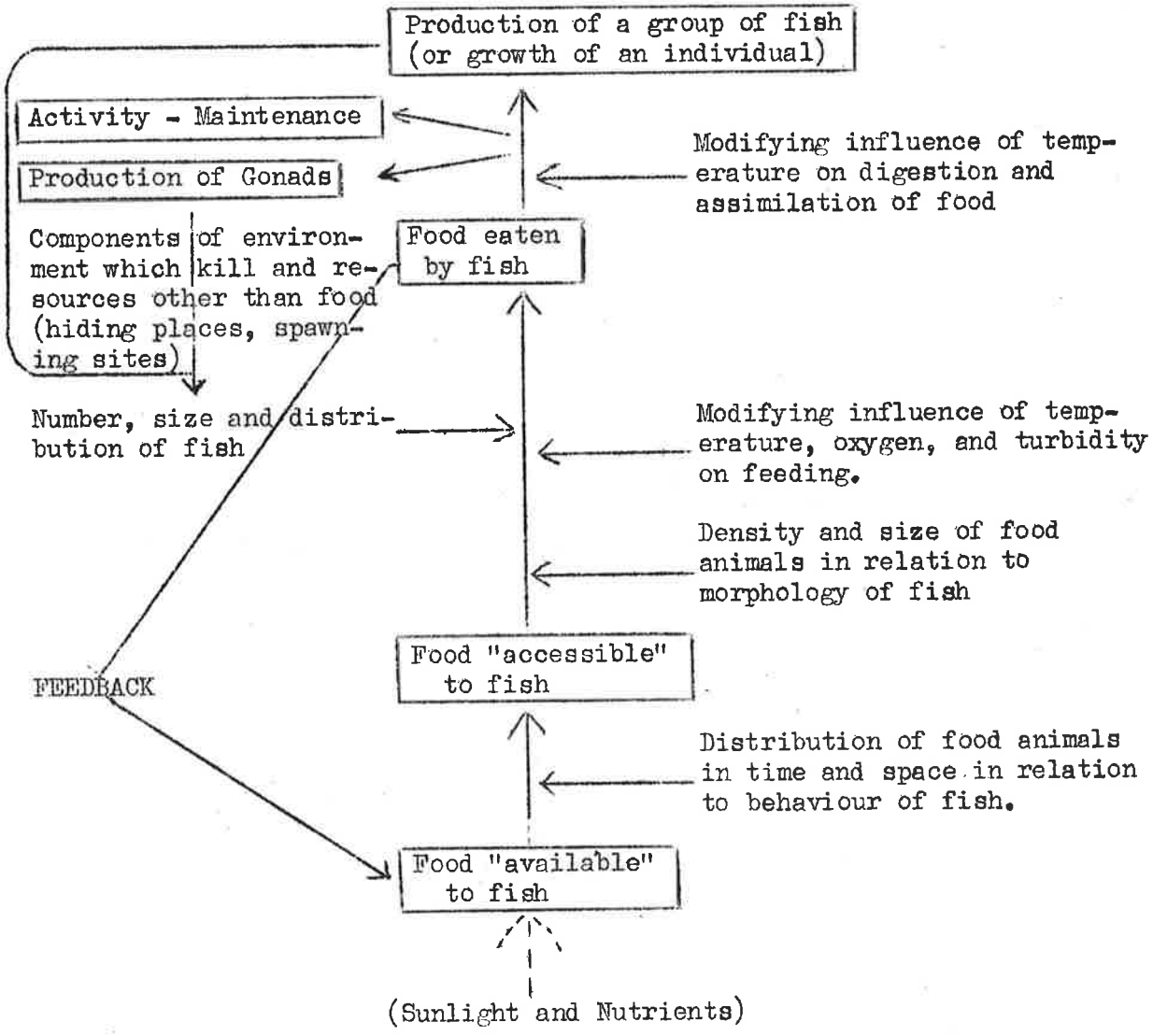

A
SENILITY
NO SURVIVORS
B
C
PRODUCTION
0
(0)
TIME FROM SPAWNING

Figure 1.3 A scheme for assessing the relation between the production of a group of fish, or the growth of an individual, and components of the environment with especial emphasis on food.



1.2 Practical considerations

Although data was gathered for many streams and some still-waters a section of a tributary of the Torrens River called Sixth Creek was chosen for intensive study (Map2). Practical advantages which dictated this choice were:-

(1) The stream is very small (about 10' wide) and shallow ($3\frac{1}{2}$' deep in the largest pools) allowing electro-fishing with a small power source and a minimum of assistance.

(2) Fish can be found in flowing water throughout the year.

(3) There is a high density of both Brown and Rainbow trout.

(4) The stream is only 15 miles from Adelaide.

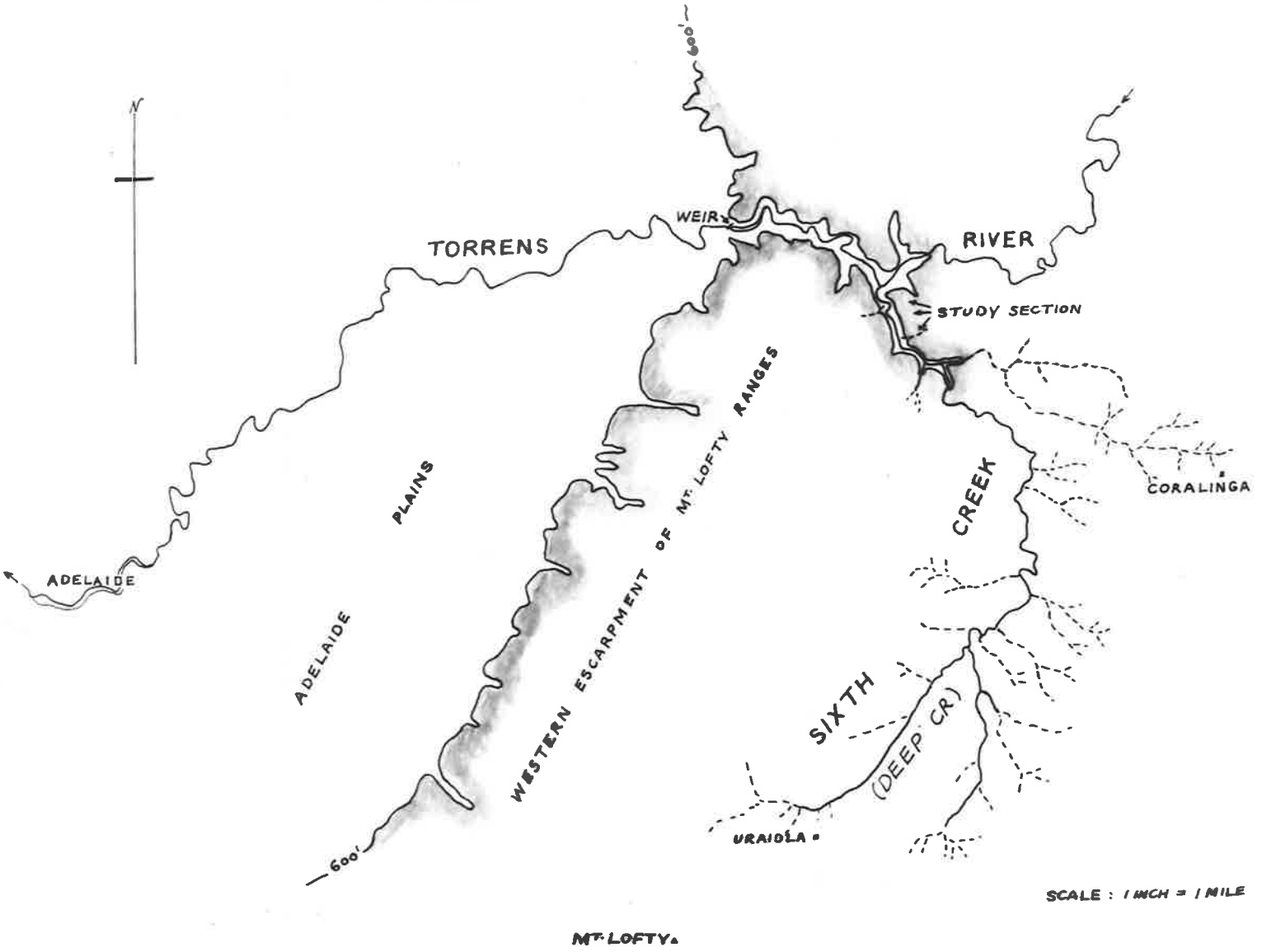
(5) A road follows the section very closely.

(6) This part of the stream is fished only by members of the S.A. Fly Fishers Association and is closely guarded.

(7) A mains power supply, potential sites for rearing ponds, and a fish trap built for an Honours project, were available on the property of Mr. H. Smith who owned most of the section of the stream where the trout were studied. Only a few other streams had any of these advantages.

MAP 2

SIXTH CREEK AND THE TORRENS REGION



Sixth Creek. The view is downstream on 300965. About 600' below the pool (S.P.5) at the bend the creek joins the Torrens River. The deep V-shaped valley and the close proximity of the road were typical of the rest of the study section.



2. THE DISTRIBUTION OF TROUT IN SOUTH AUSTRALIA

The investigation was confined to the region of the Mount Lofty Ranges. Trout may also be found in the south-east of the State, mainly in stillwaters.

2.1 The streams in which trout occur

Map 3 shows the streams, or section of streams, in which trout are to be found. All the streams known to have been stocked at some time in past years are shown and most are named (see Appendix 1 for a list of past introductions). Streams where trout were once established but are now absent, due to the activities of man (reservoirs, siltation, floods, and pollution), are marked by an *. Places where some fish may survive at least their first summer and perhaps persist in very small numbers for a few years are marked by an **. The Light, Little Para and Sturt Rivers are Rainbow trout streams. Rainbow trout have not persisted naturally in streams where Brown trout were (previously) established.

The physical components of the environment of trout which determine the limits of the overall distribution to the north and east in the Mount Lofty Ranges namely high water temperatures and lack of water during the summer act with increasing severity in these directions. Thus, if numbers are used as a measure of abundance the fish are most abundant in the region of the Ranges close to Mt. Lofty near Adelaide but become scarcer further north and east (principle of Andrewartha and Birch, 1954).

MAP OF THE DISTRIBUTION OF TROUT IN S.A.

~~~ STREAMS & SECTIONS THEREIN WITH TROUT

BROUGHTON R.
600'
WAKEFIELD R.
LIGHT R.
NORTH PARA R.
TANUNDA CR.
GAWLER R.
SOUTH PARA R.
LITTLE PARA R.
MARNE R.
GOLDEN GROVE
KERSBROOK
CUDLEE CR.
TORRENS R.
SIXTH CR.
ADELAIDE
CORALINGA
ONKAPARINGA R.
MURRAY RIVER
STURT R.
SCOTTS CR.
COX CR.
GULF ST. VINCENT
BULL CR.
ANGAS R.
BREMER R.
FINNISS R.
BLACK SWAMP
CURRENCY CR.
HINDMARSH R.
INMAN R.
DREAMERE
N
0 5 10 15
Scale of miles
~~~

The influence of these components of environment may be seen by considering the distribution of the fish within streams. For example in Sixth Creek the fish enjoy an almost continuous distribution along the stream. But in rivers such as the Bremer to the east and the Broughton to the north the fish only survive the summer in a few places.

2.2 The influence of high water temperatures in summer on the survival of trout

Are the trout in South Australia genetically adapted to survive at much higher water temperatures than in cooler climates?

With increase in water temperatures at the approach of summer do the fish develop a higher resistance to extreme temperatures?

Are the water temperatures which they experience during the intense daytime heat of the summer as great as might be expected?

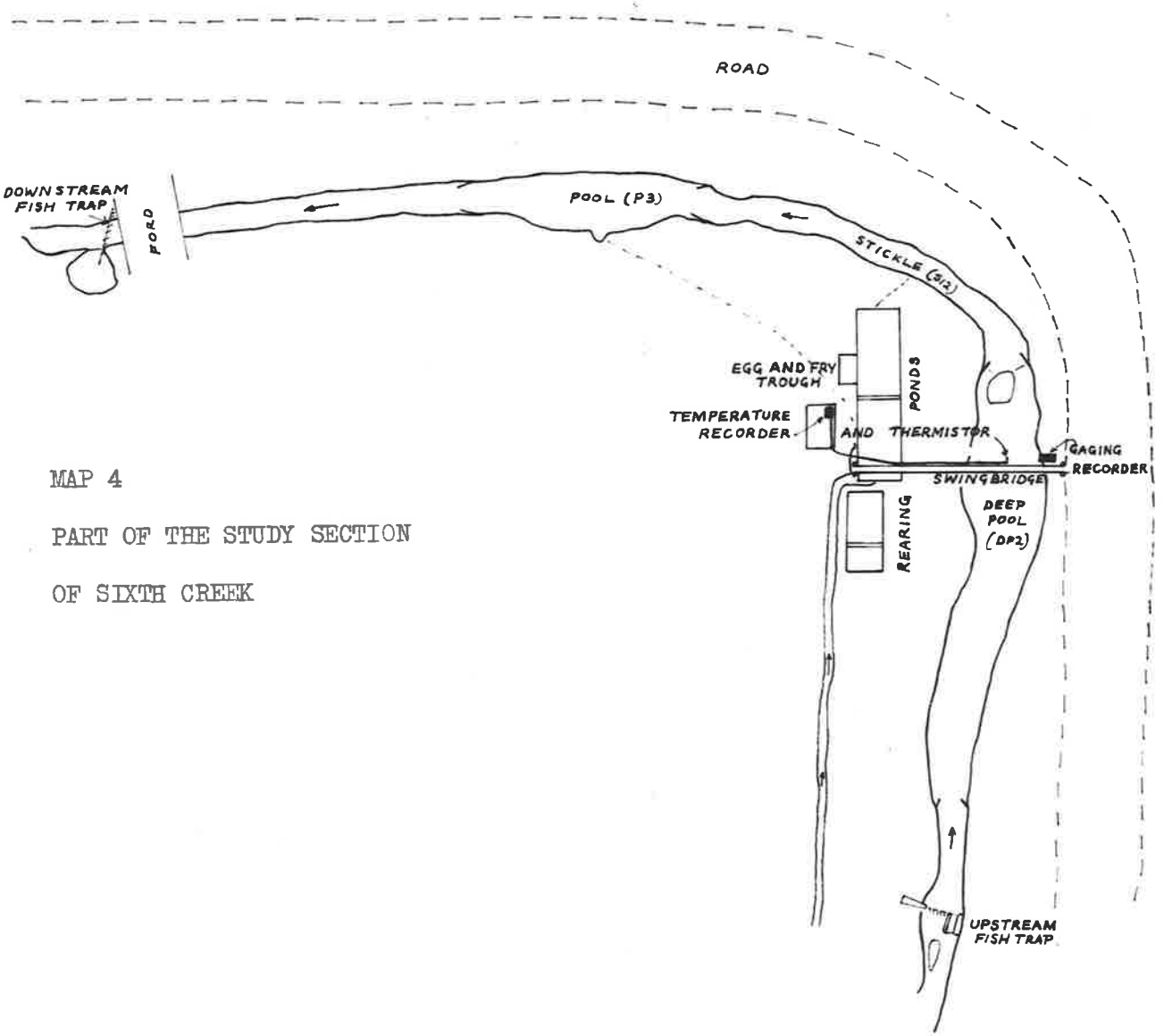
2.2.1 The estimation of the survival times of trout at lethal temperatures in South Australia

The following fish were tested at constant water temperatures of 28°, 29° and 30°C.

(1) Brown trout fingerlings, age 0+, which were the offspring of wild trout that were trapped in Sixth Creek in the autumns of 1963 and 1964 during their spawning run from the Torrens River.

(2) Brown trout, age 1+, which were the offspring of wild parents trapped, as above, in the autumn of 1963.

(3) Rainbow trout fingerlings, age 0+, which were the offspring of wild parents trapped, as above, in the late winter of 1964.



MAP 4

PART OF THE STUDY SECTION

OF SIXTH CREEK

(4) Brown trout fingerlings, age 0+, which, as eggs brought from Victoria, had been hatched at the Milbrook Hatchery and transferred to the Sixth Creek rearing ponds in late October 1964. (at 30°C only).

Except for the last group (4) all these fish were hatched and reared at Sixth Creek. They were fed regularly on a mixture of raw beef liver, oxheart, and brewer's yeast.

The tests were done alongside the rearing ponds on the bank of Sixth Creek (Map 4). Water from the creek (see Appendix 2) in a glass tank 18" x 9" x 10" was maintained at the constant temperature for each determination of survival times by a "Tecam Tempunit". In the literature accompanying this unit it is described as:- "a self-contained heat and temperature control unit for ... water baths - accuracy within $\pm$ 0.05°C - circulation in excess of 1 litre per minute." The tests could only be done when the ambient air temperature was below the constant water temperature desired. The glass tank was kept in the shade with the sides and bottom covered by black plastic. Fish in the tank were protected from the rotor of the heater by a screen of nylon mesh. Frequent checks were made of the water temperature at various positions in the tank with a mercury thermometer during each test. All the tests were made during the hours of daylight.

The fish were judged to be dead when mouth and opercular movement ceased. When the survival time was short it could be recorded to the nearest half minute but with longer times some indecision occurred and records were usually made for the nearest whole minute. The size of each fish was measured and recorded with the survival time. The

fish for each test were not necessarily a random sample of all the fish in the rearing pond. The influence of size on the survival time has therefore been investigated. Logarithms of the survival times are used in the subsequent analyses to normalize the sample distributions.

Tables 2.1-2.6: Data from lethal temperature experiments at Sixth Creek

Table 2.1 For Brown trout fingerlings (age 0+), from wild parents, at 30°C on 101263

	Started at 10.15 a.m.		Started at 12.05 p.m.		Started at 4.00 p.m.	
Order of Deaths	Size (cms)	Survival Time (mins)	Size	Survival Time	Size	Survival Time
1	5.1	15.5	6.8	20.0	4.5	21.5
2	4.9	17.5	5.1	25.5	6.3	24.0
3	5.2	20.5	5.4	26.5	6.4	26.0
4	7.3	23.5	6.3	28.0	5.3	27.0
5	5.1	23.5	6.3	29.0	5.4	27.0
6	5.5	25.0	5.9	29.0	4.2	28.0
7	4.8	25.0	5.2	30.5	4.2	28.5
8	5.1	30.5	6.7	31.0	4.6	28.5
9	5.7	33.0	5.2	32.0	5.9	29.0
10	5.9	33.5	5.8	33.0	4.6	33.0
Geometric Mean		23.97		28.19		27.09

For pooled data Geometric Mean = 26.36 mins.

95% Confidence limits for log mean = (± .03)

Table 2.2 For Brown trout fingerlings (age 0+), from wild parents, at 28°C on 101263 and at 29°C on 121263.

	29°C Started at 10.41 am		28°C Started at 1.40 pm		27°C Started at 10.42 a.m.
Order of Deaths	Size (cms)	Survival Time (mins)	Size	Survival Time	
1	4.9	54.5	5.3	174.0	Terminated at
2	5.2	57.5	4.1	176.0	7.41 pm on the
3	6.2	59.0	5.4	179.0	same day without
4	5.5	61.0	4.2	180.0	any of the fish
5	5.6	62.5	7.2	181.0	having died (540mins)
6	5.8	69.5	4.8	197.0	
7	5.3	69.5			
8	5.1	71.0			
9	6.3	74.5			
10	5.3	75.0			
Geometric Mean		65.03		181.00	
95% C.L. for log mean		(± .03)		(± .006)	

Table 2.3 For Brown trout fingerlings (age 0+), brought as eggs from Victoria, at 30°C on 121263.

Order of Deaths	1	2	3	4	5	6	7	8	9	10
Survival Time (mins)	23.0	23.0	25.0	26.0	26.5	26.5	26.5	27.0	28.0	31.0
Geometric Mean = 26.16 mins 95% C.L. for log mean (± .03)										
Started at 5.43 p.m. Average Size 3.8 cms.										

Table 2.4 For Brown trout fingerlings (age 0+), from wild parents, at 30°C and 29°C on 221264 and at 28°C on 231264.

	30°C Started at 2.00 pm		29°C Started at 3.35 pm		28°C Started at 10.40 am	
Order of Deaths	Size (cms)	Survival Time (mins)	Size	Survival Time	Size	Survival Time
1	5.3	13.0	5.2	46.0	6.0	51.0
2	7.0	13.5	6.2	47.5	5.9	84.5
3	7.0	14.5	6.1	50.5	5.6	96.0
4	6.0	19.5	6.4	53.0	6.2	97.0
5	5.4	23.5	6.8	54.0	6.5	98.5
Geometric Mean	16.34		50.10		83.07	
95% C.L. for log mean	(± .04)		(± .04)		(± .15)	

Table 2.5 For Brown trout (age 1+), from wild parents (from the same parents as for fish in Tables 2.1 and 2.2)

	30°C Started at 1.00 pm		29°C Started at 10.40 am		28°C Started at 11.35am* 3.28 pm	
Order of Deaths	Size (cms)	Survival Time (mins)	Size	Survival Time	Size	Survival Time
1	17.5	6.0	17.4	17.5	17.8	39.0
2	15.5	8.5	17.2	19.0	18.5	44.0
3	17.4	9.5	18.0	19.0	17.9	47.0
4	16.4	11.0	14.9	23.0	18.4	76.0
5	17.0	18.0	17.9	24.0	16.7	97.0
6					14.6	104.0
Geometric Mean	9.92		20.34		62.90	
95% C.L. for log mean	(± .22)		(± .07)		(± .20)	

* At the end of the test at 28°C, started at 11.35 am, the first two fish, of five, which died were found to have an old wound and a deformed operculum respectively and the results for them were therefore discarded. Three more fish were tried at 28°C starting at 3.28 pm.

Table 2.6 For Rainbow trout fingerlings (age 0+), from wild parents, at 30°C, 29°C and 28°C on 231264

	30°C Started at 1.00 pm		29°C Started at 2.00 pm		28°C Started at 3.00pm	
Order of Deaths	Size (cms)	Survival Time (mins)	Size	Survival Time	Size	Survival Time
1	5.2	5.5	5.0	33.0	5.3	38.5
2	5.5	8.5	5.1	34.5	5.7	63.5
3	5.5	12.0	5.4	39.0	5.6	79.0
4	5.9	13.0	5.2	40.5	5.7	84.5
5	5.0	13.5	5.9	43.0	5.6	89.0
Geometric Mean		9.97		37.80		67.98
95% C.L. for log mean		(± 2.1)		(± .06)		(± .18)

Tables 2.7-2.9: Statistical analyses of the data from the lethal temperature experiments

Table 2.7 Analysis of variance of the data in Table 2.1 to see if the survival times depend on the time of day

Number of Classes = 3 Number of observations per class = 10

Sum of Squares of all the observations = 60.7703

Sum of Squares of Class Totals = 605.9510 Correction Factor = 60.5681

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	Variance Ratio (F)
Between Classes	.0270	2	.0135	2.08 = F (2, 27)
Within Classes	.1752	27	.0065	P (F (2, 27) > 3.35) = 0.05
Total	.2022	29		non-significant

Table 2.8 Analysis of variance of the data in Table 2.1 to see if the orders of deaths depend on the size of the fish

Number of Classes = 10 Number of observations per class = 3

Sum of Squares of all the observations = 921.73

Sum of Squares of Class Totals = 2724.99 Correction Factor = 904.203

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	Variance Ratio (F)
Between Classes	4.1270	9	.4585	0.684 = F (9, 20)
Within Classes	13.4000	20	.6700	P (F (9, 20) > 2.36) = 0.05
Total	17.5270	29		non-significant

Table 2.9 t-tests for the difference between the mean survival times of Brown trout fingerlings (age 0+) and Rainbow trout fingerlings (age 0+) at 30°C, 29°C and 28°C (Tables 2.4 and 2.6)

30°C	t_8 = 71.5
29°C	t_8 = 490.0
28°C	t_8 = 175.7
$P(\|t_8\| > 2.31) = .05$	
All differences highly-significant	

The data are assembled in Tables 2.1 - 2.6 and analyses are given in Tables 2.7 - 2.9.

The apparent tendency for the survival time at 30°C to be highest at midday (Table 2.1) is shown to have no significance by the analysis in Table 2.7. The data in Table 2.1 are also used to show in Table 2.8, that the differing sizes of fish, of the same age, did not influence the order in which they died.

The analyses in Table 2.9 show that the Brown trout age 0+ in 1964 had significantly longer survival times than the Rainbow trout, age 0+, in the same year at 30°C, 29°C and 28°C. From these last comparisons and a graph of the summarized data Figure 2.1, it is obvious that the Brown trout, age 1+, had significantly lower survival times at the three temperatures than the Brown trout, age 0+, in 1963 and 1964. And the Brown trout, age 0+, in 1964 had smaller times than those in 1963. The spring and early summer water temperatures were lower in

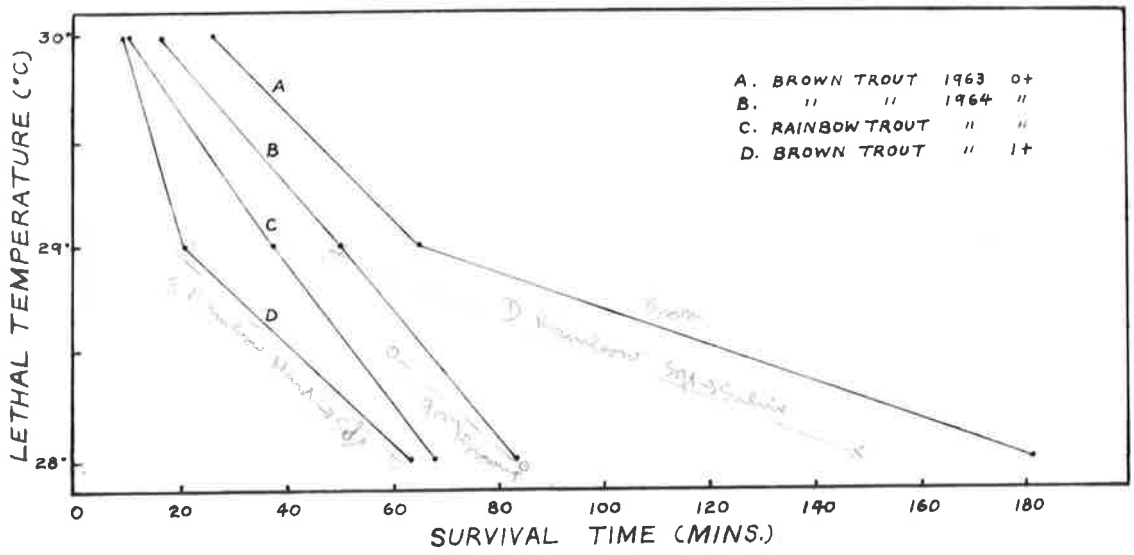


FIGURE 2.1 GRAPH OF SUMMARIZED DATA FROM LETHAL TEMPERATURE EXPERIMENTS

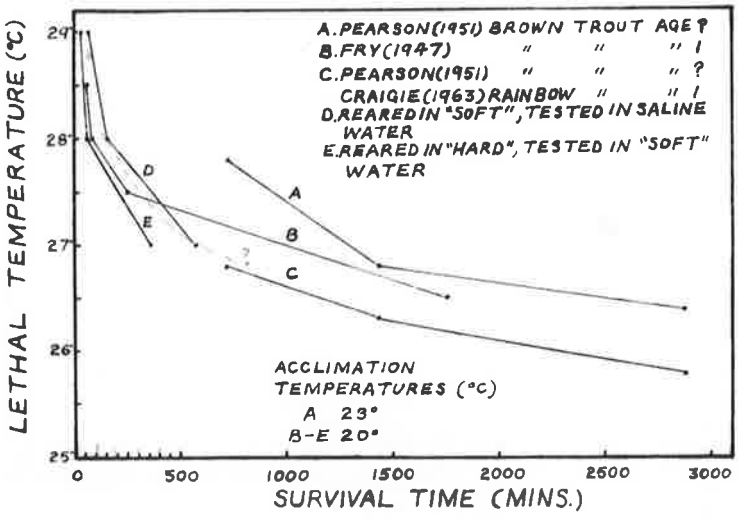


FIGURE 2.2 GRAPH OF COMPARABLE DATA FOR BROWN AND RAINBOW TROUT IN CANADA

1964 than in 1963.

Comparable data for Brown and Rainbow trout in Canada are shown in Figure 2.2.

Craigie (1963) and Halsband (1953) have shown that the survival times of Rainbow trout are increased when the test water is saline and high in Cq and Mg. The benefit to trout in the northern and easternstreams here, which are high in these minerals, is partly offset by the decreased specific heat of the water.

The idea perpetuated in the popular literature (from Embody, 1921; see also Affleck, 1952) that Rainbow trout have a higher resistance to extreme water temperatures than Brown trout has often lead to their introduction to warmer streams in preference to the latter species. The magnitude of the difference between their survival times at the highest lethal temperature used are small (but not necessarily unimportant) but it is apparent from the nature of the curves in Figure 2.2 that this difference increases (logarithmically) to considerable magnitudes with decreasing values of lethal temperature. In nature this difference between the two species could be very important.

Trout in South Australia during the summer do not appear to have a greater inherent ability to survive at high water temperatures than trout in cooler climates elsewhere.

2.2.2 The daily cycle of heating and cooling of the streams

Part of the explanation for the survival of trout during the summer could be that the water cools sufficiently overnight so that there is not enough time during the subsequent daytime heat for it to reach

lethal levels for the trout before the sun sets again.

2.2.2.1 The daily changes in the temperature of Sixth Creek

A pen recorder (Both Pty. Ltd. Adelaide) was used to record changes in the electrical resistance of a thermistor in the water. Pen deflections, of magnitudes linearly correlated with water temperature, were registered as ink tracings on long lengths of slowly moving graph paper, 5 cms wide, with rulings of 1 mm to 40 mms. The recorder had additional transistorized circuits to compensate for changes in the ambient air temperature. As an additional precaution the system was calibrated in the field by noting deflections and water temperatures at the thermistor several times a month throughout the period that it was in use. The thermistor was suspended from the swingbridge over a pool opposite the recorder (Map 4). The thermistor lay from 12-18" under the surface of the water. Departures from the recorded temperatures were found for other positions in the water during the hottest days of summer and these are documented in a subsequent section.

To reduce the labour of reading the tracings a "Venner" time-switch, powered like the recorder by 240 V mains supply, was used to record continuously for a few hours during the periods of the day when the minimum (mid-moring) and maximum (mid-afternoon) water temperatures occur and also for a short period during the late evening (total usually about 10 hours). Water temperatures were then read off the tracings (to the nearest $\frac{1}{4}^{o}C$) at points corresponding to hours of the day. Assuming linear trends for the periods not recorded each

day these were obtained from interpolation by a programme (written by D.M. Haycroft of the Computing Centre Adelaide) for the C.D. 3200 computor at Adelaide.

Print-out gave the 24 hourly water temperatures (^{o}C) for each day and as a summary (Table 2.10) the monthly mean and standard deviation for each hour of the day. The programme also computed the sum of the hourly temperatures from the maximum of one day to the minimum of the next and from the minimum to the maximum of the same day.

The records show that in summer there was insufficient time during the prevailing high air temperatures on many days for the water to warm up to levels which have been shown to be lethal for trout from the minimum values of the mid-morning (about 6 hours). The survival of the trout on hot days appears to depend very much on the cooling of the water overnight (about 18 hours).

2.2.2.2 The relationship between air and water temperatures at Sixth Creek

The daily maximum and minimum air and water temperatures at Sixth Creek were recorded by Mr. H. Smith from 120664 to 140165. The air temperatures were taken from a maximum-minimum thermometer (Zeal Ltd., England) hanging in the shade next to the rearing ponds and the water temperatures by another thermometer of the same type in an adjacent pond. Readings were made after the minimum for the day occurred as the water was heating up. Records for the subsequent period to 310365 are taken from the preceding section for water temperatures and from tracings made

TABLE 2.10

WATER TEMPERATURES, SIXTH CREEK

JUNE, 1963			JULY			AUGUST			SEPTEMBER			OCTOBER			NOVEMBER 1963		
HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.
1	11.11	.77	1	10.65	.86	1	11.08	.81	1	12.63	1.23	1	15.74	1.39	1	17.06	1.58
2	10.89	.81	2	10.62	.88	2	11.02	.83	2	12.50	1.20	2	15.47	1.35	2	16.86	1.58
3	10.50	.91	3	10.60	.91	3	10.96	.86	3	12.36	1.17	3	15.21	1.31	3	16.67	1.59
4	10.40	.96	4	10.57	.94	4	10.90	.89	4	12.23	1.15	4	14.94	1.28	4	16.48	1.62
5	10.42	1.02	5	10.53	.96	5	10.83	.93	5	12.10	1.13	5	14.68	1.26	5	16.29	1.65
6	10.45	1.10	6	10.35	1.03	6	10.77	.96	6	11.96	1.12	6	14.41	1.25	6	16.20	1.75
7	10.47	1.17	7	10.00	1.07	7	10.71	1.01	7	11.82	1.09	7	14.15	1.24	7	16.05	1.83
8	10.56	1.19	8	9.84	1.16	8	10.34	.97	8	11.53	.99	8	14.18	1.27	8	16.05	1.65
9	10.28	1.11	9	10.11	1.16	9	10.19	1.02	9	11.55	.98	9	14.21	1.37	9	16.11	1.55
10	10.06	1.01	10	10.39	1.18	10	10.18	1.04	10	11.78	.98	10	14.63	1.40	10	16.54	1.64
11	10.15	.90	11	10.56	1.12	11	10.87	.92	11	12.69	1.26	11	15.21	1.52	11	17.29	1.92
12	10.35	.74	12	10.66	1.05	12	11.96	.88	12	13.60	1.62	12	16.67	1.63	12	18.57	1.99
13	10.88	.77	13	10.68	.98	13	11.71	.80	13	13.95	1.75	13	18.13	1.83	13	19.52	1.86
14	11.40	.83	14	10.76	.89	14	11.74	.87	14	14.00	1.80	14	18.73	1.95	14	19.84	1.92
15	11.50	.67	15	10.82	.88	15	11.94	.80	15	14.32	1.85	15	18.60	1.97	15	19.98	2.18
16	11.35	.50	16	11.02	.87	16	12.13	.76	16	14.65	1.91	16	18.76	1.87	16	20.11	2.23
17	11.15	.59	17	11.21	.88	17	11.92	.80	17	14.27	1.75	17	18.92	1.81	17	19.73	1.93
18	11.15	.58	18	10.94	.87	18	11.55	.81	18	13.60	1.54	18	18.32	1.73	18	19.01	1.73
19	11.14	.62	19	10.81	.82	19	11.49	.79	19	13.44	1.50	19	17.45	1.66	19	18.53	1.87
20	11.12	.63	20	10.78	.81	20	11.42	.78	20	13.30	1.45	20	17.18	1.59	20	18.26	1.79
21	11.09	.65	21	10.76	.81	21	11.36	.78	21	13.17	1.40	21	16.91	1.52	21	17.93	1.69
22	11.07	.67	22	10.73	.82	22	11.30	.78	22	13.03	1.35	22	16.64	1.46	22	17.69	1.65
23	11.05	.69	23	10.71	.82	23	11.23	.79	23	12.90	1.31	23	16.37	1.41	23	17.50	1.61
24	11.02	.72	24	10.69	.84	24	11.17	.80	24	12.77	1.27	24	16.10	1.39	24	17.32	1.59

DECEMBER 1963			JANUARY 1964			FEBRUARY			MARCH			APRIL			MAY 1964		
HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.
1	18.81	1.19	1	19.42	1.21	1	18.97	1.80	1	17.03	.93	1	15.08	1.52	1	11.43	1.41
2	18.60	1.20	2	19.22	1.24	2	18.79	1.82	2	16.84	.93	2	14.97	1.53	2	11.29	1.44
3	18.38	1.22	3	19.02	1.27	3	18.61	1.84	3	16.65	.95	3	14.86	1.55	3	11.16	1.47
4	18.17	1.25	4	18.82	1.31	4	18.43	1.87	4	16.45	.96	4	14.75	1.57	4	11.03	1.51
5	17.96	1.29	5	18.62	1.35	5	18.25	1.90	5	16.26	.99	5	14.64	1.60	5	10.89	1.55
6	17.75	1.34	6	18.44	1.37	6	18.12	1.91	6	16.17	1.04	6	14.54	1.64	6	10.90	1.76
7	16.80	3.65	7	18.02	1.35	7	17.67	1.94	7	15.75	1.05	7	14.23	1.41	7	10.72	1.75
8	16.28	3.09	8	17.52	1.27	8	17.21	1.90	8	15.28	.99	8	13.71	1.40	8	10.37	1.71
9	16.13	2.60	9	17.23	1.35	9	17.00	1.81	9	15.08	1.04	9	13.61	1.42	9	10.19	1.70
10	16.32	2.22	10	17.50	1.45	10	17.12	1.76	10	15.18	.97	10	13.63	1.29	10	10.19	1.77
11	17.85	2.03	11	18.55	1.52	11	18.11	1.75	11	16.17	.96	11	14.49	1.30	11	11.05	1.67
12	19.39	1.93	12	19.60	1.27	12	19.10	1.78	12	17.17	.99	12	15.36	1.33	12	11.91	1.59
13	20.11	1.81	13	20.02	1.13	13	19.48	1.74	13	17.50	1.01	13	15.48	1.25	13	12.28	1.45
14	20.26	1.56	14	20.26	1.19	14	19.71	1.74	14	17.70	1.04	14	15.59	1.23	14	12.41	1.39
15	20.98	1.32	15	20.53	1.29	15	19.98	1.73	15	17.97	1.02	15	15.71	1.31	15	12.52	1.34
16	21.78	1.22	16	21.14	1.31	16	20.53	1.76	16	18.47	.98	16	15.99	1.39	16	12.70	1.38
17	21.58	1.31	17	21.74	1.35	17	21.07	1.80	17	18.98	.98	17	16.28	1.61	17	12.89	1.44
18	20.53	1.43	18	21.21	1.31	18	20.53	1.75	18	18.63	1.02	18	16.03	1.48	18	12.54	1.38
19	20.17	1.28	19	20.65	1.16	19	20.02	1.78	19	18.15	.98	19	15.60	1.49	19	12.19	1.34
20	19.93	1.28	20	20.42	1.16	20	19.87	1.79	20	17.98	.97	20	15.53	1.50	20	12.10	1.34
21	19.71	1.24	21	20.22	1.16	21	19.69	1.79	21	17.79	.95	21	15.43	1.48	21	11.97	1.34
22	19.50	1.22	22	20.02	1.16	22	19.51	1.78	22	17.59	.93	22	15.33	1.48	22	11.83	1.35
23	19.28	1.21	23	19.82	1.17	23	19.33	1.78	23	17.40	.92	23	15.23	1.48	23	11.70	1.36
24	19.06	1.20	24	19.62	1.19	24	19.15	1.79	24	17.21	.91	24	15.13	1.48	24	11.56	1.38

A

S.D. = STANDARD DEVIATION

TABLE 2.10 CONTD.

WATER TEMPERATURES, SIXTH CREEK

JUNE 1964			JULY			AUGUST			SEPTEMBER			OCTOBER			NOVEMBER 1964		
HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.
1	10.01	1.76	1	10.03	.59	1	10.34	.84	1	11.45	1.01	1	12.77	1.30	1	15.97	1.91
2	9.96	1.80	2	10.00	.65	2	10.24	.89	2	11.35	1.03	2	12.69	1.23	2	15.83	1.87
3	9.91	1.84	3	9.97	.71	3	10.15	.95	3	11.26	1.07	3	12.61	1.17	3	15.68	1.82
4	9.86	1.88	4	9.93	.77	4	10.05	1.01	4	11.17	1.11	4	12.53	1.11	4	15.54	1.78
5	9.81	1.93	5	9.90	.85	5	9.95	1.07	5	11.08	1.15	5	12.45	1.05	5	15.39	1.74
6	9.76	1.97	6	9.77	1.05	6	9.86	1.14	6	10.98	1.20	6	12.37	1.00	6	15.25	1.71
7	9.53	2.06	7	9.67	1.01	7	9.73	1.12	7	10.89	1.25	7	12.29	.96	7	15.10	1.68
8	9.26	2.01	8	9.35	.91	8	9.49	1.12	8	10.80	1.30	8	12.21	.91	8	14.96	1.66
9	9.09	1.97	9	9.21	.89	9	9.36	1.14	9	10.85	1.17	9	12.46	.94	9	15.27	1.61
10	9.11	1.98	10	9.23	.90	10	9.47	1.11	10	10.93	1.04	10	12.65	1.09	10	15.63	1.67
11	9.68	1.96	11	9.80	.84	11	10.13	.93	11	11.21	.99	11	12.94	1.27	11	16.16	1.84
12	10.26	1.96	12	10.37	.83	12	10.80	.83	12	11.99	1.03	12	13.79	1.51	12	17.24	2.09
13	10.55	1.77	13	10.45	.73	13	11.02	.82	13	12.76	1.19	13	14.65	1.81	13	18.32	2.39
14	10.65	1.63	14	10.43	.73	14	11.12	.91	14	13.54	1.43	14	15.50	2.14	14	19.46	2.72
15	10.65	1.63	15	10.43	.69	15	11.18	.94	15	13.43	1.52	15	15.31	2.24	15	19.29	2.77
16	10.79	1.64	16	10.61	.65	16	11.38	.88	16	13.17	1.46	16	14.98	2.17	16	18.82	2.66
17	10.93	1.66	17	10.79	.63	17	11.57	.81	17	12.84	1.29	17	14.57	2.05	17	18.33	2.58
18	10.61	1.57	18	10.51	.60	18	11.24	.74	18	12.53	1.20	18	14.19	1.91	18	17.87	2.43
19	10.29	1.57	19	10.25	.58	19	10.96	.76	19	12.50	1.14	19	14.08	1.82	19	17.72	2.32
20	10.24	1.59	20	10.24	.57	20	10.87	.75	20	12.47	1.09	20	13.97	1.73	20	17.57	2.22
21	10.19	1.62	21	10.20	.54	21	10.76	.75	21	12.17	1.11	21	13.51	1.68	21	16.96	2.15
22	10.14	1.65	22	10.17	.53	22	10.66	.76	22	11.74	.96	22	13.07	1.54	22	16.46	2.06
23	10.10	1.69	23	10.13	.54	23	10.57	.79	23	11.65	.97	23	12.99	1.46	23	16.32	2.00
24	10.05	1.72	24	10.09	.56	24	10.47	.82	24	11.56	.99	24	12.90	1.38	24	16.18	1.94

DECEMBER 1964			JANUARY 1965			FEBRUARY			MARCH			APRIL			MAY 1965		
HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.
1	16.67	1.08	1	19.22	.90	1	19.87	.86	1	17.34	1.57	1	13.81	1.17	1	12.08	1.05
2	16.55	1.07	2	19.05	.87	2	19.69	.88	2	17.16	1.63	2	13.66	1.14	2	12.07	1.08
3	16.43	1.07	3	18.88	.84	3	19.51	.89	3	16.99	1.69	3	13.51	1.12	3	12.05	1.12
4	16.31	1.09	4	18.70	.82	4	19.33	.92	4	16.82	1.75	4	13.42	1.15	4	12.03	1.15
5	16.19	1.13	5	18.53	.82	5	19.15	.95	5	16.64	1.81	5	13.33	1.18	5	12.02	1.20
6	16.07	1.18	6	18.36	.81	6	18.96	.98	6	16.47	1.87	6	13.25	1.21	6	12.00	1.24
7	15.95	1.24	7	18.18	.82	7	18.78	1.01	7	16.30	1.94	7	13.16	1.25	7	11.98	1.29
8	15.79	1.31	8	17.97	.85	8	18.59	1.03	8	16.18	1.99	8	13.11	1.29	8	11.88	1.40
9	15.84	1.14	9	17.80	.79	9	18.33	1.03	9	15.92	1.92	9	13.07	1.26	9	11.83	1.30
10	16.09	1.11	10	17.71	.74	10	18.35	.95	10	15.90	1.81	10	13.22	1.35	10	11.68	1.20
11	16.52	1.29	11	18.73	.81	11	19.22	.94	11	16.35	1.64	11	13.78	1.44	11	11.85	1.21
12	17.59	1.25	12	19.74	1.04	12	20.15	.89	12	17.43	1.50	12	14.71	1.24	12	12.59	1.19
13	18.57	1.34	13	20.29	1.28	13	20.70	.83	13	18.51	1.40	13	15.57	1.10	13	13.33	1.27
14	19.53	1.48	14	20.58	1.38	14	21.05	.75	14	19.59	1.35	14	15.79	1.21	14	13.31	1.24
15	19.45	1.59	15	20.74	1.42	15	21.32	.78	15	20.67	1.35	15	15.82	1.44	15	13.11	1.27
16	19.20	1.61	16	20.70	1.34	16	21.42	.74	16	20.48	1.42	16	15.58	1.41	16	12.85	1.20
17	18.81	1.54	17	20.91	1.27	17	21.67	.73	17	19.86	1.56	17	15.43	1.30	17	12.86	1.15
18	18.40	1.51	18	21.11	1.24	18	21.89	.83	18	19.08	1.55	18	15.29	1.29	18	12.82	1.12
19	18.32	1.41	19	20.70	1.15	19	21.45	.84	19	18.91	1.53	19	15.08	1.22	19	12.78	1.10
20	18.21	1.29	20	20.12	1.12	20	20.84	.84	20	18.74	1.52	20	14.86	1.16	20	12.75	1.08
21	17.61	1.22	21	19.95	1.06	21	20.65	.83	21	18.57	1.52	21	14.66	1.15	21	12.71	1.07
22	17.04	1.22	22	19.77	1.01	22	20.47	.82	22	18.40	1.53	22	14.44	1.23	22	12.65	1.06
23	16.92	1.16	23	19.59	.97	23	20.27	.82	23	17.98	1.50	23	14.15	1.24	23	12.38	1.03
24	16.80	1.12	24	19.42	.92	24	20.05	.84	24	17.45	1.53	24	13.81	1.25	24	12.08	1.01

B

by a thermograph recorder (Casella, Lond.) kept in the same place as the previous air thermometer.

The data were analysed by the statistical method of multiple regression. Input variables were : the maximum air temperature (x_1), minimum air temperature (x_2), maximum water temperature (y_1), minimum water temperature (y_2), and $x_3 = (y_1 - y_2)$ for the same day, and $x_4 = (y_1 - y_2)$ where y_1 was the maximum water temperature on the preceding day. Differences were used for x_3 and x_4 to avoid the correlation between minima and maxima which is the result of the parallel trends in the two variables during the year. The data were treated in three groups corresponding to low "winter" temperatures, 12064 to 310864, rising "spring" temperatures, 010964 to 301164, and high "summer" temperatures, 011264 to310365. For each group two regressions were computed

y_1 on x_1 and x_3 -----(1)

y_2 on x_2 and x_4 -----(2)

These analyses are summarized in Table 2.11.

In each case the water temperature is positively correlated with the corresponding air temperature. However, while the maximum water temperature in the "spring" and "summer" is positively correlated with the minimum water temperature for the same day the minimum water temperature is not correlated with the maximum water temperature of the previous day. The period of cooling of the water overnight is sufficiently long for the minimum water temperature to be determined solely by the temperature of the air and ground during the night, with which the minimum air temperature is correlated. The minimum water

Table 2.11 Analysis, by multiple regression, of the relationship between air and water temperatures* at Sixth Creek

y_1 on x_1 and x_3 --- (1)					
Season	Constant Term	Coefficient for x_1	Coefficient for x_3	Degrees of Freedom	Multiple Correlation coefficient R^2
"Winter"	35.66	0.2983 $t_{78} = 4.84$	-04863 $t_{78} = 0.429$ non.sig.**	78	0.255
"Spring"	33.94	0.3532 $t_{85} = 7.73$	0.4557 $t_{85} = 3.94$ significant	85	0.667
"Summer"	50.08	0.2082 $t_{117} = 10.10$	0.3990 $t_{117} = 5.27$ significant	117	0.562
y_2 on x_2 and x_4 ---(2)					
Season	Constant Term	Coefficient for x_2	Coefficient for x_4	Degrees of Freedom	Multiple Correlation coefficient
"Winter"	38.40	0.2577 $t_{78} = 6.60$	-0.2893 $t_{78} = 2.28$ significant	78	0.575

Table 2.11 (Contd.)

"Spring"	31.05	0.4698 $t_{85} = 8.66$	0.1874 $t_{87} = 1.92$ non-significant	85	0.476
"Summer"	35.14	0.4947 $t_{117} = 10.45$	-0.00225 $t_{117} = 0.24$ non-significant	117	0.547

* Results are for temperatures ^{o}F. To transpose to ^{o}C multiply regression coefficients by 5/9 and constant term by 5/9 after subtracting 32.

** $P\ (|t_{60 \to 120}| > 2.00 \to 1.989) = .05$

All the coefficients for x_1 and x_2 are significant.

temperature during winter is, negatively correlated with the maximum water temperature on the day before since warm days with clear skies during winter are usually followed by cold nights with frosts in the early morning.

2.2.2.3 A comparison of maximum and minimum air temperatures at (1) Sixth Creek and Adelaide, and (2) other places in the region

(1) A record was kept of the maximum and minimum air temperatures (^{o}F) for Sixth Creek (by a thermograph kept in the shade at the rearing ponds 15' above the level of the creek) and for Adelaide on the plains (Bureau of Meteorology) from 150165 to 310365.

Computation of the linear regression of maximum air temperature at Sixth Creek (y), altitude 600', on the maximum at Adelaide (x), altitude 140', gave the equation -

$$y = 1.6103 + 0.9577\ x.$$

with standard deviation 3.1273 and correlation coefficient 0.9560.

A plot of the minima at Adelaide on the corresponding values at Sixth Creek, however, did not reveal a similar relationship (Figure 2.3). The minima at the Creek were always smaller than those at Adelaide and the difference between the two values was positively correlated with the maximum for the same day (Figure 2.4).

The difference between the maximum and minimum air temperatures reaches a maximum in summer and the difference is accentuated in the valleys of streams on the hottest days.

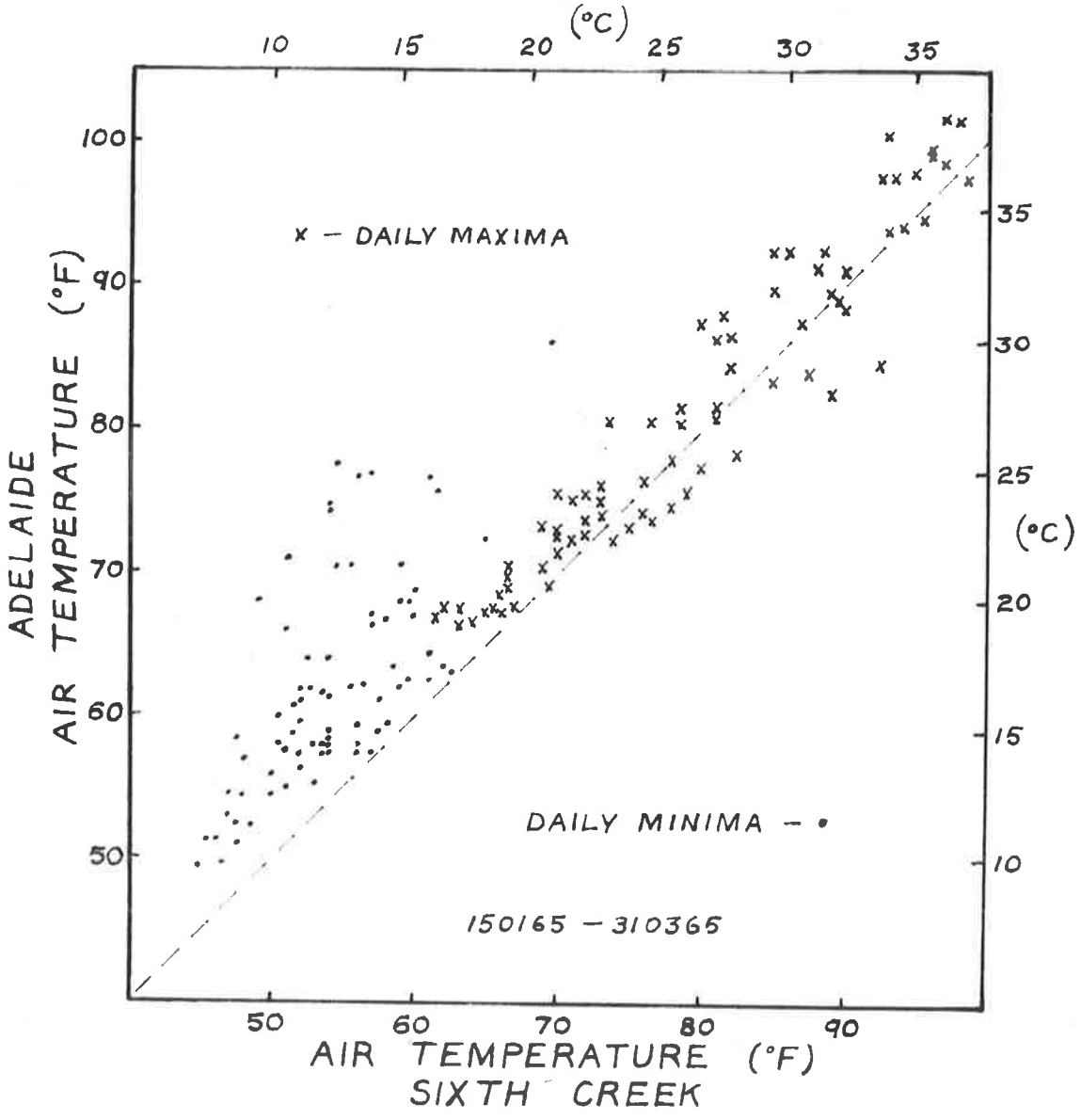


FIGURE 2.3 GRAPH OF AIR TEMPERATURES AT ADELAIDE ON THOSE AT SIXTH CREEK

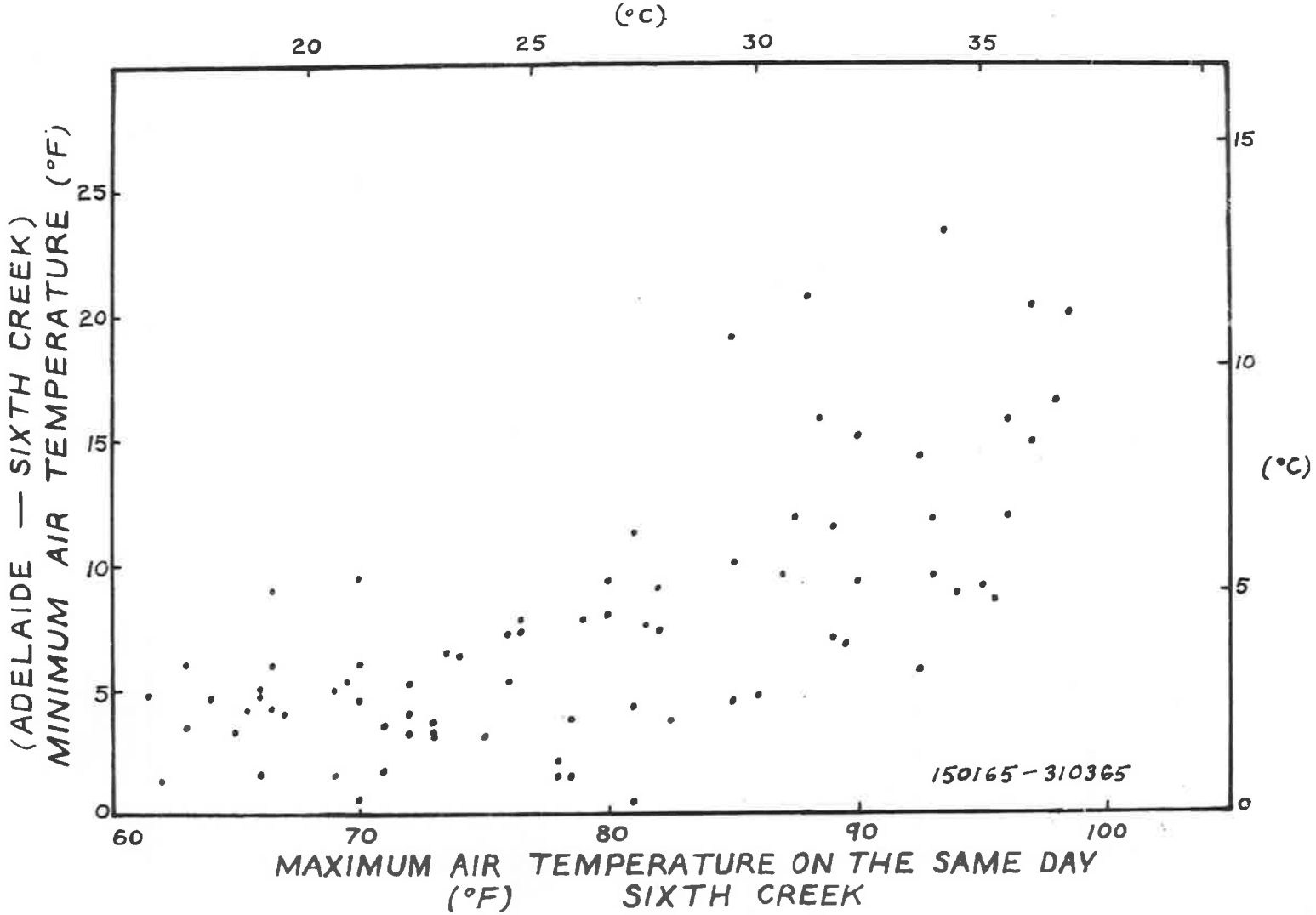


FIGURE 2.4 GRAPH SHOWING THE DIFFERENCE BETWEEN MINIMUM AIR TEMPERATURES AT ADELAIDE AND SIXTH CREEK ON THE MAXIMUM AIR TEMPERATURE AT SIXTH CREEK

Sixth Creek is small, rather unshaded by trees, and for the most part very shallow (see Section 3.1.3). Since the interface of the small volume of water with the air is fairly high (probably about 40%) the stream heats up rapidly during the daytime in the summer mainly as a result of direct insolation. On the other hand the stream flows down a deep V-shaped valley from the highest part of the ranges. Cold air flowing down into the valley from the high altitudes each night during the summer cools the water sufficiently to prevent it reaching lethal levels for the trout the next day.

(2) Mean monthly air temperatures (^{o}F) were available (Bureau of Meteorology) for 22 places in the general region centred on the Mount Lofty Ranges from 32^{o} 29' in the north to 36^{o} 04' in the south (latitude), 136^{o} 30' in the west to 139^{o} 27' in the east (longitude), and from 16' to 1682' (altitude). (1 minute of longitude or latitude is equivalent to about 60 miles).

The highest maximum and minimum values (in January or February) were used in a multiple regression analysis to determine their trends with latitude, longitude, and altitude (Table 2.I2).

Table 2.12 Analysis by multiple regression of the influence of altitude, latitude and longitude on summer air temperatures

(1) maximum air temperature on altitude, latitude and longitude (2) minimum air temperature on altitude, latitude and longitude					
Constant Term	Coefficients			Degrees of Freedom	Multiple Correlation Coefficient (R^2)
	Altitude	Latitude	Longitude		
(1) 88.43	-0.002732 t_{18} = 3.63 significant*	-0.08014 t_{18} = 11.75 significant	+0.05261 t_{18} = 5.73 significant	18	0.896
(2) 66.41	-0.003694 t_{18} = 4.58 significant	-0.03014 t_{18} = 4.12 significant	-0.01039 t_{18} = 1.06 non-significant	18	0.684

* $P(|t_{18}| \geq 2.101) = .05$

The maximum temperature decreases by 0.27°F for each 100' increase in altitude, increases by 4.8°F for each minute (about 68 miles) northwards, and increases by 3.2°F for each minute (about 56 miles) eastwards. The minimum temperature decreases by 0.37°F for each 100' increase in altitude and increases by 1.8°F for each minute northwards.

Table 2.13 The influence of the floating algal mat in Sixth Creek in absorbing direct insolation

Date	Time Place	Pen Recorder Temperature °C	Temperature* of shallow running water nearby °C	Temperature* of water on surface of mat °C	Temperature* of water just under mat °C (ca. 3" from surface)
150265	2.45 pm DP 2	21.5	21.7	28.9 30.1	21.4 21.6
160265	3.30 pm DP 2	22.0	24.2	29.7 29.1	24.3 24.2

* Temperature measured with a "Thermophil" electronic thermometer (described in Section 2.2.3)

Air temperatures measured directly in the sun are considerably higher than standard meteorological shade temperatures. Streams in the southern and central Mount Lofty Ranges near Adelaide are still well shaded by native Red Gums lining their banks and by introduced elms and willow trees. In the drier mallee areas to the north and east most of the Red Gums have been cut down for fenceposts and the streams are unshaded. Lack of shade along Sixth Creek is partly compensated for by a very heavy growth of filamentous algae (Cladophora sp.) during the

A Deep Pool (D.P.2), Sixth Creek on 120265, showing the floating mat of algae. The view is upstream from the swingbridge over the pool. The algae has been removed on the righthandside to allow access for electro-fishing. Bulrush (Typha angustifolia), sedges (Cyperus sp.), rushes (Juncus sp.), and Yorkshire fog grass (Holcus sp.) grow along the banks of the creek.



summer. This forms a floating mat which absorbs a considerable amount of heat from direct sunlight (Table 2.13). The period of direct sunlight on the water during the day is reduced for streams by the hills of their valleys and steep banks. The data from places that were used in (2) cannot be expected to show the behaviour demonstrated for the minimum air temperatures in (1) since the places are not in river valleys.

During the summer in South Australia cloudless skies are characteristic of the long spells of very high daytime heat. Somewhat cooler and cloudy conditions occur at about weekly intervals as a result of the passage of weak "lows" from west to east. However in some years warm moist winds from the north of Australia reach Adelaide. On these occasions the high maximum air temperatures are accompanied by higher minimum air temperatures since the heat of the day is contained overnight near the ground by the clouds. When this happens trout are known to die though this is not solely due to the high minimum air temperatures when there is also rain (Section 2.4).

2.2.3 How trout avoid the high water temperatures during the daytime in summer

The survival of trout through the summer in streams greatly exposed to direct insolation during the day, e.g. the Light River to the north; and the absence of fish during the heat of the day near the surface of pools suggested that the fish were avoiding high water temperatures at the surface.

The decrease in temperature with increase in depth from the surface of water during the summer is well known in temperate lakes. In comparison thermal stratification in small bodies ("thermomicroclines")

of water has received scant attention (review by Young and Zimmerman, 1956). The importance of deep pools in streams for the survival of trout through the summer is well known to experienced anglers.

The phenomenon accounts for a considerable extension of the distribution of trout from cool summer regions into hotter ones but this has apparently gone unrecognized. For example, Lake (1957) in a major survey of trout in N.S.W. did not include it in his appraisal of streams (Group I) which are very similar to most of the streams in South Australia.

The trout in these streams do not experience very high water temperatures continually through the summer. Not only is there the daily relief from the overnight cooling of the water after the comparatively short period of heat during the day but also cool periods, of several days, alternate with hot periods. And during the comparatively few hours of daytime heat the water of the streams is not uniformly heated. It seems reasonable to expect that, through their behaviour, the trout make full use of these natural variations, in time and place, not only to survive from day to day but also to feed efficiently and hence grow and produce gonads during the summer. The ranges of temperatures within which the last processes can proceed successfully, so that the population can survive in time, are narrower than that for short-term survival (Brett, 1962).

Table 2.14 Some preliminary observations of the change in temperature with depth of water in Sixth Creek

Date	Place Time	Surface* Temperature °C	Bottom** Temperature °C	Total Depth (Feet)
090262	DP5 3.30 pm	24.4	20.0	3'
	DP4 3.45 pm	25.6	18.9	$3\frac{1}{2}$'
140362	DP5 3.00 pm	23.3	19.4	$2\frac{3}{4}$'
	DP4 3.15 pm	25.6	19.4	$2\frac{1}{2}$'

* Temperatures taken with an ordinary mercury thermometer

** Temperatures taken with a reversing mercury thermometer

Deep pool = D.P.

2.2.3.1 The decrease in temperature with increase in depth of pools in the summer

A few preliminary measurements with a reversing thermometer in Sixth Creek indicated the reality of the phenomenon (Table 2.14) and also the necessity for better equipment. Subsequently a "Thermophil" electronic thermometer was used to obtain readings of temperature at short intervals from the surface of the water to the bottom of pools. The instrument and the 30' lead to the metal probe thermistor com-

pensate for varying ambient air temperatures. Readings can be made to 0.05°C and the speed of response is 0.55 seconds. Except for Sixth Creek, where a pole could be used, measurements were made from a small rubber dinghy anchored over the centre of the pool (usually the deepest part). Temperatures in several pools in a stretch of stream could be measured during the hour or so at mid-afternoon when maximum temperatures occur. Measurements of the dimensions of the pools were made with a "Federal" optical range finder or a steel tape. Except for Sixth Creek all the pools where measurements were made were unshaded by trees. The maximum air temperature on each occasion was read from a maximum thermometer in a white slatted box, of convenient size for transport (24" x 12" x 18"), on grass in the sun.

Measurements for Sixth Creek are given in Table 2.15. Stratification occurred only in the "deep" pools (D.P.) which are the longest (greater than 60') and deepest (3 - 4') stretches of water in the creek. There are five of these pools in the 4,400' of stream which was studied and in the summers of 1963-64 and 1964-65 they held about 50% of the fish. The large number of fish milling about in the deepest part of the pool tended to disrupt the stratification; but the blanket of algae on the bottom of the pools held a cool layer of water and the fish were often observed to dive into it during the day. The steepest changes in temperature with depth were measured in January of 1966. This difference, from the previous year, was caused by turbidity due to a "bloom" of biflagellates which replaced the normal growth of filamentous algae after very heavy flooding in December. In previous summers the water was very clear.

Table 2.15 Measurements of the change in temperature with depth in Sixth Creek

Date	Pool Time	Temperature water at run-in of pool °C	Pen recorder Temperature °C	Maximum Depth	Depth (feet) Surface	½	1	1½	2	2½	3	Bottom Temperature °C
120265	DP5 4.30pm	23.0	21.7	3'2"	23.0	-	23.0	-	22.5	21.5	21.0	19.5
150265	DP5 1.20pm	21.0	20.1	3'	21.4	-	21.4	-	21.4	21.4	21.3	21.3
"	DP4 1.45pm	21.6	20.3	3'2"	21.6	21.6	21.6	21.5	21.5	21.5	21.5	21.5
"	P7 2.00pm	21.6	20.3	2'6"	21.6	-	21.5	-	21.5	21.4	-	21.4
"	DP3 2.30pm	21.6	20.3	2'2"	21.6	-	21.6	-	21.6	-	-	21.5
"	DP2 3.00pm	21.8	20.3	3'	21.6	-	21.4	21.4	19.6 ※	18.8 ※※	17.5 ※※	17.5 ※※
"	P2 3.20pm	21.9	20.4	2'	21.9	-	21.9	-	21.9	-	-	21.9
160265	DP5 1.15pm	22.7	21.0	3' Place where fish lie	22.3	-	22.3	22.2	21.7 Shaded	21.1	21.0 ※※	21.0 ※※
"	" "	"	"	" Away from fish	22.5	22.5	22.3	22.4 Shaded	22.2	20.7	19.8 ※※	19.8 ※※
"	" "	"	"	" Away from fish	22.6		22.6 Shaded	22.5	22.1	21.1	20.7 ($2\frac{3}{4}$)	18.9 ※※
"	DP4 1.30pm	23.9	21.2	3' Away from fish	23.6		23.5 Shaded	23.4	23.3	21.6	20.1 ※※	20.1 ※※
"	" "	"	"	3'3" Place where fish lie	23.8		23.7 Shaded		23.3	23.0	22.4 (18-9 ※※※)	20.3
"	"	"	"	3'6" Away from fish	23.9		23.7 In sun partly	23.7	23.7	22.3	21.5	19.3 ※
"	" 1.45pm	"	"	1'9" Run out	23.8	23.8 No fish	23.8	23.8 Shaded				23.7
"	DP2 3.15pm	23.9	21.5 Shaded	2'	23.5		23.4		21.2 ※※			
"	" "	"		3'6"	23.6		23.5		19.5	18.5 ※※	17.7 ※※	17.2 ※※
"	DP1	24.4	21.5	2'9"	24.4		24.3		23.7			21.7 ※※※
250166	DP5 3.15pm			3'3"	24.7		22.0		19.1		18.55	18.5
				3' Shaded	24.7		22.2		19.25		18.65	18.65
"	DP2 3.30pm			2'6"	27.05		21.5		20.55			20.25
				2'9" In sun	27.05		21.4		20.45			18.2

※ Thermistor on layer of algae over the bottom of pool

※※ Thermistor in layer of algae over the bottom of pool

Table 2.16 Measurements of the change in temperature with depth in some streams and a dam in South Australia

Date	Time	No.	Place	Depth Feet	Max. air Temp. in sun	Surface Temp. °C (S.T.)	Bottom temp. °C (B.T.)	S.T.-B.T.	Area S. feet	Area of a circle with the same perimeter/ circle (ACR)
130265	3.45pm	(1)	Light R.	4½	85°F	25.7	21.4	4.3	400	2.0
"	3.55pm	(2)	"	1½	" (83)*	26.9	26.9	0	106	1.1
"	4.05pm	(3)	"	6½	"	26.1	19.9	6.2	3300	5.3
"	"	(4)	"	5	"	26.1	20.2	5.9	"	"
210265	3.30pm	(5)	Delamere Dam	9¼	84(102)	22.3	18.1	4.2	137000	1.54
270265	3.30pm	(6)	Light R.	6½	83	27.1	20.4	6.7	3275	1.6
"	"	(7)	"	5½	"(82)	26.7	21.1	5.6	"	"
"	4.00pm	(8)	"	7	"	26.7	20.75	5.95	6300	2.3
"	"	(9)	"	4½	"	26.7	22.1	4.6	"	"
"	4.25pm	(10)	"	3½	"	26.3	23.0	3.3	2414	1.02
"	4.40pm	(11)	"	4¼	"	26.1	21.9	4.2	7500	2.7
"	5.00pm	(12)	"	6	"	25.7	21.0	4.7	1525	2.1
280265	3.00pm	(13)	Bremer R.	4¼	99	26.9	22.1	4.8	943	1.02
"	3.15pm	(14)	"	6	"(89)	26.3	21.25	5.05	7860	1.00
"	3.35pm	(15)	"	3½	"	28.45	21.4	7.05	3100	2.4
"	3.50pm	(16)	"	9½	"	26.5	21.1	5.4	7871	1.9
140166	3.15pm	(17)	Broughton River	17	114	23.35	20.45	5.9	13070	3.81
"	4.30pm	(18)	"	8½	"(105)	28.3	26.25	2.05	25080	4.78
"	"	(19)	"	16	"	28.1	21.3	6.8	25030	2.37
"	4.45pm	(20)	"	3½	"	30.45	26.3	4.15	645	10.96
"	5.00pm	(21)	"	7	"	30.9	24.5	6.4	4500	4.25
"	5.45pm	(22)	"	3½	"	27.7	27.65	.05	65330	1.22
210166	3.00pm	(23)	Light R.	4½	100(89)	26.3	20.7	5.6	24000	9.35
"	"	(24)	" *	7½	"	26.5	18.95	7.55	"	"
"	"	(25)	"	4¼	"	26.3	21.2	5.1	"	"
"	3.30pm	(26)	" *	5	"	27.75	18.7	9.05	4010	1.22
"	"	(27)	"	5	"	27.3	18.8	8.5	"	1.22
"	4.00pm	(28)	"	9½	"	26.0	18.85	7.15	8820	1.59
"	"	(29)	" *	9¾	"	26.0	18.9	7.1	"	"
"	"	(30)	"	7	"	25.7	19.3	6.4	"	"
220166	3.00pm	(31)	Delamere Dam	14½	77	24.35	16.25	8.10	137000	1.54
"	"	(32)	"	16¼	"(87)	24.35	15.2	9.15	"	"
"	3.30pm	(33)	"	4¾	"	27.	26.65	.45	28350	1.37
250166	3.15pm	(34)	6th creek	3¼	95(98)	24.7	18.5	6.2	880	3.00
"	3.30pm	(35)	"	2¾	"	27.05	20.25	6.8	1610	3.29

* Maximum air temperature at Adelaide

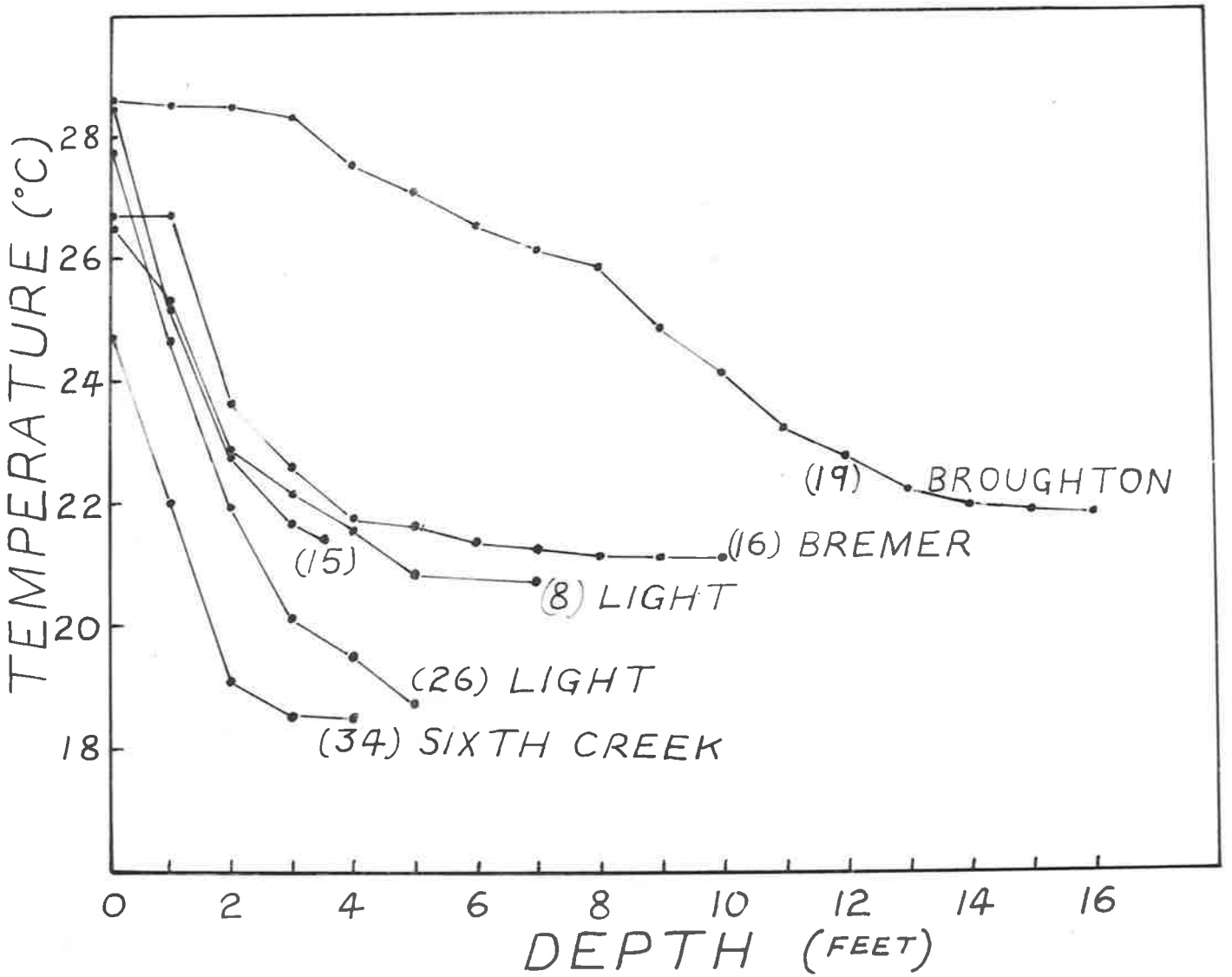


FIGURE 2.5 GRAPH OF CHANGES IN TEMPERATURE WITH DEPTH IN SOME POOLS IN STREAMS

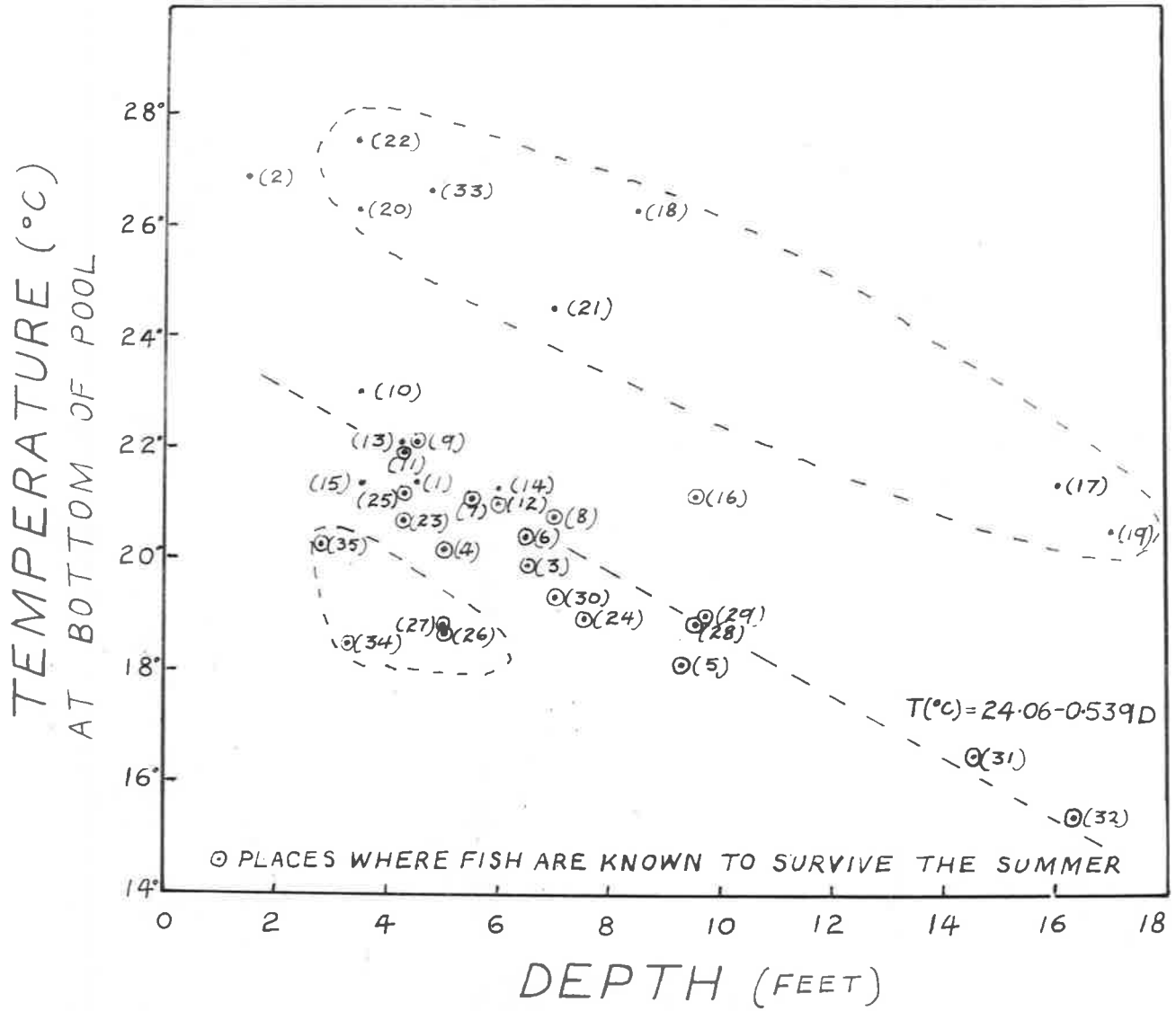


FIGURE 2.6 GRAPH OF TEMPERATURES AT THE BOTTOM OF POOLS ON THEIR DEPTH

Measurements for other places are given in Table 2.16. Where the surface was not subject to evaporative cooling by gusts of wind the decrease in temperature with depth was exponential following the theoretical light-absorption curve for clear water (Hutchinson, 1957). In most of the places the temperature decreased most rapidly within 2' of the surface (Figure 2.5).

In most cases measurements were made on the hottest days of summer where trout were known to survive through the summer in pools greatly exposed to direct radiation from the sun. For most of the data the correlation of the temperatures at the bottom of the pools on the depth of the pools, alone, accounted for 51.3% (R^2) of the variance in the temperatures ((5) in Table 2.17). Figure 2.6 illustrates that the temperature characteristics of pools cannot be accounted for by such a simple model. Starbeck and Greene (1961) showed that the surface temperature of lakes and ponds increased with increase in area. A negative correlation was obtained by the analysis (2) in Table 2.17. On the larger pools wind gusts apparently increased evaporative cooling of the surface water. Light penetration into the pools, as determined by the turbidity of the water, is an important variable as shown by the measurements, (34), (35), (26) and (27), in pools where the turbidity was high. The minimum air temperature in the early morning of the same day will be shown to have the major influence on the temperature at the bottom of the pool (17)-(22).

Table 2.17 Analysis of data in Table 2.16, Regressions of :

(1) Surface temperature minus bottom temperature on depth, area, ACR*, and maximum air temperature.

(2) Surface temperature on area, ACR and maximum air temperature

(3) Bottom temperature on depth, maximum air temperature, area and ACR.

(4) Bottom temperature on depth and maximum air temperature.

(5) Bottom temperature on depth (excluded data from (17), (18), (19), (20), (21), (22))

Degrees of Freedom	Constant Term	Coefficients (in the order above)	Multiple Correlation Coefficient (R^2)
(1) 26	0	0.320, 0.000, 0.110, 0.0296 t_{26} = 2.50 = 0.44 = 0.60 = 2.63 sig. n.s. n.s. sig.	0.864
(2) 26	20.84	-0.0000164, 0.0902, 0.0635 t_{26} = 3.06 = 0.92 = 3.47 sig. n.s. sig.	0.577
(3) 25	13.90	-0.4158, 0.1137, 0.000, -.1005 t_{25} = 2.99 = 2.75 = 0.77 = 0.48 sig. sig. n.s. n.s.	0.441
(4) 27	14.34	-0.4039, 0.1053 t_{27} = 3.78 = 3.03 sig. sig.	0.436
(5) 22	24.06	-0.5392 t_{22} = 4.81 sig.	0.513

$P\ (|t_{22-26}| > 2.1) = .05$

* The ratio of the area of a circle with the same perimeter to the actual area of the pool

The disproportionate length of the pools in many streams in relation to their width (as expressed by the ratio of the area of a circle of the same perimeter to the actual area (ACR)) may result in lower temperatures than in circular pools of the same. This hypothesis could not be established because most of the pools where measurements could be made were long and narrow.

2.2.3.2 The behaviour of the fish

Some results from the fish sampling of the study section (4400') of Sixth Creek for two years are shown in Table 2.18 a and b. Wild fish in their second year or older (greater than about 18 cms in length), were individually tagged and released in five subsections one of which was fished each fortnight during the spring, summer, and autumn, 1963-65. Fish were free to disperse into, within, and out of the section (downstream to the Torrens River) throughout the summer. About a third of the released fish were subsequently recaptured usually in the same subsection when it was fished again in 3 months time. About two-thirds of the recaptures were fish which remained in the deep pools or moved to them from shallow runs and pools. The deeper pools provide better hiding places for the trout, especially during the summer when the flow is low, and cooler water during the day in summer. In most of the other streams the dispersion of the fish for the summer appears to be determined at the latest by the end of spring when the greatly reduced flow together with physical barriers between pools, often a considerable difference apart, prevent movement.

TABLE 2.18 Recapture data for Sixth Creek trout

(a) For each season the number tagged and released, and the number of these which were recaptured subsequently, in shallow and deep water.

(b) For each season the number of fish captured and of these the number of recaptures, in shallow and deep water.

* Recapture numbers are given for (2) the next sampling, in about 3 months, of the subsection in which the fish were released, (1) an intermediate date and (3) a later date in other sections.

B = Brown trout

R = Rainbow trout

Table 2.18 (a)

Season	Spring		Summer		Autumn		Total	
Species	B	R	B	R	B	R	B	R
	(1)*(2)(3)							
No.of trout which stayed in shallow water	0,6,0	0,3,1	0.8,1	0,4,0	1,4,2	0,0,0	1,18,3	0,7,1
	Total 6	4	9	4	7	0	22	8
	% 6.4	7.1	16.7	14.3	8.6	0	9.6	6.4
and, moved to deeper water	2,11,1	6,6,3	5,9,1	3,8,1	3,3,4	0,1,2	10,23,6	9,15,6
	Total 14	15	15	12	10	3	39	30
	% 14.9	26.8	27.8	42.9	12.4	7.3	17.0	24.0
No.of trout tagged and released in shallow water	94	56	54	28	81	41	229	125
No.of trout which stayed in deep water	0,12,1	0,4,4	0,20,1	1,20,2	0,6,7	1,3,3	0,38,9	2,27,9
	Total 13	8	21	23	13	7	47	38
	% 19.4	11.9	36.2	46.9	14.4	10.8	21,9	21.0
and, moved to shallower water	1,5,0	3,2,2	4,7,0	0,7,3	2,4,3	1,0,5	7,16,3	4,9,10
	Total 6	7	11	10	9	6	26	23
	% 9.0	10.5	19.0	20.4	10.0	9.2	12.1	12.7
No.of trout tagged and released in deep water	67	67	58	49	90	65	215	181
% subsequently recaptured in :								
shallow water	7.5	8.9	17.9	18.2	9.4	5.7	10.8	10.1
deep water	16.8	18.7	32.1	45.5	13.5	9.4	19.4	22.2

Table 2.18 (b)

Season	Spring		Summer		Autumn		Total	
Species	B	R	B	R	B	R	B	R
	(1)*(2)(3)							
No.of trout which stayed in shallow water	1,5,1 Total 7 % 10.1	0,0,0 0 0	0,3,2 5 8.1	0,1,0 1 1.8	0,10,0 10 10.1	0,6,1 7 9.5	1,18,3 22 9.6	0,7,1 8 4.0
and, moved to shallower water	2,4,1 Total 7 % 10.1	1,0,2 3 4.2	1,4,2 7 11.3	2,2,3 7 12.7	4,8,0 12 12.1	1,7,5 13 17.6	7,16,3 26 11.3	4,9,10 23 11.5
% recaptures in shallower water	20.3	4.2	19.4	14.6	22.2	27.0	20.9	15.5
No. captured in shallow water	69	71	62	55	99	74	230	200
No.of trout which stayed in deep water	0,7,1 Total 8 % 8.3	1,3,2 6 10.5	0,7,5 12 20.7	1,4,2 7 20.1	0,24,3 27 31.0	0,20,5 25 55.6	0,38,9 47 19.4	2,27,9 38 29.0
and, moved to deeper water	0,4,1 Total 5 % 5.2	2,2,1 5 8.8	4,8,4 16 27.6	7,5,1 13 44.8	6,11,1 18 20.71	0,8,4 12 26.7	10,23,16 39 16.1	9,15,6 30 22.9
% recaptures in deep water	13.4	19.3	48.3	65.0	51.7	82.2	35.5	51.9
No. captured in deeper water	97	57	58	29	87	45	242	131

Catches from fly fishing in streams fall away dramatically with the advent of hot weather in the summer. Fish can still be caught during the heat of the day however by fishing weighted flies close to the bottom in the deep pools. Activity of the fish at the surface of the water appears to be restricted to the late evening and very early morning during the summer. Apparently there is enough oxygen in the depths of these pools to support the fish through the day.

2.2.3.3 Oxygen

Micro-Winkler apparatus, as described by Fox and Wingfield (1938), was used to measure the oxygen content of the water in Sixth Creek on three of the hottest periods in the summer 1963-64 (Table 2.19). Super-saturation can be related to the photosynthetic activity of the abundant filamentous algae.

Of more interest are the conditions in the cool water at the bottom of the deep pools.

In temperata climates a steep temperature gradient (thermocline) with depth is established in lakes and reservoirs in the spring and remains as a permanent physical feature until the autumn. The cold water below the thermocline in eutrophic lakes becomes depleted in oxygen until the autumn. Fish in these places are found just above this stagnant water in the thermocline (Reid,1961).

In streams in South Australia the fish lie close to the bottom during the heat of the day. Since the fish can be caught (by angling) quite readily, and some of those caught have had fresh food in their stomachs, it was evident that the cool bottom water was not depleted in O_2 and that this meant that circulation and mixing with the surface

Extracting a Rainbow trout from a deep pool in the Light River during the summer. The fish was hooked on a weighted fly near the bottom of deep water close to the bank on which the angler is standing. The high near bank is shading the water (late afternoon) while the fierce sun continues to beat down on the far side.



Table 2.19 Oxygen determinations - Sixth Creek

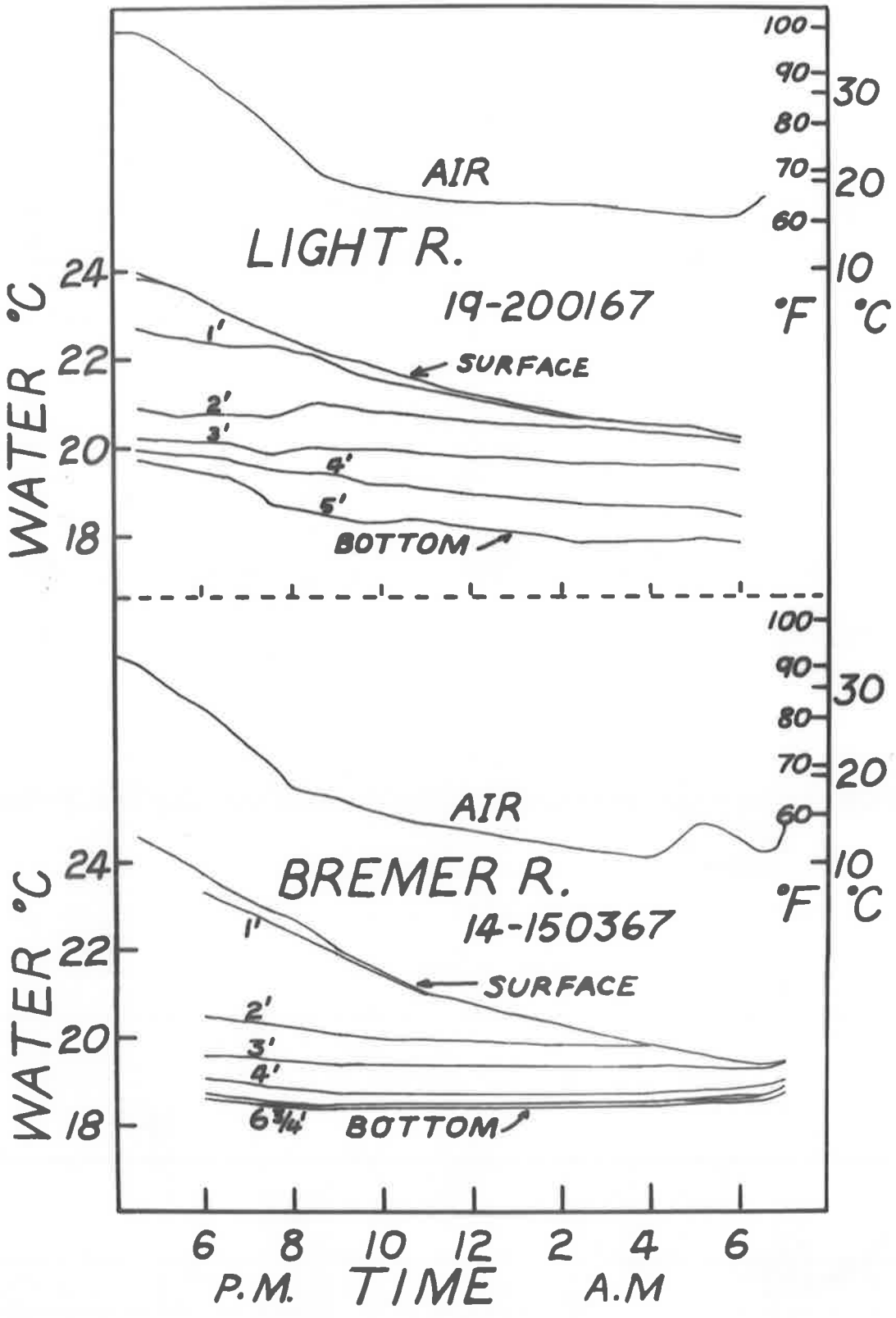
Place		310164 Time	Water Temp. °C	Water Temp. °C Recorder	O_2 mls/litre	% Sat.	050264 Water Temp.	Water Temp. Recorder	O_2 mls/litre	% Sat.
DP5	Run In	11.30am	22.25	21.2	8.04	131	24.0	22.4	5.90	99
	Run Out		"		9.11	148	"		7.90	132
DP4	R.I.	11.40am	22.5		8.64	125	24.75		7.77	132
	R.O.		"		7.10	116	24.5		7.64	129
DP3	R.I.	11.50am	22.0		6.97	113	24.0		7.10	119
	R.O.		"		6.43	104	23.75		7.90	132
DP2	R.I.	12.00pm	22.0		6.44	104	23.5		6.97	116
	R.O.		"		7.50	121	23.75		8.44	141
P3	R.I.	12.05pm	-		-		24.25		7.50	126
	R.O.		-		-		24.5		8.04	136
DP1	R.I.	12.10pm	22.5		6.03	98.4	25.0		7.37	126
	R.O.			21.5	7.24	117	"	23.0	8.04	137

310164 : overcast (heavy cloud), very humid, very hot.

050264 : overcast (light cloud), very humid, very hot.

Run In P 5	200264				210264		
Time	11.45am	1.25pm	3.30pm	5pm	5.30am	7am	9.30am
Water Temp °C	18.5	20.75	22.0	22.0	17.0	16.25	16.5
Water Temp °C Recorder	18.5	19.25	20.4	21.5	17.6	17.0	16.5
O_2 mls/litre	8.04	7.37	6.42	6.42	6.97	6.97	7.23
% Saturation	121	117	104	104	102	101	105

Figure 2.7 Measurements of temperature with depth in pools in streams overnight. The flow in the Light River was very small and non-existent in the Bremer River. The sky during the night was overcast with clouds on the first date but clear on the second occasion resulting in lower air temperatures.


AIR
LIGHT R.
19-200167
SURFACE
1'
2'
3'
4'
5'
BOTTOM
WATER °C
24
22
20
18
100
90
80
70
60
30
20
10
°F
°C
AIR
BREMER R.
14-150367
SURFACE
1'
2'
3'
4'
6¾'
BOTTOM
6 8 10 12 2 4 6
P.M. TIME A.M

water occurred during the summer. A reasonable hypothesis is that the water in the pools during the day corresponds to the epilimnion, the surface water, and the thermocline of lakes and that the lower stagnant water (hypolimnion) of lakes is absent; so that the trout at the bottoms of the pools are living in the thermocline as they do in lakes (e.g. see Horak and Tanner, 1964).

Although there is a vast amount of literature about the "permanent" temperature stratification of lakes during the summer (e.g. Hutchinson, 1957), temperature changes in the upper layers of water overnight are apparently undescribed. However Vaas and Sachlan (1955) found that mixing, due to an inverse stratification overnight, followed the steep temperature gradient of the previous day in a pond. Low productivity of some marshes was attributed by Carter and Beadle (1930) to lack of mixing whereas mixing occurred frequently in a highly productive lake according to Beadle (1932).

The frequency of mixing in pools of different depths in streams can only be determined by metering temperatures at different depths in pools over long periods with transducers from an automatic multi-channel recorder. How frequently mixing needs to occur, relative to the requirements of the trout, could be found with an additional transducer metering dissolved oxygen at the bottoms of the pools. Measurements of temperature with depth overnight, using the manual apparatus described previously, showed that some degree of stratification persisted to the early morning in two pools during hot weather (Figure 2.7). Perhaps the temperature at different depths becomes uniform during the "cool changes" between hot spells when winds could cause mixing.

The distribution of trout cannot be extended into hotter regions by providing ever deeper pools. A depth is reached where circulation of the water near the bottom of the pool does not occur (or infrequently) because the surface water does not cool overnight to as low a temperature as that of the water near the bottom. The temperature of the water near the bottom of the pool might be low enough (from winter cooling and the low temperature of the ground at this depth) for the trout to survive it but there would not be enough oxygen for the fish to survive through the summer. Such a (natural) pool would as well as behaving as lakes do also have the dimensions of one.

2.3 The influence of lack of water on the survival and spawning of trout in South Australia

2.3.1 The annual cycle of flow down streams

At Sixth Creek a drum recorder (Figure 2.8), with a ga(u)ging post, opposite the rearing ponds kept a continuous record of the changes in level of the long deep pool (DP 2) there which acted as a control section (Map 4). The recorder was mounted on a stand made from "Dexian" built into the steep clay bank on the road side of the pool. To prevent the apparatus from being swept away by the winter floods the float from the recorder, which was 5' above the water, was suspended in a narrow inlet cut into the bank. The outlets to the pool, about 1' and 3' wide respectively were fairly stable. In summer the wider outlet was dammed and the flow restricted to a width of about 6" to increase the sensitivity of the recordings. Separate calibrations of total flow on gaging were made for each winter and summer flow after the outlet was dammed. Total flow was estimated from measurements of velocity, at

a number of points in the cross-section profile of the stream, with an "Ott Minor" propellor current meter. Calculations were made by Harlacher's graphical method (Addison, 1940) at first and later from an arithmetic expression derived from this method. Estimates of high flows during heavy flooding in winter could not be made. Extrapolation of the calibration curves for the winters were made to 1,400,000 litres/hour. At about this flow the creek started to overflow its banks at the gaging site (by definition, a flood - Leopold, 1962).

Flows, in litres per hour, (1 litre = 0.22 gallons) for 1964 and 1965 are shown in Figure 2.9. Changes in the slope of the curve correspond to persistent trends over a number of days in summer and large abrupt changes to rainfall mainly in winter. The small daily changes in flow which occur throughout the summer as a result of the daily cycle of heating and cooling of the ground and pumping of water from the stream by farmers are not shown.

The southern part of South Australia has a mediterranean type of climate. About three-quarters of the annual rainfall occurs in the months May to October, inclusive, from the passage of low pressure systems in the prevailing Westerlies across the Great Australian Bight. During the rest of the year this system is far south of the continent and only occasional intrusions to the northward result in light showers and cooler conditions which increase stream flows indirectly by reducing the need for pumping to irrigate crops and orchards. The flow in Sixth Creek falls through the summer until the cooler month of March arrives when there is some increase due to a reduction in pumping. Naturally in the absence of pumping by farmers the flow would be much higher and

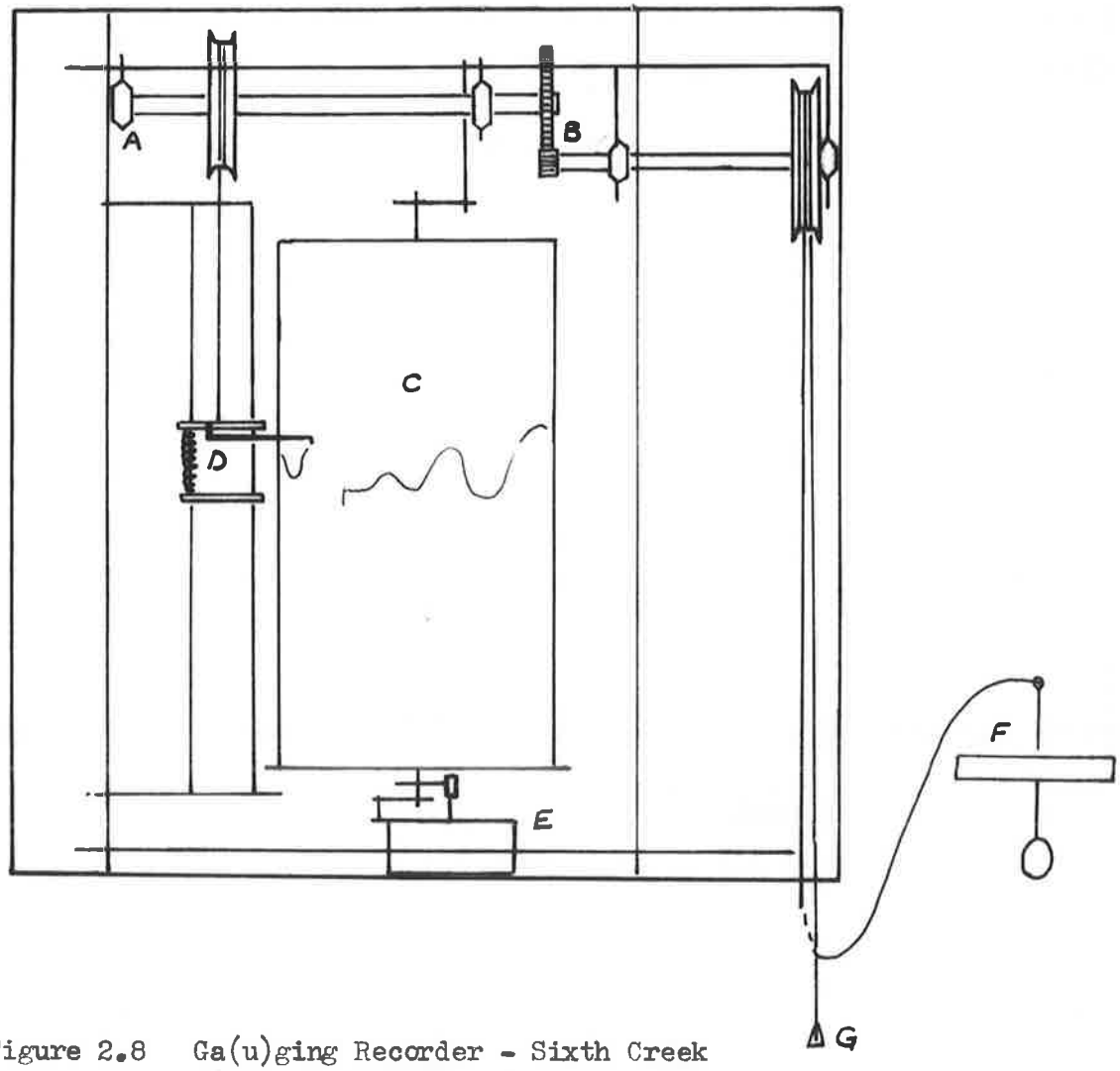


Figure 2.8 Ga(u)ging Recorder - Sixth Creek

A. Ball-bearing support housing
B. Reduction gears $4\frac{1}{2}$:1
C. Recording drum : 6" dia., 10" high
D. Weighted ink pen
E. 10 - day clockwork motor (10 days = 1 rotation of recording drum)
F. Weighted float (sealed 5" dia. tin)
G. Counter-weight

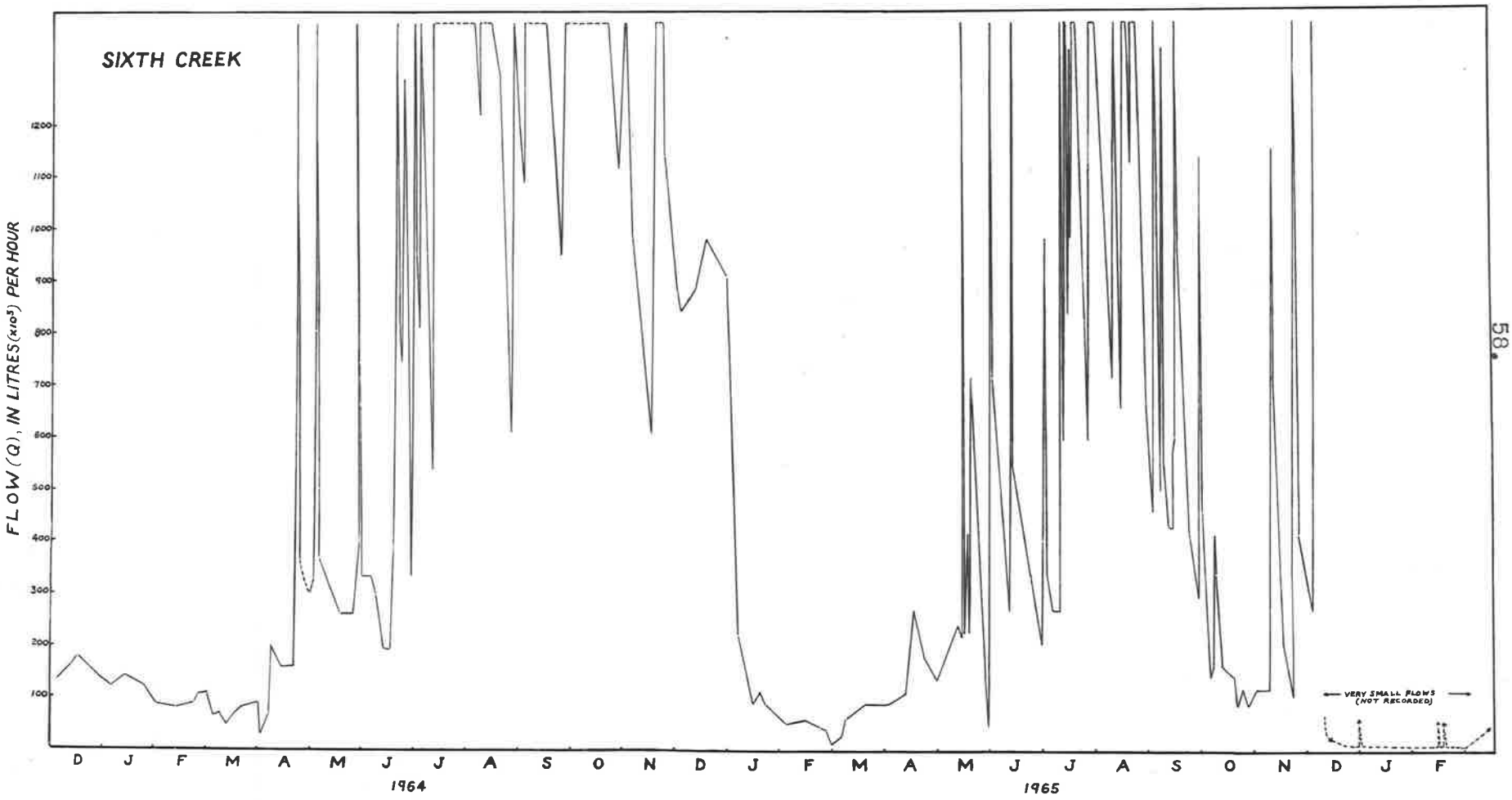


Figure 2.9 Graph of total flow - Sixth Creek - for two years

decrease until late April, or early May, when the opening rains of the wet season commence. The first floods are usually not very large but the water is extremely turbid with road washings, top soil and autumn debris. The water is always muddy during the numerous floods of winter. Only if heavy rain continues into the spring does the stream run fairly clear at high flows, e.g. in 1964. Annual rainfall at Adelaide near the Torrens R. is 20", at Sixth Creek rearing ponds 30" and on the eastern slopes of Mount Lofty, where the creek rises, about 40".

Records of flow for a few streams which supply Adelaide with water are to be found in a publication of the local Engineering and Water Supply Department called "Surface Water Resources". The seasonal changes in flow are similar to those in Sixth Creek.

Coote and Cornish (1958) showed by the method of multiple regression that the average annual rainfall of places in the region increased by 1½" for each 100' increase in altitude, decreased by 5" for every 50 miles northwards, and decreased by 16" for every 60 miles east. The leeward (eastern) slopes of the Mount Lofty Ranges are in a pronounced rain-shadow. With the above data Gerney (1961) related stream flow to rainfall by the use of stochastic models for records up to 1950 after which pumping from streams introduces considerable bias. Streams in an area bounded by the 25" (rainfall) isohyet (Figure 2.10, after Trumble, 1948) were given a high probability of flowing through the summer until the opening of the wet season. Whereas the other streams to the north, of which the North Para R. was given as the most southerly, were given a low probability of doing so. Observations of streams in the region have shown that this categorization is not generally

true. For example the Wakefield and the Light Rivers have reliable flows through the summer and the Broughton River had a greater flow than any other stream that I saw in the summer of 1964-65, after a "dry" winter. These streams are not subject to pumping because they have a high salt content. Also their beds are clay. The Finniss R. in the area of "reliable" flow habitually stops flowing on the surface over a considerable length where the bed is composed of rocks and flow can only be seen at places where ridges of solid rock force water to the surface.

The crux of the problem is that the natural flow in most of the streams is very small, less (usually much less) than 100,000 litres/hour, during the summer and in the rest of the streams zero for all, or part, of the summer. Even the streams with the most reliable natural flows (e.g. Sixth Creek) may be stopped for short periods by excessive pumping by farmers.

2.3.2 The survival of trout in relation to flow

"The country from Cape Jervis upwards is very picturesque and generally well-timbered,... There are many streams running into the sea, with very deep channels. These in summer are low, and a few of them dry." "Of course the tiny little Torrens all but vanishes before such a sun and in the few places where it runs at all, there would be plenty of room for the whole of it to run through an Irishman's hat. There are however, several pretty good holes which have too much water in them to be entirely exhausted by the summer's heat." (from "Six months in South Australia" - T. Morton James, 1838).

The trout streams in South Australia differ considerably in appearance from those in cooler, wetter climates. In summer at the best a tiny trickle of water in a narrow channel connects the long,

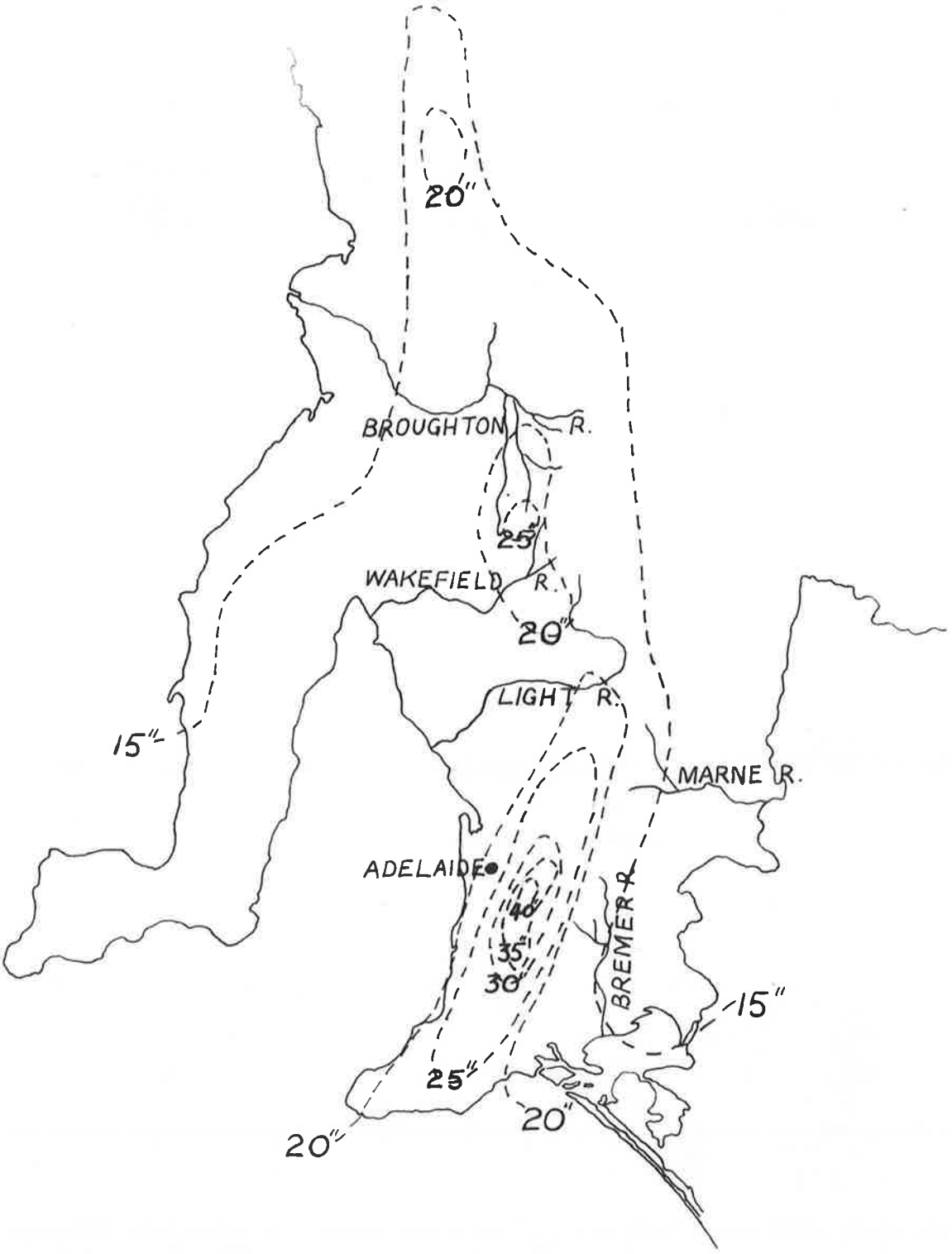


Figure 2.10 Map of South Australia showing Rainfall isohyets

narrow, deep and steep-sided pools where the fish live. In section 2.2.3 the importance of temperature stratification of the water for the survival of the trout was demonstrated. The small flow in summer suffices to maintain the depth of water in the pools but is not large enough to prevent the stratification.

Even when the flow stops the fish live, provided they are not crowded as in hatchery ponds, for as long as there is a sufficient depth of water to insulate them from the heat of each day. For example trout which were stocked as fingerlings in the autumn of 1964 in two of the deepest pools which could be found in the Bremer R. survived the next summer in these pools even though there was no surface flow throughout the summer. The levels of the pools were maintained by springs in each pool. In the following summer a large Brown trout survived in a much smaller pool above one of the large pools from 231065 when flow into and out of the pool had ceased, until at least 301265. On 090266 the fish could not be found and the pool had all but disappeared. A fish, feeding actively, was found in a similar situation, except that the pool was well shaded by a gum tree, in the Finniss R. on 050266.

The distribution of trout within streams during the summer is determined by the frequency of deep pools along their lengths. A deep pool usually occurs at each bend in the stream.

The main rivers in the Mt. Lofty Ranges are of the antecedent type. They have maintained their channels to the sea, or the Murray R., during the uplifting and folding of the Ranges. Their valleys are deepest and most tortuous, and their gradients steepest, in the middle of their lengths just before they flow out onto the plains. Flow is

Upper. A deep pool in the Light River (210166). The run-out of the pool and the stretches above and below the pool are choked with Bulrush.

Lower. A pool in the Finniss River (150566). The stream is flowing for the first time since the previous winter.





most reliable in these deep gorges and, from section 2.2.2.3, minimum air temperatures are likely to be lowest during the summer.

2.3.3 Spawning of trout in relation to flow

Adult female trout lay their eggs in depressions which they "dig" with their tails in gravel in streams. After fertilization by the male the female then covers up the eggs with gravel from just upstream of the redd. The size of the gravel which can be moved depends on the size of the fish and the force of the current over the site. Silt is washed away during redd-digging and the female selects an area of gravel inclined toward the current so that afterwards fresh water continually percolates around the eggs, and then the alevins, bringing oxygen. In streams this combination of size of gravel, flow, and gradient of the stream-bed is usually found at the run-out of a pool. Where the combination is optimal and the redd is not disturbed by other fish later the survival of the young is very high until they emerge from the gravel to feed for the first time (Hobbs, 1937).

A few male Brown trout were captured in the "upstream" fish trap at Sixth Creek (Map 4) with the first floods each year (1962-65). The main spawning run of Brown trout from the Torrens R. started at the end of May with heavier rain and continued through June. Spawning activity by Rainbow trout regularly started early in August in Sixth Creek and several other places and continued into September.

Two natural phenomena (seemingly peculiar to local conditions) that are detrimental to the spawning success of trout were observed during the course of the study.

(a) Areas of gravel suitable for spawning redds are small and sparsely distributed through most of the streams due to the narrowness of their channels particularly at the run-out of pools. In Sixth Creek the number and areas of these places (surveyed in the winter of 1962) decreased noticeably from 1962 to 1966 due to the lack of very heavy sustained winter flooding capable of eroding the banks and creating wide stretches where gravel could remain. Abundant silt from the floods that did occur consolidated behind sedges, bulrush, and even water-cress in the water, and built out the banks.

Superimposition of redds, indicating a shortage of suitable spawning material, by Brown trout in Sixth Creek was observed in 1962, 1963 and 1964. Catches of adult fish in the trap were 1962 (58), 1963 (60), 1964 (138) and 1965 (23), (in 1962 and 1963 many fish swam over the trap during floods). Despite poor conditions during the summer of 1965-66 the catch of Brown trout fingerlings (age 0+) in the autumn was much higher than in the previous years (Table 2.20). Apparently even with the decrease in suitable areas the few adult fish were not crowded in 1965 and the spawning was therefore more successful.

Rainbow trout commence spawning before Brown trout fry emerge from the gravel. In 1963 Brown trout fry (stripped on 160663) started feeding at the rearing ponds on 190863 and in 1964 somewhat later about 100964 (stripped on 190663) due to lower water temperatures. Brown trout that spawned in Sixth Creek were large fish from the Torrens R. (up to 45 cms in length) and smaller (because of poor growth) fish which lived in the creek. Few Rainbow trout were ever caught in the trap (which captured fish above about 28 cms in length) and the fish observed

spawning in the creek were small and assumed to be resident fish. Alevins from the large Brown trout thus probably escape interference because the small Rainbow trout dig shallower redds in smaller gravel.

(b) Today in both the Broughton and Light Rivers sustained increases in flow of appreciable magnitude are only produced by several inches of rain in a short period of time. This is in striking contrast to streams further south, such as Sixth Creek, and is not entirely due to the lower rainfall and less steep watersheds to the north.

In a short stretch of the Light River where cattle and sheep have broken down the banks and eat the bulrush there is gravel in the wider channel. But the Rainbow trout could only use one small patch of this gravel in August of 1965 and 1966 because the flow was very small. In the Broughton River in August 1966 Rainbow trout, which had survived in one of four deep pools stocked with advanced fingerlings in the autumn of 1965, had abandoned redd-digging in some stones at the run-out of the pool because of the poor flow over unsuitable material and could not run upstream to more suitable gravel because of the intervening obstacles in the shallow channel. Photographs of the Broughton River in the early years of this century show long wide stretches of water (from Mr. E. Le Page, Koolunga). From the same viewpoints today vestiges of these expanses of water remain as long narrow pools, at bends, ringed with bulrush and the intervening lengths of streams are choked with the same growth. Before man started farming in the north these watersheds were covered with scrub (mallee mainly) little of which now remains. About twenty to thirty years ago farming methods were improved, by less intensive grazing, sowing of grasses on slopes,

Table 2.20 Catches in the autumn of three years in the same stretch (1529') of Sixth Creek

Dates		Length Groups (cms)																					Totals	
		7.5-	8.5-	9.5-	10.5-	11.5-	12.5-	13.5-	14.5-	15.5-	16.5-	17.5-	18.5-	19.5-	20.5-	21.5-	22.5-	23.5-	24.5-	25.5-	26.5-	27.5	0+	1+ & older
030364 and 060464	B			2	2	2	3	1	1	1	1	2	1	1	1	7	4	2	5	2	9	4	15	36
	R				4	3	4	1	4		3	2						6	3	2	3		21	14
200465 and 230365	B	1		2	1	1	2	2	1						3	4	3	5	3	5	3	5	10	31
	R				7	13	10	12	12	8	3			2	3	2	5	3	7	3	2	4	65	31
180466 and 190466	B	2	2	12	11	14	8	4	3				1	2	8	3	1	2	2	6	2	3	56	30
	R	1	1	1	2	1			1	1			4	1		2	4						8	11

(0+ up to 18.5 cms; 1+, 18.5 — 23.5).

Brown trout (B), Rainbow trout (R)

and contour ploughing of grain fields to reduce the heavy winter run-off which was removing much of the top soil (Kelly, 1962). Grass covered watersheds retain more rainfall than the original forest cover. A similar history of transition probably applies to the Light River since it is very similar in appearance and the farming (grain crops and sheep grazing) on the surrounding land is the same.

Despite the obstacles that low flow over the infrequent and small patches of gravel seem to present, capture of egg-bound females in the Light River was rare.

High flows are not only important to allow the fish to get to gravel and use it but also for the survival of the eggs and alevins in the subsequent two months until they emerge from the gravel. Large numbers of Rainbow trout, age 0+, which were seen in the Light River in the autumn of 1965 have been attributed to the high flows in the spring of 1964. Larger numbers of Rainbow trout fry were also present in Six Creek (Table 2.20).

2.4 The unfavourable influence of too much rain in summer

Occasionally warm moist winds from the oceans north of Australia reach the Mount Lofty Ranges during the summer and produce localized falls of heavy rain. During October 1965 the flow in Sixth Creek fell towards the summer level but in November two minor floods occurred, due to rain from this influence, culminating in a heavy flash flood early in December when 4½" of rain fell over the eastern slopes of Mount Lofty in 1½ hours. Run-off from heavily grazed land and freshly turned orchards on steep slopes was particularly high and turbid. Some dead trout, mainly Rainbows, were found by farmers on the banks of the

creek after the flood abated. The weather continued to be very hot and humid for the rest of December. Water temperatures were very high immediately after the flood (Table 2.21). Flow was reduced to a trickle, after a smaller flood on 111265, towards the end of December by excessive pumping upstream. Water temperatures were lower during January by which time the mud had settled and a bloom of biflagellates gave steep temperature gradients in the deep pools. Table 2.22 gives the hour by hour water temperatures for a short very hot period when Mr. H. Smith observed some trout to die in the creek in the deep pool opposite the rearing ponds. Fish were gasping at the surface on 281265 and some dead fish were seen on the evening of 291265. From the description and dates an oxygen deficiency is indicated as the cause of death. The solubility of oxygen in water is lower at higher temperatures. Since the flow was very low there was little aeration and fish were crowded in the pool (see below).

Table 2.20 shows the catches by electro-fishing in the autumns of 1964, 1965 and 1966 in the same stretch of the creek. The results of the last sampling were surprising and indicate the superiority of the Brown trout. Of 10 Brown and 23 Rainbow trout tagged and released in DP2 on 191165 5 Browns and 1 Rainbow were recaptured in the same pool on 190466. However Brown trout planted in the Gorge of the Broughton River in 1926 (500 fry) and 1934 (500 fry) which grew to large sizes by the late '30's, and spawned successfully, were eliminated by an enormous flood in January 1941 (information from Mr. F.L. Nykiel). For the 8 rivers further south for which there are flow records above average flows were recorded in this month but not of the magnitude indicated by

TABLE 2.21 WATER TEMPERATURES AT SIXTH CREEK - NOVEMBER, DECEMBER AND JANUARY 1965-66

	November 1965		December 1965			January 1966	
HOUR	TEMP	S.D.	HOUR	TEMP	S.D.	HOUR	TEMP	S.D.
1	15.99	1.56	1	20.37	1.81	1	21.15	1.69
2	15.92	1.54	2	20.18	1.77	2	20.86	1.68
3	15.85	1.52	3	19.98	1.73	3	20.58	1.68
4	15.79	1.51	4	19.79	1.70	4	20.29	1.70
5	15.72	1.50	5	19.60	1.68	5	20.00	1.73
6	15.66	1.50	6	19.41	1.66	6	19.72	1.77
7	15.59	1.50	7	19.21	1.65	7	19.43	1.83
8	15.47	1.52	8	19.02	1.65	8	19.05	1.90
9	15.63	1.43	9	19.50	1.53	9	18.96	1.79
10	15.80	1.40	10	20.27	1.47	10	18.80	1.65
11	16.30	1.49	11	21.21	1.38	11	18.92	1.53
12	18.06	1.84	12	22.62	1.17	12	19.73	1.43
13	19.82	2.38	13	24.02	1.13	13	20.53	1.36
14	19.36	2.35	14	25.03	1.43	14	21.33	1.33
15	18.50	2.13	15	25.92	2.10	15	22.13	1.35
16	17.78	1.91	16	25.31	2.38	16	22.17	1.41
17	17.68	1.87	17	24.41	2.06	17	21.96	1.34
18	17.58	1.83	18	23.31	1.92	18	21.82	1.24
19	17.48	1.80	19	22.98	1.90	19	21.91	1.25
20	17.38	1.78	20	22.64	1.85	20	22.04	1.29
21	17.28	1.75	21	22.30	1.82	21	22.17	1.39
22	17.18	1.73	22	21.85	1.76	22	22.33	1.49
23	16.72	1.67	23	21.33	1.85	23	22.07	1.64
24	16.11	1.59	24	20.59	1.76	24	21.46	1.68

C

Table 2.22 Hour by hour water temperatures for a short period during December 1965 at Sixth Creek

Day												
26th	Hours 1 - 12											
	20.0	19.8	19.5	19.3	19.0	18.8	18.5	18.3	19.0	20.0	21.3	22.9
26th	Hours 13 - 24											
	24.5	26.1	27.8	27.3	26.0	23.5	23.3	22.9	22.6	22.3	22.0	21.3
27th	Hours 1 - 12											
	21.0	20.8	20.6	20.4	20.2	19.9	19.7	19.5	20.0	20.5	22.0	23.8
27th	Hours 13 - 24											
	25.5	27.3	29.0	28.8	27.3	26.0	25.4	24.8	24.1	23.5	23.0	22.5
28th	Hours 1 - 12											
	22.3	22.1	21.9	21.8	21.6	21.4	21.2	21.0	21.0	21.3	22.5	24.1
28th	Hours 13 - 24											
	25.8	27.4	29.0	28.5	28.0	26.8	26.4	26.1	25.8	25.5	25.0	23.8
29th	Hours 1 - 12											
	23.3	22.9	22.5	22.1	21.7	21.3	20.9	20.5	20.5	21.3	22.0	23.2
29th	Hours 13 - 24											
	24.4	25.6	26.8	27.0	26.0	25.5	25.3	25.0	24.8	24.5	24.3	23.3
30th	Hours 1 - 12											
	23.1	22.9	22.8	22.6	22.5	22.3	22.2	22.0	22.0	22.5	23.5	24.7
30th	Hours 13 - 24											
	24.5	26.1	27.8	27.3	26.0	23.5	23.2	22.9	22.6	22.3	22.0	21.3

Upper. Sixth Creek. View downstream of Stickle 12 below Deep Pool 2 after the opening rains of the wet season (mid-May 1965).

Lower. View downstream of Stickle 12 during late January 1966 after the heavy summer floods of December. Pumping by farmers reduced the flow to an intermittent trickle. However fish survived in Deep Pool 2 just above the Stickle. Sheep graze down the green herbage along the banks during the summer and autumn.





photographs of the Broughton River in flood (from Mr. E. Le Page, Koolunga).

The danger to trout of even small floods during the summer when they occur in hot weather is the high temperature of the water afterwards particularly if the rain occurs during the day and runs off the hot ground - the December flood in Sixth Creek occurred about midnight. While the flow is still high temperature stratification cannot occur and the silt in the water absorbs considerable heat (Reid 1961). From 1884, records show that floods during the summer have occurred about once in every 5 years.

2.5 Changes in the distribution of water suitable for trout due to man

Within the existing stream systems the distribution and abundance of the trout are determined largely by the occurrence of pools of water and in a sense Man competes with the fish in summer for a limited resource by pumping the water from pools. By allowing land to remain fallow on the watersheds Man has caused a widespread reduction in the number and depths of pools due to silting with topsoil. Chemical pollution is not a serious problem in South Australia because the low flows during the summer prevent this use of streams. Some streams are known where fish have been killed by deliberate pollution. Tanunda Creek (fruit cannery, now no longer in operation), Scott's and Nairne Creek (pyrites mine), Mt. Barker Creek (tannery).

On the other hand reservoirs and a multitude of farm dams, of which the irrigation dams kept full by springs or bores through the summer are the most suitable, have considerably increased the amount of

water suitable for trout.

Since the early 1950's the Torrens and Onkaparinga Rivers have been used as channels to carry a large flow of water pumped from the Murray River (lately via Milbrook Reservoir for the Torrens) to Adelaide through the summer.

The creeks and the rills in and around Adelaide's hills
Run weaker and weaker each year
Why in summer if some even trickle
I'm weak in the eye and the ear.
They've been dammed and have silted
Whilst their valleys are all bulldozed and cleared
I ponder what thoughts
Some old timer would sense if he could reappear.

W.K. Cloy.

3. ABUNDANCE

The sparse and patchy distribution of trout along most streams in South Australia, the frequent heavy floods in southern streams during winter and the retirement of the trout to the depths of pools during the summer made impracticable the estimation of more than the growth component of abundance in most places. Adequate numbers of trout were captured for this purpose between October and April (the "open" season for trout in South Australia) by fly fishing although the effort involved was considerable. For an introduction to the literature on the techniques of this art see the appendix (3).

Fortunately a section of the Sixth Creek had, on the other hand, a multitude of advantages (outlined in 1.2) which brought a detailed assessment of the numbers, movements, and growth of the trout there within the realm of practicability.

3.1 Capture of trout in Sixth Creek

3.1.1 Methods

Electro-fishing

The most efficient method of capturing trout in streams at present is by electrical narcosis. Of many references on this topic those by Halsband (1959) and Burnett (1959) provided the most useful introduction to the technique. Vibert (1963) examines the neurophysiological reaction of the fish.

A pulsatory direct current is most efficient in capturing fish and least likely to injure them. When a direct current is emitted from a probe (anode) in the water close enough to a fish it cannot move away

but turns and swims toward the probe. The fish swims up the potential gradient until a voltage is reached very close to the probe where narcosis occurs and it turns onto its side. The effectiveness of the direct current is increased if it is pulsed at the frequency of the waves of muscular contraction, producing swimming, of the fish. Control over the direction of swimming is best when the "on time" of each pulse cycle is long.

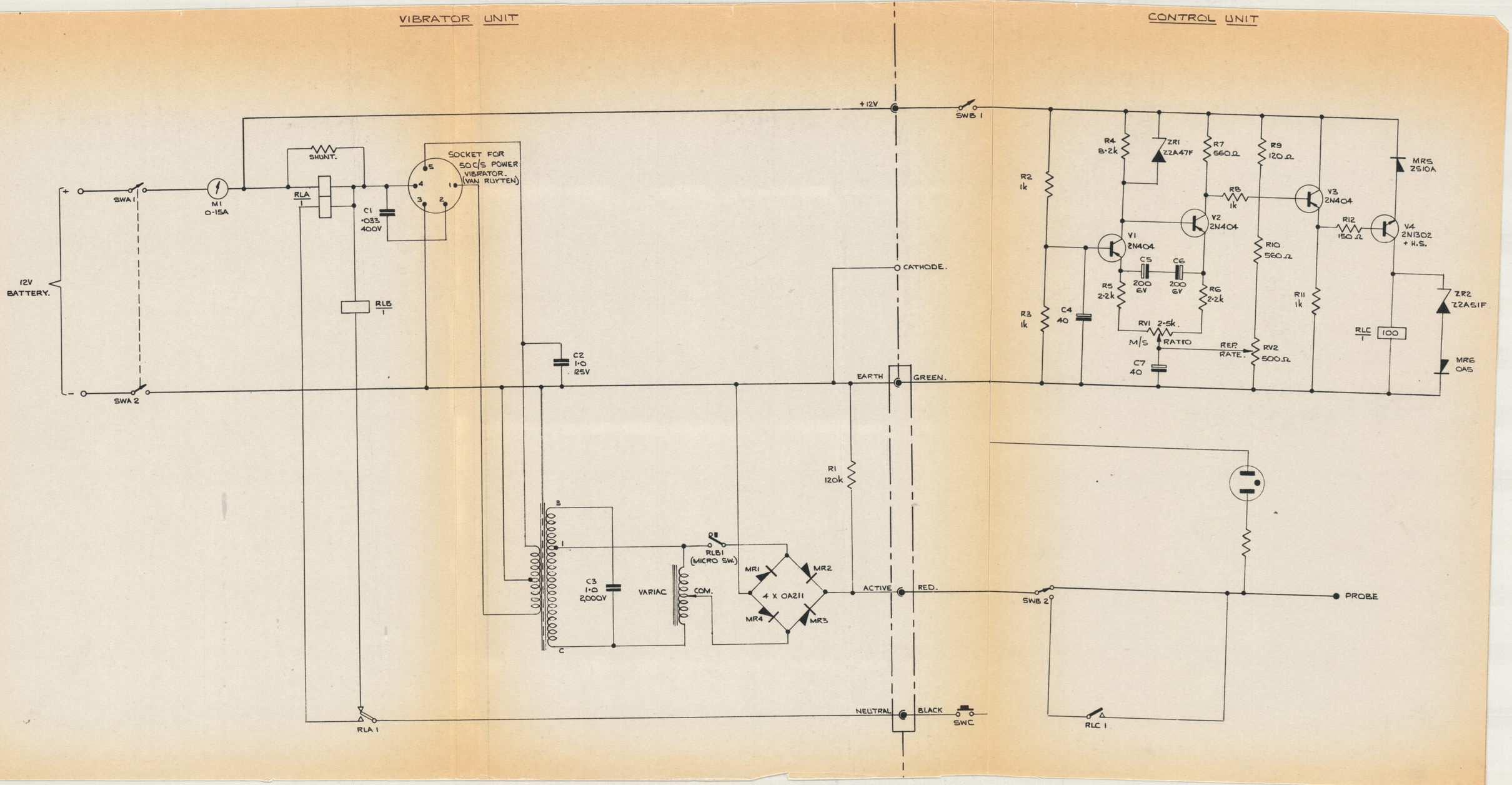
A 12 volt, 9 plate, car battery provided enough power to effectively fish at least 1000' of Sixth Creek without recharging. The conductivity (1/p) of Sixth Creek water is high (resistivity (p) was about 1300 ohm-cm at 20°C during summer). The control unit, 14" x 11" x 7" - 20 lbs, was made by Eilco, Adelaide, to step up the voltage from the battery to an effective working range (adjustable)of 90-120v. D.C. From this unit, alongside the battery on the bank of the stream, 300 feet of P.V.C. insulated 4-core cable (handled and stored on a plastic-coated garden-hose reel) led to the vibrator unit clamped to the handle of the probe (anode) pole. The vibrator unit, 6" x 4" x 2" - 2 lbs, produced the pulses in the D.C. from the control unit and was powered by 12v. D.C. from the battery. This unit was designed and made by Mr. P. Schultz (W.R.E.). The pulse rate and "on time" controls of the vibrator unit were calibrated on an oscilloscope at the University in the range of 2 to 5 pulses/sec. for an "on time" of 0.8 of the pulse cycle as recommended by Burnett (1959). P.V.C. insulated flexible hookup wire connected the vibrator to the anode at the end of the wooden pole (6' long, $\frac{3}{4}$" dia.). The anode was small-mesh brass bound with copper wire

to an oval frame (9" x 6") of brass rod. The cathode, connected to the control unit by a few feet of hookup wire, was a square (2' x 2') mat of steel mesh that was staked to the bed of a stickle with a steel rod. This provided an earth-return system for the anode so that the effectiveness of the gear was independent of the distance between the two electrodes. However this set-up was found to be ineffective in the five deep pools in the study section because the depth of the water (3-4') caused overloading and automatic cut-out at the control unit. Luckily it was discovered that if the cathode was floated (with polysterene foam) just submerged the effectiveness of the system was restored.

A circuit diagram of the fish shocker is shown in Figure 3.1. and a photograph of the fishing gear at the streamside is included.

Fish which turned over at the anode of the shocker were lifted out of the water with a linen net (mesh opening contracting to $\frac{1}{8}$" at the bottom of the 1' deep bag) on a 1' diameter hoop with a 6' wooden handle. Captured fish were held in steel mesh baskets to protect them from further electricity before handling. Both containers were 24" long and 12" deep and had lids to stop fish from jumping out. One of these was only 6" wide so that it could trail in the water from a long shoulder strap without offering much resistance to movement while wading upstream in shallow running water. The other basket was 12" wide with blocks of foam fitted under the top so that it floated just submerged and could be towed around the deep pools. The capacity of these containers was about 10 and 20 fish respectively.

Fig. 3.I


VIBRATOR UNIT
CONTROL UNIT
+12V
SWB 1
12V BATTERY.
SWA 1
SWA 2
M1 0-15A
SHUNT.
RLA 1
C1 ·033 400V
SOCKET FOR 50 C/S POWER VIBRATOR. (VAN RUYTEN)
RLB 1
C2 1·0 125V
CATHODE.
EARTH
GREEN.
R1 120k
RLB1 (MICRO SW.)
C3 1·0 2000V
VARIAC
COM.
MR1
MR2
4 X OA211
MR4
MR3
ACTIVE
RED.
NEUTRAL
BLACK
SWC
RLA 1
R4 8·2k
ZR1 Z2A47F
R7 560Ω
R9 120Ω
MR5 Z510A
R2 1k
R8 1k
V3 2N404
V2 2N404
V1 2N404
R12 150Ω
V4 2N1302 + H.S.
R10 560Ω
C5 200 6V
C6 200 6V
R5 2·2k
R6 2·2k
R11 1k
ZR2 Z2A51F
R3 1k
C4 40
RV1 2·5k. M/S RATIO
RLC 1
100
REP. RATE.
RV2 500Ω
C7 40
MR6 OA5
SWB 2
PROBE
RLC 1

In fishing a long stretch of shallow running water the probe was carried downstream from the control unit and battery on the bank to the full extent of the cable (300') and the water was then fished upstream, in thigh waders, past the units on the bank to the full extent of the cable upstream. Two operators were needed to fish (including processing of the captured fish) such a stretch of stream in a working day. One wielded the probe and the other (N.M.) the landing net and holding basket. The deep pools in the stretch were best fished separately - usually on the next day - by one operator (N.M.) in chest waders with the control unit and battery on the bank of the pool so as to allow the cathode to be floated in the pool. Towing the floating basket with the net in one hand and the probe in the other a toggle switch on the vibrator unit, for turning the current on and off to the anode, was less tiring to use than a faster pressure switch.

When trout are disturbed by an unnatural movement (as they are very easily during the daytime) they swim rapidly to a hiding place usually under an overhung bank or rock. Since the range of attraction of the shocker was limited to about 5' catching fish depended to some extent on the probe operator knowing where fish were likely to be hidden and also on the net operator anticipating a catch especially in running water where the fish are carried off downstream by the current once they are stunned. As in angling polaroid glasses were very helpful for seeing fish in the water. In a stretch of shallow running water most of the fish were easily caught from hiding places and refishing for the occasional fish missed by the netter was usually not undertaken. In the long deep pools however fish were numerous and after capturing fish from

Electro-fishing Sixth Creek. The operator holds the probe, to which is attached the vibrator unit, the landing net, and a fish holding basket. (Usually two people worked such a stretch of Runs, Pocket Pools, and Shallow Pools). On the bank is the fish handling tank in the foreground and further back the cable reel, control unit, and battery.



hiding places further runs up and down the pool were needed to corner loose fish that swim back and forth. Stop nets were set at the run-in and run-out of these pools.

Trout could not be captured when the creek was in flood and turbid. Sampling therefore stopped in the late autumn when the first rains of the wet season produced flooding and commenced again in the spring when the frequency of floods abated.

Trapping

In years prior to the study large numbers of Brown trout were observed spawning in Sixth Creek during the winter. Most of these fish were thought to have come from the Torrens River (S.A.F.F.A. Bulletin, November 1957). The possibility that some of these fish would remain in the creek for a time after spawning, and be included in the spring catches from electro-fishing, made it desirable to capture and tag them earlier. Also some of these fish could provide experience in stripping spawn and rearing young fish which were needed for experiments. And some information about the growth and movements of trout in the Torrens River (too large for electro-fishing) might be gained. The migration of Brown trout started each year, during the study, in the late autumn after the first floods of the wet season.

A permanent upstream trap was built in 1962, at a site 1700' up the creek from the Torrens River opposite the home of Mr. H. Smith. The trap was close to suitable sites for holding, hatching and rearing ponds, which were built before the winter of 1963, and could be guarded against interference. The basis of the trap was 3 concrete walls and a number of removable steel grids. The banks of the stream (14' across) at the

site were stable with underlying solid rock suitable for foundations. The walls of the trap, which ascending trout entered through a cone in the downstream end, were built against the high left bank close to which passed the fastest current at moderate flows. During the first winter the top of the fence of grids - sloped up to the left to guide fish toward the trap proper - was supported by a 3" x 2" steel channel resting at each end on the outer wall of the trap and the wall on the right bank. In this rigid almost vertical position large floods (the heaviest in the four years of operation) out out the stream-bed under the fence and caused damage to the grids when debris, including tree trunks, accumulated against the fence. After this experience the stream-bed under the channel bar supporting the bottom of the fence was concreted and in subsequent years the fence was sloped downstream more by supporting it at a number of points by light twine tied to a cord running from the right wall through a pulley on the left wall and back. Then when a heavy flood started the force of water on accumulating debris was sufficient to break the twine so that the fence fell flat into the stream bed where it was held by hooks on the bottom bar. In this way the trap would be got back into operation quickly with little trouble after the peak of a heavy flood - fortunately heavy floods only occurred again in the second year of operation (1963). Trout were observed swimming upstream during heavy winter floods. Catches that were made when the trap was operating at lesser flows occurred at minor floodings so that not all the migrating fish were captured in the winters of 1962 and 1963 because of large floods.

The width of the openings between the $\frac{1}{8}$" vertical steel bars of the grids was 1". The width of the head of 58 Brown trout and 86 Rainbow

trout (killed - see 3.4.2) was measured with vernier calipers at the point of maximum width and inflexibility (the preopercular bone). For Torrens trout this width was also the maximum width of the body because of their poor condition. A linear regression equation using untransformed variates was found to give a better description of the bivariate relationship between the length of the fish (L - cms) and the width of the head (Hw - cms) than a log-log equation. For Brown trout :

$$\hat{L} = 3.601 + 9.000\ Hw \text{ - males}$$

$$r = 0.9686$$

$$\hat{L} = 6.496 + 8.510\ Hw \text{ - females}$$

$$r \quad 0.9775$$

The males had wider heads than the females (intercepts significantly different at 1% level of probability) for the same length of fish.

For Rainbow trout:

$$\hat{L} = 2.488 + 9,782\ Hw -$$

$$r = 0.9747$$

There was no difference between the sexes.

These equations can be used to predict the (average) length of the smallest trout which were unable to pass between the bars of the fish trap. For a head width of 1 inch the mean lengths (95% Confidence Limits for the mean in brackets) for Brown trout are 26.5 cms ($\pm$ 0.7) for males and 28.1 cms ($\pm$ 0.8) for females, and for Rainbow trout 27.3 cms ($\pm$ 0.5).

3.1.2 Handling

Most of the fish which were caught in Sixth Creek by electrofishing were returned to the place of their capture after measurements

and scale samples were taken and they had been tagged. Because trout are very fractious they had to be anaesthetized to allow processing. A number of tubes containing 0.5 gms of Tricaine Methanosulphonate (M.S. 222 Sandoz) were carried and each time a stop was called to process fish the contents of a tube was added to 11 litres of water (1:22,000) bucketed fresh from the creek into a plastic tank (22" x 14" x 9"). The tank was held in a foam padded wooden frame-work on the front of which was a box, 22" x 5" x 6", for holding anaesthetic, tagging gear, etc., inside the lid of which was inlaid a centimetre ruler. When the box was opened up its lid formed a conventional board for measuring the fish.

Fish were measured to the nearest tenth of a centimetre from the snout to the end of the centre line (fork) of the caudal fin. Fish less than 100 gms in weight were weighed, in a funnel of thin plastic suspended from a 100 gm Salter spring balance to the nearest $\frac{1}{2}$ gram. For fish above 500 gms a similar set-up was used with a 1000 gm Salter spring balance (read to nearest 5 gms). The majority of the fish were weighed on a Salter dietary balance (0-500 gm). This was the best balance, giving instant readings, suitable for field use that was available. The large circular scale was much easier to read than the vertical scale of the other Salter balances in the range although the accuracy was no better. Possible bias in the balance was checked frequently using known weights. On 010565 10 readings to the nearest $\frac{1}{2}$ gram for each of 6 known weights in the range 50 gms to 500 gms were used to estimate the variability of the weighings. The regression equation for the reading (Wr) on the actual weight (Wa) was :

$$\hat{Wr} = -1.3393 + 1.00495\ Wa$$

$$S^2 = 0.80603$$

Ninety-five percent random limits for a further reading using a 200 gm. weight were ± 1.63 gms.

The fish were tagged with 3/16" dia. silver disc tags weighing (in air) 45 gmms each. These were marked with a letter of the alphabet and a number from 1 to 100. A tag was threaded on a No. 25 hypodermic needle through which was threaded monel wire (36 gauge). The needle was then pushed through the flesh and bone at the base of the leading edge of the dorsal fin. Then the needle was withdrawn leaving the tag on the wire through the fish after grasping the end of the wire protruding from, and bent back over, its tip. The wire was then cut near the tip of the needle leaving the tag on a few inches of wire through the fish (a long length of wire was wound on a spool so that there was no need to re-thread the needle each time). At first the ends of the wire were twisted down until the tag was pressed flat against the fish and the wire was cut off leaving about $\frac{1}{8}$" of twisted wire. Misgivings about this tie (when a few fish were recaptured with evidence of having lost their tags) early in the study led to the use of a double overhand knot. A stronger needle (No. 21) had to be used for tagging the larger trout captured in the fish trap each winter. Although the twisted tie appeared to be secure with the thicker wire (31 gauge) that could be used with these needles an overhand knot was also adopted. The tags were supplied by Mr. H.W. Washbourn of Timaru, N.Z. "I have personally tagged many hundreds of 5" to 7" trout .... with these tags without any observable untoward effect. We kept one batch for a week to see if they had any effect, but without dire results.

Also, two trout tagged when 6" long grew to be two pounders within two months of being tagged...." Although there were no indications of any adverse influence on the fish caused by the handling process during this study and the tagging method appears to be the best available it is obvious that fish such as Salmonidae, more perfectly streamlined than the best model man can devise (Osborne, 1961), are when tagged at a disadvantage under certain conditions as Clancy (1963) has shown for their swimming endurance in a high velocity flow.

In the first season of fishing, spring, summer and autumn 1963-64, scales were removed from the shoulder of each fish where Nicholls (1957) stated "it is customary to take scales for age determination in trout." (position A in Figure 3.2). When these scales were first examined in the following winter the suspicion grew that scales from elsewhere might be larger, and therefore show more detail, more symmetrical and less variable in size. Six scales were therefore taken from each of ten positions (1-10 in Figure 3.1) on the left-hand sides of a Brown (1+) and Rainbow (2+) trout both 38.1 cms long. The maximum radius of each readable scale, from the nucleus to the anterior edge, was measured to the nearest thousandth of an inch using a Nikon Shadowscope with a micrometer stage (see 3.3.1). The average radius for each position and fish is shown in Table 3.1.

Table 3.1 Average radius of scales from each of ten positions on the side of a Brown and a Rainbow trout.

Position	Average radius (inches)	
	Brown trout	Rainbow trout
1	.101	.081
2	.102	.091
3	.098	.083
4	.087	.072
5	.088	.077
6	.087	.076
7	.086	.071
8	.073	.066
9	.071	.063
10	.060	.063
No. of readable scales	(54)	(47)

The largest scales are to be found in an area close to, and probably below as well as above, the lateral line containing positions 1, 2 and 3. The large scales here are the ones that first appear on Salmonidae fry at a small size (e.g. see Neave, 1936; Snyder, 1838; Wallin, 1957; Warner and Havey, 1961). Maher and Larkin (1954) have shown that scales of Rainbow trout are least variable in size and tend to be oval-shaped and symmetrical from this area. Scales samples from trout were therefore taken from position B after the winter of 1964.

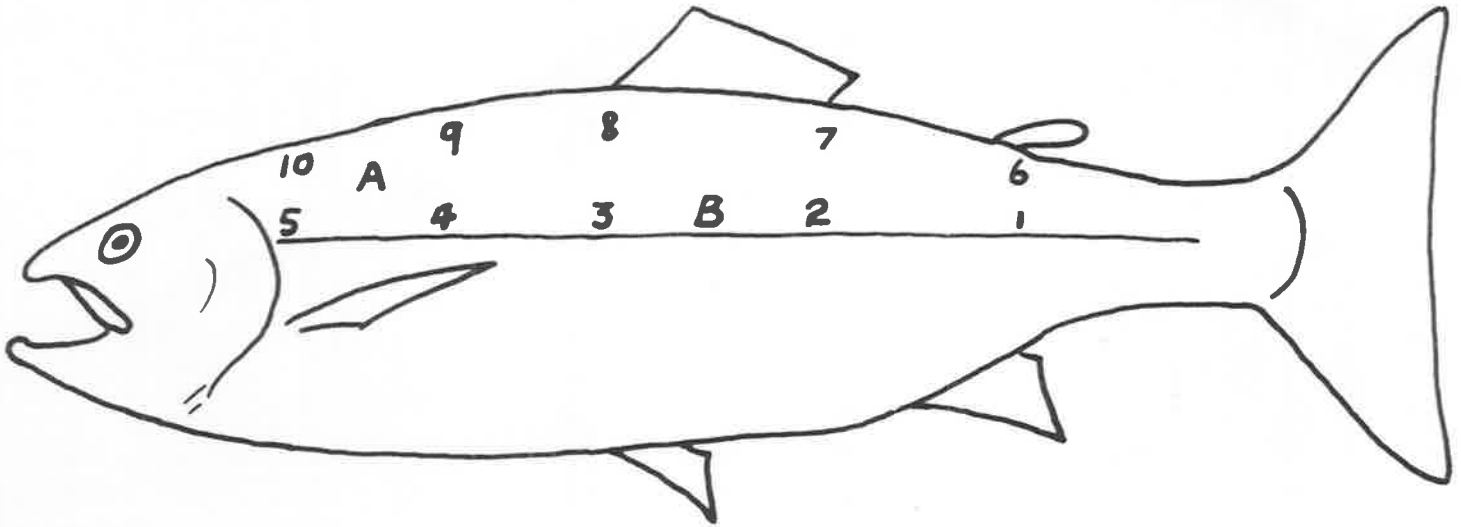


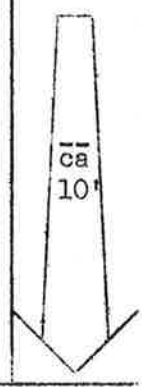
FIGURE 3.2 OUTLINE OF A TROUT SHOWING THE POSITIONS FROM WHICH SCALES WERE TAKEN

3.1.3 Description of the Study Section

Sixth Creek is the largest tributary of the Torrens River. The Creek rises just north-east of Mt. Lofty and flows in a northerly direction parallel to the western escarpment of the Ranges. It joins the Torrens River about 3 miles upstream from where the river emerges from the rugged 'Gorge' to flow out onto the Adelaide Plains. (see Map 2 and Figure 3.3). The study section was the last 4,400' of the creek before it joined the Torrens River.

This length of stream was surveyed during the summers of 1963-64 and 1964-65 when the flow was low. A free-hand strip map of the course of the stream was drawn and the length and maximum depth of different types of water were noted. From these measurements each of these water-types was then given a character according to the definitions shown in Table 3.2.

Table 3.2 Designation of the classes of water-types in the study section of Sixth Creek.

Water-type	Character	Maximum Depth (inches)	Length (feet)	Cover for trout	Width
Stickle* (Riffle)	S.	0-6	-		
Run	R.	7-15	-		
Pocket Pool	P.P.	16-24	<30		
Shallow Pool	S.P.	16-24	>30		
Pool	P.	>25	<60		
Deep Pool	D.P.	>25	>60		

* Stickle included Cascades

The stretches of stream falling into each class were numbered consecutively proceeding upstream. The total number in each class of water-type are shown in Table 3.3.

Table 3.3 Number of water-types in each class from the two surveys of the study section.

Water-type	1963-64	1964-65
S.	37	33
R.	49	52
P.P.	11	10
S.P.	22	26
P.	11	9
D.P.	5	5
Total	135	135

The % frequency of water-types in different depth and length classes are shown in the histograms of Figure 3.4. Map 5 of the lower end of Sixth Creek shows the position of places mentioned in this chapter and the next.

The relationship between the length (L, feet) amd maximum depth (D, - inches) of a water-type is described by the regression equation:

$$\hat{L} = -3.45 + 2.30\ D.$$

correlation coefficient (r) = 0.7024.

where the measurements for the surveys of 1963-64 and 1964-65 were pooled since there was no significant difference between the separate bivariate distributions.

FIGURE 3.3 LONGITUDINAL PROFILE OF SIXTH CREEK (HEIGHT ABOVE SEA-LEVEL ON DISTANCE FROM TORRENS RIVER)

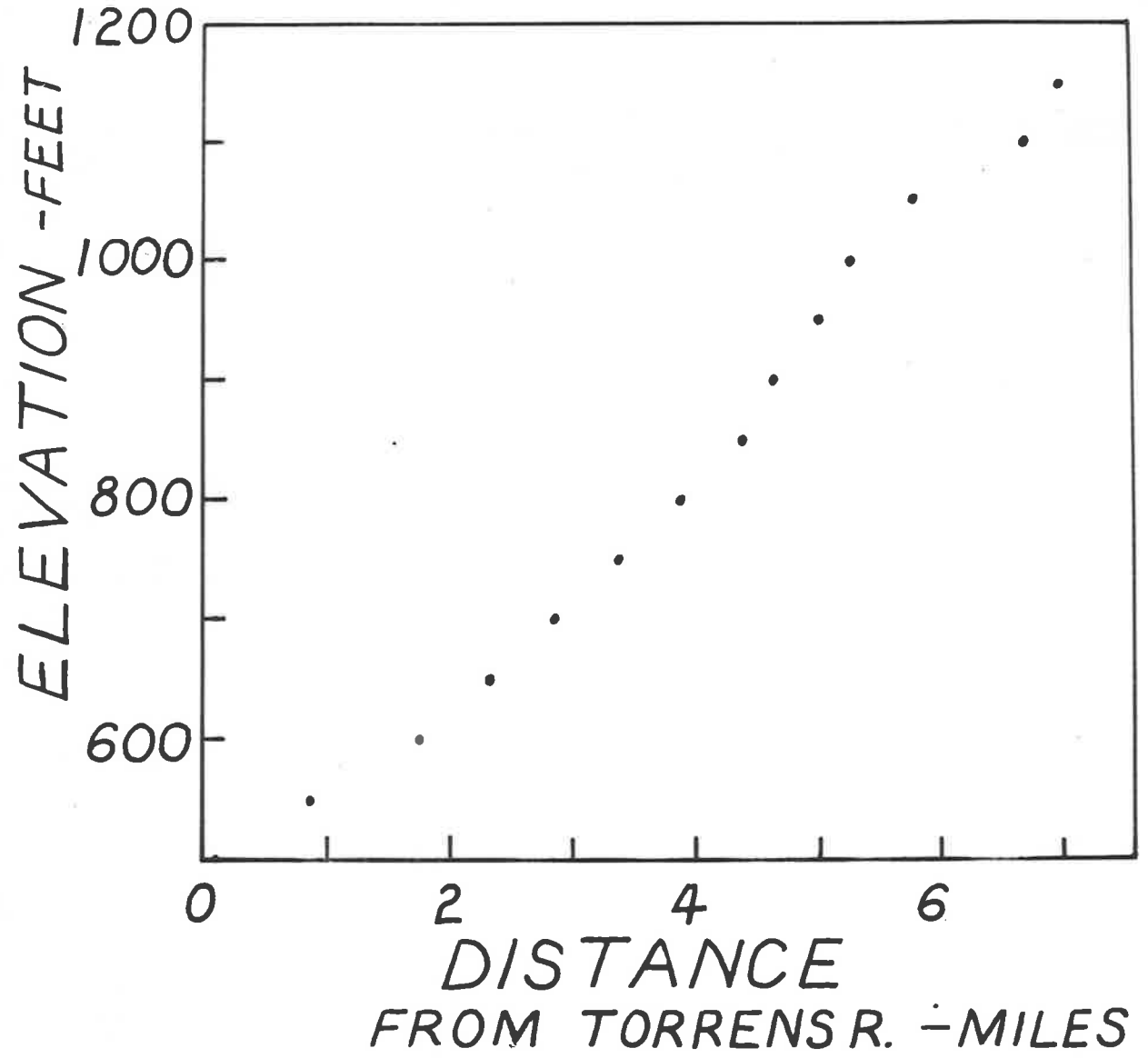
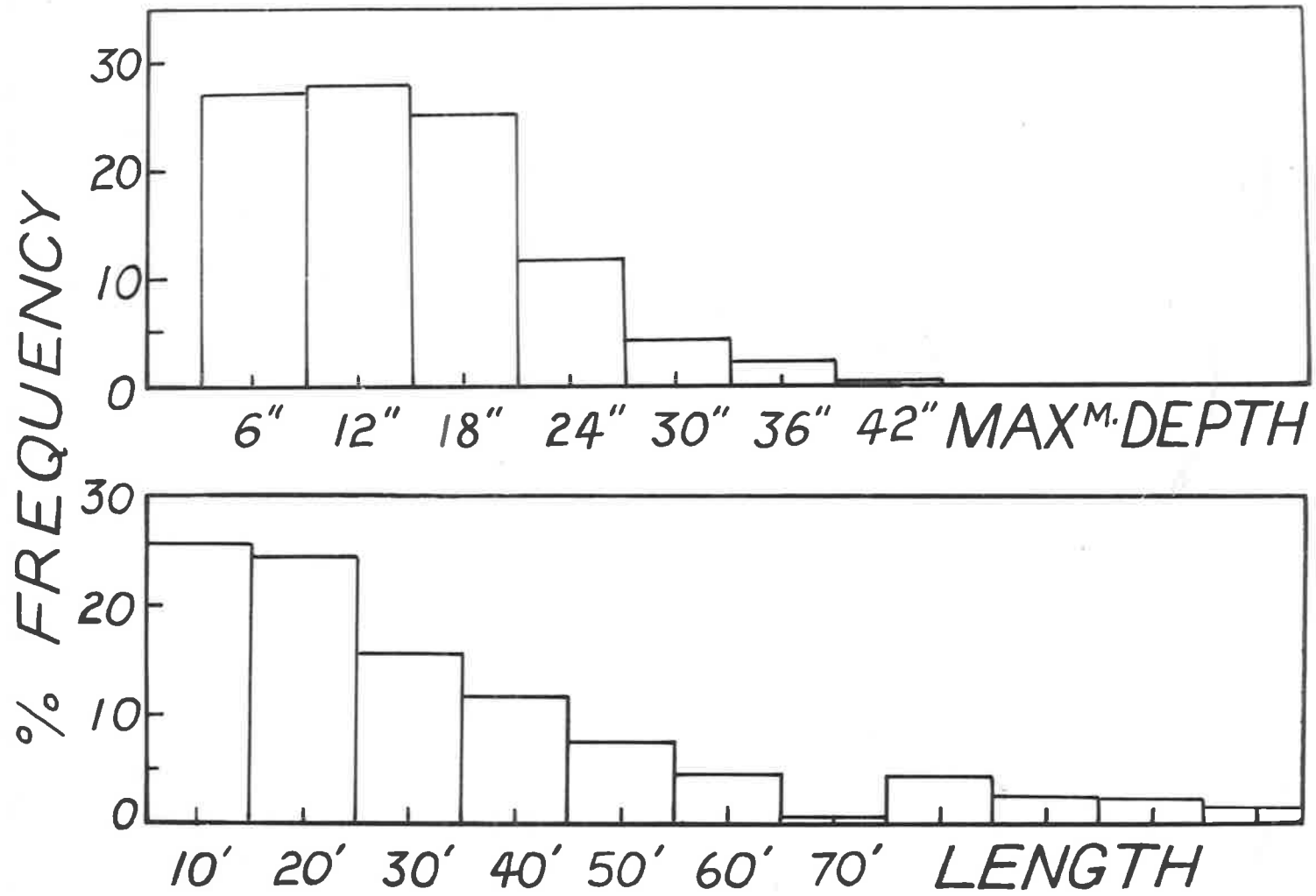
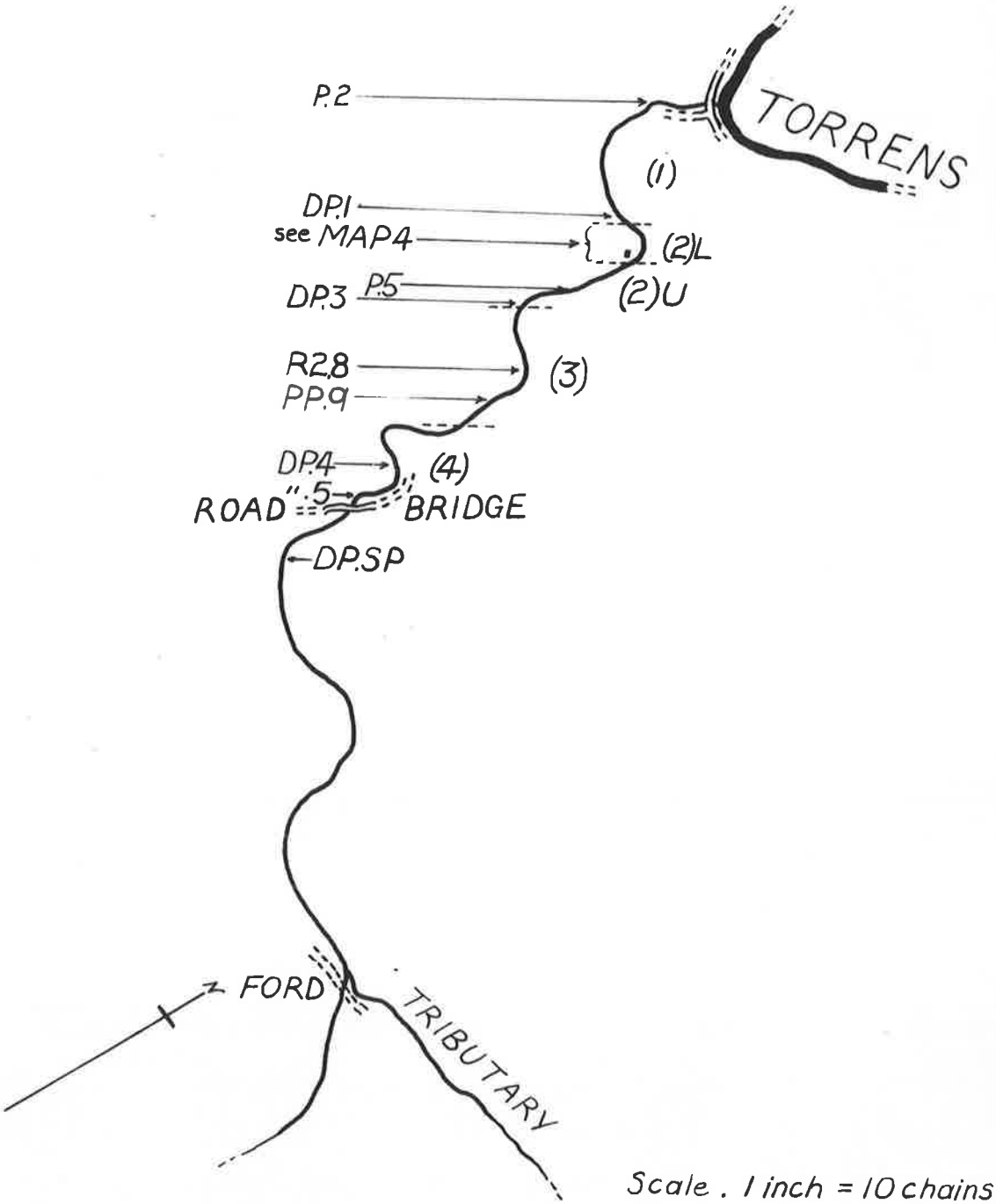


FIGURE 3.4 % FREQUENCY OF WATER-TYPES IN DEPTH AND LENGTH CLASSES

(1963-64 SURVEY)





MAP 5 THE LOWER END OF SIXTH CREEK,
INCLUDING THE STUDY SECTION

3.1.4 Procedure in electro-fishing the study section

Before the start of fishing in 1963 the study section was partitioned into 6 subsections. Proceeding upstream these were numbered (1), (1) L and (1) U; (2), (2) L and (2) U; (3); and (4) (see Map 5). This was done from a judgment of the length of stream which could be fished carefully in one day (plus part of the next for deep pools) with necessary movement of heavy gear up and down steep banks kept to a minimum. Lengths of the subsections are shown in Table 3.4.

Table 3.4 Lengths of the subsections that were fished in Sixth Creek

(1), 1113' - with 1 D.P.;
(2) L, 528' - with 1 D.P.;
(2) U, 742' - with 1 D.P.;
(3), 933';
and (4), 1184' - with 2 D.P.s.

Each subsection was to be fished 3 times in the period spring, summer and autumn by fishing a different subsection each fortnight where possible. This allowed an interval of about 3 months between fishing and refishing the same subsection. At the start the sequence of fishing the subsections was ordered randomly. When all the subsections had been fished once in the spring of 1963 it was considered practicable to fish (1) L and (1) U on the same date henceforth. The sequence of further fishing tended to favour the immediate capture of fish which moved up rather than downstream (Table 3.5).

Table 3.5 Sequence of fishing the subsections.

1963-64	(4), (2)U, (1)L, (2)L, (3), (1)U, (4), (2)U, (2)L, (3), (1), (4), (2)L, (2)U, (3).
1964-65	(1), (4), (2)L, (2)U, (3) (1), (4), (2)L, (2)U, (3) (1), (4), (2)L, (2)U

Every effort was made to catch all the fish in a subsection. The number and location of fish which escaped were noted. Fish were returned to their place of capture after processing (a small number of fish were killed in 1963-64 for food studies and a considerable number in 1964-65 for this reason and also for studies of their component parts). Fish 1+ and older (from about 18 cms) were individually tagged.

An attempt was made to sex all fish caught on the basis of secondary (external) characteristics. With large mature, or fast growing trout, e.g. from the fish trap or elsewhere (usually killed), the following were reliable criteria. General shape of head (rakish in males), in particular length of lower jaw (longer and upturned in males), shape of the operculum (pointed in males), length of the maxilla (larger in males relative to the position of the eye); epidermis over the scales (much thicker in males particularly at spawning); colouration (males more brightly coloured). With practice the larger Sixth Creek trout (23 cms on) presented no problem but differences between the smaller fish were not apparent.

3.2 Numbers of trout in Sixth Creek

Electro-fishing in the study section was started in August 1963 during a lull in flooding when the apparatus became available. Table 3.6 shows the numbers of trout which were captured, recaptured (including those with signs of having lost tags) or lost for all of the dates of fishing within the study section. Regular fishing was attempted only in 1963-64 and 1964-65. Some of the early estimates are low because of failure to catch or see fish in fast turbid water (100963) or in a Deep Pool (210164). When the vibrator was added to the fishing gear, and a better technique of fishing the deep pools was used in early 1964 and thereafter few fish were missed except in the spring of 1964 after floods when the creek was flowing very rapidly (the fish missed were however seen and recorded).

The fish in the catches ranged from 8 to 34 cms in length comprising 5 age-groups. It was possible to distinguish the youngest fish, age 0+, in the catches by their size alone (8 cms to 17 cms) from the other fish. Overlap in length between the other age- groups was considerable and length-frequency distributions for the catches were erratic. Also the incidence of replacement scales in the scales taken from the trout was high so that the number of fish in each age-class in a catch could not be determined with a reasonable degree of certainty.

The youngest trout 0+, were not catchable until the late summer when they had grown to about 10 cms in length. Their inclusion in the catches at this time occurred quite suddenly. In the spring and early summer fry were rarely "turned over" by the fish shocker. As fry they were seen to live in slow currents in shallow water over stones which

provided abundant cover for such small fish very close at hand. At fingerling size in the late summer when the flow of water was lowest they were caught in the, then, fastest currents, in Stickles and Runs. Sigler (1951) and Horton (1961) showed that the efficiency of capture by electrical fish shockers decreased markedly for fish smaller than about 10 cms. Apparently the voltage needed to stimulate the fish is inversely related to their size (Haskell, 1955) and the actual output of the fish catcher falls below the required level for fish smaller than 10 cms.

Two aspects of the numbers of trout in the study section were, or became, of immediate concern. Firstly, if the low proportion of recaptures in the catches (recapture index - Table 3.6) was caused by extensive movements of the fish the relationship between the growth of the fish and the supply of food at different places may be too complicated to estimate. If the number of fish, which reside for long enough in different water types to reflect the supply of food there in their growth or condition, is too small, statistical estimates of the relationship may not be made. Simplicity in these calculations is guaranteed if the trout population can be assumed to be stationary (Allen, 1951). Usually the movements of trout, and other fish, in streams have been found to be "restricted" (see, e.g. Cobb, 1933; Gerking, 1959; Bjornn and Mallet, 1964). Secondly the distribution of the trout through the different water types was interesting because the high numbers in the catches suggested that the fish were crowded with respect to the amount of living space in some places and hence perhaps also to the food supply.

Table 3.6 Catches from electro-fishing in Sixth Creek

Date	Sub-Section	No. captures		No. recaptures		Lost	Total	Recapture Index %
		B	R	B	R			
120863	(4)	16	9	0	0	17	42	0
100963	(2)U	3	2	0	0	10*	15+	0
230963	(1)L (2)L	8	16	0	0	21	45	0
091063	(3)	12	21	1	0	5	38	3.0
241063 041163	(1)U	26	11	1	1	8	37	5.4
191163 221163	(4)	34	19	2	2	10	63	7.6
031263 041263	(2)U	17	15	1	2	4	36	9.4
210164	(2)L	9	1	2	0	3*	11+	20.0
110264	(3)	12(3)	1(12)	0	0	9(4)	22(19)	0
030364 040364	(1)	26(5)	2(18)	4	0	3(1)	31(14)	14.3
160364 180364	(4)	28(3)	10(27)	2	1	3(13)	41(43)	7.9
060464	(2)L	16(10)	12(8)	6	1	1(1)	29(19)	25.0
170464	(2)U	11	6(15)	3	5	(2)	17(17)	47.1
200564	(3)	8(2)	7(32)	4	1		15(34)	33.3
220964	(1)	12	14	7	1	15	41	30.8
211064	(4) only 1 D.P.	17	4	4	1	9	30	23.8
291064	(2)L	15	21	8	5	11	47	36.1

Table 3.6 (Contd.)

Date	Sub-Section	No. captures		No. recaptures		Lost	Total	Recapture Index %
		B	R	B	R			
121164	(2)U	16	21	3	3	13	57	16.2
261164	(3)	18	14	5	4	16	51	28.1
101264 – 111264	(1)	30	19	16	4	1	50	40.8
080165 – 130165	(4)	28	24(6)	15	4	2	54(6)	36.5
090265	(2)L	17(6)	20(36)	6	11	1	38(42)	36.0
230265	(2)U	13	14(17)	6	7	1(4)	28(21)	48.2
090365	(3)	17(5)	6(33)	12	2	1(1)	24(39)	50.9
230365 – 240365	(1)	24(4)	13(27)	13	8	(4)	37(35)	56.8
060465 – 070465	(4)	31(5)	19(29)	16	13	2(7)	52(41)	58.0
200465	(2)L	11(10)	23(40)	8	16	(1)	34(51)	63.5
040565	(2)U	18(7)	25(42)	9	16	(3)	48(52)	58.2
290965	(1)	18	27	8	4	3	48	
180466	(1)	13(34)	3(2)	5	0	(4)	16(40)	
051165	(2)L P3 only	4	23	0	3	0	27	
191165	(2)L	16	38	7	18	12	66	
190466	(2)L	17(22)	7(6)	8	3	(3)	24(31)	

B = Brown trout R = Rainbow trout
parentheses -- number of 0+ fish
* many fish not captured or seen
recaptures includes fish which were thought to have lost their tag.

3.2.1 Movements

The length of time that a fish will persist in one place is likely to vary from fish to fish because of differences in the influence of components of their environment. In practice an estimate of the length of time for which 50% of a group of fish persist from an initial date could be found from the frequencies of their recapture at successive points in time. Each of the successive recapture frequencies could be taken as an estimate of the probability that a fish will persist for a specific length of time. The frequency of recapture at one of these dates as defined here will usually be different from the recapture index - the number of recaptures in a catch divided by the total number of fish in the same catch.

The problem is one of accounting for bias in the estimates of frequency which is introduced by the fishing procedure and determining the influence of natural events.

Sources of bias and variability due to the fishing procedure and natural events

The primary causes of bias, which are relevant to all further considerations, are that recapture frequencies may be minimal because either the mark distinguishing the fish (tag) does not persist with the fish or else if both fish and tag persist then the fish may not be recaptured because of inefficiency in fishing.

Different groupings of fish can be considered for the calculation of successive recapture frequencies. Either the fish in one water-type, in a subsection, or the whole study section may be used with a con-

sequent increase in the variance of the estimates if the fish do not persist equally well in each water-type. The fish could also be summed for any of these situations for different dates. The estimates then may be influenced by variability in the length of the interval between fishing and refishing and biassed downward if some intervals are much longer than the average. Not only must a stretch of stream be refished before recaptures can be made in it but also the fishing must be stopped at some stage so that fish captured in the last fishings of the subsections have no chance of being recaptured in the same place at least once. For fish which are captured in the first fishings of the subsections there are n chances of being recaptured in the same place where n is the subsequent number of refishings of each subsection. For fish captured for the first time in the next sequence of fishing the subsections there are only n-1 chances and so on down to 0 for fish captured for the first time in the last fishings of the subsections.

Frequency estimates from the fish in one water-type at one date therefore are the most desirable. However summing of groups of fish at different places, or different dates, or both, is necessary because of the small numbers of fish.

Fish could disappear from the study section either by dying or moving out of it.

If frequencies of recapture are to be used, to estimate a population parameter, mortality from angling and natural causes must not be different for a marked fish. Most of the fish (up to 3+) were below the legal size limit of 28 cms but those above it which carried tags were supposed to be returned to the water by anglers. Many fish of all

sizes were however captured by angling during the early months of the "open" season (spring). Fish when returned are in some cases at least sufficiently damaged to die immediately (hooks through blood vessels in the mouth and gills), or from starvation due to the loss of an eye (16 were captured during the study - all were in very poor condition). Except when mass deaths occurred on two occasions above the study section due to lethal high temperatures, no dead fish were seen during the study. This is a common experience (Chitty, 1960). Besides man the only other predator which occurred on the creek through the study was a native water-rat, Hydromys chlorogaster. This animal was a nuisance with fish in the ponds but was never seen attacking wild fish, or rather heard attacking wild fish since it is largely nocturnal. It is possible that the rats caught and ate weak fish which were soon doomed to die.

Mortality can only be estimated from the rate of decrease in the numbers of fish of succeeding age-groups in catches ("catch curves", Robson and Chapman, 1961). When the assumptions can be made that the initial numbers of each year-class were the same and the mortality for fish of each age is the same each year the seasonal changes in mortality can be estimated from catches taken through the year. In this case if the relative numbers of fish in different age-groups are determined by randomly sampling only part of the population of fish in a stretch of stream at each date estimates may be biassed if fish of different ages move in and out of the stretch to different extents. When the above assumptions cannot be made it is necessary to follow a year-class of fish through each year of its existence and to base the estimates of

mortality on the rate of decrease in the absolute numbers of the year-class from one date to the next.

The main reason for marking fish in catches is usually to estimate the absolute number of fish in the population at the date of their release (when it is practical to catch only some of the fish) from the proportion of recaptures in a subsequent catch. The basis of the method, first proposed by Petersen (1896) and first used by Dahl (1919) for trout, is the proportional relationship -

$$No = NT \times \left(\frac{N_1}{R}\right) = N_1 \times \left(\frac{NT}{R}\right)$$

Where No is the number of fish at one date of which NT are marked and released. At a subsequent date N_1 fish are caught of which R are marked.

Part of the right-hand side of the equation is the reciprocal of the recapture frequency $\left(\frac{NT}{R}\right)$ which was defined previously. Unlike the recapture frequency the estimate of No is not biassed by mortality or movement out of the specified area of sampling if the marked and unmarked fish are influenced to the same extent. However movement of unmarked fish into the area, between fishing and refishing, has the effect of biassing the estimate of the initial number of fish (No) towards high values. (Theoretically if movement occurs the same proportion of marked to unmarked fish should move in and out of the area for the equation to be valid).

In this study an attempt was made to catch and tag all the fish in a specified subsection of stream at each fishing date. When this was achieved the recapture index $\left(\frac{R}{N_1}\right)$, which included some marked fish which moved into the subsection between fishing and refishing and fish thought to have lost tags, was about 50%, and at the most 60%. If



other sources of bias were low this ratio implies that about 50% of the catch on these occasions was composed of unmarked fish which had moved into the subsection between fishing and refishing it.

If No = NT

then $\frac{N_1}{R}$ should be = 1, if there is no movement of unmarked fish (U) into the subsection; i.e. N_1 = R but not necessarily = No if there is movement out of the subsection, or mortality.

if actually $\frac{N_1}{R}$ = 1/0.50 = 2.

and since N_1 = R + U

$$\frac{R + U}{R} = 2.$$

Therefore U = R

and U is 50% of N_1.

The probability that a fish will not move from a place, during the interval between fishing and refishing it, may depend on its species and the presence of another similar species, e.g. the probability may be lower for a Rainbow trout when some of the other fish are Brown trout rather than the same number of Rainbow trout. Characteristics of each particular place and the other fish in it may influence the duration of the residency of a fish - the number and quality of the hiding places - the number of fish in relation to the amount of living space or the supply of food - the size of a fish in relation to the sizes of the other fish. The previous history of movement of a fish may be important. It is possible that a fish which is able to gain residency in a place so that it is recaptured there will then be less likely to move on than a fish which has been there a short-time.

Seasonal changes in the physical components of the environment of the fish may play an important role in influencing movement. During the winter there is plenty of cool running water. In the spring decreasing flow and rising water temperatures signal the coming heat and lack of water during the summer. With the decreasing amount of living space, the clarity of the water and the brightness of the daylight, the fish fall back into water-types with better hiding places and deeper water. From the end of winter to the end of summer one would expect the jostling for positions to be most severe. Trout which are stressed by an unsuccessful encounter may tend to drift downstream (Chapman, 1962; Mason and Chapman, 1965). Also the study section is at the lower end of a fairly extensive creek system in which trout occur to the headwaters. The contraction of the amount of living space for the fish due to decreasing flow during the dry season becomes more severe as one proceeds upstream.

The movement of young trout down tributaries of rivers is a usual and necessary part of the life-cycle which is initiated by the upstream migration of the adult trout to spawn (Nicholls, 1958; Margalef, 1963; Hunt, 1965). In Sixth Creek at least 2 age-groups of adult fish are present at all seasons and in addition adult fish migrate up the creek from the main river to spawn during the winter.

A movement of fish downstream may be expected then which is more extensive than is indicated by recapture frequencies since the younger fish were not tagged until the spring of their second year.

Interpretation of recapture results

The numbers of trout which were released with tags on each date of fishing in the study section are shown in Table 3.7. A comparison of the cumulative numbers released to each date with the cumulative numbers of recaptures to the next date is made in Figure 3.5. The total returns became proportionally greater as the tagging effort built up. The marked increase in the early stages of fishing was caused by the fishing procedure and improvements in the technique of catching the fish. During the early stage when each subsection was being fished for the first time the only tagged fish which could be recaptured were those which had moved from one subsection already fished to another before it was fished. The number of recaptures then was relatively small since most of the subsequent recaptures were made in the subsection where they were released when it was refished (Table 3.7). The data in Table 2.18 (see 2.2.3.2) showed that most of the recaptures were fish which either stayed in deepwater-types (Pools and Deep Pools) or moved to them from shallower ones. The fish in Deep Pools made up a larger proportion of all the fish captured and released with tags after improvements in the fishing technique and gear in the first summer. These were the fish which were the least likely to move, because the Deep Pools had the best hiding places. They were also the most difficult fish to capture. It is not true, as has been stated (see Waters, 1960), that the efficiency of electro-fishing, unlike trapping, does not depend on the behaviour of the fish.

A continuing small increase in the slope of the curve in Figure 3.5 was probably the result of increasing experience in fishing

and knowledge of the places where the fish were likely to hide. A contribution to the increase in the slope could also be made by recaptures for the second, or more, times if the probability of recapture for these recaptures was greater than that for a recapture for the first time. Tables 3.8a and b show the number of fish released with tags and recaptured. Since fishing was erratic in the 1965-66 season recapture frequencies (Table 3.8c) are considered for only the first two fishing seasons. The number of recaptures in each cell is divided by the appropriate number of (different) fish released with tags to the end of 1964-65 season. Some of these fish which were released towards the end of the season had only a small chance of being recaptured (only if they moved to an adjacent subsection) for the first time while a greater number had only a small chance of being recaptured for a second time. If this bias could be removed the frequency of a second recapture for Brown trout would then be even higher than that for a first recapture while the frequency for a second time recapture for Rainbow trout would not be so much lower.

Otherwise Rainbow trout had a slightly greater tendency to be recaptured than Brown trout. A greater proportion of Brown trout recaptures were however made in the water-type where they were released, or within a short distance of it within the same subsection (Table 3.8d). This explains why they were recaptured more often a second time. Table 3.8c also shows the number of the recaptures which were missed at the first, or second, refishing of a subsection but recaptured again at a later fishing of it. The difference between the two species could be either that the same proportion of each was missed on the first refishing or that Brown trout were better at evading recapture than Rainbow trout.

Table 3.7 History of fish, caught by electro-fishing in Sixth Creek, which were released with tags and subsequently recaptured (1963-64 and 1964-65).

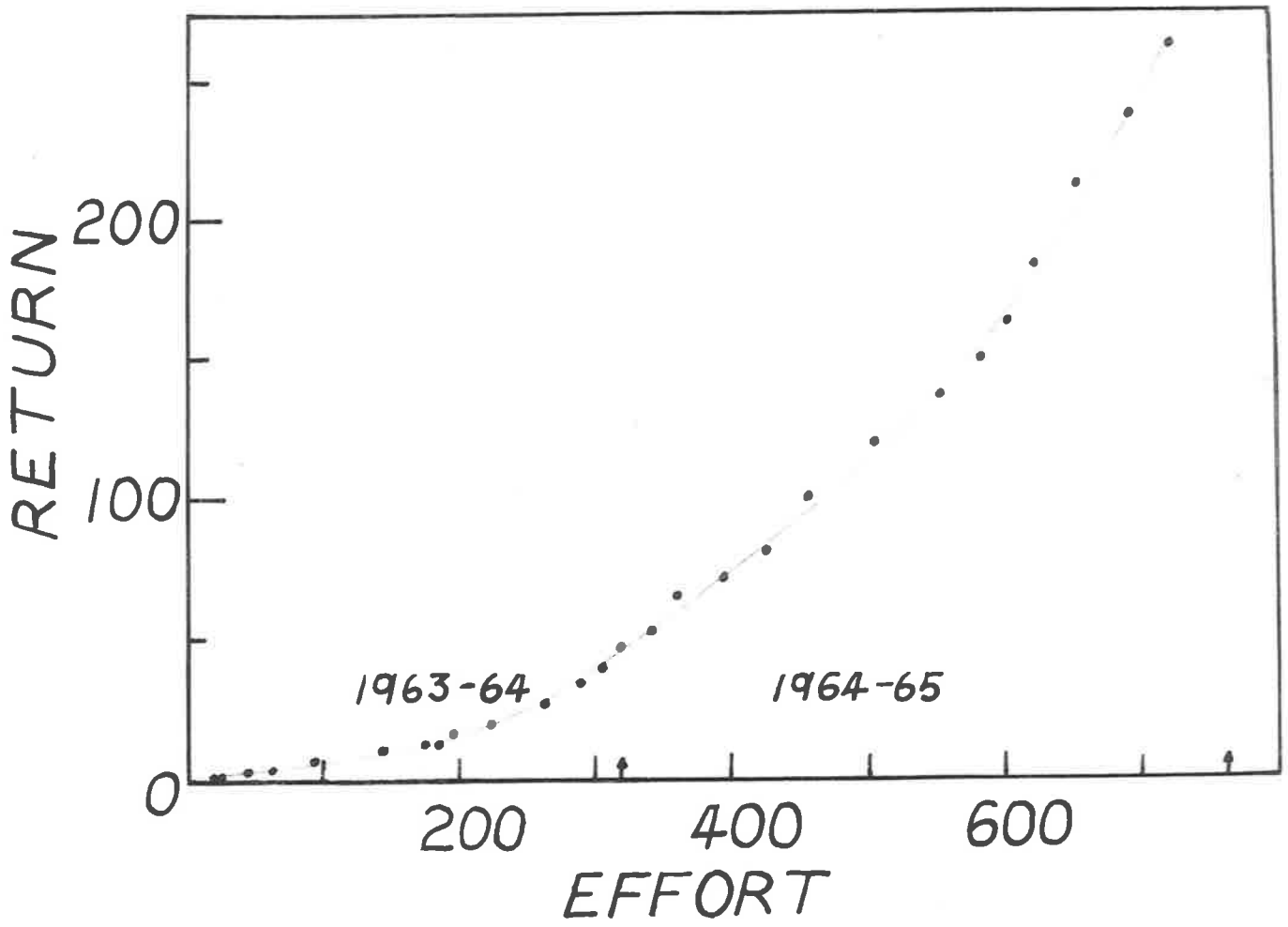
Date	Sub-Section	No. Tagged and released	No. recaptured subsequently in Sixth Creek			
			S.I. < 5	S.I. = 5	S.I. >5	
			Other subsections*	Same subsection*	*	**
120863	(4)	20	1	3		
100963	(2)U	5				
230963	(1)L	19	1			
	(2)L					
091063	(3)	19	4	2	1	
241063	(1)U	30		2	1	
041163						
191163	(4)	52		3		
221163						
031263	(2)U	31		3		1
041263						
210164	(2)L	10	2	6		
110264	(3)	12		3		2
030364	(1)	27		5		9
040364						
160364	(4)	37		4	2	5
180364						
060464	(2)L	28	1	8	4	2
170464	(2)U	16	4	1	2	1

Table 3.7 (Contd.)

Date	Sub-Section	No. Tagged and released	No. recaptured subsequently in Sixth Creek			
			S.I. <5	S.I. = 5	S.I. >5	
			Other subsections*	Same subsection*	*	**
200564	(3)	13	1	3	1	
220964	(1)	22		8		
211064	(4) only 1 D.P.	19		10		
291064	(2)L	35		10	4	
121164	(2)U	33	3	6	2	3
261164	(3)	30	3	7	2	
101264 - 111264	(1)	47	7	18	1	2
080165 - 130165	(4)	47		22	2	
090265	(2)L	30	2	17	3	2
230265	(2)U	22	1	13		
090365	(3)	19	2			
230365 - 240365	(1)	29		6	3	
060465 - 070465	(4)	44			1	
200465	(2)L	29		5		
040565	(2)U	36				

S.I. = sampling interval.

FIGURE 3.5 CUMULATIVE NUMBER OF TROUT RELEASED (EFFORT) IN SIXTH CREEK PLOTTED AGAINST NUMBER OF RECAPTURES (RETURN) TO THE NEXT DATE



Nearly all of the fish which were missed at the next refishing were recaught in the same water-type at the next refishing. Also they were released in the autumn of 1964, missed in the spring of 1964 and recaptured in the next summer. These fish may have been in other (shallower) water-types in the spring.

Fish were known to move out of the Deep Pools when the flow increased in the autumn (in particular this movement was most noticeable in DP2 when the first small floods washed the remaining summer algae away) and of course there was an extensive movement into deeper water with the coming of summer. In the early spring of 1963 when the creek was running strongly the catches in Deep Pools were very small but this could have been due to ineffective fishing. Under the same conditions in 1964 efficient fishing revealed that there were few fish in DP1 when it was fished on 220964.

Most of the recaptures for different fish were made only once. The movements of fish which were recaptured more than once however created a strong suspicion that many of the fish which were recaptured were familiar with other water-types both upstream and downstream from their original place of release, that they retained a memory of these places for considerable periods, and that they often moved to a water-type more suitable for a particular season of the year. The movements of a few of these fish, illustrating this Kinesthetic sense (Southern, 1964), are shown in Table 3.9. Miller (1954) has shown that when trout are transported upstream and downstream (about 1000') from their living places those that were moved downstream were more successful in getting back to them. Fish which were put upstream moved up and down in equal

Table 3.8 Recapture analyses

Table 3.8a Numbers of trout recaptured one or more times(1963-66)

	No. of times recaptured					Total recaptures	Total released with tags
	1	2	3	4	5		
Brown Trout	105 (96)*	36	11	2	1	155	487 (341)**
Rainbow Trout	85 (81)*	25	4	1	0	115	380 (269)**

* The number of first recaptures released with tags

** The number of different fish.

Table 3.8b Numbers of trout recaptured one or more times (1963-65)

	No. of times recaptured			Total recaptures	Total released with tags
	1	2	3		
Brown Trout	92 (91)*	33	7	133	444 (315)**
Rainbow Trout	77 (74)*	18	4	99	317 (224)**

* The number of first recaptures released with tags

** The number of different fish

Table 3.8c Frequencies of recapture (%) (1963-65)

	Recapture Frequency			
	Overall	For Different Fish	For the First time	For the second time
Brown Trout	30.0 (133/444)	42.3 (133/315)	29.2 (92/315)	36.3 (33/91)
Rainbow Trout	31.2 (99/317)	44.2 (99/224)	34.4 (77/224)	24.3 (18/74)

Table 3.8d Percentage of the recaptures which were caught, for the first time, again in the same subsection at the next or subsequent refishings

	S.I. = 5	S.I. = 10	S.I. = 15	Total	Total Number Recaptures
Brown Trout	83.1 (93)	15.2(17)	1.7 (2)	84.2(112)	133
Rainbow Trout	93.5 (57)	4.9 (3)	1.6 (1)	61.6 (61)	99

S.I. = sampling intervals

parentheses = actual number

numbers in their searching. He thought that the fish put downstream were more successful because they were guided in moving upstream in the right direction by smell.

The influence of the fishing procedure itself on the chance of recapturing a fish which was released within the study section must be considered. Because most of the recaptures were made in the subsection in which they were released and few in other subsections it cannot be concluded that most of the fish did not move from the subsection. After one of the 5 subsections was fished the other 4 subsections were fished at four subsequent dates before it was refished again on a fifth date. For each subsection the sequence in which the other subsections were fished subsequently is shown in Table 3.10a. These sequences are summed in Table 3.10b as if on the date of release of fish all 5 subsections were fished and then refished on a fifth subsequent date. If all of the 5 subsections had actually been fished at each of the 4 intermediate dates fish which had moved to 20 different situations from their subsection of release could have been recaptured at each date. Thus on each date fish which had moved to 8 adjacent subsections (4 upstream and 4 downstream), 6 one subsection away, 4 two away, and 2 three subsections away could have had a chance of being recaptured by fishing all 5 subsections. With the procedure adopted the situations actually fished on the 4 intermediate dates was only 20 out of the possible 80, or 5 out of 20 on each date. Not only was the actual sampling too inadequate to allow the movements of fish to other subsections to be described but also the marginal frequencies are biassed by the sequence of fishing adopted. Also even if all 5 subsections had been fished on

Table 3.9 Movements of a few individual fish

	Date Place	Moved	Date Place	Moved	Date Place	Moved	Date Place
Rainbow Trout	121164 " P5	D	090265 " DP2	U	040565 " P5		
	121164 P4	D	090265 " DP2	U	040565 " P4		
	031263 " R15	U	170465 " P5	D	121164 " R15		
	121164 " R15	U	230265 " DP3	D	040565 " R18		
Brown Trout	040364 DP1	D	220964 SP8	U	111264 DP1	D	290965 " SP2
	180364 DP4	U	211064 SP20	D	130165 " R46	D	060465 " DP4
	030364 SP1	U	101264 R2	D	230365 " SP1		
	261164 " S25	D	230265 " DP3	U	090365 " R28		

D = downstream

U = upstream

each date fish which moved out of the study section, even if this involved moving only a short distance, would not be accounted for.

The actual recaptures are amassed in a similar table (Table 3.10c). To reduce the bulk of the table fish recaptured only after between 6 and 10 sampling intervals are placed in intervals 1 to 5 and similarly for 11 to 15. Fish which moved to an adjacent water-type have been included with those which were recaptured in the same place except in the few cases where they also moved to an adjacent subsection. Each recapture is treated as a new release.

The fish which moved did so more often in an upstream direction. This tendency lies more in the short movements within each subsection than in the movements to other subsections. There was no obvious correlation between the distance moved by a recapture within the study section and the time interval between release and recapture.

Of the 358 Brown and 246 Rainbow trout released (including recaptures), which had at least one chance of being recaptured in the same subsection, 113 and 61 were recaught in the same subsection (mostly at the next fishing). Of the remaining 245 and 185 fish respectively, only 20 Brown and 38 Rainbow trout were caught in other subsections because of the few times that they were fished. If a greater amount of fishing could have been done in a way to give a more systematic unbiassed coverage many of the fish which moved out of the subsection where they were released could perhaps have been accounted for before they moved on out of the study section.

To test whether the frequency of recapture was influenced by the different sizes of the released fish the number of recaptures in

Table 3.10a For each subsection the sequence in which the other subsections were fished subsequently

	Subsequent Sampling on				
Sub-section	1	2	3	4	5
(4)	(2)L	(2)U	(3)	(1)	(4)
(2)L	(2)U	(3)	(1)	(4)	(2)L
(2)U	(3)	(1)	(4)	(2)L	(2)U
(3)	(1)	(4)	(2)L	(2)U	(3)
(1)	(4)	(2)L	(2)U	(3)	(1)

Table 3.10b Number of times different situations were fished within the study section

		Number of Sampling Invervals on									Total	
		1		2		3		4		5		
	Same subsection									5	5	
Number of inter-mediate subsections		Up	Down	Up	Down	Up	Down	Up	Down		Up	Down
	0 Adjacent	2 (4)	0 (4)	2	0	0	2	0	2		4	4
	1	0 (3)	0 (3)	1	2	2	1	0	0		3	3
	2	0 (2)	2 (2)	0	0	0	0	2	0		2	2
	3	1	0	0	0	0	0	0	1		1	1
	Total	3	2	3	2	2	3	2	3	5	25	

U = upstream D = downstream

parentheses - number of different situations fished if all five subsections had been fished at each date.

Table 3.10c Recaptures presented in the format of Table 3.10b

Total Number of fish released[*]			Number of Sampling Intervals after the fishing of a subsection											Total		
			1		2		3		4		5 same subsection					
			U	D	U	D	U	D	U	D	U	O	D	U	O	D
358	Same sub-section	B									20	80	13	20	80	13
246		R									12	41	8	12	41	8
Number of intermediate subsections	0 Adjacent	B	5		2			4		5				7	-	9
		R	11		6			6		5				17	-	11
	1	B				1								0	-	1
		R				2	2	2						2	-	4
	2	B							1					1	-	0
		R		2										0	-	2
	3	B	1							1				1	-	1
		R	2											2	-	0
	Total	B	6	0	2	1	0	4	1	6	20	80	13	29	80	24
		R	13	2	6	2	2	8	0	5	12	41	8	33	41	25

U = Moved upstream D = Moved downstream

O = did not move [*] to 230265

B = Brown trout R = Rainbow trout

each of 17 size-classes (using the size at release) was regressed on the number of releases (total 1963-64 and 1964065) in each of the same size-classes and the mid-point of each size-class. The range of size-classes was 17.0 to 34.0 (none in 33.0 cms), but 95% of the fish (1+ to 4+) fell within the range 19.0 to 29.0 cms. The differing sizes of the released fish did not contribute significantly to the variance of the number of recaptures. About 90% of the variance was accounted for by the first determining variable, the number of releases in each size-class (Table 3.11).

During the 3 fishing seasons 24 trout (including 7 after the summer floods 1965-66) were caught by electro-fishing which were noted as possibly having lost their tags. In most cases the suspicion was based on slight skin marks around the base of the leading edge of the dorsal fin but on a few the fin rays near the edge were actually deformed in a way which could have been caused by the wire that held a tag on the fish. The possibility existed that if a tag fell off soon after it was attached the puncture holes in the skin could heal without leaving an obvious mark. However the tags were attached very securely and unless the wire was actually torn out of the flesh by the fish accidentally, or deliberately (as they do with hooks in their mouth), catching it on an object it is hard to see how they could be lost. Apart from the impression gained from the recapture frequencies there was no suspicion formed in handling the fish that many of those untagged were in fact ones which had been tagged at a previous date (e.g. from peculiarities of individual fish). Also the length-frequency distributions for the catches were extremely erratic in time for catches in

Table 3.11 Results of the regression of recapture numbers on release numbers (x1) and size (x2) of fish for 1963-64 and 1964-65 fishing seasons

Statistics	Brown Trout	Rainbow Trout
b for x1	0.3044	0.3258
standard deviation of b	0.0291	0.0227
t_{15}	10.45 sig.	14.36 sig.
b for x2	-0.0114	-0.0282
t_{15}	-0.10 nonsig.	-0.41 non sig.
Variance Ratio (F)	62.67	115.66
Multiple correlation coefficient (R^2)	0.945	0.969

b = regression coefficient

$P\ (t_{15} > 2.13) = 0.05$

$P\ (F_{2\ 15} > 3.68) = 0.05$

the same subsection (see 3.3). However Allen (1951) concluded, admittedly from very sparse data, that about 29% of trout in a small stream lost their (similar) tags within 3 months although he did not mention the method of tying them onto the fish.

To discover whether loss of tags was a large source of bias for the recapture frequencies it was necessary to mark fish in a different way. One alternative to tagging is the amputation of a fin. This practice has disadvantages also, for if the fin is not cut very close to the base it may regrow sufficiently for a cursory inspection to overlook the mark (Heacox, 1942). Also one has to remember to look for the mark. Fish lacking a fin may also be handicapped in fast water (Ricker, 1962).

Either some, or all, of the fish which were released with tags at each fishing date could have been marked in this way; or else a number of fish reared in the ponds could have been released with or without tags as well. Because of the policy adopted at the start of the study of interfering as little as possible with the wild fish it did not seem reasonable to burden them with both tags and cut fins. Also anglers object to the mutilation of wild fish. So Brown trout, age 1+, reared from eggs taken from wild fish were used. In view of the growing complexity in the interpretation of the recapture data the release of the fish at one date seemed desirable.

On 240964 sixty fish with a left pelvic fin clipped were released in the creek between the top of the study section and the upper ford (see Map 5) - and another 60 fish, with their right pelvic

fin clipped were released within the study section. The range of sizes of the fish was :

length (cms) class	-12-,	-14-,	-16-,	-18-,	-20-,	-22-,	-24-.
number	3	20	40	30	17	9	1

At subsequent fishing dates 23 fish were caught with the right pelvic fin clipped. Captures were tagged and 3 fish were recaptured a second time and one a third time. Overall recapture frequency was therefore 38.3% and for the first time 31.7%. This would indicate that loss of tags was not a serious source of error in the study.

A possible source of bias in these estimates is the assumption that a reared fish released in a place was just as likely to persist there as a wild fish after capture, tagging and release. Hatchery trout, and even transplanted wild trout, are known to have a lesser ability to establish a territory where they are released when there is a large population of resident fish already there (Miller, 1958). The released fish drift downstream because they are unable to wrest positions from the wild fish. If however most of the wild fish are not residents but are continually moving for the most part downstream then the reared fish may not be at an appreciable disadvantage. The fin-clipped fish were released in pools which held fewer fish in the early spring. Another possible source of bias is that about one-half of the released fish were smaller than the length above which tags were affixed to wild fish. The size range of the fin-clipped fish which were recaptured was:

length (cms) class	18	20	22	24
number	3	11	5	4

The growth of the fish which were tagged at their first capture and recaptured again was similar to that of wild fish. There was no way of telling the length at first release of a recaptured fish. It may be possible that the smaller fish grew more rapidly in length than the larger fish in the group but it is more likely that the smaller fish persisted less well where they were released. Of 17 Brown trout and 45 Rainbow released in 1963-64 and 1964-65 with wire only in the tag position (because of their small size) only 3 and 4 respectively were recaptured. These fish were large 0+ Rainbow trout caught in the autumn and small 1+ fish of both species caught in the spring (12-20 cms). They tended to be recaptured more in the lower part of the study section.

Sub-section	(4)	(3)	(2)U	(2)L	(1)
No. released	9	20	2	7	3
No. recaptured	0	1	1	2	3

Also the very smallest of the tagged fish (only 5% of all those tagged) were recaptured less frequently than the larger fish of the 1+ age-group.

Length (cms) class		-17-,	-18-,	-19-
No. released	Brown	2	8	17
	Rainbow	1	4	9
No. recaptured	Brown	0	1	9
	Rainbow	0	1	4

It is known that the smaller members of an age-class are dominated by the larger fish when there is competition for a limited number of territories in a stream and drift downstream (Mason and Chapman, 1965)

To determine whether trout entered Sixth Creek from the Torrens River, apart from during spawning migrations, 50 Rainbow Trout, age 1+, (from eggs brought from Victoria) which had been reared at Sixth Creek were tagged and released on 061263 in the Torrens River. The fish (average length 23.0 cms) were placed in 4 pools 2 of which were immediately above and 2 just below the confluence of Sixth Creek with the Torrens River. Anglers reported the tag numbers of 11 fish which they captured in the Torrens River - one was caught 5 miles downstream on 171064. Only 2 fish were captured in the study section of Sixth Creek - one on 220964 and the other on 211064. Since the trout spawn as 2-year-olds these fish most probably entered the Creek for this purpose.

Only 2 of the fish which were released above the study section with their left pelvic fin cut off were recaptured in the study section and one of these was recaptured a second time there. Of 6 Brown and 7 Rainbow trout (size-range 20-30 cms) which were caught above the study section on 250164, when the vibrator unit of the fish shocker was first tested, and tagged none were ever recaptured downstream. A large deep pool above the bridge at the top of the study section was fished on 120165. If upstream movement from the section was prevalent such a pool might have been expected to "trap" a number of tagged fish. Of interest in the catch of 13 Brown and 13 Rainbow trout, 1+ and older, were 2 Brown trout with clipped left pelvic fins. One of these (21.4 cms) was subsequently caught by an angler 4 miles downstream below the weir across the Torrens and weighed $2\frac{1}{4}$ lbs (011065). Other recaptures were a Brown trout (33.8 cms) which was tagged at DP4 on 180364 and 2

Rainbow trout, one (27.2 cms) from DP3 on 121164 and the other (19.6 cms) from a shallow pool under the bridge just downstream on 211064.

The main purpose of trapping trout which ran up Sixth Creek from the Torrens River to spawn each winter was to affix tags to them so that the number which remained in Sixth Creek after spawning could be determined. The numbers of fish that were caught and released with tags each winter are shown in Table 3.12a and the recaptures of these fish in Table 3.12b. Only a few of these fish were caught by anglers and by electro-fishing in Sixth Creek in the Spring. Anglers were obliged to return all tagged trout, in both Sixth Creek and Torrens River even if takeable ($\geqslant$ 11"), and report the tag number. There was no doubt that most of the fish spawned and then fell back into the Torrens River during the years of the study. However the return of tagged fish to the trap each year was very small. The Torrens River above and below Sixth Creek was heavily fished by members of the S.A.F.F.A. who lease the fishing rights to the stream. The bag and size-limits for the river are the same as the state limits (5 fish per day - minimum length 28 cms), although the stretch is called a "nursery". Allowing for natural deaths between one winter and the next the poor return to the trap of tagged fish would seem to be caused by a heavy mortality from fishing. The number of tags reported by anglers from these fish in the Torrens River was very small. Also only 20 of the fish tagged during electro-fishing were reported from the Torrens River. Of these fish 7 (+ 2 trap fish) were reliably reported by one angler (I. Smith) during his first fishing season (1964-65). A failure to report the capture of some fish in the Torrens that were tagged at the

Table 3.12a Number of trout trapped and released with tags each winter

Year	No. trapped		No. released with tags
	Brown trout	Rainbow trout	
1962	59	13	67
1963	59	3	57
1964	138	6	76
1965	21	0	17

Table 3.12b Number of recaptures of tagged fish released at the fish trap

Year of Release	Caught in Sixth Creek			Caught in Torrens R.
	In trap next year (x)	By anglers	By electro-fishing	
1962	1 (1)	4	-	4
1963	1 (7)	5	2	1
1964	4 (7)	2	3	7

(x) Number of fish which were thought to have lost their tags.

fish trap is therefore indicated possibly because they were killed. Tagged fish which were caught in the evening may have been unknowingly released if they were undersized (as most of the fish from Sixth Creek electro-fishing would be) or killed if takeable after which discovery of the tag may have induced a reluctance to report it. The tags tended to become less obvious with time because of tarnishing. Some fish which were tagged in Sixth Creek during electro-fishing might have been expected after falling back to the Torrens River (where the fish grew somewhat better than in Sixth Creek) in the spring to have returned to Sixth Creek to spawn. None were ever recaptured in the fish trap. The disappearance of many of these tagged fish (or possibly of their tags) is therefore difficult to account for. There were rumours of tagged trout in and just below the weir downstream from Sixth Creek which were caught by the general public. Fishing in these places was illegal and only 1 tag was confirmed.

The 9 tagged trout reported by one angler (I. Smith) from the Torrens River were part of a catch of 75 fish (21 takeable) from the river close to Sixth Creek. It is thus possible that the tagged fish which entered the Torrens from Sixth Creek were lost in a multitude of other fish. Since the stretch of the Torrens River up and downstream from Sixth Creek has few spawning sites and the fish there do migrate up the Creek to spawn, migration of young fish downstream must occur to account for the large proportion of small fish which occur in the angling catches from the Torrens River. Also many of the Rainbow trout age 0+ which figured so prominently in the catches within the study section during the autumns of 1964 and 1965 must have moved down to the Torrens

River before fishing was resumed in the spring.

A smaller fish trap was placed on Sixth Creek at the ford near the lower end of the study section in the early Spring of 1965 (Map 4). The main purpose of this barrier was to capture fish of ages 1+ (from about 16 cms) and older that were moving downstream. By releasing captured fish in the Torrens River rather than immediately downstream into subsection (1) an expected decrease in the numbers of fish in the subsection, as a result of downstream migration primarily, was to be measured. Unfortunately the barrier was swept away by the large flood in December 1965 before the subsection could be fished for a second time (first time - 290965).

The trap rested on the concrete apron on the downstream side of the ford. Except during floods all the flow of water emerged through a 4' diameter pipe. The fence of grids (opening - $\frac{1}{2}$inch) was bolted to a frame-work of Dexian. The fence, sloped back downstream to increase the filtering area of the grids, was angled downstream so that fish which came down to it would be led to a fibreglass channel on one side. Some of the flow ran down this channel and fell into a small pool cut off from the main stream.

Operation of the trap was started on 130965 when the Creek was running clear for the first time after the winter floods. After a small flood on 200965 there were 6 consecutive days of hot humid weather as the flow decreased during which 22 fish were trapped. On three of these days when the maximum air temperature exceeded 80^{o}F, 15 of the fish were caught. Frequent observations indicated that the fish entered the trap overnight. The presence of parr marks on the Rainbow

trout, and later scale readings showed that 18 of the fish were aged 1+. They were not under-sized for their age. A significant feature of the fish was their very silvery appearance which is a characteristic of anadromous salmonoids at the time of their seaward migration ("silvery smolt stage") and is caused by a deposit of guanine on their scales (Jones, 1959). The small Brown trout which were captured on 290965 in subsection (1) had their usual sombre colouration although 1+ Rainbow trout were always silvery in the spring of each year of the study. The weather continued to be intermittently hot and humid and 4 more fish were caught when a small flood occurred in early October. At this time however fish were observed jumping out of the side pool into the channel and swimming back upstream. The flow of water down the channel of the trap had deepened the side pool under the end of the channel sufficiently for the fish to gain enough momentum to jump the necessary 6". This was stopped by placing a grid just under the surface of the water. During October the flow dropped to about 100,000 litres/hour and although the side flow of water down the channel on the side of the trap was maintained it became evident that fish were accumulating in pools immediately upstream. On 051165 P3 was found to have 15 more Rainbow trout than at about the same time in the previous year (only 8) and the same number of Brown trout. A precursor to the major flood in early December occurred on 121165 when 9 more fish (6 Rainbows) were trapped. On 191165 both P3 and DP2 were fished and an estimated excess of 6 fish remained in P3 and 24 in DP2 mostly Rainbow trout. Earlier on 181065 24 Brown and Rainbow trout (1+ - average length 23.4 cms and 20.8 cms respectively) were released, from the ponds, with tags, varying distances

upstream from the trap to see how long they might take to be recaptured in it. A batch of 3 fish of each species was released in Deep Pools 209', 1020', 2549' and 37476' above the trap. None were caught in the trap but 3 Rainbows were captured in (2)L on 191165 - one each from the nearest two pools (DP2 and DP3) and one from the furthest pool.

In total only 38 fish were trapped of which 22 were Rainbow trout.

3.2.2 Distribution

The distribution of trout along the lower reaches of Sixth Creek is almost continuous because fish can live in nearly all the water-types and there are many fish. Of the fish of age 1+, and older, none were caught, or seen while fishing, in Stickles (and Cascades) while about 50% of Runs and Pocket Pools, 90% of Shallow Pools and Pools, and all of the Deep Pools which were fished had at least one fish (Table 3.13). The youngest fish (0+) in the late summer, when they began to be caught, occupied the shallower water-types to a greater extent. It was evident that they were moving into the deeper places during the autumn and that earlier they occupied the shallower water to an even greater extent. The number of the older trout per (occupied) water-type were least in the Runs and Pocket Pools, and greatest in the Deep Pools. For young fish this trend was partly reversed at least in the late summer.

Which features of the stream can be used as bases for determining the degree of crowding of the fish in the different water-types? For this purpose desirable features are those which are related to the main needs of the fish.

The carrying capacity of any particular body of water is usually considered to be the maximum quantity of fish that can be supported over a long period (Rounsefell and Everhart, 1953). This capacity may be expected to depend on the supply of food, the number of hiding places, and the amount of living space for the fish. It seems reasonable to assume that the study section of Sixth Creek, at least, was saturated with fish because of the high numbers, poor growth, and the movements of the fish.

Most of the food animals in Sixth Creek become accessible to the trout when they drift downstream in running water (Section 4). In the shallow water-types the fish then can feed quite near their hiding place. In a Run a fish may lie under a bank, or stone, close to the current and actually feed from what is also its hiding place. This coincidence of feeding site and hiding place can also occur at the Run-in and Run-out of a Deep Pool where it is occupied by the largest fish. However in the pools, where there is usually more than 1 or 2 fish, the majority of the fish cluster and hide in the deepest part of the pool, which is generally near the middle of its length, during the daytime. Only a few fish make sporadic movements up and down to the best feeding sites at the Run-in and Run-out. With growing darkness at sunset, when there is a large increase in the amount of accessible food in the current, the fish disperse up and down the pool with the largest fish assuming the best feeding positions right at the head and tail of the pool. The other fish are spaced up and down the pool with the least successful fish in the most unfavourable positions near the middle of the pool.

Table 3.13 % of the water types, fished during 1964-65, with at least one trout

Fish Age		Stickles (S)	Runs and Pocket Pools (R. & P.P.)	Shallow Pools and Pools (S.P. & P.)	Deep Pools (D.P.)
1+ and older	Spring	0	51.6	88.6	100
	Summer	0	51.1	88.0	100
	Autumn	0	47.6	91.4	100
0+ (from 090265)		34.1	56.4	88.4	100

Since the stream is narrow the fish, when feeding, may be considered to have a linear distribution along its course. The number of fish which were caught, or seen, in a water-type can then be related to its length if the assumption is made that they did not move elsewhere to feed and were spaced along its length as result of aggressive behaviour displayed in establishing individual feeding sites.

Table 3.14 shows the average number of fish per water-type and the average length of stream per fish in each of the classes of water-types for three seasons in the two years of fishing. Figure 3.6 illustrates that the fish were considerably more crowded on this basis in the Deep Pools than in the shallower water-types; some interesting seasonal changes that were expected; and the movement of 0+ fish into deeper water in the autumn.

Although with experience one can become very familiar with the places where the fish hide, these cannot be described in quantitative

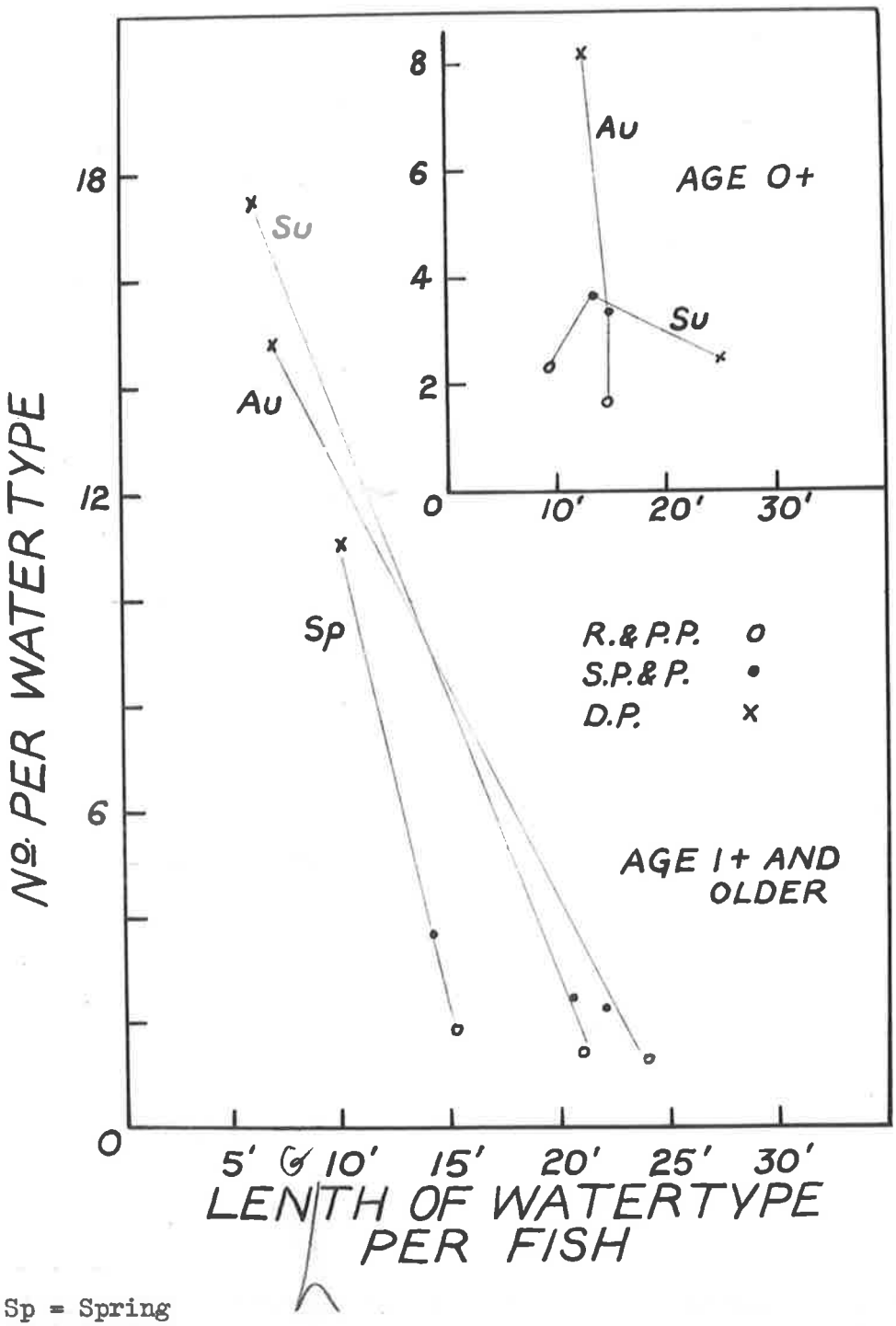
Table 3.14 Density of fish as the number of fish in terms of the number of occupied water-types of each class, and the lengths (feet) of the water-types

Season Year	Water-Types	Fish age 1+ and older		Fish age 0+	
		Average number per water-type *	Average Length water-type per fish **	*	**
Spring 1963	R. & P.P.	2.09	18.06		
	S.P. & P.	4.16	13.27		
	D.P.	11.67	7.16		
Summer 1963-64	R. & P.P.	2.10	15.52	2.00	9.93
	S.P. & P.	2.21	20.35	2.75	19.09
	D.P.	7.50 low	15.00high		
Autumn 1964	R. & P.P.	1.75	17.07	2.52	12.47
	S.P. & P.	2.19	22.71	3.35	17.19
	D.P.	11.00	8.41		
Spring 1964	R. & P.P.	1.88	15.25		
	S.P. & P.	3.74	14.27		
	D.P.	11.00	10.05		
Summer 1964-65	R. & P.P.	1.42	21.10	2.40	9.22
	S.P. & P.	2.50	20.60	3.67	13.45
	D.P.	17.51	6.13	2.50	25.22
Autumn 1965	R. & P.P.	1.30	24.00	1.77	14.83
	S.P. & P.	2.31	22.09	3.38	15.06
	D.P.	14.8	7.08	8.20	12.78

terms. The loose term in general use - "cover" - may be defined as anywhere in the stream where a fish can get out of sight of predators. In shallow water cover must be a hiding place under a rock, or under a bank, but in deeper water the fish may disappear out of sight by simply moving down nearer the bottom because of the opacity of the water. Trout lie in shallower water more when the current is swift and turbulent and the daylight is diffuse and weak. "Cover" also includes natural obstructions such as bushes or tree branches trailing in the water under which trout often lie when feeding in the current. The use of this cover in streams makes capture by angling more difficult. The largest fish in streams which are heavily fished lie in such places. McCrimmon and Kwain (1966) have shown that fingerling Rainbow trout have a random distribution between overhead cover and the open, whereas yearlings preferred cover when the light intensity was high. However all salmonids "prefer" hiding places to open water when they are alarmed either in nature or in experimental setups. McCrimmon (1948) concluded that survival of Salmo salar from the fry to the migratory smolt stage was very dependent on the amount of protective cover (for fry, stones in stickles) because of predation by other fish species. Boussu (1954) and Boceardy and Cooper (1963), among others, have pointed out the important influence that the amount of cover in streams has on the carrying capacity and the efficiency of capture of the trout, by a predator, e.g. man.

A physical feature of the stream which can be measured quantitatively is the amount of living space - the volume of water in different water-types. However from the foregoing descriptions it is

FIGURE 3.6 THE DEGREE OF CROWDING OF TROUT IN SIXTH CREEK IN RELATION TO THE LENGTHS OF DIFFERENT WATER-TYPES

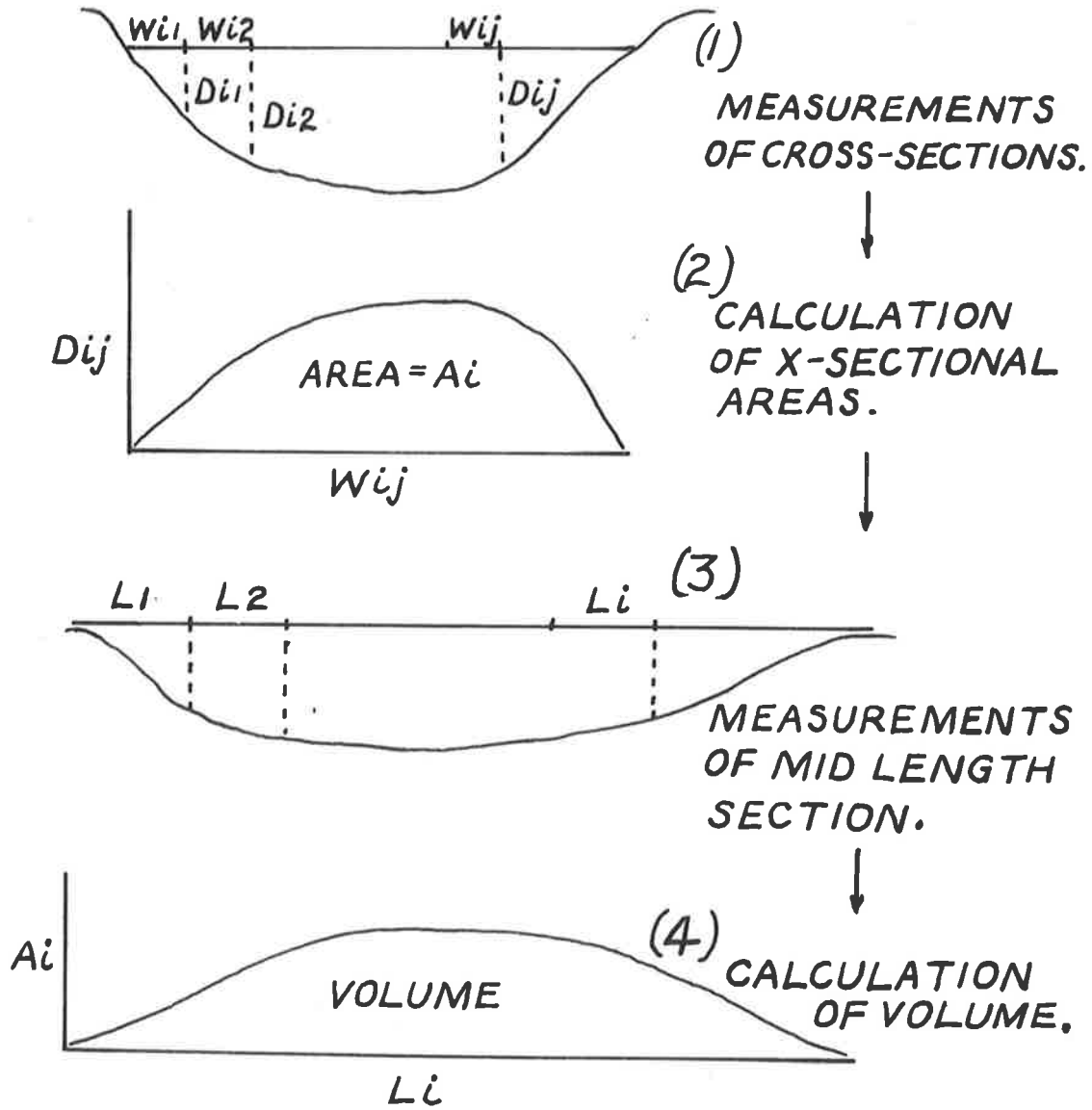


Sp = Spring
Su = Summer
Au = Autumn

apparent that there is a significant positive correlation between these volumes of water and the extent of cover, either as hiding places or depth of water. The variability in the numbers of trout not accounted for by the different volumes of the water-types where they live can then be expected to be due mainly to differences in the extent of cover in water-types of the same volume if the assumption is made that the stream is saturated with fish. The relationship between numbers of fish and size of water-type is obvious. The problem is rather one of determining whether the fish in the larger water-types (Deep Pools) are more crowded than in the smaller ones. Gerking (1949) was the first to show quantitatively that the numbers of fish (not trout) in warm-water streams were strongly correlated with the volume of water (amount contained by the 2' depth contour - bank cover, unlike in trout streams, was unimportant to these schooling fish).

The volumes of 40 water-types were estimated during the 1964-65 survey of the study section at a low water period. The volumes of all the Deep Pools (including one above the study section), 7 (out of 9) Pools, 13 (26) Shallow Pools, 4(10) Pocket Pools, 4 (52) Runs and 6 (33) Stickles were found. These were not selected randomly as it was necessary to include as many as possible of the few deeper water-types to give a large range of values. Also the places not measured were very irregular in shape, or had large rocks in them. For example P3 had several very large boulders in it. The reduction of living space by the volume occupied by these was more than compensated for by the extensive shelter under them for the trout which were always more numerous in this pool than in others, similar in size, elsewhere. The

FIGURE 3.7 ESTIMATION OF THE VOLUME OF A WATER-TYPE



volume of a water-type was estimated by measuring the cross-sectional depths and widths at short intervals along its length. The measurements for each cross-section were graphed and the area of paper representing the area of cross-section was then cut out, weighed and the weight was converted to an area. The volume of a water-type was then found similarly by graphing these areas against the corresponding length measurements (Figure 3.7).

The regression equation which best described the relationship between the volume (V, x 10^3 litres) and the length (L, feet) and the maximum depth (D, inches) of a water-type was :

$$\hat{V} = 4.096 + 0.00223L^2 - 0.5812D + 0.02237D^2$$

Multiple correlation coefficient (R^2) = 0.974.

Graphs of numbers of fish, N, (including 0+ and fish that were lost) and total weight, W - in grams, of fish against the volume of water in the place where they are living did not suggest that the number, or weight, of fish was proportionally greater at higher volumes (Figure 3.8; i.e. that the fish were relatively more crowded on this basis in the Deep Pools. Numbers and weights of trout from fishing in the summer and autumn of 1964-65 were used to calculate the regression equations:-

$$\hat{N} = 1.2577 + 0.4165V$$

$n = 59$

$r = 0.9009$

S.D. = 3.4537

$$\hat{W} = -6.9158 + 58.3151V$$

$r = 0.9284$

S.D. = 401.878

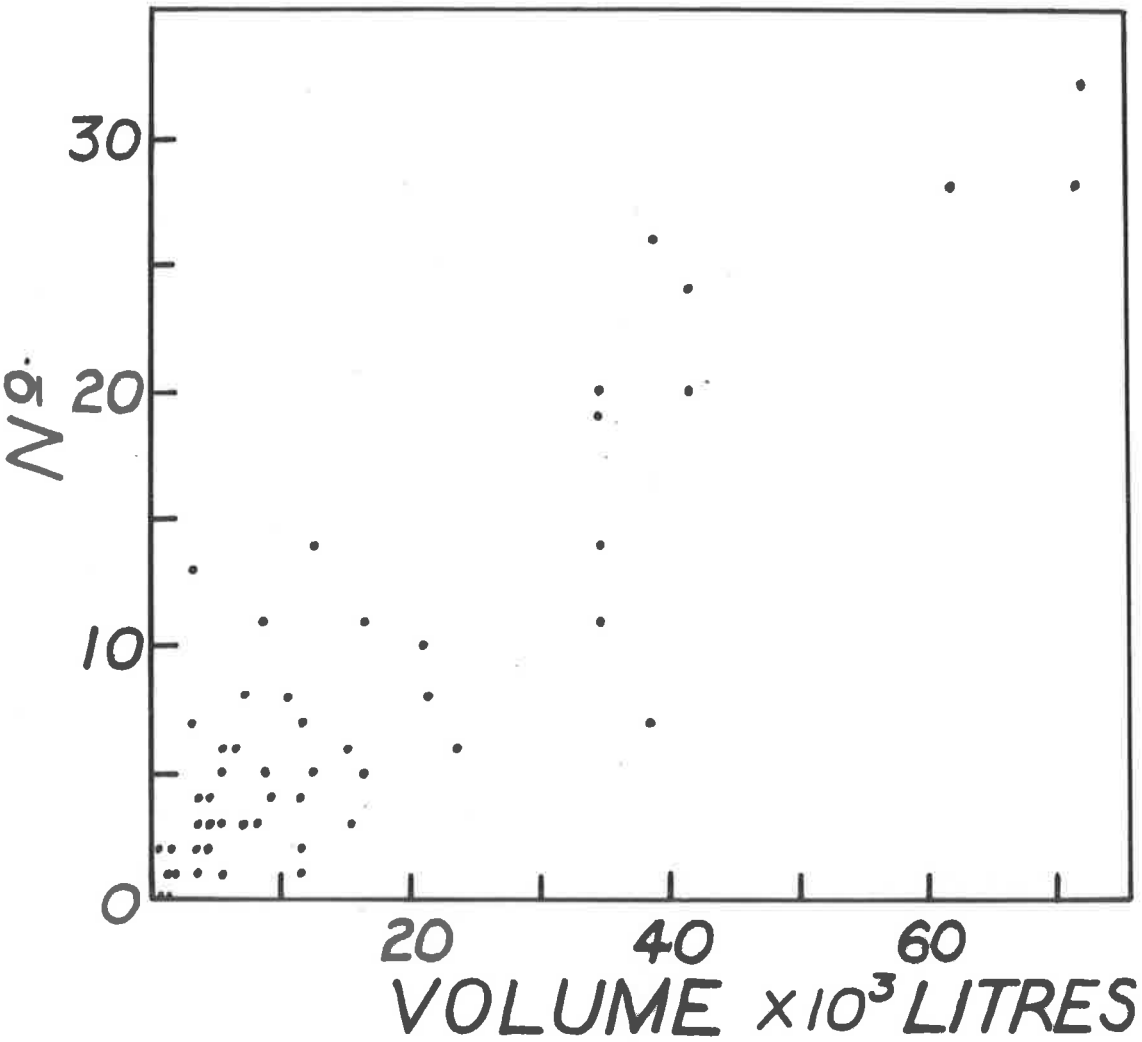


Fig. 3.8. The number of trout in water-types of different volume in Sixth Creek.

'r' is the correlation coefficient of the regression

S.D. is the standard deviation of the regression.

The positive intercept for numbers was significantly larger than zero, (t_{57} = 2.115, P (t_{57} >/2.00/) = 0.05) indicating a slight decrease in the numbers per unit volume with increasing volume. The intercept for weights was not significantly different from zero (t_{57} = $\overset{\sim}{\uparrow}$0.115). Thus the numbers of fish decreased, per unit volume, but their average size increased with progression to the water-types of greater volume.

3.3 Growth

3.3.1 Aging

The aging of individual trout in the catches is necessary for the estimation of the average rate of growth of the fish in each year-class. The ages of fish of different sizes in a catch can be found easily by inspection of the size-frequency distribution of the fish if: all sizes of fish from the smallest ones are represented by the catch; the catch is a large random sample of all sizes of fish in the population; the spawning season of the fish occupies only one small part of the year; and the increase in size of the fish from year to year is greater than the range of sizes of the fish in each age-group present. The size-frequency distribution is then composed of a number of discrete subdistributions each corresponding to an age-group and tending towards a normal distribution. Usually however there is an overlap in the sizes of the largest fish of each age-group with the sizes of the smallest fish in the succeeding age-group. The degree of overlap

Table 3.15 Length - frequency distributions of the catches from electro-fishing in Sixth Creek

Date	Species	CM. LENGTH GROUPS 8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30 >	Total
120863	B								2	2		2		2	2	1	3			1	1		1		17
	R						1								2	1	2	1			1			1	9
10-	B						1								1		1	2	2	2	1		1		11
230963	R							1	2	1	1	2		2	2	1	1		1	2			1		18
091063	B														1	2	3	4			2				12
	R							1	2	6	3	1	2	2		1				1		2			21
241063	B									3	4				4	4	5	1	2	2	2	1	1		26
041163	R										1	1	2	1			1	2	1	2	1				10
19-	B										1	2	4	3	5	5	6	1	4	2		1			34
221163	R												2		1	2	4	2	4	1		3			19
03-	B														2		2	3	3	2	1	3		1	17
041263	R													2	1	3	3	1		4		1			15
21-	B														1	2	1	3	3		1	2	1		1	15
250164	R													1		1		2			1	2		1		8
110264	B			2		1									4			5		1			2			15
	R			2	3	3	3	1									1									13
03-	B				1	3	1					1	1	1		10	4	2	2	1	3			1	31
040364	R			1	3	5	4	1	2		1	1						1			1				20
16-	B					1	2						1	5	3	4	3	4	2	1	2		1	1	1	31
180364	R			6	7	1	5	1	4	3				2		3			2	2	1					36
060464	B			2	1		2	1	1	1	1	1			1			2	3	1	6	2		1	26
	R				1		1	1	2		2	1						5	3	2	2				20
170464	B															2		1	1			4	2	1	11
	R			1	1	1	1	3	3	1	2		1		1		1	2	1	1		1				21
300564	B					1	1		1		1				1	1	2		1	1		1			11
	R				1	4	4	8	2	4	6	3			2		1	2			1		1		39

Table 3.15 (Contd.)

Date	Species	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	>	Total
220964	B														1	2	1	2	1	1	2	1	1			12
	R											2	1	1			2		1	1	4				1	13
21-	B									1	1		1	2	3		4		7	3	4	3	2		1	32
291064	R											2	1	5	4	1	2	2	3	1	1		3			25
121164	B										1	2	5	2	1		1			1	1		2			16
	R													2	3	1	1	2	4	2	4	2				21
261164	B									1		1	2	1		1	1		2	4		2	1	2		18
	R												1		2	1	4	2			1	3	1			15
101264	B											2		3	2	2	3	1	5	1	3	6			2	30
	R												1		3	1	1	4	3	3	2	1				19
08-12-	B	1												2	6	2	5	4	2	6	3	6	1		3	42
130165	R		2	4		1						2	4	1	5	5	3	2	3	3	5		2	1	1	41
090265	B	1	1	2	2							1	2	5	2		2		1	1	2	1				23
	R	3	7	8	3	5	6	4							5	2	2	2	4	2		3				56
230265	B											1	2	3	2	4							1			13
	R		3	2	1	5	3	1	2						1	3	1	3	2	1	2	1				31
090365	B		1	3	1								2	2	3	2	2		1	1	1	1	1	1		22
	R		1	3	4	6	8	8	4	1						3	2		1							41
230265	B			2	2			1					1	1		1	1	4	2	3	6	3	1		1	29
	R				3	6	2	6	4	3	3			1	1	2	1	3		2	2		1			40
06-	B			1	1		3	1					1	2	1	3	3	3	3	4	2	3	4	1	1	37
070465	R				1	5	5	6	6	5				2	1	3		4	5		1	1	1		1	48
200465	B	1		2	1	1	2	2	1						3	2	2	1	1	1		1				21
	R				4	7	9	7	8	5	1			1	2	1	3		7	2		2	1			60
040565	B			1		2	4	1	1			1		3	3	3	3	2	1	2						27
	R				3	4	8	4	10	5	3	4	1		2	3	2	5	3	3	4	2				66

Table 3.15 (Contd.)

Date	Species	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	>	Total
290965	B										2	2		1	2		1	1	3		1	3	1		1	18
	R								1		2	5	2	5	2	1	5		3		1					27
18-190466	B	2	2	12	11	15	9	4	3				1	2	8	3	1	3	2	6	2	3				89
	R	1	1	1	2	1			1	1	1		4	4		2	3									22

B = Brown trout

R = Rainbow trout

increases with age since the annual increments in size commonly decrease with age while the range of sizes of the fish in a year-class increases with age. When the degree of overlap is small it is possible to proportion the numbers of fish within the overlap between the adjacent age-groups by using the shapes of the subdistributions on either side of the overlap (see Tanaka, 1962).

Table 3.15 gives the length-frequency distributions for the catches of fish made by electro-fishing in Sixth Creek. The youngest fish (age 0+) can be readily distinguished from the older fish. However there is a considerable overlap between the succeeding age-groups (1+ to 4+ as will be shown). Also it is not obvious at all just where the modal lengths of each of these age-groups occur because of the small numbers in the length classes. To estimate the rate of growth of the fish it is therefore necessary to age the individual fish by reading their scales.

The method depends on the occurrence of seasonal changes in the growth in size of the fish and significant growth between each year and the next. The growth in size of a scale is positively correlated

with growth in size (length) of the fish. Changes in the rate of growth of the fish are recorded as changes in the spacing between successive circuli, or rings, on the scale. When the changes in growth are similar in each year of life the age of the fish can be read off the scale from the record of the number of completed yearly cycles of growth. In cold temperate climates there is an abrupt increase in the growth of trout, and hence the spacing of the circuli on their scales, in the spring. The circulus before the widening starts is called the annulus. Since this change occurs at about the time of emergence of a new year-class the number of annuli on the scales of a fish is read as the age of the fish.

The growth rate of trout varies through the year when there are seasonal changes in the abundance of available food and of other components of their environment, notably water-temperature and flow, which determine the proportion of this food which the fish can eat and use for growth in size (Figure 1.2, section 1.1). Under equable conditions the pattern of spacing of the circuli on scales may thus be featureless until maturation occurs when the annual demands of the production of gonads and spawning provide the only distinctive changes by detracting from the growth of the fish for a part of each year (e.g. see Van Someren, 1950). There is therefore no reason to assume that the scale characteristics used for aging trout in cold temperate climates apply elsewhere and it is necessary to "validate" the method afresh for trout in South Australia.

If the method is to be used successfully the reader must be able to recognize for each year in the life of a fish at least one particular characteristic on its scales which is formed at a specific time of the year and occurs consistently amongst the other fish in the population. For aging this mark must be distinguished from other (misleading) irregularities (often called "false checks") which usually occur less consistently. All recognizable marks however can be used for estimating the lengths of fish at times in their life prior to capture (so called back-calculation of lengths). The times during the life of the fish when these records are formed on the scales can be determined from the scales of fish in catches taken through the year. Scales from the marked fish, or fish of known age, can be used to confirm the criteria. It is also useful to know the causes of at least the major changes in the growth of the fish through the seasons of the year and the life of the fish.

The scale samples which were available for analysis were firstly those taken from live fish captured by either electro-fishing or the upstream trap in Sixth Creek and numbering about 1100. Only a few scales were taken from each of these fish. Samples with at least one readable scale after the elimination of replacement scales numbered 78 for the trap and 610 for electro-fishing. Among the latter were scales from small fish of known age (0+) and recaptures. The remaining scales were taken from dead fish which were captured mainly by angling in a number of streams and still-waters. Since larger samples could be taken nearly all of them contained readable scales. Of these there

were 196 from fish of known age and 520 from fish of unknown age.

A considerable amount of time was spent during the first years of the study mounting some of the early scale samples under coverslips on microscope slides and examining them with a microscope projector. Although some experience in recognizing scale patterns was gained and the need for a validation of the readings was realised these methods of preparation and viewing were extremely tedious and impractical for such a large number of scales. Also the dimensions of the scales could not be measured quickly or accurately. Fortunately a trip during February 1965, to the C.S.I.R.O. Division of Fisheries and Oceanography in N.S.W. revealed a much simpler and faster method of mounting scales and a viewing machine which was far superior to others which have been described. All the scales were then mounted (or remounted), read, and measured during the autumn and winter of 1966. A somewhat more sophisticated model of the viewing machine (Nikon Shadowscope) was available in the Department of Mechanical Engineering, Institute of Technology, Adelaide.

Readable scales (up to 6 whenever possible) from each sample were cleaned in water under a binocular microscope. Excess water on these scales was then removed by touching them briefly on filter paper and they were arranged in a column along $\frac{1}{2}$" wide Sellotape. The reel of tape on an office dispenser was reversed so that the adhesive side of the tape was uppermost and the smooth (non-ridged) face of each scale was applied to the tape. (The viewing machine does not project an image of the circuli on the scales if excess water is left on them

or the other face of the scale is stuck onto the tape). The strip of tape with a particular sample of scales was then stuck down onto, and smoothed out on, a microscope slide. Each sample on a slide was identified by a code, scratched onto the slide, consisting of letters, distinguishing the name of the place where they were caught and the species, and different numbers for each fish. These codes were also kept separately with the date of capture, sex, length and other details and no reference was therefore possible to dates or sizes when the scales were read.

To read and measure the scales each slide was placed on the horizontal stage of the Shadowscope and moved by hand to a position where the crossed-lines on the 18" diameter viewing screen facing the reader were centred on the nucleus of a scale. The distance (between the 20° dorsal and ventral radial lines about the anterior-posterior axis - Clutter and Whitesel, 1956) out to each noticeable change in the spacing of the circuli, and the edge of the scale, was measured by turning a micrometer gauge which moved the stage. Distances were measured to the nearest thousandth of an inch. It was found that this process could only be continued for about 4 hours at a time because of the numerous decisions as to what constituted a significant change in spacing of the circuli and visual tiredness. In the time available it was possible to read the scales only once (124 hours) and there was no one else available with sufficient experience to check the decisions.

All the data from the reading of the scales were entered directly onto punch sheets in anticipation of subsequent back calculation of lengths by computer. In some of the first 20 columns of the sheets the code number of a sample, the number of scales read, and an opinion of the age of the fish and the number of times it had spawned were entered during the reading process. The rest of these columns were filled in later with the date of capture, length, and sex, of the fish. In the other columns (using a new row when necessary) measurements (up to 6) for each mark and the radius of scales of a fish and a coded comment, of two letters, on the change of spacing characterising the mark and the edge of the scale, were filled in. (W = wide, N = narrow, C = narrowing or anastomosing of only a few circuli, E = erosion).

The next step in the analysis was the back-calculation of the lengths corresponding to these recorded marks on the fish scales. A plot of total scale radius (RT) on total length of fish (LT) revealed a considerable amount of variability about a positively sloped trend line. There was no obvious tendency toward a curvilinear trend which sometimes occurs and necessitates logging the axes, or the use of a polynomial equation, to describe the relationship. If Ri is the radial distance of a mark from the nucleus of a scale corresponding to a previous length of fish Li, then the proportional relationship between the four measurements gives

$$Li = LT \times \frac{Ri}{RT}$$

But if c is the intercept of the regression line for RT on LT on the length axis $Li = (LT-c) \times \frac{Ri}{RT} + c$ is an unbiassed estimate,

and $Ld = Ri/b + c$

where b is the slope of the line.

The value of c was once thought to represent the average length of the fish at an early age when, after some growth, the initial scale platelet was formed. Nicholls (1957) has pointed out that the reason why the first few circuli on trout scales are always wide is that the growth of the scales shortly catches up to that of the fish as a whole (a similar phenomenon of course occurs when a scale is lost and a new scale is generated in its place). When the trend line is extrapolated back towards the origin it does not cut the length axis at the length when the initial platelet formed but at a smaller length closer to the origin. However scales from different positions on a trout vary in size mainly because they were formed at different stages during the early growth of the fish. Therefore the regression line describing the relationship between RT and LT for scales from position A (Figure 3.2) may be expected to be parallel to that for scales from position B but to intercept the length axis at a larger value. This possibility was one reason for separating the scale data into different groups before calculating linear regressions of RT and LT and was supported by the results (Table 3.16). The other reason was that some of the scales samples (from anglers) were large and therefore represented many scale positions. Although the largest scales were selected from these samples for reading (Brown and Rainbow trout - positions A

Table 3.16 Details of linear regressions of total scale radius (inches) on total length (cms) of fish

Group	Slope (b)	Intercept (a)	Standard Deviation of the regression	Number of fish	Number of scales	Intercept on length axis (c) cms.
Brown trout scales from position A (including Sixth Creek Trout)	0.0025107	-0.0170550	0.0105489	270	660	6.8
Brown trout scales from position B	0.00203338	0.0104367	0.0109214	196	609	-5.1
Rainbow trout, scales from position A. (including Sixth Creek trout)	0.00220924	-0.0126001	0.0107930	262	779	5.7
Rainbow trout, scales from position B	0.00220827	-0.0018941	0.00874205	213	855	0.9
Brown trout, caught by electro fishing in Sixth Creek. Scales from position B	0.00227645	0.0042139	0.0054172	159	323	-1.9
Rainbow trout, caught by electro-fishing in Sixth Creek. Scales from position B.	0.00213500	-0.0007571	0.0054183	174	404	0.4

and B) the standard deviations of the regressions for these scales were almost twice those that were estimated for scales taken in small samples, and therefore more precisely, from position B. (Brown and Rainbow trout caught in Sixth Creek).

The use of the equation $Li = Ri/b + c$ to back calculate lengths will result in a considerable over, or under estimation, of the lengths of fish which are represented by scales much greater, or smaller in size, than the average because of the use of the average value of c. If a and b are the intercept (on the scale radius axis) and the slope of the regression line - then,

$$\hat{Ri} = a + b\,Li$$

and $$Li = \frac{\hat{Ri} - a}{b}$$

but $$\hat{RT} = a + b\,LT$$

and $$a = \hat{RT} - bLT$$

therefore $$Li = LT - \frac{(\hat{RT} - \hat{Ri})}{b}$$

If the actual values of the scale measurements (Ri and RT) are used to back-calculate lengths for each fish, then

$$Li = LT - \frac{(RT - Ri)}{b}$$

and the influence of different scale positions as a source of variability is eliminated.

The calculations were performed by the 3200 C.D. computer at Adelaide using a program written by W. Pierce of the Computing Centre. Print-out gave the statistics of the regressions, the details for each of the fish from which the scales were taken (columns 1-20 on the input cards), and the average back-calculated length for each scale

characteristic together with the code describing the mark for each fish.

The back-calculated lengths were then sorted into groups corresponding to particular scale characteristics and the total lengths into age-groups. Besides the comment on the output, use was also made of other descriptions recorded, when scales were read, on the punch sheets. The Sixth Creek trout were the first group of fish which was considered. Despite the poor growth of these fish and the overlap in size between age-groups the lengths fell fairly readily into distinct groups so that little difficulty was experienced in the sorting process in cases where a particular mark on the scales was not read, or not recognized in character, or a length occurred which corresponded to a superfluous mark.

For the Sixth Creek trout there were 3 significant scale characteristics during the first year of life (Table 3.17). After the first few wide circuli around the nucleus of a scale the circuli were closely spaced until a length of about 8 cms was reached at what was judged, from the growth of 0+ fish in the catches (Figure 3.9), to be the end of Spring. Then there was a widening followed by a further narrowing until the stream flow increased and the water-temperatures fell during the autumn. This late summer check in growth was most pronounced on the scales of fish which were captured after the severe summer of 1965-66. Wider spacing followed the summer check in the rest of autumn but then, apparently in the early winter, there was usually a further narrowing. However at mid-winter, or soon after there was a very marked widening in the spacing of the circuli. This

Table 3.17 Average back-calculated lengths (cms) of fish from Sixth Creek of different age-groups for scale characteristics corresponding to the end of their first Spring (Sp), Summer (Su) and Winter (W) and to spawnings as 2, 3 and 4 year olds.

	Age	Sp	Su	W	2	3	4
Brown trout	0+	6.5(11)	¤10.9(22)				
	1+	8.4(34)	12.5(98)	17.0(105)			
	2+	7.4(18)	12.2(43)	17.0(81)	22.7(87)		
	3+	7.5(11)	12.4(19)	17.2(22)	22.7(32)	25.7(26)	
	4+	7.3(1)	13.9(2)	18.4(3)	22.8(4)	26.1(4)	28.0(3)
Total	Mean	7.7(75)	12.2(184)	17.0(211)	22.7(123)	25.8(30)	28.0(3)
	S.D.	7.68	2.28	1.94	1.63	1.41	-
	% Consistency	24.9	61.1	77.0	89.1	81.1	75.0
Rainbow trout	0+	8.7(10)	12.3(29)				
	1+	7.5(37)	12.4(105)	17.5(66)			
	2+	8.0(11)	13.2(38)	17.8(63)	22.5(62)		
	3+	7.5(8)	12.9(13)	16.6(16)	22.8(19)	25.6(7)	
	4+		16.2(2)		24.4(2)	26.6(2)	29.1(1)
Total	Mean	7.8(66)	12.6(187)	17.5(145)	22.6(83)	25.8(9)	29.1(1)
	S.D.	2.13	2.11	2.33	1.63	1.34	-
	% Consistency	22.4	63.4	65.0	85.6	39.1	-

¤ scales mostly from fish caught in the Autumn of 1966 after a severe summer.

S.D. = standard deviation of the sample; number of fish in parentheses

increase was present on the scales of 1+ fish in the earliest catches in the spring and presumably the increase in growth was due to the increasing amount of accessible food which reached a maximum in the spring. There was no evidence that the feeding activity of the fish was reduced by the lowest water temperatures in the winter although it may have been impeded by the very turbid floods of early winter. Fish of the same age (0+) and size in the autumn which were kept in the ponds and measured regularly grew continually through the winter to about the same average size as the 1+ wild fish in the spring (see Section 3.4.1).

These 3 marks are called Sp, Su, and W in Table 3.17 and subsequent tables. The mark which was the least often measured, of these 3, was 'Sp' (in about 23% of the fish) because it often merged indistinguishably into the summer check. In other places where the fish grew better through their life the spacing of the circuli abruptly widened after a similar summer check and became very much wider later in a similar fashion to the characteristic 'W' on the scales of the Sixth Creek trout. This reasonably consistent change of spacing can then be read as the first annulus.

The only other prominent scale characteristics following these early changes were abrupt annual increases in the spacing in the spring each of which occurred after a narrowing, apparently due to the production of gonads, which was often terminated by an erosion scar. From both Brown and Rainbow trout reared in the Sixth Creek ponds and the fish of known age which were caught and killed elsewhere it was found that the female trout spawned for the first time at the end of their second year of life. Of the fish of known age (most of which

were 1+) only 4 were found to be female trout that were not ripening to spawn in their second year. These were not fish which had grown poorly as Alm's (1959) work would suggest. Of the 18 1+ Brown trout used in lethal temperature experiments on 211264 9 were ripening females and 8 were ripening males although their average length was only 16.5 cms. Most of the male Rainbow trout in Sixth Creek apparently ripened in the autumn of their first year (11 out of 27 0+ Rainbow killed). Confirmation of a spawning of a fish read as 2+ was also provided by the presence of old eggs (usually a few) and the old egg sac. The summer check on the scales of ripening fish, 1+ and older, was not distinguishable usually because of the subsequent retardation of growth due to the accelerating production of gonads. Brown trout in the Finniss River where the fish grew well, often showed a few narrowly-spaced circuli after the spawning mark before the late winter increase. The less than 100% occurrence of spawning marks on the scales of mature Sixth Creek trout (Table 3.17), and elsewhere, occurred because the mark was at the edge of the scales in some fish and thus corresponded to the total length of the fish. This occurred because spent fish which were caught in the spring had not started to grow in length although they were improving in condition (see Section 3.4.3). When these fish did start to grow in length the spacing of the first few circuli at least was nearly always very wide.

The spawning mark of Sixth Creek trout of both species was terminated by a slight erosion scar (sometimes this was detectable at the first annulus (W) on the scales of male Rainbow trout). Apparently this scar is the replacement of the edge of the scale which is absorbed

(erroneously - "eroded"), to meet a demand of the fish at the spawning time for inorganic salts. Erosion is unusual on trout scales, but commonly occurs on the scales of anadromous salmonids when they migrate long distances up rivers from the sea using energy and producing gonads from growth made in the sea (Jones, 1959). The erosion scar was most pronounced on the scales of fish from the Light River, Delamere Dam and Myponga Reservoir. These fish grew very well and were in excellent condition up to the time of their first spawning. These fish (both species) however had difficulties in actually spawning and captured females were often found to be egg-bound in the following season. Erosion was however unusual on the scales of (Brown) trout from streams south of Sixth Creek. It appears then that the erosion is associated with a protracted period of searching for a spawning site when the fish fast, and not in the actual production of the gonads.

There was no indication that the successively older age-groups gave smaller values of a back-calculated length corresponding to a scale characteristic (Lee's phenomenon - Lee, 1912). However a deterioration in the growth of the fish in successive years (Table 3.18) may have opposed this tendency.

Table 3.19 shows that where the growth of individual fish could be checked to some extent, the back-calculated lengths were similar to those for all the fish (with readable scales), in fact the lengths of recaptures might have been expected to be somewhat greater than the average if the reason for their persistence is a dominance of smaller fish of the same age-group.

Table 3.18 Average back-calculated lengths (cms) of fish from Sixth Creek belonging to different year-classes for scale characteristics corresponding to the end of their first Spring (Sp), Summer (Su) and Winter (W) and to spawnings as 2, 3 and 4 year olds.

	Year-class	Sp	Su	W	2	3	4
Brown trout	1959		14.7(1)	18.9(2)	22.3(2)	25.5(2)	27.8(2)
	1960	7.3(1)	14.6(3)	18.2(5)	23.6(8)	26.2(7)	28.4(1)
	1961	7.5(10)	12.2(23)	17.3(66)	22.9(69)	25.7(20)	
	1962	7.5(19)	13.0(76)	16.6(91)	22.1(40)		
	1963	8.9(30)	11.9(49)	17.1(35)	22.3(4)		
	1964	5.4(7)	10.4(14)	18.1(10)			
	1965	6.1(8)	10.7(18)				
Rain-bow trout	1960		14.7(2)	18.1(5)	22.7(7)	25.7(4)	
	1961	7.9(9)	13.7(26)	17.5(41)	22.7(47)	25.9(5)	29.1(1)
	1962	7.9(13)	12.7(59)	17.4(56)	22.4(28)		
	1963	7.7(33)	12.3(81)	17.9(38)	23.2(1)		
	1964	7.5(8)	13.0(14)	16.3(5)			
	1965	8.3(3)	11.0(5)				

Table 3.19 Average back-calculated lengths (cms) of recaptures from Sixth Creek (readable scales for at least one release and recapture). Scale characteristics as in previous tables.

		Sp	Su	W	2	3
Brown trout	Mean	7.7(18)	12.5(37)	16.6(44)	22.4(38)	25.6(14)
	S.D.	1.072	1.936	1.368	1.538	1.477
Rain-bow trout	Mean	7.3(15)	12.8(29)	17.6(22)	22.2(11)	
	S.D.	1.912	1.650	1.666	1.270	

Table 3.20 Mean lengths and other statistics of fish of different ages in the catches made by electro-fishing in Sixth Creek.

		Age-Group			
		0+	1+	2+	3+
Brown trout	Mean	12.7(27)	20.7(136)	24.5(101)	27.2(33)
	S.D.	2.118	1.080	1.556	1.089
	95% Interval for sample	(8.4,17.0)	(18.6,22.8)	21.4,27.6)	25.0,29.4)
Rain-bow trout	Mean	14.6(72)	20.4(126)	24.6(74)	27.1(21)
	S.D.	2.254	2.560	1.550	1.180
	95% Interval for sample	(10.1,19.1)	(15.3,25.5)	(21.5,27.7)	(24.6,29.6)

The average total lengths of fish, with readable scales, belonging to different age-groups in the catches from Sixth Creek are shown in Table 3.20. The opinions of the age of each of these fish which were recorded during the reading of the scales were retained in the case of 91.9% of the Brown trout and 92.3% of the Rainbow trout after the sorting of the back-calculated lengths. The mistakes were made with scales where the spacing narrowed right to the edge of the scale. The date of capture was then needed to confirm whether the fish was about to spawn (i.e. caught in the autumn), or had spawned (i.e. caught in the spring). Table 3.20 also shows the extensive overlap in sizes of fish of adjacent age-groups which increase with age. Thus the lower size limit (smallest fish of an age-group in the spring) for 95% of the fish of each age-group from 1+ is, in all but one case, less than the upper size limit (largest fish in the Autumn) of the age-group one year younger. To get estimates of the average length of the fish at different dates through the fishing seasons (1+ and older in Figure 3.9) the data for Brown and Rainbow trout and pairs of catches had to be pooled because of the small numbers. The overlap and small numbers also precluded the estimation of the ages of the rest of the older fish in the catches by probabilistic inference.

The poor growth of trout in Sixth Creek is illustrated in Table 3.21 by reference to the growth of trout in other places in South Australia. The best growth was that of Rainbow trout (also Brown trout) in the reservoir after it filled for the first time in the first winter of their life. The growth of trout in the Torrens River

FIGURE 3.9 GROWTH OF SIXTH CREEK TROUT

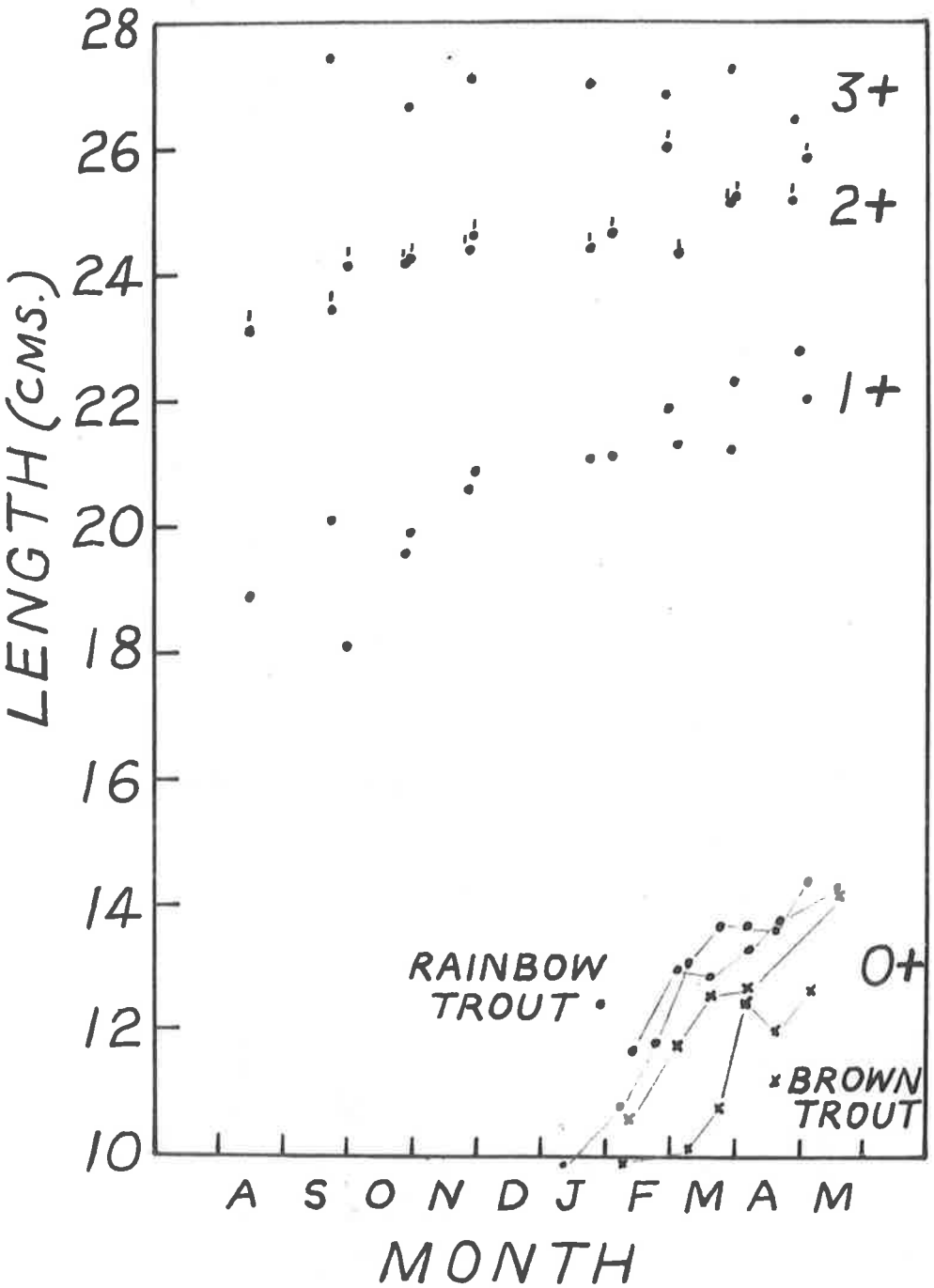


Table 3.21 Average back-calculated lengths (cms) and weights (gms) in parentheses, for scale characteristics, as in previous tables, of fish from different places. Weights are calculated from a growth equation given in section 3.4.1

Place	Species	Sp	Su	W	2	3	4	5
Sixth Creek	B	7.7 (4.3)	12.2 (18.6)	17.0 (54)	22.7 (135)	25.8 (203)	28.0 (263)	-
	R	7.8 (4.5)	12.6 (20.7)	17.5 (59)	22.6 (133)	25.8 (203)	29.1 (298)	-
Torrens River	B	7.4 (3.8)	13.4 (25.1)	18.3 (68)	27.6 (251)	31.6 (387)	35.0 (536)	37.6 (673)
	R	7.5 (4.0)	13.3 (24.5)	17.8 (62)	25.6 (198)	28.9 (291)	30.7 (352)	-
Coxes Creek	B	7.5 (4.0)	14.6 (33.0)	22.7 (135)	27.8 (257)	31.2 (372)	-	-
Scotts Creek	B	9.1 (7.3)	12.7 (21.2)	19.7 (86)	28.0 (263)	33.3 (457)	-	-
Bulls Creek	B	4.6 -	11.6 (15.9)	18.3 (68)	27.8 (257)	34.5 (512)	38.7 (738)	
Finniss River	B	5.7 (1.6)	13.3 (24.5)	24.3 (168)	29.7 (3.8)	36.8 (629)	41.5 (922)	48.8 (1546)
Light River	R	7.9 (4.7)	16.6 (50)	24.4 (170)	32.7 (432)	41.5 (922)	-	-
Little Para River	R	9.7 (9.0)	17.5 (59)	29.8 (321)	34.4 (507)	43.3 (1056)	-	
Delamere Dam	R	5.7 (1.6)	13.2 (24.0)	19.9 (89)	31.0 (364)	-	-	-
Myponga Reservoir	R	-	-	-	46.5 (1325)	52.7 (1975)	-	-

Table 3.22 Length-frequency distribution for male and female Brown trout captured in the trap (1962-1965).

	Length (cms) groups																			
	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	Total
Male	1	5	12	10	22	20	20	11	11	4	7	4	5	2	3	0	4				144
Female			1	7	9	26	25	10	12	6	9	3	4	0	1	2	0	1		2	118

unfortunately shows that most of the Brown trout (and the few Rainbow trout) which were captured in the fish trap each year were aged 3+ and older and that the 2+ fish were too small to be trapped efficiently (Table 3.22). However only 7 Brown trout and 4 Rainbow trout, all 2+, from the Torrens River were detected from the growth shown by their scales among the catches made by electro-fishing in Sixth Creek so the previous conclusion that most of the Torrens River fish moved down out of the Creek after spawning need not be amended.

3.3.2 Growth shown by fish recaptured in Sixth Creek

The increments in lengths and weights of fish which were released with individual tags in the study section and subsequently recaptured provided the earliest evidence during the study that the growth of Sixth Creek trout with time was very poor. A plot made by joining the points representing the lengths at release and recapture of each fish on the corresponding dates showed two trends although the magnitudes of the increments for fish of similar size between the same dates were extremely variable. Firstly despite the long interval between release and recapture (usually about 3 months) the seasonal

changes in growth in length, with a maximum in the Spring, that were recorded by the scales were more obvious in the plot than in Figure 3.9. Also the largest increments in length occurred with the smallest fish (1+) while the lengths of the largest fish showed little, or no increase, over long periods of months. While the fish showed an increase in weight in the Spring the larger fish usually decreased in weight at other times. Some of these larger recaptures actually decreased in length by a few tenths of a centimetre. They were always fish which had the greatest losses in weight and it was obvious from their very poor condition that they were starving (See 3.4).

An attempt was made to partition the variability shown by the growth increments among various sources so as to gain a clearer description of the seasonal changes alone. Multiple regressions were computed with either the length, or weight, increment as the dependent variate. The determining variables used were the interval between release and recapture (days), the size of the fish at release (cms), and the sex of the fish (a value of 1 for females, 2 for fish of unknown sex, mainly 1+ fish, and 3 for males). The values of size represent the ability of different fish to get food from a restricted supply and also the influence of size in determining the proportion of the food eaten used for growth. "Size" does not represent a restriction imposed on the magnitude of the growth increment either by the amount of fish capable of growth at the start of a period, or the maximum amount a fish can eat when food is unlimited, since the fish were not growing, or feeding, maximally.

If Δs is the size increment, S the absolute size, and t the time interval then the regression equation is

$$\Delta s = a + b_1 t + b_2 S$$

where a, b_1, and b_2 are statistics.

It is usual to calculate for each fish a relative growth rate $\frac{\Delta s}{t.S.} = g$ say.

then $\Delta s = g.t.S.$

or $\log \Delta s = \log g + \log S + \log t.$

The relative growth rate is approximately equal to the instantaneous growth rate, k

$$k = \frac{\log e\, S_1 - \log e\, So}{t} \quad \text{where } S_1 - So = \Delta s$$

i.e. $S_1 = So\, e^{kt}$

which is the integrated form of the differential equation,

$$\lim_{t \to o} \frac{\Delta s}{t.S} = k$$

The instantaneous growth rate is based on an equation which describes the geometric increase in size of an individual (or the numbers in a population) where the supply of food does not limit the amount eaten by an individual and so its growth.

The results of the regressions are shown in Table 3.23. The significant negative coefficients for "size" where the dependent variate was length increment are to be expected as a consequence of the relationship between length and weight (see 3.4 and Fig. 3.10) since length increments decrease with increase in size when growth in weight increases uniformly. The decrease in weight increments with increase

Table 3.23 Regression analyses for the growth increments of recaptures.

Length increments (cms) on time interval (days), initial length(cms), and sex					
Species	Intercept	Coefficients			Multiple Correlation Coefficient (R^2)
		Time	Size	Sex	
Brown (133)	4.5585	0.00876 $t_{129} = 7.59$	-0.18518 $t_{129} = -6.17$	0.00562 $t_{129} = -0.04$	0.415
Rainbow (99)	4.4117	0.00829 $t_{95} = 6.24$	-0.20025 $t_{95} = -6.31$	0.14498 $t_{95} = 1.55$	0.448

Weight increment (gms) on time interval, initial length, and sex					
Species	Intercept	Coefficients			R^2
		Time	Size	Sex	
Brown (133)	66.75	0.12535 $t_{129} = 5.10$	-2.9691 $t_{129} = -4.65$	3.0522 $t_{129} = 1.21$	0.257
Rainbow (97)	50.18	0.15527 $t_{93} = 4.33$	-2.7911 $t_{93} = -3.24$	3.9648 $t_{93} = 1.57$	0.251

$P(t_{129} > /1.98/) = 0.05$. $P(t_{93-95} > /1.99/) = 0.05$

in size however agree with the yearly changes in weight shown for Sixth Creek trout in Table 3.21 and is in marked contrast to the increase shown by fish in other places. Even allowing for the production of gonads and the increase in maintenance requirements with size it appears that Sixth Creek trout could not get increasing amounts of food as they grew. This means that there will be a size at an early age at which the fish will not grow any more in length in succeeding years. Over shorter intervals during each year the length at which fish cease to grow may be expected to vary with seasonal changes in the food supply, production of gonads, and maintenance requirements (see next section). A demonstration of this phenomenon was not possible with the recapture data because the seasonal changes could not be described. The expected average increment was computed for each of the recaptures from the equations above. But the difference between the actual and average increments for each fish still contained about 60% and 75% of unexplained, or undescribed, variability for length and weight increments respectively. The growth of the fish obviously varied considerably during the interval between release and recapture (usually 3 months). The resulting difficulty is that of assigning the difference between the actual increment and the expected increment covering the whole period to some point in time, e.g. on a graph, during the interval.

3.4 "Condition"

An alternative to the description of changes in growth in time by growth rates is the use of a condition factor which is a ratio of the actual weight of a fish at one time to some function of its length. Seasonal variations in condition reflect changes in growth which are not detectable from growth rates based on length. The actual weights shown by fish, particularly salmonids, of a certain length, can vary widely. The condition factor has often been shown to be positively correlated with the abundance of food, and hence the growth rate, at different seasons of the year (e.g. Ellis and Gowing, 1957). There is however considerable controversy about the interpretation of various condition factors based upon either arbitrary or empirical functions of the length particularly when comparisons are made between fish of different lengths.

Of the two measurements, length and weight, which are commonly made on fish, only weight and increments in weight, as representations of size and growth, are dimensionally and ecologically relevant for comparisons with the food the fish. The weights of both fish and food animals are, of course, a conglomeration of principally water, protein fat, and bone components which are not necessarily in constant proportion through the life of an individual fish, or between fish of the same age or size at one time, or between different food animals. In view of this fact the recording of the length of fish appears to be made because it is, or was, (for fish) much faster and more accurately determined than weight (particularly for live fish).

If the length (L) and weight (W) of individuals in a sample of fish are measured the L-W relationship can be described by an equation, for allometry of size, proposed by Huxley (1924).

$$W = a\,L^{b}$$

The values of the constants a and b are determined from the intercept and slope, respectively, of the linear transformation by regression analysis.

$$\log W = \log a + b \log L \quad \text{(Subsequently } \overset{*}{a} = \log a\text{)}$$

When only the length is recorded for a fish a corresponding weight is calculated from such an equation. It is important to realise that this is only the average weight of fish of the same length in the sample of fish whose measurements were used to calculate the equation. Considerable variability occurs in the constants, $\overset{*}{a}$ and b, for samples taken at different times, or at different places. It is therefofe important, as will be shown, to distinguish between this equation, describing allometry of size, from the one similar in form which describes the allometry of growth for length and weight measurements recorded at successive times in the life of an individual fish (Simpson et al, 1960). The form of these equations is shown in Figure 3.10.

Statements about the changes in the successive (annual) increments in size of fish have no obvious meaning ecologically if the increments are given in the linear dimension. With increase in size length increments always decrease (exponentially) unless at some stage in the life-cycle there is a sudden marked increase in the weight increments. For example even if the annual increments in weight are similar the corresponding increments in lengths decrease (figure 3.10).

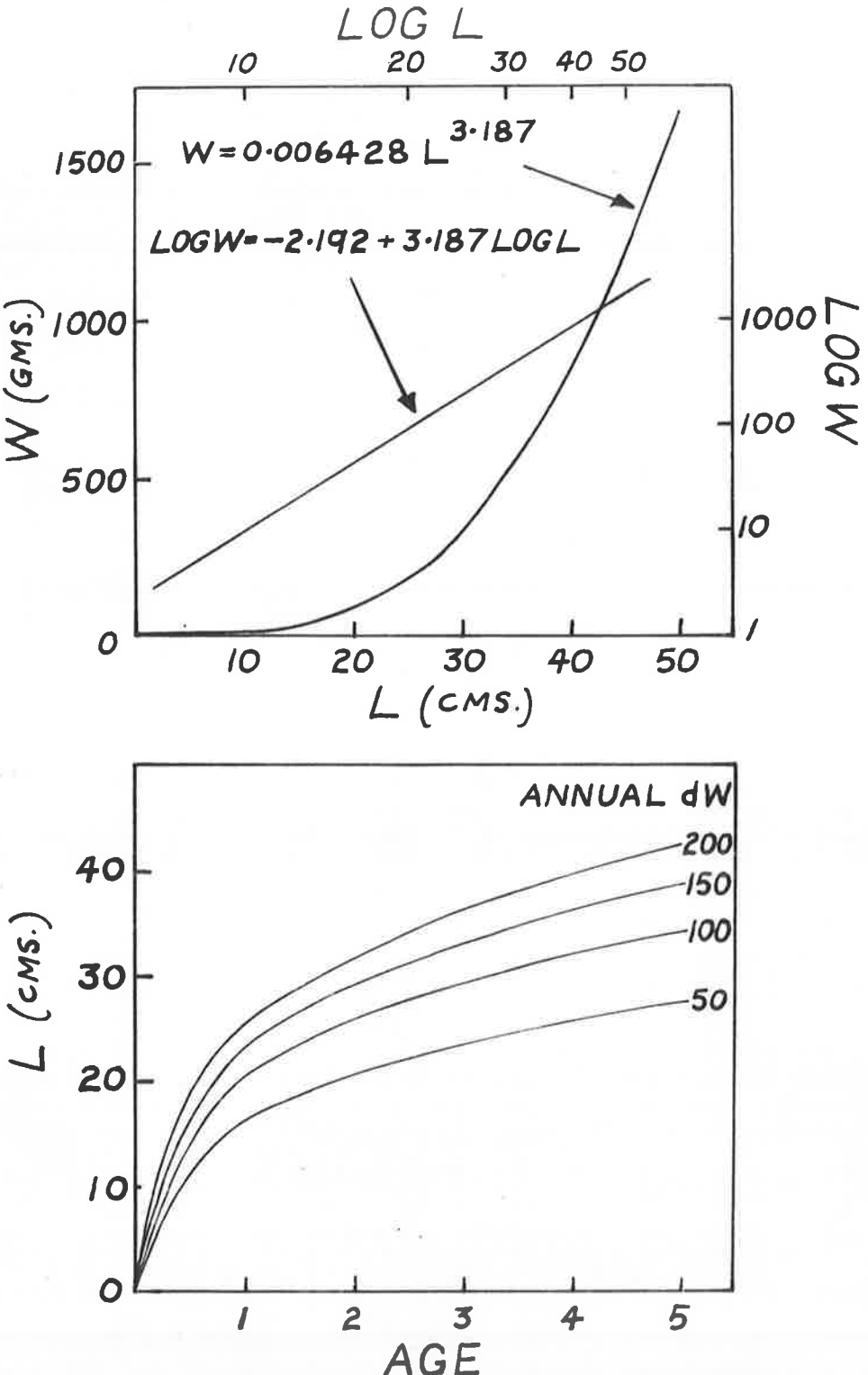


FIGURE 3.10 THE RELATIONSHIP BETWEEN LENGTH AND WEIGHT OF TROUT

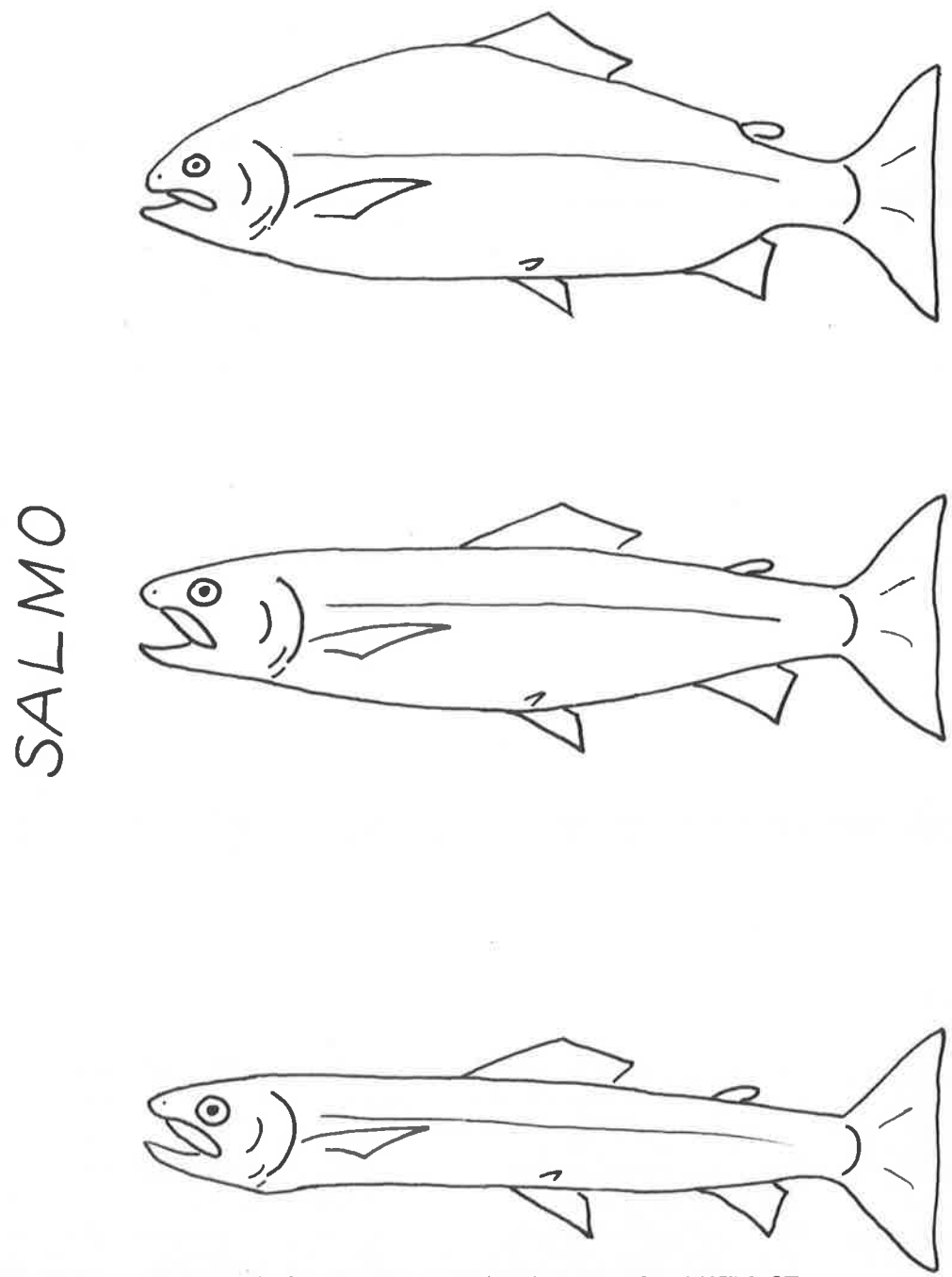


FIGURE 3.11 OUTLINES OF TROUT ILLUSTRATING THE RANGE OF WEIGHTS FOR A GIVEN LENGTH

In this case the fish are actually eating more food per unit time as they grow since as they get larger they have to produce gonads as well, and their maintenance requirements increase. The value of b in the L-W equation, for allometry of growth, is the ratio of the instantaneous rates of growth in weight and length.

The use of the length measurements of individual fish to calculate "condition" factors when weights are also measured appears to have evolved from the expediency of measuring length without any recognition as to what feature of the growth of the fish the length measurement represents.

A length increment may be pictured as representing an expansion of the skeleton of the fish which is necessary to accommodate a (preceding or concurrent) increment in the major part of the fish which the skeleton supports, the muscle.

(a) One consequence of this idea is that for each fish of a certain length there must be a weight at, or above, which (depending on whether the length and weight increments are concurrent or alternate) the fish must grow further in length and below which variations in weight are not accompanied by (positive) increases in length. It is convenient to picture the actual weight, and this length-specific "growth weight", as a total weight minus the weight of gonads.

Living trout display a great range of individual weights at a given length. Figure 3.11 illustrates the extremes. The lower outline is from a starving Sixth Creek trout and the upper one from a very fast growing trout captured in Myponga Reservoir (the latter is known not to be quite the greatest possible extreme in this direction). The middle

outline is from a fish judged to be at about the growth weight. There appears to be number of reasons why the actual weight of the fish can exceed the "growth weight". The growth in length does not appear to be able to keep up with the growth in weight when the fish is growing very rapidly in weight in an environment where there is abundant food. Also growth in length may not be in response to the fat that is deposited on the gut in an increasing amount above the "growth weight". On a short-term basis for trout, at least, growth in length and weight appear to alternate with periods of a few weeks (e.g. Brown, 1946; see also Phillips et al, 1960). There is no explanation of this phenomenon which may represent a basic growth mechanism common to all fish. This phenomenon may be expected to occur, from the growth model proposed, when the weight of a fish is oscillating around the "growth weight" and a preceding increment in weight above the "growth weight" triggers off a subsequent increase in length during which there is little or no further increase in weight. The inherent mechanism of growth producing these alternations may not therefore be apparent when the fish is growing rapidly in weight and is well above the growth weight necessitating continuous growth in length. It is thought that this phenomenon may be reflected in the discrete increments in growth shown by the circuli of the scales of the fish for which there is also no known explanation.

It should be possible to derive an equation of the form $W = a L^b$ describing the relationship between the "growth weight" (Wgr.) and the length (L) for an "average individual" trout.

(b) The ratio of the actual weight of an individual fish to the "growth weight" for its length would provide a useful condition factor. A value for an individual fish could be readily interpretable biologically in terms of the growth of the fish, and values for different fish would be directly comparable.

At present either an arbitrary or an empirical function of length is used as a basis for calculated condition factors. In the first case the condition factor, K say, is given by, for metric units $\frac{W}{L^3} \times 100$ (Fulton, 1902). The function of L used is thus $0.01L^3$. The use of the value of 3 for the exponent of L gives the function the dimensions of volume so that K is dimensionless. Also the L-W equation describing the growth of a, so-called, ideal fish whose "condition" (defined as the interaction of body form (shape) and specific gravity) does not change with increase in length has a value of $b = 3$, i.e. growth between L and W is isometric. When $b > 3$ the condition increases, and when $b < 3$ decreases, with increase in length (allometric growth). The value of the constant multiple, $100 = 1/0.01$, in the condition factor gives for trout, and fish similar in form, values of K dispersed about unity. As one might expect the values of the intercept (log a) and the slope (b) of the log-log plot of W and L from samples of trout, although displaying allometry of size, are usually about -2 and 3, respectively.

$$\log W = -2 + 3 \log L$$

$$W = 0.01\, L^3$$

$$\frac{W}{L^3} \times 100 = 1$$

If the proposed growth weight (Wgr) occurs for fish of different lengths at exactly the same condition then the L-Wgr equation would be Wgr. = a L^3 and a = 0.01. There are however reasons why the growth may not occur at exactly the same condition at different sizes. There are probably some inherent changes in the growth of different parts of the body of the fish , or in the proportions of components of different spe cific gravity (discounting gonads), or both, with increase in age (size). Thus the growth weight equation must take into account inherent changes in condition with increase in age or size.

Reasons for the use of an alternative condition factor, which has laterly found more favour among fishery workers, are given in detail by Le Gren (1951). In populations of trout the average values of K usually decrease with increase in size (age), i.e. the calculated L-W equation for a sample of fish, taken through a year, representing all or most of the sizes (ages) of fish in the population has a value of $b < 3$. Some of this decrease in K with increase in size is probably due to inherent changes in condition. However only if the fish were growing at the maximum rate of which trout are inherently capable would all of the decrease in K be inherent. Trout rarely enjoy an unlimited food supply (see 4.3.4) and the growth of individuals in most of the populations in the world is actually very low. That most of the decrease in K is due to the influence of the environment is shown by the fishes progressively poorer rate of growth in weight relative to the phenomenal potential growth rates which increasing size confer on trout.

In the discussion which follows a method is proposed for estimating the slope of the log-log growth weight equation from the slope of the regression of the $\Delta \log W$ values on the concurrent $\Delta \log L$ values of a growing trout. This method has been shown to yield a range of values of slope, instead of estimates of a single value, for different fish and over varying intervals of time because growth in weight and length alternate in time.

The range of these values of slope has been described in terms of the correlation between slope and intercept which results from the use of the log-log equation. This range of values contains the value of slope which is sought for the growth weight equation. If the growth of the fish did conform to the discarded model of growth, the estimate of the slope of the growth weight equation and the intercept, using the model, would be a pair of values defined by the correlation which was obtained instead.

The use of the log-log equation to describe the L-W relationship of fish of varying sizes in a sample also results in a correlation of slopes and intercepts from equations calculated for different samples of fish. This correlation defines the possible combinations of slopes and intercepts of the log-log equations describing the L-W relationships. One of these combinations is that of the slope and intercept of the log-log growth weight equation.

Thus within these two sources of correlation of slope and intercept - from the log-log equations describing size changes and the equations describing absolute sizes - there is a common set of values of slope and intercept which are those values of the growth weight equation.

The purpose of calculating an empirical condition factor (Kn) of the type described by Le Gren (1951) is to remove both of the length-specific inherent and environmental influences on condition so that fish of different sizes can be compared!

The method involves firstly the calculation of the L-W equation of a sample of fish from the population. Then the value of Kn for a fish is the ratio of its actual weight $(\hat{W})$ to the average weight (W) predicted from the equation for its length

$$Kn = \frac{W}{\hat{W}}$$

Apart from the removal of an important trend of ecological interest, the decrease in condition due to the environment, there are several other objections to Kn. The values of Kn are comparable only between fish in the sample used to calculate the L-W equation, or if the sampling was random the fish represented by the sample in the population, except in the unlikely circumstance when different samples of fish have the same L-W relationship. What is the interpretation in terms of growth when fish of different sizes have identical values of Kn? If the value of b for the L-W equation is less than 3, for example, then a small fish in very good condition and growing rapidly will have a similar value of Kn to a large lean fish which is not growing. Thus values of Kn for fish of different lengths give a considerably biassed interpretation of the often readily observed deterioration in the condition of fish with increase in size because of the assumption that the cause of the change is entirely inherent.

A condition factor based upon the growth weight proposed can be defined as :

$$Kgr. = \frac{Wtotal - Wgonads}{Wgrowth}$$

The range of Kgr. like that of K and Kn is $0 < Kg < 1$ and $Kg > 1$. To overcome this skewed distribution Kgr. can be logged to give a symmetrical distribution about zero.

(c) A further use of this growth model can be made when the growth of the trout deteriorates very markedly with increase in size and there are times during each year when the older fish above a certain length (Lgr.) are not growing in length. In these cases, when, as in Sixth Creek, the condition of the fish decreases consistently with increase in size, because there are no sudden changes in the food supply available to fish of different ages and there is considerable overlap in size between age-groups, the L-W relationship of the fish captured at each sampling date can be described by an allometric equation. Thus functions of length predicting the 3 weights in the equation for Kgr. above can be substituted in it and the resulting equation solved for Lgr. when Kgr. = 1. The changes in value of Lgr. through the year may then be related to seasonal changes in the food supply and the production of gonads.

The later formation of the winter annulus (i.e. the formation of wider spaced circuli at the edge of the scale) on the scales of older fish, which have spawned, which was described earlier for Sixth Creek trout and has often been noticed (e.g. McFadden, 1959; Bilton and Ludwig, 1965), supports the concept of a growth weight at each size. If after

spawning the weight of the fish is well below the growth weight, the annulus will not form until the fish has fed for long enough to build up its weight to the level where growth in length commences and the annulus appears. At successive ages after spawning the current annulus may be expected to form progressively later (in the spring) and the growth in length to slow down and stop progressively earlier after the spring.

3.4.1 Estimation of length-specific growth weights

It was concluded in the preliminary discussion on this subject that the equation giving the growth weight for each length of fish would have similar values, in the log-log form, of intercept, $\overset{\kappa}{a}$, and slope, b, to log W = -2 + 3 log L. This is an arbitrary equation which has been used for many years to calculate the condition factor, K, from the weight, W', = $0.01L^3$; $K = \frac{W}{W'}$, actual. The use of the whole number 3 for the coefficient of L results in weights for fish of the same condition (isometry of size) at different lengths. A value of -2 for $\overset{\kappa}{a}$ (as opposed to -1, or -3) is known to give weights of approximately the same magnitude as natural ones. There then appeared to be no a priori reason why the growth weight equation should have exactly these values.

It is clear that the equation should describe the relationship between the growth weight and length during the growth of an "average" individual trout. Since trout as individuals display, phenotypically, a great deal of variability in many characteristics it may be difficult to establish statistically that values of $\overset{\kappa}{a}$ and b which are estimated

from only a few individuals are in fact significantly different from -2 and 3 respectively.

There are also some peculiar characteristics of the L-W equation arising from the log-log transformation. The values of $\bar{a}$ and b were computed for the lengths and weights of Brown and Rainbow trout in each catch made during the study in Sixth Creek. It is a curious fact that $\bar{a}$ and b were very highly correlated ($r = -0.9987$). The value of b varied in the range, 2.5-3.2 (see 3.4.3 for further details). This is said to be a usual finding by Le Gren (1951) but no reasons are given. The consequence of the correlation at least for Sixth Creek trout, is that a plot of the L-W curves shows that they intersect and pivot about approximately a co-ordinate of 23.6 cms and 146 gms. For progressively smaller values of b (and therefore larger values of $\bar{a}$) the weights of fish above this point decrease and for fish below it they increase. Thus apparently when the smallest fish were in very good condition the largest fish were in very poor condition and vice versa. The pivotal length appears to be of biological significance for Sixth Creek trout in that it is about the average length of 2 year-old trout soon after their first spawning and the reciprical relation between the condition of large and small fish is ecologically feasible. Another feature of the log-log transformation which can be seen in Table 3.24, is that superficially small changes in values of $\bar{a}$ and b either along the correlation trend, or departing from it, represent quite large differences in weight for a given length. The often apparent closeness of calculated values b to 3 and a^1 to -2 is misleading. (The calculated values may also be appreciably influenced by the number of significant

Table 3.24 A comparison of the weights (gms) calculated from different L-W equations for certain lengths (cms) of fish

$\log_{10} W = \overset{*}{a} + b \log L$

b ($\overset{*}{a}$)	10cms	15	20	25	30
3.5 (-2.6196)	7.6	31.4	85.9	187.5	355.0
**3.18697 (-2.19187)	9.9	36.0	90.1	183.4	327.9
***3.0 (-2)	10.0	33.8	80.0	156.3	270.0
3.0 (-1.9363)	11.6	39.1	92.6	180.9	312.6
2.5 (-1.2531)	17.7	48.7	99.9	174.5	275.2

** "growth weight" equation derived later.

*** 'a priori' L-W equation

other values are taken from the trend line for the negative correlation of $\overset{*}{a}$ and b which was found for Sixth Creek trout.

figures which are carried during the calculations). Beverton and Holt (1957) have stressed the need for statistical tests of the difference. For example a L-W equation was calculated for the 461 trout captured in Sixth Creek during the first fishing season. Only the average weights and lengths for fish in 2 cms. length-classes (13) were used (these were however weighted by the numbers in each size-class). The equation was $\log W = -1.8067 + 2.9122 \log L$. The null hypothesis that the values of $\overset{*}{a}$ and b were not significantly different from -2 and 3, respectively, was tested for both values simultaneously using an uppertail F-test.

$$F(2,11) = 32.55$$

$$P(F(2,11) > 2.86) = 0.05$$

At this point one has to decide whether to abandon the attempt to find the growth equation and use the arbitrary, but perhaps approximately real, values of $\overset{*}{a}$ and b, or to accept that since the equation must be derived in the log-log form the peculiarities, shown above, of the transformation, whether representing reality or not, will be present in any case. It was decided to continue the quest and to apply to other problems (next sections), any values of $\overset{*}{a}$ and b that were found so long as they did not appear too unreal.

The log-log form of the equation which describes the growth in length and weight of an individual fish is shown in Figure 3.12. The ratio of the difference between the log weights at time t_1 and t_o to the difference between the log lengths at the same times is an estimate of the slope (b^1) of the line. The consequences of assuming that the co-ordinates of any point on this line are the growth weight for a given

length are: Any increment in weight will be simultaneously accompanied by an increment in length so that b^1 remains constant as $t_1 - t_o \rightarrow 0$. (b' is in fact the true estimate of the ratio of instantaneous growth rates in weight and length and is not the slope of the allometric equation for size). The fish should not be growing so rapidly in weight that growth in length cannot keep up with it (it is impossible to see how this could happen if growth in length and weight were concurrent). If growth in length does not respond simultaneously to growth in weight the line will represent instead a trend line of a scatter of points. Since this does actually happen, as has been mentioned,, and will be shown shortly, the value of b' will be biassed with a severity which increases with decrease in the length of the interval $t_1 - t_o$ and also by losses in weight. Besides these difficulties this approach does not supply an estimate of the intercept of the growth equation.

To explore the above possibility use was made of the length and weight increments of 12 trout (including 2 Rainbow trout) which were held in a rearing pond from 250364 (0+) to 240964 (1+). The weights and lengths of these fish were measured weekly until 210564 and then fortnightly. The fish were fed on other days of each week with a mixture of fresh liver, oxheart and brewers yeast, and commercial fish pellets. They grew, on the average, at a slightly higher rate than the wild fish in the adjoining creek (Figure 3.13). The fish were sufficiently distinct in size to allow records of the growth of each fish to be kept separately. The largest fish in the pond appeared

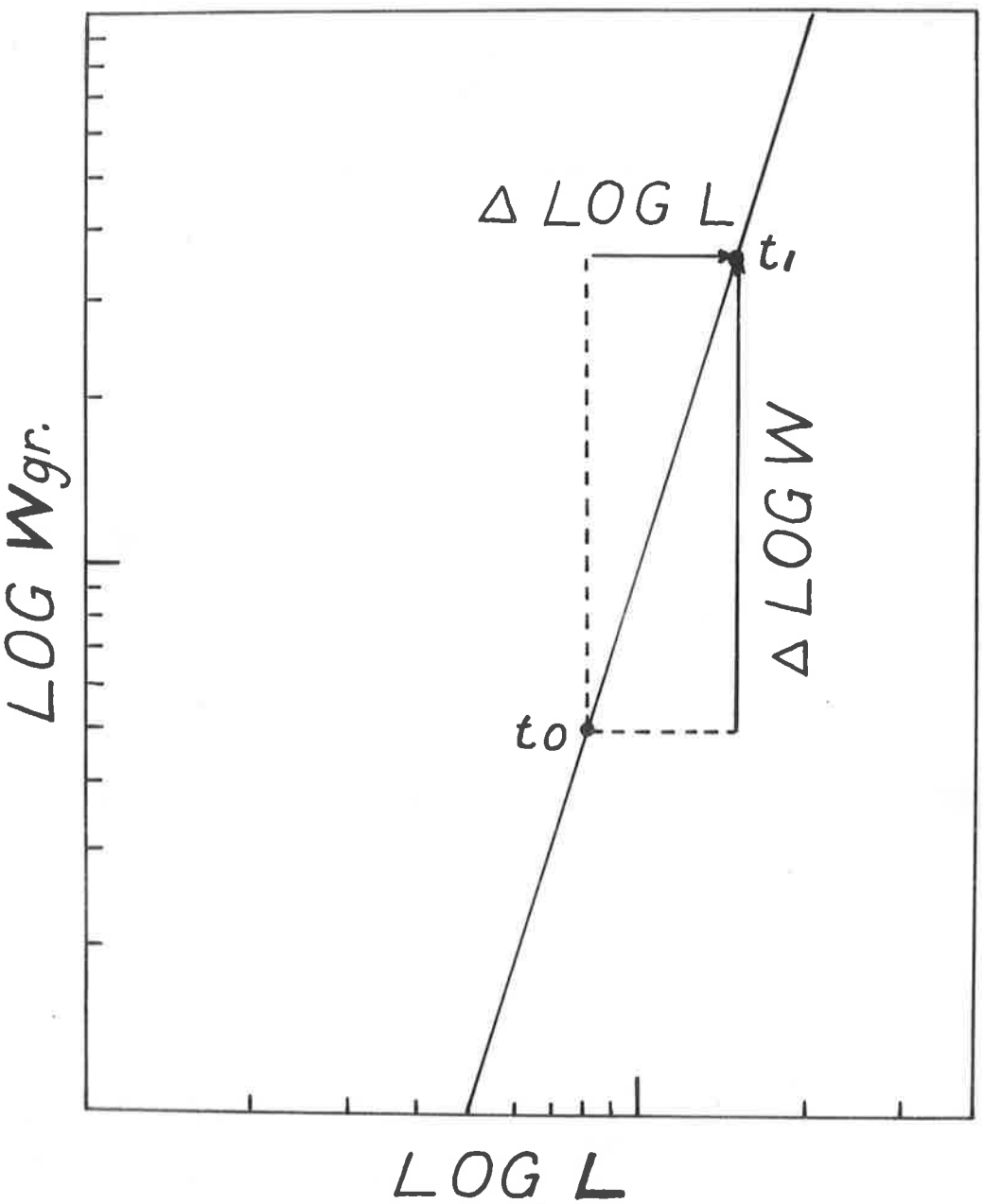


FIGURE 3.12 A METHOD OF CALCULATING THE SLOPE OF THE "GROWTH WEIGHT" EQUATION FOR AN INDIVIDUAL FISH

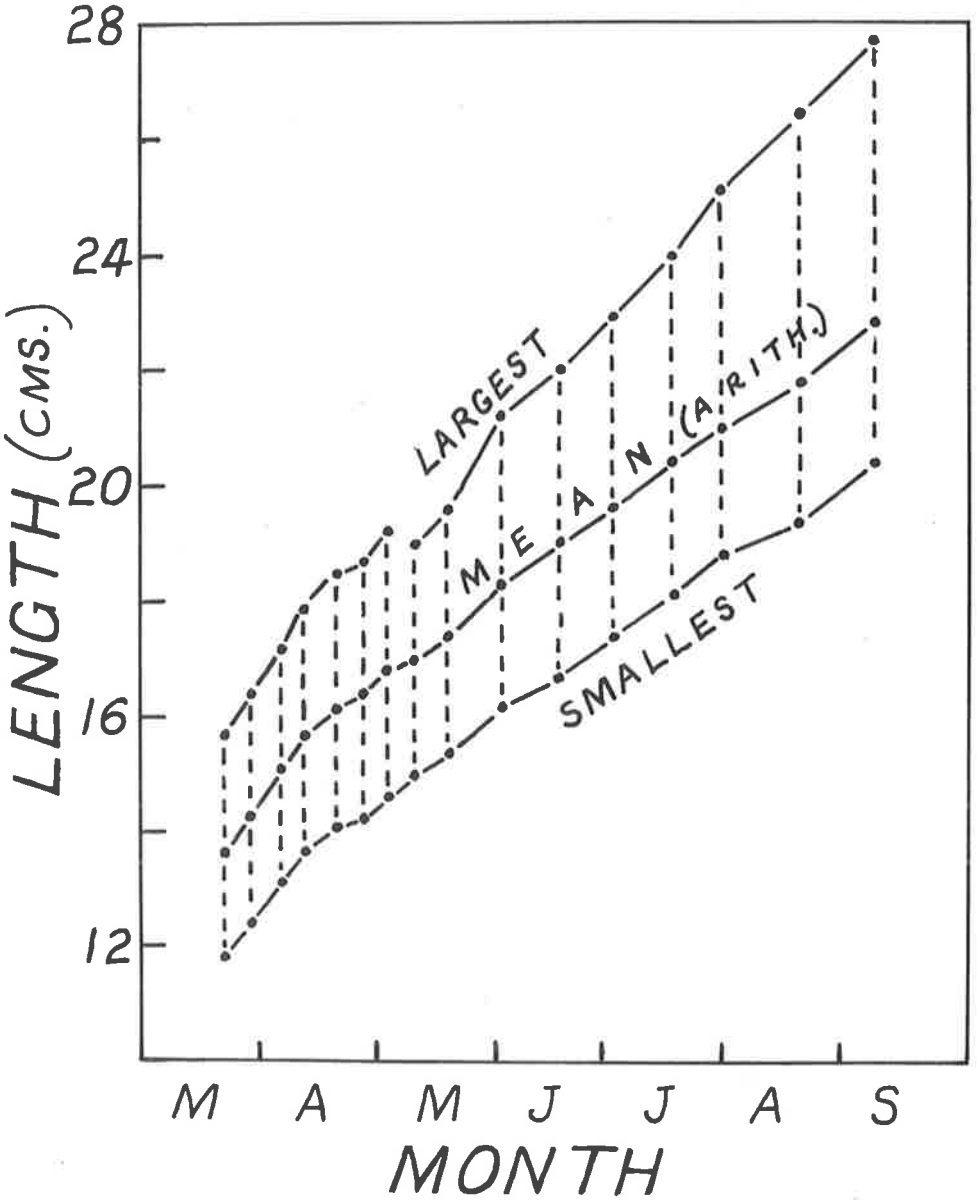


FIGURE 3.13 GROWTH OF TROUT HELD IN A REARING POND

to dominate the other fish from the start and grew more rapidly until 130564 which it jumped out of the pond and died. Its role was then taken up by the next largest fish which commenced to grow more rapidly.

For each fish the difference between the log weights (Δ log W) from one measuring date to the next was regressed on the difference in the log lengths (Δ log L) for the same interval. The results showed the consequence of assuming, for the purpose of regression, that the differences for successive intervals were independent, i.e. that growth in length occurred simultaneously with the increment in weight necessitating it. An unbiassed estimate of b', for the growth weight equation, from each fish should have been close to 3 with a correlation coefficient (r) for each regression that was approaching 1. In fact the values of 'r' ranged from 0.1841 ($b' = 0.94207$) to 0.8045 ($b' = 4.74587$). The values of r and b' were positively correlated so that for $b' = 3$, 'r' was not close to 1 but $\simeq 0.5$. Thus the weight and length increments were not independent between successive intervals of time and the periods of the alternation for different fish were not in phase. Also available were the changes in weight and length from Brown and Rainbow trout which were recaptured in Sixth Creek. The correlation coefficient, 'r', for the regression was higher in these two cases since the interval between release and recapture was long (usually about 3 months).

Brown trout $r = 0.9017$, $b' = 2.4859$, $n = 95$

Rainbow trout $r = 0.8097$, $b' = 2.16098$, $n = 63$

Fish which showed large losses in weight were omitted from these calculations but the influence of losses in weight obviously lowered the values of b'.

To reduce the influence of the short-term alternation in length and weight on the estimate of b' for the 12 fish that were reared in the pond a regression was calculated using the overall increments in length and weight for each fish during the time they were studied. The correlation coefficient was 0.9704 and the equation $\log W = -0.019724 + 3.01269 \log L$. An F-test of the null hypothesis that the intercept and slope were not significantly different from 0 and 3, respectively, gave the value

$$F\ (2,10) = 1.468$$

$$P\ (F(2,10) > 4.10) = 0.05$$

Little confidence can however be given to the conclusion that $b' = 3$ from measurements of only a few fish since the slope (= 3.01269) did not differ significantly from the value of $b' = 3.18697$ which was eventually used. ($t_{10} = 0.7113$, $P\ (t_{10} > /2.23/) = 0.05$).

The discovery was then made that the intercepts and slopes of the regressions of $\Delta \log W$ on $\Delta \log L$ for the pond fish and for the Sixth Creek recaptures were very highly correlated. When these values of $\bar{a}$ and b and those from the regression equations describing the allometry of size ($\log W$ on $\log L$) of Sixth Creek trout at different dates were plotted, the two trend lines were found to intersect close to $b = 3$ and $\bar{a} = -2$ (Figure 3.14). The lengths of the lines in the figure represent the range of values of $\bar{a}$ and b in each case. The regression equations for intercept ($\bar{a}$) on slope (b) were :

for log W on log L

$$\bar{\bar{a}} = 2.16317 - 1.36651\ b$$

$$r = 0.9987 \qquad n = 53$$

for Δ log W on Δ log L

$$\bar{\bar{a}} = 1.04908 - 1.01694\ b$$

$$r = 0.9999 \qquad n = 14$$

The co-ordinates of the point of intersection were found by solving these two equations simultaneously for $\bar{\bar{a}}$ and b.

$$\bar{\bar{a}} = -2.19187$$

$$b = 3.18697$$

Some weights calculated using these values were given in Table 3.24. It is clear from the values of the correlation coefficients above that these values differ significantly from the values of $\bar{\bar{a}} = -2$ and $b = 3$.

The values of $\bar{\bar{a}}$ and b found above were used to compute weights at 0.1 cm intervals for lengths from 5 cms to 55 cms. In the next section these weights are used as "growth weight" (Wgr) to calculate condition factors (Kgr) for individual trout using the formula given in part (b) of the previous section. In the subsequent section the L-W equation incorporating the above values of $\bar{\bar{a}}$ and b is used to define Wgr so as to calculate, by the method described in part (c) of the previous section, the length above which Sixth Creek trout stopped growing at different times of the year.

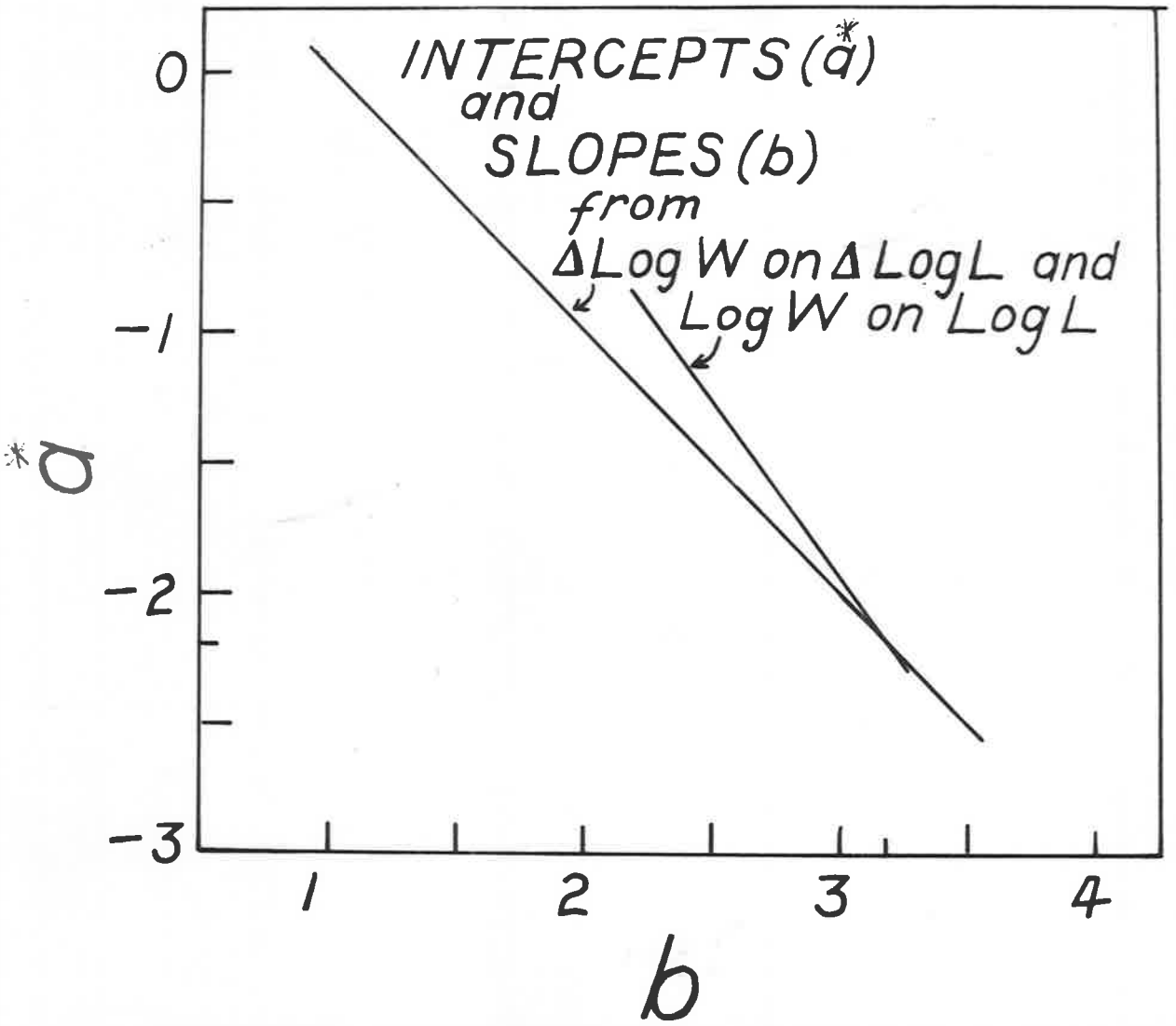


FIGURE 3.14 THE CORRELATION BETWEEN THE INTERCEPTS AND SLOPES FROM L-W EQUATIONS DESCRIBING ALLOMETRY OF GROWTH AND SIZE

3.4.2 Components analysis of trout of different conditions

The purpose of this analysis was to discover what the total weights of trout of different condition represented. The condition factor, Kgr, was used to describe, quantitatively the departures in weight and energy content of different major components of trout from the average values for fish of different condition but of the same length.

The trout, of both species, were captured and killed during the 1964-65 season in Sixth Creek, most of the other streams in South Australia, and some still-waters. They ranged in age from 0+ to 5+, in length from 10 cms to 55 cms, and in condition between the extremes indicated earlier.

A practical problem in a study involving the length and weight of fish is that the measurements vary with the state of the fish, e.g. whether the fish is alive, anaesthetized or not, just killed or long since dead, preserved in fixative or frozen (see Le Brasseur and Parker, 1964). To reduce this contribution to the error associated with measuring it is therefore necessary to measure the fish under the same conditions.

The lengths of the fish used in this study were measured in the field as soon as possible after they were killed. A significant decrease of 0.6 cms was found in the average length of 18 trout (14-18 cms) which were measured immediately after death and again 6 hours later. The lengths of limp freshly-killed are more easily measured than at a later time when the fish have stiffened up. Also they can be accurately measured in the field. The weighing balances that were suitable for

field use were however not sufficiently accurate for this study. The weights for a fish were measured after the return from a day's fishing on an Ohaus Triple Beam Balance. The fish were kept in plastic bags, packed in ice during the summer, before the weighings. However during the summer heat a loss in weight occurred between the time the fish were killed and stored in this way. The loss was due to evaporation from the surface of the fish.

$$\log W \text{ loss} = -0.6703 + 0.6418 \log W \text{ total}$$

$$n = 54 \qquad r = 0.7750$$

About 4 gms of water were lost by a 100 gm fish.

The total weight, the weight after removal of gut and gonads, and the weight after the further removal of head and kidneys were measured. The weights of small gonads, muscle samples, and fat were determined on a more sensitive Mettler balance. A small cube of muscle was cut from the shoulder of each fish. The fat attached to the stomach and intestine was removed and the section of the gut from which the pyloric caecae arise with attached fat was cut out. The muscle and gonads were dried out in a vacuum dessicator operated by a Metravac rotary vacuum pump at room temperature to determine dry weights and also to allow (immediate) bomb calorimetry. The calorific content of the muscle, fat on stomach and intestine, and gonads, (subsamples where necessary), were determined in a Gallenkamp bomb calorimeter kept in a constant temperature room ($79^{\circ}F$-$84^{\circ}F$). Calibration of the instrument with varying amounts of Benzoic acid (A.R.) of known calorific value showed that 1 unit of (corrected) deflection was equivalent to 73.7 ± 0.39 calories. At intermediate stages of this

processing the samples were kept in sealed waxed cartons in a freezer.

In the subsequent regression analyses of the data the following abbreviations are used: ln = log e, n = number of fish, S.D. = standard deviation of the regression, R^2 = multiple correlation coefficient, r = (bivariate) correlation coefficient, S.E. = standard error of a regression statistic (intercept or slope), t_n = value of "t" with n degrees of freedom for the null hypothesis that a statistic is equal to zero. Amount of fish, or component, was analysed in grams. All the statistics were computed.

(1) "Weights"

If the condition factor, Kgr, is an efficient measure of condition then its inclusion as a second variate in the regression of weight on length should account for all this additional variability in the weights of the fish. The regression should then account for all the variance of the weights except for that due to errors in measurements. Table 3.25 shows the results of regression analyses using the total weight of the fish and also the weights after the removal of various parts. The coefficients for the (log e = ln) condition factor in each case were all significantly different from zero and the two variates L and Kgr (which can be pictured as variables determining weight) accounted for (R^2) nearly all the variance of the (log e) weights, In the first case, (a), the intercept and the slope of L were not significantly different from the values of a^* and b^1 that were used in the growth weight equation. The coefficients for Kgr in (a) and (b) were significantly different from 1 but in (C) the coefficient was not. This indicates that the variations in the condition of the fish were

largely due to changes in the mass of the muscle of the fish. The overall correlation was not quite as high in (C) because some error was introduced during the processing when the head was cut off.

Table 3.25 Regression analyses for "weights"

(a) For total weight (Wt) on length (L) and Kgr

$\ln Wt = \underset{\uparrow}{-}5.030 + 3.187 \ln L + 0.9405 \ln Kgr.$

$n = 172$ S.D. $= 0.034349$

$R^2 = 0.9990$

t_{169} for the coefficient of ln Kgr = 38.0

intercept as $\log_{10} = \underset{\uparrow}{-}2.1845$

S.E. of intercept = 0.0315, S.E. of coefficient for ln L = 0.0100

S.E. of coefficient for ln Kgr = 0.0248.

(b) For total weight minus gut and gonads (W-g.g.) on L and Kgr

$\ln (W\text{-g.g.}) = \underset{\uparrow}{-}5.062 + 3.155 \ln L + 0.8380 \ln Kgr$

S.D. = 0.029427

R^2 = 0.9993

t_{169} for the coefficient of ln Kgr = 39.5

S.E. of coefficient for ln Kgr = 0.0212

(c) For total weight minus gut, gonads, head and kidney (W-g.g.-h.k.) on L and Kgr

$\ln (W\text{-g.g.-h.k.}) = \underset{\uparrow}{-}5.435 + 3.210 \ln h + 1.005 \ln Kgr.$

S.D. = 0.045689

R^2 = 0.9982

t_{169} for the coefficient of ln Kgr = 30.5

S.E. of coefficient for ln Kgr = 0.03294

$$P\ (t_{169} \geq 1.97) = 0.05$$

(2) "Muscle"

In Table 3.26, the fresh muscle of the trout, (a) is shown to contain about 70% by weight of water. The water content of the muscle decreased significantly with improvement in the condition of the fish. The coefficient for ln Kgr was not significantly different from unity. The energy content of the fresh muscle of the trout, (b), was 1496 calories per gram, when Kgr = 1, and increased significantly with increase in condition. For dried muscle, (c) the energy content was 5855 calories per gram when Kgr = 1. Although the significant coefficient for ln Kgr indicated in increase in calories per gram with improvement in condition for dried muscle most of the increase for fresh muscle was obviously due to the decrease in water content of the muscle with increase in Kgr. There was a considerable difference in the appearance of the muscle from fish which were in poor condition and in very good condition. In the former trout it was white and flaccid while the latter fish had firm, pink flesh which was distinctly fatty. The pink colouration of the flesh is due to fat-soluble xanthophylls from crustacea which the fish eat (Petersen, et al, 1966).

Table 3.26 Regression analyses for "muscle"

(a) For fresh weight (F.W.) on dry weight (D.W.) and Kgr

F.W. = 0.2266 + 3.553 D.W. -0.8827 ln Kgr

n = 166 S.D. = 0.20004

R^2 = 0.9308

t_{163} for the coefficient of ln Kgr = 8.02

S.E. of intercept = 0.05445, S.E. of the coefficient for D.W. = 0.08428

S.E. of the coefficient for ln Kgr = 0.1101

(b) Calories (CALS) on fresh weight and Kgr

CALS = 1496 F.W. + 1678 ln Kgr

S.D. = 499.15

R^2 = 0.9836

t_{164} for the coefficient of ln Kgr = 6.07

S.E. of the coefficient for F.W. = 16.32

S.E. of the coefficient for ln Kgr = 276.3

(c) Calories on dry weight and Kgr

CALS = 5855 D.W. + 540.7 ln Kgr

S.D. = 406.86

R^2 = 0.9891

t_{164} for the coefficient of ln Kgr = 2.45

S.E. of the coefficient for D.W. = 51.91

S.E. of the coefficient for ln Kgr = 220.9

(3) "Fat"

The analyses for the depot fat taken from the trout are shown in Table 3.27. The total weight of fat on the stomach and intestine of the trout (a) was significantly related to both their size and condition. There is no reason why the absolute amount of depot fat should increase with increase in size except that larger size allows a larger amount to be deposited. The increase with size was small:

for Kgr = 1 L = 10 cms, 0.014 gms of fat

20 , 0.223

30 , 1.26

40 , 4.26

and some of it was caused by increase in the size of blood vessels with growth. The rest of the apparent increase could be due to larger fish depositing a slightly larger proportion of their food as fat when at the same condition as smaller fish. Although it is easily observed that the amount of deposited fat increases with, and is in a small way responsible for, increase in condition of trout, the presence of fat was not a prerogative of fish above the growth weight for their length (the amount in fish near or below their growth weight was small - a few milligrams). Only 50% of the variance of the amounts of fat was accounted for by the two variates, L and Kgr. There is evidence that the proportion of the food eaten by trout which is deposited as fat depends on the quality of the protein in the food (Phillips, et al, 1957). Apparently when, as for hatchery fish, the diet protein is deficient (in certain amino acids?) and cannot be

converted into fish protein it is deaminated and deposited as fat, or used for energy. It is also possible that diet protein may be preferentially deposited as fat in (larger) mature fish for direct use in the production of eggs and as an energy source for spawning activities.

The results of the analysis for the weights of pyloric caecae, (b), were similar in that the coefficients for L and Kgr were significant but much more of the variability in the amounts was accounted for by the variates. Most of this sample was an organ which could be expected to grow in size. The size of the pyloric caecae is also a sensitive indicator of the amount of food a fish is getting, and hence its condition, since it is a major site of absorption of food in the gut.

The energy content of the fat, (c), was determined for all the fat when the amount was small ("fat + blood vessels") but for only a small sample, not including any obvious blood vessels, when the total amount was larger ("whole fat"). The energy values from these two types of samples were significantly different. For "whole fat" there were about 7,500 cals per gm of fat. The energy content of the fat was not correlated with the condition of the fish.

Table 3.27 Regression analyses for "fat"

(a) Total weight of fat (W.F.) on length and Kgr

$\ln W.F. = \underset{\uparrow}{-}13.64 + 4.081 \ln L + 6.145 \ln Kgr$

$n = 177$ S.D. = 1.1165

$R^2 = 0.4915$

t_{174} for the coefficient of ln L = 12.8

t_{174} for the coefficient of ln Kgr = 7.40

S.E. of intercept = 1.006, S.E. of the coefficient of ln L = 0.3189

S.E. of the coefficient for ln Kgr = 0.8300

(b) Weight of pyloric caecae (W.P.C.) on length and Kgr

$\ln W.P.C. = \underset{\uparrow}{-}12.15 + 4.025 \ln L + 3.164 \ln Kgr$

$n = 177$ S.D. = 0.38793

$R^2 = 0.9081$

t_{174} for the coefficient of ln Kgr = 10.97

S.E. of intercept = 0.3497, S.E. of the coefficient for ln L = 0.1108

S.E. of the coefficient for ln Kgr = 0.2884

(c) Calories (CALS) on weight of fat (Wf) and Kgr for "whole fat"

CALS = 7494 Wf

$n = 90$ S.D. = 200.0

$r = 0.9746$

S.E. of the coefficient for Wf = 183.0

for "fat + blood vessels"

CALS = 5610 Wf

n = 47 S.D. = 305.0

r = 0.9595

S.E. of the coefficient for Wf = 245.0

"Gonads"

Usually in the estimation of growth rates of trout the possibility of a difference between the values for male and female fish is not considered. There is always the practical difficulty of distinguishing with reliability the sexes of trout unless they are killed and opened up. It was noticed early in the study that when the lengths of fish, of the same age, from a fairly large sample were arranged in order of increasing size the females were more often than not the smaller fish. Later other samples also revealed a significant difference between the average lengths of the two sexes (Table 3.28). Nikolsky (1961) states that this is a usual phenomenon with fish but no reasons are given. Unfortunately only 1+ fish and usually Rainbow trout, which are easier to catch than Brown trout, could be obtain in sufficient numbers to show this phenomenon. Three possible explanations are:

(1) If male trout are more aggressive than female trout in their behaviour to both other male and female fish at times other than during spawning (where aggression is directed only at other males) it is possible that they would get more food than female trout even if these were of the same size. It has never been suggested that the sex of

trout is a source of variability in behaviour at times other than during spawning.

(2) It is also possible that the difference in sizes is an inherent sex-linked dimorphism such as occurs in higher animals.

(3) The difference may also arise if the female trout must divert a greater proportion of their food towards the production of gonads.

One purpose of this section is to show that the production of the ovaries of female trout represent a much greater expenditure of the food they eat from growth than do the testes of male trout. Usually only the number of eggs produced by female trout are considered - as a measure of fecundity. In this analysis both the weight and energy content of ovaries and testes will be used.

Whatever the cause of the difference in size one logical consequence is that the number of female fish should be reduced by competition for feeding territories when the food supply is limited and the fish are numerous. If the larger male trout do not, or cannot, distinguish between the sexes of the smaller trout which they drive away there should be a decrease in the proportion of female trout. This could be one method of reducing the numbers of fish in the next generation.

The relationship between the weights of gonads (W gonads) at different dates prior to spawning and the lengths of the fish was found from a preliminary sample of ovaries (collected by anglers during the 1963-64 season and fixed in 5% formalin) to be of the form:

$$\log W \text{ gonads} = c - b_1 Ts + b_2 \log L$$

Table 3.28 Comparison of the sizes of ripening male and female trout, age 1+

Place	Males	Females	No. of fish	"t"
Lightburn's Dam (Rainbow trout)	$\bar{L}$ = 35.6 S.D. = 2.669	31.5 2.757	23	3.55*
Delamere Dam (Rainbow trout)	30.0 2.814	27.7 1.992	28	2.56*
Pond (Rainbow trout)	38.2 1.993	34.2 2.400	16	3.58*
Pond (Brown trout)	16.7 1.068	16.4 1.067	17	0.59
Myponga Reservoir (Rainbow trout)	43.7 3.341	41.9 3.654	39	1.62
Kersbrook Dam (Brown trout)	37.2 3.252	32.6 2.877	14	2.76*
Golden Grove Dam (Rainbow trout)	28.1 1.726	26.9 0.922	10	2.24

* The value of "t" for the null hypothesis of no difference between the mean lengths of male and female trout is significant at the 5% level of probability.

where b_1 and b_2 are coefficients and Ts is the number of days prior to the attainment of full ripeness of the ovaries (Table 3.29). Ts = 0 was taken as the end of May for Brown trout and the end of July for Rainbow trout. The fish started spawning in South Australia from these dates. Whether or not these dates are the average dates of the attainment of full ripeness is unimportant to the establishment of the coefficients of the statistical equation since only the constant value (c) is shifted by a biass. However variability in the date of Ts = 0 for individual fish may be expected to have a considerable influence on the variance of the regression equation. The ovaries (and testes) grow at an accelerating (geometric) rate (Figure 3.15).

Although the amount of the variance in ovary weights which was accounted for by the two determining variables was high ($R^2 \simeq 85\%$) in this preliminary analysis it was thought that there was a third variable which was causing some of the remaining variability. It seemed reasonable to expect that fish which were experiencing a shortage of food would perforce produce a smaller amount of eggs. Further these fish might be expected to use all the food above the requirements of their maintenance and therefore would not be growing in length. As well they may have been drawing on muscle growth made previously. Their condition, which could be got from the fish when they were captured, would therefore be an index of this variability. Unfortunately the anglers who collected the fish that were used in the preliminary analysis did not weigh them, or did not weigh them sufficiently accurately, so that a condition factor could not be calculated for each

Table 3.29 The relationship between ovary weight (W gonads), time from spawning (Ts), and length of fish (L). The ovaries were collected by anglers during the 1963-64 fishing season and fixed in 5% formalin. The dry weight of the ovaries was used.

For Brown trout

$$\log_{10} W \text{ gonads} = 8.101 \underset{\uparrow}{-0.00825} Ts + 3.438 \log_{10} L$$

$n = 46$, S.D. = 0.31496, $R^2 = 0.832$

*t_{43} for the coefficient of Ts = -12.64

t_{43} for the coefficient of $\log_{10} L = 6.24$

For Rainbow trout

$$\log_{10} W \text{ gonads} = 10.297 \underset{\uparrow}{-0.006299} Ts + 2.157 \log_{10} L$$

$n = 42$, S.D. = 0.28627, $R^2 = 0.852$

t_{39} for the coefficient of Ts = -9.02

t_{39} for the coefficient of $\log_{10} L = 8.84$

* The value of "t" for the null hypothesis that the coefficient is zero.

$P\ (t_{40} > /2.02/) = 0.05$

fish. In the subsequent analysis of gonads which were collected during the following season, 1964-65, use will be made of the condition factor Kgr to test this hypothesis.

$$Kgr = \frac{W \text{ actual} - W \text{ gonads}}{W \text{ growth}}$$

Support for this hypothesis came from Scott (1962) who found experimentally that Rainbow trout produced smaller numbers of eggs when they were starved.

The implication of this phenomenon is that the fish restrict the number of eggs so as to maintain a certain (minimal) level of quality of each ripe egg which is necessary to ensure the survival and growth of the progeny until they can feed. This hypothesis will be tested by using the number of calories per gram of ovary as a measure of quality.

McFadden et al (1965) also found that an equation of the type proposed above provided an efficient description of the ovary weights of Brown trout. They were able to show that positive differences between the actual weights and the weights predicted from the equation occurred for fish from "fertile streams" (where the fish grew well) and negative differences for fish from infertile streams (where the fish grew poorly). They concluded that individual trout produced fewer eggs when the basic productivity of their environment was low.

When the growth rates of trout are poor the fish spawn for the first time at a later age (when consequently there are fewer of them), as Alm (1959) showed, and when growth is not slowed sufficiently for this to happen the smaller fish produce fewer eggs. The inference that these changes and the phenomenon described previously produce a density-dependent regulation of the numbers in trout populations is not borne out by the status of trout populations in nature.

Although the production (growth x numbers) of population of trout is low when the food supply is poor the numbers of fish appear to be higher than in populations where the food supply, and hence growth rate, is higher. Streams which provide a poor food supply seem to have abundant spawning material (swift streams) and highly productive streams (slow ones) poor spawning facilities. It may also be pointed out that for the pressure on the food supply to be slackened by a decrease in the numbers of fish a low level of food production must be caused in the first place by the fish. In streams where trout are indigenous, or have been established for a long time, the production of food seems to be determined by the amount of nutrients in the water (e.g. fast acid mountain streams as compared with slow alkaline plains streams).

The problem of comparing the numbers of eggs from different fish is complicated by differences in the size of eggs which both Scott and McFadden et al describe. It is thought by these workers that the changes in egg size are only influenced by genetic selection but that rapid selection may occur. In both cases examples are quoted of an inverse relationship between egg number and egg size. Scott favoured

the suggestion of Svardson (1949) that when populations are dense (and aggressive competition for feeding territories is fierce) the larger young fish produced from large eggs will be at a selective advantage and hence changes in egg size may occur from one year-class to the next.

Rainbow trout have smaller eggs than Brown trout (a ratio of numbers of about 4:3 for the same volume) which is probably a consequence of their spawning occurring nearer to the annual spring rise in the food supply of streams.

Asymmetry of the sizes of the gonads of the trout was noticed and the weights of each pair were recorded in most cases. For Brown trout the left ovary, or testis, was larger than the right one more frequently than could be expected by chance alone (χ^2 - test) and the difference in weights (as a proportion of the sum of both sides) of the two sides was significantly different from zero ("t" - test).

$$\text{ovaries} - \chi^2 = 5.35, \quad t_{26} = 3.46$$

$$\text{testes} - \chi^2 = 4.45, \quad t_{18} = 4.01$$

$$P(\chi^2_1 > 3.84) = 0.05, \quad P(t_{18} > /2.10/) = 0.05$$

For Rainbow trout only the χ^2 - test for testes was significant at the 5% level of probability.

$$\text{ovaries} - \chi^2 = 2.62, \quad t_{42} = 1.948$$

$$\text{testes} - \chi^2 = 5.35, \quad t_{26} = 0.207$$

Table 3.30 gives the results of the regression analyses for the gonads.

The fresh weights of the gonads, (a), were significantly related to both time from spawning and the length of fish for each species and sex. The coefficient for Kgr, the condition factor, was significantly greater than zero at the 5% level of probability for Brown trout only. It is obvious from the values of the coefficients for Kgr that the influence of varying condition is quite large. The difference in the size of ovaries in fish of the same length but varying greatly in condition is noticeable visually. It seems that the fish produce smaller amounts of eggs where their food supply is poor but that the lesser effort is still at a considerable expense to their own condition. Although the trout are prepared to use up a great deal of their flesh to produce eggs a lower limit must be set to this expenditure by the need to retain sufficient energy to lay the eggs. The influence of a poor food supply through the condition of the fish on the quantity of eggs may then be detectable when the sample includes fish of poor condition as occurred with the Brown trout. For the Rainbow trout the coefficients for Kgr were not significant since these fish were captured in places where the food supply was better and their condition was higher, than that of Brown trout.

It may be postulated that where the fish can easily produce a maximum weight, or number, of eggs the quality of the eggs may then be improved. The eggs of Rainbow trout contained less water when the trout were at a higher condition, (b). The reduction in the water content of their eggs proceeded during the course of the development of the eggs. The number of calories per gm in the (fresh) ovaries of

Table 3.30 Regression analyses for "gonads"

(a) Fresh weight of gonads (F.W.) on time from next spawning (Ts), length (and Kgr)

Brown trout - females

$\ln F.W. = \underset{\uparrow}{-}19.25 \underset{\uparrow}{-}0.01577\ Ts + 6.970 \ln L + 4.292 \ln Kgr$

$n = 32$, S.D. = 1.0014, $R^2 = 0.7638$

t_{28} for the coefficient of ln Kgr = 2.30

S.E. of intercept = 4.187 S.E. of coefficient for Ts = 0.00256

S.E. of coefficient for ln L = 1.298

S.E. of coefficient for ln Kgr = 1.868

Rainbow trout - females

$\ln F.W. = \underset{\uparrow}{-}13.00 \underset{\uparrow}{-}0.01481\ Ts + 4.828 \ln L$

$n = 49$, S.D. = 0.5539, $R^2 = 0.8763$

S.E. of intercept = 1.316 S.E. of coefficient for Ts = 0.00114

S.E. of coefficient for ln L = 0.3816

Brown trout - males

$\ln F.W. = \underset{\uparrow}{-}18.03 \underset{\uparrow}{-}0.02026\ Ts + 6.271 \ln L + 4.961 \ln Kgr$

$n = 31$, S.D. = 0.9582, $R^2 = 0.8150$

t_{27} for the coefficient of ln Kgr = 2.22

S.E. of intercept = 3.458 S.E. of coefficient for Ts = 0.00241

S.E. of coefficient for ln L = 1.091

S.E. of coefficient for ln Kgr = 2.234

Table 3.30 (Contd)

Rainbow trout - males

$\ln F.W. = \underset{\uparrow}{-6.519} \underset{\uparrow}{-0.01706} Ts + 2.785 \ln L$

$n = 38$, S.D. = 1.3240, $R^2 = 0.5262$

S.E. of intercept = 1.861 S.E. of the coefficient for Ts = 0.00324

S.E. of the coefficient for ln L = 0.5967

(b) Fresh weight on dry weight (D.W.) (and Kgr or Ts)

Brown trout - females

F.W. = 2.519 D.W.

$n = 32$, S.D. = 1.6510, $r = 0.9967$

S.E. of the coefficient for D.W. = 0.0373

Rainbow trout - females

$F.W. = 2.533 D.W. \underset{\uparrow}{-4.319} \ln Kgr$

$n = 45$, S.D. = 1.5257, $R^2 = 0.9863$

t_{42} for the coefficient of ln Kgr = 2.27

S.E. of the coefficient for D.W. = 0.0521

S.E. of the coefficient for ln Kgr = 1.905

F.W. = 2.566 D.W. + 0.00483 Ts

$n = 44$, S.D. = 1.2961, $R^2 = 0.9926$

t_{42} for the coefficient of Ts = 4.81

S.E. of the coefficient for D.W. = 0.03503

S.E. of the coefficient for Ts = 0.00101

Brown trout - males

F.W. = 4.447 D.W.

$n = 27$, S.D. = 1.2650, $r = 0.9792$

S.E. of the coefficient for D.W. = 0.1840

Table 3.30 (Contd.)

Rainbow trout - males

F.W. = 4.869 D.W.

n = 37, S.D. = 0.9363, r = 0.9910

S.E. of the coefficient for D.W. = 0.1108

(c) Total calories (CALS) on F.W. or D.W. (and Kgr)

Brown trout - females

CALS = 2853 F.W.

n = 32, S.D. = 4940, r = 0.9964

S.E. of the coefficient for F.W. = 44.0

CALS = 7228 D.W.

S.D. = 3120, r = 0.9985

S.E. of the coefficient for D.W. = 70.0

Rainbow trout - females

CALS = 2631 F.W. + 17140 ln Kgr

n = 45, S.D. = 4190, R^2 = 0.9844

t_{42} for the coefficient of ln Kgr = 3.22

S.E. of the coefficient for F.W. = 56.0

S.E. of the coefficient for ln Kgr = 5328

CALS = 6656 D.W.

S.D. = 3870, r = 0.9910

S.E. of the coefficient of D.W. = 138.

Table 3.30 (Contd)

Brown trout - males

CALS = 1154 F.W.

n = 27, S.D. = 1202, r = 0.9863

S.E. of the coefficient of F.W. = 38.0

CALS = 5299 D.W.

S.D. = 517.1, r = 0.9974

S.E. of the coefficient of D.W. = 75.0

Rainbow trout - males

CALS = 1006 F.W.

n = 37, S.D. = 2002, r = 0.9621

S.E. of the coefficient of F.W. = 48.0

CALS = 4988 D.W.

S.D. = 1782, r = 0.9701

S.E. of the coefficient for D.W. = 210.0

Rainbow trout was positively correlated with their condition, (c). For the dried ovaries of Rainbow trout this was not the case. Thus the female Rainbow trout were producing a maximum weight of eggs but with improvement in condition less water was present in the eggs and its place was taken by more energy reserves. However there was no improvement in the actual energy content per gm of this reserve material with increase in Kgr.

The Brown trout in poor condition were able to maintain both the amount of the energy store in each egg and the energy content of each gm of this store at the expense of a large reduction in the total weight of eggs produced.

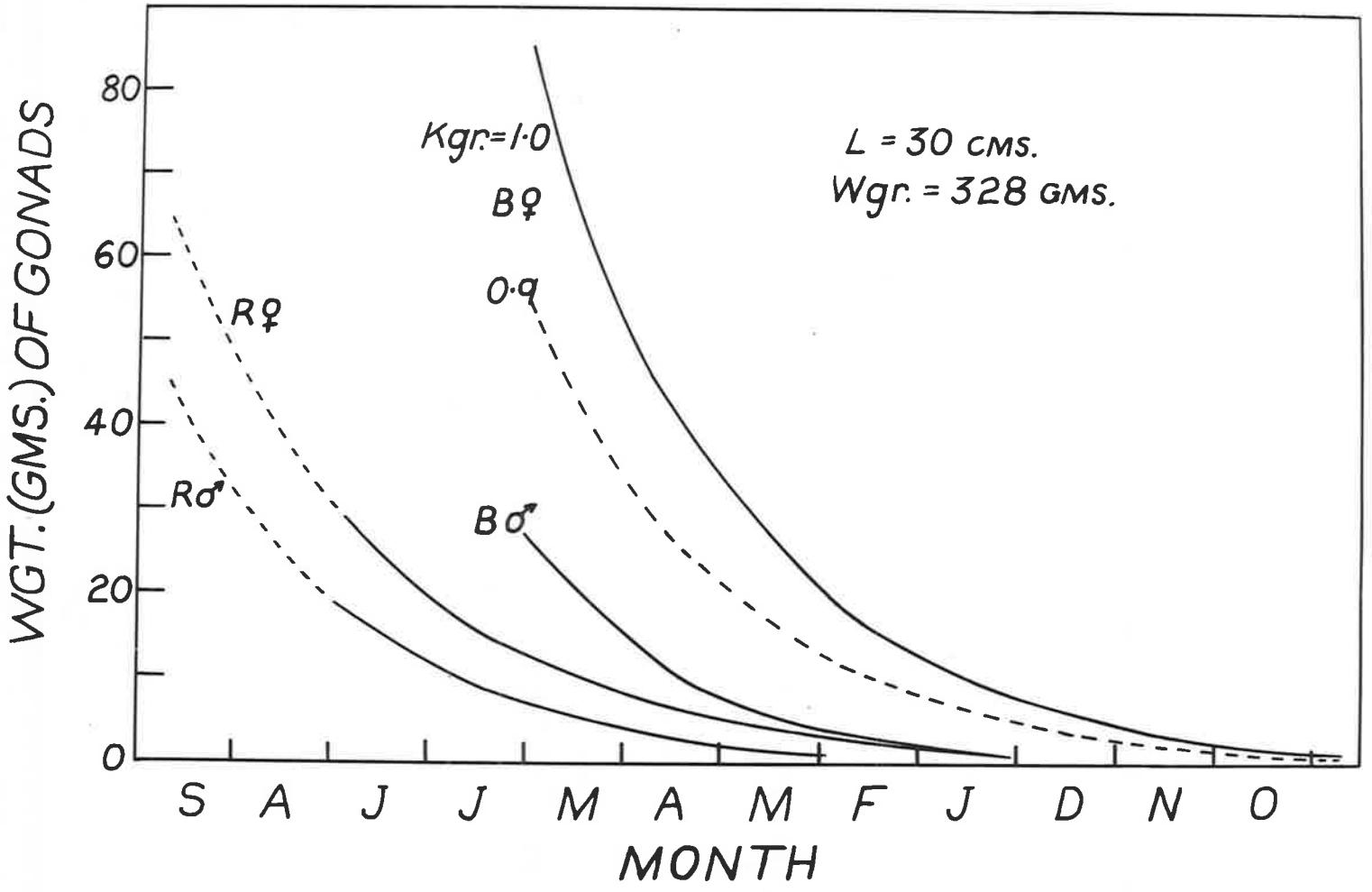
In Table 3.30, (c), it was shown that the energy content of fresh ovaries, as calories per gm, was over twice that for testes. A comparison of the growth of gonads with time for each sex and species of trout is shown in Figure 3.15. The dates of attainment of ripeness (Ts = 0) for Brown and Rainbow trout that were used appear to have been too late and too early, respectively, by a week or so. It is possible to conclude that the weight of eggs produced greatly exceeded that of testes because male fish ripen before female fish.

3.4.3 Estimation of the length above which trout in Sixth Creek were not growing further in length at different times of the year

In the initial discussion of the concept of a growth weight for fish of each length it was proposed that the length, Lgr, above which the fish in Sixth Creek were not growing further in length at each date, could be found from the relationship

FIGURE 3.15 GROWTH OF OVARIES AND TESTES PRIOR TO SPAWNING

B = Brown trout
R = Raimbow trout



$$\frac{W \text{ actual} - W \text{ gonads}}{W \text{ growth}} = Kgr$$

The value of Lgr would be found by substituting equations expressing the weights in terms of length, L, for the fish at each date and then by solving the resulting equation for L = Lgr when Kgr = 1.

The equation describing the allometry of the L-W size relationship for the fish captured at each date is substituted for W actual.

$$\log_{10} W \text{ actual} = {}^{\ast}a + b \log_{10} L$$

(* denotes logged value)

$$\text{therefore } W \text{ actual} = aL^{b}$$

(the weight is really an average value for the fish)

For W gonads the equations which were estimated in the preceding section can be used.

$$\ln W \text{ gonads} = {}^{\ast}g + c \ln L + d\,Ts + f \ln Kgr$$

$$\text{therefore } W \text{ gonads} = g\,L^{c}.\,e^{dTs}.\,Kgr^{f}$$

For W growth the equation which is thought to describe the allometry of the relationship between the growth weight and length is substituted

$$\log_{10} W \text{ growth} = {}^{\ast}a' + b' \log_{10} L$$

$$W \text{ growth} = a' L^{b'}$$

Thus when Kgr = 1

$$a\,L^{b} - \frac{g.L^{c}}{a'\,L^{b'}}\,e^{dTs} = 1$$

$$\text{hence } \frac{a}{a'}\,L^{(b-b')} - \frac{g}{a'}\,L^{(c-b')}.\,e^{dTs} - 1 = 0$$

This function of L, f (L), can be solved for Lgr by an iterative process using only the first derivative of f (L), f'(L), when the value of Lgr is known approximately. The approximate value of Lgr, L_1 say, was obtained by neglecting the presence of gonads and solving the equation

$$W \text{ actual}/W \text{ growth} = 1$$

i.e. $\log_{10} W \text{ actual} - \log_{10} W \text{ growth} = 0$

and substituting for weights

$$(a^{*}-a^{*'}) - (b-b') \log_{10} L = 0 \quad \text{for L.}$$

The calculations for Lgr in the more complicated equation were computed by a program written by J. Hawkes and M. Ahrend of the C.S.I.R.O. Math. Stats. Department, Adelaide.

If the value of L_1 is used to start a loop in the iterative process then $f(L_1) = \frac{a}{a'} L_1^{(b-b')} - \frac{g}{a'} L_1^{(c-b')} e^{dTs} - 1$

and

$$f'(L_1) = \frac{a}{a'} (b-b') L_1^{(b-b'-1)} - \frac{g}{a'} (c-b') L_1^{(c-b'-1)} e^{dTs}$$

A closer value to Lgr, L_2 is then given by $L_1 - \frac{f(L_1)}{f'(L_1)}$ and a new loop is started using $L_1 = L_2$. The process was continued until $|L_1 - L_2| \leq 0.05$ cms and then the particular value of L_2 for a species, sex, and date was accepted as Lgr.

The approximate values of Lgr and the values obtained by the computations, taking into account the weight of gonads, are shown in Table 3.31. Despite a number of sources of variability that were ignored and the incomprehensibility of the intermediate log-log relation-

ships the values of Lgr were within the expected range and showed the changes that were expected from the annual cycle of gonad production. The changes otherwise paralleled changes in the supply of accessible food which will be described in the next section.

Criticism may be levelled at the use of only one equation to describe the L-W relationship of fish of all lengths at one date. It was thought that one equation was adequate to describe the consistent downward trend in condition of the fish over the range of sizes in Sixth Creek. Le Gren (1951) proposed for the calculation of the condition factor, Kn, described previously, that separate L-W equations should be calculated for different ranges of lengths and tested for equivalence of the statistics by covariance analysis. It is probably more realistic to ignore small differences between the L-W relationships for different ranges of length unless a marked change occurs because the fish move at some stage in their life to a place where the food supply is much better or worse. For example Allen (1951) pointed out that the condition factor, K, for the different lengths of fish in a year class tended to form a normal distribution.

The L-W equations, for Sixth Creek trout, were computed for each species at each date and the difference between the slopes and intercepts of the two equations for each date was tested. In Table 3.31 * signifies a significant difference between slopes at the 5% level of probability and ** a difference between intercepts.

Table 3.31 The average length (Lgr) above which the trout in Sixth Creek were not growing further in length at different dates

Date	L for W actual/ W growth = 1		L for W actual-W gonads/W growth = 1			
	Brown trout	Rainbow trout	Brown trout		Rainbow trout	
			female	male	female	male
120863**	16.4	24.8	16.4	16.4	14.0	18.5
100963) 230963)	18.0	21.1	18.0	18.0	21.1	21.2
091063	23.0	21.5	22.9	23.0	21.3	21.5
041163) 241063)	23.9	25.2	23.7	23.9	24.9	25.2
191163) 221163)	27.3	25.9	26.5	27.2	25.4	25.8
031263) 041263)	26.2	25.8	25.4	26.1	24.4	25.7
210164) 250164)	24.3	27.0	23.3	24.1	25.7	26.9
110264	29.0	-	26.8	28.4	-	-
030364) 040364)	27.1	24.4	24.6	26.4	23.2	24.3
160364) 180364)	22.0	24.0	20.6	21.5	21.4	23.6
060464**	22.5	22.9	16.5	17.5	20.7	22.5
170464	23.9	22.8	19.1	21.4	19.8	22.2
200564	26.5	25.8	20.7	23.1	19.3	24.2
220964	21.5	22.8	21.5	21.5	22.7	22.7
211064**	24.4	22.1	24.3	24.4	22.0	22.1
291064	24.8	25.0	24.6	24.8	24.8	25.0
121164	23.8	23.8	23.7	23.8	23.6	23.7
261164	25.3	25.0	25.2	25.4	24.8	25.0
101264) 111264)	24.2	24.8	23.9	24.1	24.3	24.8
090165) 130165)	21.3	20.9	20.9	21.2	20.3	20.8

Table 3.31 (Contd.

Date	L for W actual/ W growth = 1		L for W actual-W gonads/W growth = 1			
	Brown trout	Rainbow trout	Brown trout		Rainbow trout	
			female	male	female	male
090265	22.3	20.6	20.7	21.1	19.9	20.5
230265	21.2	21.8	21.2	21.6	20.6	21.6
090365 [illegible]	20.9	24.6	20.1	20.6	22.5	24.3
230365) 240365) [illegible]	21.6	24.7	20.4	21.2	22.3	24.3
060465) 070465)	21.2	21.6	20.0	20.7	19.6	21.1
200465	23.0	21.6	21.2	22.3	19.3	21.1
040565	22.3	19.5	19.8	21.1	18.4	20.1

Since the sexes of the fish could not be distinguished reliably the equation for each species at each date expresses an average value for them. Thus the actual value of Lgr for male and female trout may be larger and smaller, respectively, than the values shown in Table 3.32.

In conclusion it therefore seems that it is better to use deterministic equations so as to override a welter of stochastic complications which may frustrate the derivation of any results at all.

4. FOOD

The food of trout can be any of the other members of the aquatic community of animals, including aerial stages of insects which have aquatic larvae, and terrestrial animals which fall onto, or fly above, the surface of the water. However the majority of the animals which are found in the stomachs of trout in most places are aquatic invertebrates, mainly insects, crustaceans, and molluscs.

Most of these animals in streams can be found in silt, or plant detritus, at the bottom of still water, on, or under, stones in running water, or in beds of aquatic plants. The estimation of their abundance has been commonly made by removing a small area of substrate to a depth of a few inches by devices such as the well-known Surber bottom sampler, and counting and weighing the animals found in the sample. Considerable differences are found between the relative numbers of most of the species from such samples and the relative numbers of the same species in the stomachs of trout which lived in the stretch of stream where the Bottom Fauna was sampled. The ratio for each food species of the relative number of animals in the stomachs to the relative number in the Bottom Fauna was called, for example, the "index of food preference" by Shorygin (1939), the "availability factor" by Allen (1941), and the "forage ratio" by Hess and Swartz (1941). These terms illustrate the earlier confusion as to the cause of the phenomenon which is widespread with fish at least.

There are a number of possible explanations (Idyll, 1943).

(1) The sampling of the Bottom Fauna may not be representative of the substrate over which the fish range.

(2) The relative proportions of the species measured by the bottom sampling technique may be different from those of the animals which are accessible to the fish.

(3) The fish may select more of some species to eat, because they "prefer" to eat them, to the (partial) exclusion of others which they see.

Even with seemingly more reliable estimates (usually with very large variances) of the Bottom Fauna based on large numbers of randomly selected samples the possible influences of preference and accessibility have not and cannot be resolved from a consideration of the "forage ratio" alone.

From a knowledge of the biology of the food species Slack (1934) thought that trout feed on the most easily accessible food. Neill (1938) concluded that "the predatory relationship between the brown trout and its organic environment therefore is that the trout feeds on the whole range of animals present in whatever type of habitat it finds itself to an extent dependent on the degree of accessibility and the extent of their representation in the fauna. This is sufficient to account for the nature of its stomach contents without involving discrimination on the part of the fish."

The bottom sampling technique appears to measure the food which is potentially available to the trout only part of which is accessible to the fish at any one time.

However there is one good reason for expecting selection by the fish among the accessible animals. In terms of the return in energy, in the form of food, from the energy expended in feeding it is more efficient for a fish to feed on larger animals as it grows and its energy requirements for maintenance increase (Karzinkin, 1939), or as Ivlev (1961), in translation, puts it: "Predators prefer to devour victims of the largest possible size". Selection of food animals on the basis of size is wellknown for trout. Ivlev also concluded from laboratory experiments on some common freshwater fish that a fish which hunts its food like trout eats practially all the food items which it finds while hungry but as it becomes satiated selection commences until at almost maximum satiation "it eats only the items it likes best". Selection, then, may not be significant when the density of accessible food animals, and particularly the larger items, is low relative to the requirements of the trout.

An exhaustive theoretical and experimental analysis of this subject is given by Ivlev (1961). The term selection is used by Ivlev to cover all of the differences between the available food animals and those animals which are consumed by the fish. The cause of the selection is attributed to relative characteristics of both predator and prey which influences both the preference shown by the predator for particular food animals and the degree of accessibility of the available food animals to the predator.

The estimation of the food which is actually accessible to trout then appears to be more relevant for establishing a relation between the production, or growth, of the trout and their food. Concurrent measurements of the Bottom Fauna should show that the accessible food is less abundant than its source, the food which is potentially available. Since the growth of individuals in most populations of trout is known to be very much less than the maximum which is possible this indicates that a relative shortage of food (Andrewartha and Browning, 1961) is responsible.

In waters where trout are introduced for the first time they can be expected to reduce the abundance of, or even eliminate, the largest and most accessible of the indigenous animals.

The behaviour of trout when feeding provides the necessary information for establishing techniques to measure the food which is accessible to them. The art of upstream fly-fishing (Stewart,1857) for trout in streams is based on the observation that an individual fish maintains a more or less fixed position in running water facing upstream and eats animals coming down to it in the current. In rapid streams the fish lies in slack water close to the fast current into which it darts for food. Bainbridge (1962) has shown that trout are adapted to long periods of sustained slow swimming interspersed with short bursts of very rapid swimming. In still waters trout can be seen feeding as they cruise around a well-defined "beat" in shallow water close to banks and weed-beds.

Trout can be observed feeding at any time of the day; intense activity is commonly found at sunset. This suggests that the accessibility of the Bottom Fauna may be higher at sunset.

4.1 Methods

4.1.1 For accessible food in running water

Small nets (of the type described below) were first set in Sixth Creek during the late summer of early 1963. The catches through the day and through the night were disappointing. The animals in the samples were so few and small that it was difficult to imagine that they could be an important source of food for the trout since at this early stage the fish were thought to grow well in Sixth Creek. There was no means available at that time for measuring the flow through a net but the total flow was small.

The discovery of Waters (1962a) paper dispelled this pessimism and gave encouragement for further work. Waters showed that the drift of aquatic invertebrates downstream in a small stream in the U.S.A. rose abruptly from rather low values during the day to a maximum from one hour after sunset and then declined rather more slowly through the night. The stimulus for his discovery came from the knowledge that many aquatic animals are more active at low light intensities (Moon (1944) had shown that invertebrates colonized trays of substrate material more at night than during the day in a stream and a lake), and from Dendy (1944) who realized that the drift of invertebrates in streams is a result of their own activity and a normal part of their life-cycle. Independent work by Tanaka (1960) on the

diurnal changes in drift was found later. The presence of these animals in the current of streams was known earlier (Needham, 1928), but attributed solely to the action of high flows dislodging the animals from the substrate (Maciolek and Needham, 1951; Muller, 1954). In Sweden the swift restocking by invertebrates of razed sections of forest streams led Muller (1954) to realize the importance of the "organic drift" but no distinction was made between day and night movements. Good agreement was found between the animals in the drift and those in the stomachs of trout from the relative proportions of the species present (Muller, 1954; Nilsson, 1957).

There is no doubt that this phenomenon is an important discovery in freshwater biology as shown by the papers associating it with the feeding of trout (Horton, 1961; Elliott, 1965), and for improving the sampling technique (Müller, 1958, 1965; Mundie, 1964; Cushing, 1964). See also Waters (1961, 1964, 1966); Muller (1963); Logan (1963); Coutant (1964).

The net used to catch the drift in Sixth Creek presented a rectangular opening 50 cms wide but only 5 cms deep to the current so that it could be used in shallow water during low flows with the opening entirely submerged. The net tapered back (50 cms in length) to a smaller (12 cms wide) flat opening which was sealed during sampling by a large chromed spring clip. The weight of the clip kept the bag of the net submerged during sampling. The material used for the net was "Lyds" grit gauze - a fine interwoven silk mesh - size No. 32 which has individual openings of 0.5 x 0.5 mm., and was sown with

double inverted seams. A rectangular frame (50 x 5 cms) of $\frac{1}{8}$" dia. brass rod, with a centre post for rigidity, was bound to the bag of the net. A net was supported on each side in the current by $\frac{1}{8}$" dia. steel rods pushed down through holes, 50 cms. apart, in a heavy T-section bar ($1\frac{1}{2}$" x $1\frac{1}{2}$" x $\frac{1}{4}$") permanently set in the bed of the stream across a sampling point. Ten of these bars were initially set through the study section in the late winter of 1963 at suitable places in running water. The number of nets which could be set across these bars ranged from one (e.g. R.I. P 5) to five (e.g. R.I. DP 2).

The apparent flow through a net, in litres per unit time (q), was estimated from measurements of velocity at the midpoints of where the sides and centre of the net would rest in the current. The bar in the bed of the stream was used as a base for depth measurements. Velocity was measured by an "Ott" laboratory current meter. With the smallest propeller No. 2-3, 3 cms. dia. and 0.1 m. pitch, this very small cigar-shaped meter enabled measurements of velocity to be made in very shallow water down to a value of 8 cms/sec. The meter was calibrated by the maker (A. Ott, Kempten, W. Germany) for propellers No. 3 and 4 (5 cms dia., pitch 0.25 m and 0.5 m. respectively) and No. 2-3 by their method known as "Bargo" on 111063. During the summer in early 1964 revolutions of the propeller were counted aurally using the earphones provided. For higher flows, later, an "Elmeg" high impulse counter, in series with the contacts of the meter, was used to automatically record the revolutions in an interval of 30, or 60, seconds.

The catch was washed from a net by a fine spray of water under pressure from a hose at the rearing ponds whenever possible, or by using a washbottle, into a large plastic funnel set in a glass cylinder, 1½" dia. and 10" in length, held in a retort stand. The sample collected in the cylinder on a disc of brass mesh (40 meshes/inch) glued to the lower end. The cylinder was then inverted over a waxed paper cup and the sample was washed into it. The animals were preserved by topping up the cup with formalin. This method was used for the other types of food samples as well.

The total area of the mesh openings in a net was about 2.3 X the area of the net opening facing the current. The nets were calibrated on 09 and 101265 in a square-section horizontal flume (25' in length and 2' wide) in the Engineering Department of the University. For this purpose the ten nets were assumed to have the same filtering coefficiant, since they were all cut from the same piece of material and to the same specifications, and only one was tested. The sides of the flume were built out near the outlet so that a net could be fitted into the flume flush with the sides and the bottom. Flow was estimated from measurements of velocity at 0.6 of the depth of water at three points in the current across the width of the net position. Different flows down the flume could be found by varying the width of the outlet while keeping a depth of 5 cms over the net site. Depth was measured by a Vernier slide-rule the pointer of which made and broke electrical contact with the surface of the water with equal periods at the required depth. For each of

these flows (q) the net was then put in and the flow reduced until the net again accepted all the flow. The net was then removed and the total flow (qn) measured as before. The relation between q (the apparent flow through the net) and qn (the actual flow through the net) is shown in Figure 4.1 and expressed by the second order polynomial equation:-

$$\hat{q}n = 1176 + 1.219\ q - 0.0127q^2$$

Multiple correlation coefficient (R^2) = 0.944. This relationship was used when the value of q exceeded 21,500 litres/hour.

4.1.2 For accessible food in still water

The appearance of large numbers of animals in the running water after sunset suggested that this was fundamentally a reflection of the increased activity of the animals in the stillwater out from the bottom material and weed-beds of streams.

A large bloom of filamentous algae (Cladophora sp.), and associated pennate diatoms, occurs in Sixth Creek during most summers (e.g. 1963 and 1964 during the study). The algae first appeared in the spring when high flows cease and in early December very quickly filled the stream. At the end of February the algae started to break up in running water but persisted in the still-water of pools until the late autumn floods. This algae was observed to contain large numbers of invertebrates during the summer of 1963 some of which by February were of a relatively large size (e.g. larvae of Stratiomyidae and Corduliidae). However these animals in the dense beds of algae appeared to be inaccessible to the trout.

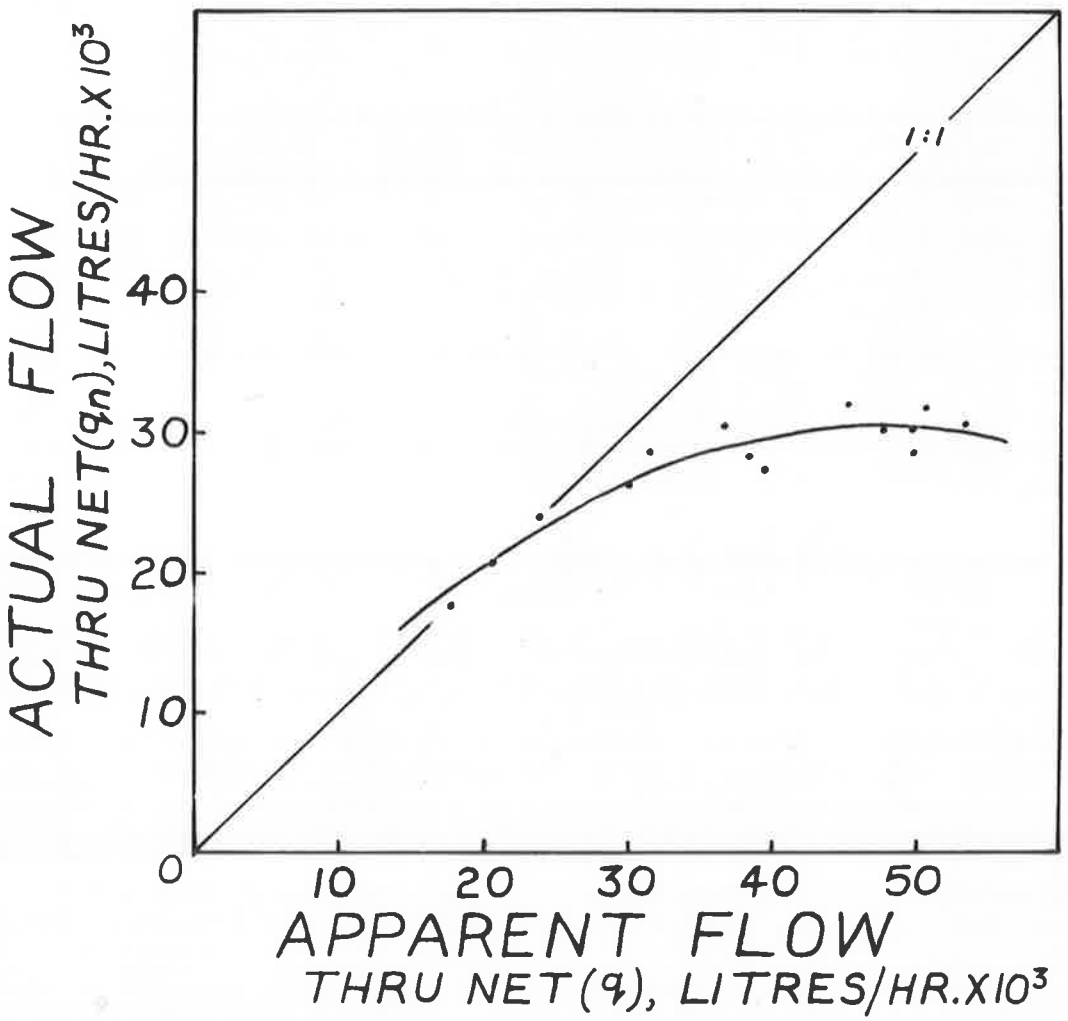


FIGURE 4.1 GRAPH OF THE RELATIONSHIP BETWEEN THE APPARENT AND ACTUAL FLOW THROUGH A NET FOR SAMPLING FOOD IN RUNNING WATER

During the summer and early autumn of 1964-65 the movements of animals in open still water were measured in Sixth Creek and by way of comparison in two other streams, a dam, and a reservoir.

A portable 1½" self-priming centrifugal pump (Finsbury Eng. Ltd., Adelaide) was used to collect the animals in a known volume of water. From the inlet of the pump 25' of 1" dia. plastic irrigation pipe led to 12" of 1½" dia. perspex tubing, positioned at mid-depth in the water by a large float and sinker, in which a removable long (9") conical filter of brass mesh, 40 meshes/inch, retained the animals during each sampling. All routine samplings in Sixth Creek were made just upstream from the runout of a long Deep Pool (D.P. 3) in 1½' of very slowly moving water. The inlet to the filter was centred in a cage of ½" wire mesh, 2' wide, 3' long, and 2' high, to prevent algae, and leaves slowly floating down the pool, from being sucked in. At the end of each sampling a rubber stopper was pushed into the inlet before the pump was stopped to prevent loss of the sample. Water from the outlet of the pump ran back into the creek below the pool.

The amount of water that passed through the filter was found by measuring the time that the pump took to lower a small head of water, corresponding to a known volume, in one of the rearing ponds. On 011264, and 080965, the average value was 3250 litres per 20 minutes.

The sampling was done through 4 20-minute invervals centred, respectively, in the hour before and the 3 hours after sunset on each date.

4.1.3 For Bottom Fauna

To show that only some of the animals in the Bottom Fauna become accessible to the trout in running water, or open still water, measurements should be made on an absolute basis. The animals in a certain volume of running water, or open still water could be related to the animals in a certain volume of bottom material. The practical difficulties however are numerous. For example the drift downstream from an area of substrate enclosed by a fine mesh screen would be influenced by the unnaturally small flow permitted by the screen. Needham and Usinger (1956) found that the customary routine sampling (by a Surber square foot sampler) of the Bottom Fauna in streams requires very many samples to get reliable estimates of weights and numbers of animals even in a relatively uniform stickle. However only a few samples were needed to estimate the relative frequencies of the different species of animals present since these were much less variable.

Part of the difference between the Bottom Fauna and the accessible food may be due to differences in the behaviour of different species and different sizes of animals in each species. Assuming that the animals in the catches of accessible food are derived from the source that is represented by the animals in the samples of Bottom Fauna any significant difference in the relative numbers of the species, or of the animals in different size groups, between the two types of samples would be a partial demonstration of the phenomenon that only part of the Bottom Fauna becomes accessible to the fish.

Samples of the Bottom Fauna were carefully taken immediately upstream from a drift sampling site with a net, 12" dia., of 34 meshes/inch and in still water during the summer by putting a small amount of algae into the net.

The catches are assumed to be random samples of the species and size-groups of each species present. The sizes of the samples were dictated by the anticipated labour that would be involved in their sorting.

4.1.4 Sorting of samples

A sample was put into a long (4') and narrow (1") perspex container which was moved over rollers by hand through the field ($1\frac{1}{4}$" dia. at 6 x magnification) of a binocular microscope. The animals were picked out of the sample with jewellers' forceps and the species present were first separated into different compartments of a plastic icecube container. Then the individuals of each species were measured on a millimetre scale and the numbers in different size-groups were recorded. The animals were measured from the anterior end of the head to the posterior end of the last abdominal segment. Snails were measured overall along the major axis of the shell (height). Henceforth size-group (1) will refer to lengths from 0.5 to 1.4 mm., size-group (2) to those from 1.5 to 2.4 mm., etc. When there were many hundreds of individuals of a species they were all counted but only a few hundred, picked out in a random manner, were measured. The relative proportions of the numbers in the size-groups in the subsample were used to partition the total number amongst the size groups. Although records for individual

species were kept, in some cases these were only identified down to families to maintain the distinctions. A list of specific taxonomic references is given at the end of the bibliography. Numbers, and weights, of food items presented in subsequent sections (e.g. Tables 4.1 and 4.3) apply only to wholly aquatic animals and to the aquatic stages of animals with aerial adult stages.

4.1.5 Conversion of numbers of animals in size groups to live weights

Live individuals of different sizes were weighed on a Mettler balance after drying on moist filter paper for 30 seconds. After fixing in 5% formalin their lengths were measured. By plotting the weights against lengths on log-log paper the length-weight relationship for a species was found from a few dozen individuals. Care was taken to include the largest individuals of a species since in one case (Gomphidae) the intercept of the line through the points increased when wing-cases appeared on the nymphs. Extrapolation to the smallest size-groups was needed in most cases. More measurements were made for species known to be abundant. In some cases rare species were assigned the L-W relationship of a species similar in form (e.g. Diptera larvae). Tables were made up giving the weight for each size-group of a species as read off the graph with a freehand line drawn through the points.

4.2 Food sampling experiments in Sixth Creek

4.2.1 Changes in the drift through the day

a. On 041264 10 consecutive samples were taken in Stickle 12 (S.12, Map 4) during 20-minute intervals around sunset (Table 4.1). The actual sampling interval was less than 20 minutes since 1-1½ minutes were needed to replace a net (at 0.6 of the depth) in the dark. The tracing from the gauging recorder showed no change in the total flow from 7 to 10 p.m.

The numbers of animals in the current reached a maximum in the mid 20-minute interval (6) of the second hour after sunset. The total weight of the catches was highest in the next interval (7) due to the presence of larger items (the largest two were larvae of Gomphidae and Stratiomyidae). The influence of moonlight was noticed in these and other catches when the moon set or rose during the samplings. The catches were smaller for the third hour after sunset, relative to the peak catch in the second hour, when the moon rose soon after sunset and vice-versa. This appears to be the only possible explanation for the increase in numbers during sampling interval (10) for the moon set in sampling interval (2).. Perhaps the animals are unable to detect the presence or absence of moonlight until after twilight.

The average values of the absolute light intensity and the rates of change of it during the sampling intervals were calculated from tables relating lux values to "Creps" given by Nielsen (1963).

TABLE 4.1 CHANGES IN THE DRIFT AROUND SUNSET

	Light intensity (Lux)		Water Temp °C	Sampling Interval p.m.	Numbers and Weights (mgms) in SIZE-GROUPS												TOTAL		Density 10^3 (Nos./litres)
	Absolute	Rate of change (per 20 mins)			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)			Nos.	Wgts. (mgms)	
Date 041264	549.5	1.82	19.3	(1) 7.00-7.20	13 3.43	46 13.30	32 21.14	7 4.80	4 4.70		1 7.50			1 12.00			104	66.87	10.3
Place S12	288.4	2.04		(2) 7.20-7.40	28 4.03	38 10.46	23 16.79	10 9.00	1 3.80								100	44.08	10.9
Sunset 7.18 pm	125.9	2.51		(3) 7.40-8.00	41 7.59	66 17.17	57 39.01	9 11.40			1 1.90						174	77.07	17.2
Moonrise 4.55 am	44.67	3.02	19.0	(4) 8.00-8.20	43 10.26	84 19.54	79 60.02	21 37.40	4 15.30	1 5.90							232	148.02	22.9
Moonset 7.29 pm	13.49	3.63		(5) 8.20-8.40	56 8.14	174 39.82	168 129.46	59 105.60	10 32.50	2 11.80	1 9.00	1 9.80					471	346.12	46.5
(New moon) clear sky	3.72	3.55		(6) 8.40-9.00	26 6.57	340 75.33	317 248.79	110 194.80	12 45.30	3 16.80	1 90.00	1 9.80					810	606.39	79.9
qn 30,400 litres/hour	1.07	3.24	18.3	(7) 9.00-9.20	17 5.86	241 54.66	254 198.31	117 213.40	21 73.00	4 18.20					1(11) 23.00	1(12) 85.00	656	671.43	64.7
	.363	2.82		(8) 9.20-9.40	11 2.96	207 49.32	179 139.96	78 145.10	10 36.50	2 10.60							487	384.44	48.1
q 47,252 litres/hour	.135	2.57		(9) 9.40-10.00	23 7.38	188 42.93	176 135.94	55 98.60	13 52.00	2 11.80	1 8.70				1(16) 30.00		459	387.55	45.3
	.053	2.51	17.5	(10) 10.00-10.20	37 6.57	220 48.14	170 126.31	67 100.60	24 75.72	2 18.40	1 1.90				1(11) 66.00	1(13) 108.00	523	551.64	51.6

$$\text{"Creps"} = \frac{\text{time of day - time of sunset}}{\text{duration of twilight}}$$

The time of civil twilight was found from "The American Ephemeris and Nautical Almanac".

Nielsen (1961) proposed that such values would be useful in explaining the increased activity of many animals after sunset.

The changes in numbers, in Table 4.1, are not simply correlated with either the absolute, or rate of change of, light intensity individually but with some complex function of the two variables. The same rate of change is associated with higher numbers in the catches at lower absolute values. However the relationship may be even more complex since Van Someren (1940) has pointed out that true twilight does not occur under water since the onset of darkness is comparatively sudden on water.

Values of absolute, and rate of change of, light intensity for hourly intervals around sunset are given in Table 4.2. These are average values from calculations for 24 different dates in spring, summer and autumn. (The differences between dates for the same interval are small compared with the differences between intervals on the same date). The end of twilight is the moment when the rate of change of light intensity changes from an accelerating to a decelerating value.

Table 4.2 Values of light intensity around sunset

Hourly sampling Interval	1	2	3	SUNSET	4	5	6
Absolute L.I. (Lux)	4610	3160	1058		89.4	1.20	.0363
Relative* Rate of change of L.I. (Lux/hour)	1.22	1.98	5.20		41.2	71.0	18.5

* difference between log Lux values.

Hardy (1958) has pointed out that marine zooplankton by swimming a relatively short distance towards the surface at dusk and then down again at sunrise feed in a different part of the ocean each day. In the oceans these animals are given "seven-league boots" by the movement of the water in different directions at varying speeds at different depths.

Similarly in a stream animals by swimming a short distance out from their positions in, or on, the bed of the stream at sunset are then carried a relatively much greater distance by the current. And a short time later when they swim out of the current, or settle out when the current slows in a pool, they come to rest on different areas of the substrate.

The initial movement out from the substrate can be expected to be greater when the animals are crowded in their feeding areas (Roos, 1957). Obviously if all of the animals moved out and remained in the current for more than a short period at sunset the stream would be swiftly depopulated of invertebrates at least at high flows. Most of the downstream movement of both the invertebrates and the fish which prey on them, may be made by only those animals which are jostled from places where there is competition among individuals for limited

resources of food and living space. However to counteract the removal downstream of both fish and food by violent flows and a necessary movement downstream of a fish predator to find larger prey, there is a need for an adaptation in behaviour resulting in a movement upstream by the adults when they reproduce. Muller (1954) has proposed that the upstream migrations of the aerial adult stages of some aquatic insects (movements which were found later by Roos (1957) to be prevalent on swift Swedish streams) was the "recolonization" period of their life-cycle. How crustacea, of which Gammaridae at least have high drift rates (but perhaps only when their density is high in the Bottom Fauna - Macan and Mackereth, 1957), maintain populations in streams has not been shown. As a general rule there appears to be an increase in the size (and age) of the invertebrates (see for example Allen, 1951, p. 53 on) and of the fish which feed on them (Thompson and Hunt, 1930), in the downstream direction. Salmonidae at least among the stream fishes migrate upstream to spawn.

b. From 11 a.m. on 200264 to 10 a.m. on 210264 14 drift samples (1 hour sampling interval) were taken at the Run-in of P 5 (Table 4.3). The flow decreased through the first part of the samplings and then increased. From measurements of velocity at the net position in the intervals between samplings during daylight and the tracing from the gauging recorder values of qn (= q) were calculated for each of the samplings.

The main feature over the period was the maximum in numbers and total weight in the second hour after sunset.

c. Table 4.4 shows the changes in abundance around sunset of the species which contributed the most to the total numbers and weights of drift catches in Sixth Creek. The four sampling intervals are, respectively, the hour before sunset (1) and the three hours after sunset, (2) - (4). The catches shown were taken at dates when the species were most abundant in the drift. The ratio of the numbers for intervals (2), (3) and (4) to that for interval (1) are probably highest for a particular species when it, at least, is most abundant since the movement of individuals out from their feeding positions on the substrate in search of new areas is likely to be greater then, when they are crowded as suggested by Roos (1957). In Sixth Creek the larger individuals of the species which grow to the largest sizes are conspicuously absent from the drift and the bulk of the catches are individuals of the smallest size groups. Moon (1940) showed that the increase in activity of aquatic insects at night was not predominantly related to emergence.

Also shown are the changes for two species which were very rare in Sixth Creek but important food species in other places.

4.2.2 Drift at different depths in the current

Because of the shallowness of the running water in Sixth Creek nets had to be set at about the mid-depth of the water flowing over the bar set across the bed of the stream at each site. In a uniform channel through which the flow of water is laminar, as opposed to turbulent, the average velocity in a vertical profile occurs at 0.6 of the total depth (Figure 4.2). Nets were set at this depth

TABLE 4.3 CHANGES IN DRIFT THROUGH A DAY

DATE	NOTES	qn (=q)	Water Temp. °C	Sampling Interval	Numbers and Weights (mgms.) in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Total Nos	Total Wgts.
20-210264		7,775	18.0	(1) 11-12 am	5 .77	33 13.67	2 5.08	3 5.15					43	24.67
PLACE RIP5		7,475	28.8	(2) 1-2 pm	7 1.44	32 13.27	2 5.85	3 5.40					44	25.96
SUNSET 7.07 pm	4 pm. Shade on water upstream.	7,230	22.0	(3) 3-4 pm	1 .11	19 7.19	1 .79						21	8.09
SUNRISE 5.53 am	5 pm. Sun behind hill.	6,300	21.8	(4) 5-6 pm	-	8 2.46	3 2.48						11	4.94
MOONRISE 12.39 pm	7 pm. Hatch of Caenis sp.	5,900	20.8	(5) 7-8 pm	6 1.05	19 7.23	22 19.78	5 9.40					52	37.46
MOONSET 11.27 pm (MOON 1ST QUARTER)		5,850	20.3	(6) 8-9 pm	5 .55	56 17.93	48 42.63	31 57.02	1 3.40			1 2.20	142	123.73
CLEAR SKY	9 pm. Moonlight off the water	5,825	19.7	(7) 9-10 pm	11 2.07	49 15.81	40 34.74	12 21.60		1 15.50			113	89.72
	11 pm. Very dark.	6,000	19.1	(8) 11-12 pm	10 1.81	59 18.66	34 29.64	14 25.20	3 7.52				120	82.83
		6,000	18.2	(9) 1-2 am	11 2.03	41 12.59	32 29.58	11 20.40	1 3.80				96	68.40
		6,125	17.5	(10) 3-4 am	8 1.20	40 12.57	21 18.30	6 10.80	1 3.40				76	46.27
	4 am. Small trout feeding in Run-in though quite dark.	6,250	17.1	(11) 4-5 am	6 1.15	32 11.48	13 10.48	6 10.80					57	34.27
	5 am. First light. 6 am. Big hatch of Caenis sp.	6,425	17.0	(12) 5-6 am	2 .47	10 33.13	9 7.16	2 3.60	1 3.10				24	17.46
	8 am. Sun over hill	6,740	16.1	(13) 7-8 am	3 .31	12 3.26	3 3.11	2 3.60					20	10.28
	9 am. Sun partly on water.	7,320	16.5	(14) 9-10 am	2 .61	17 5.09	1 .88	2 2.50					22	9.08

TABLE 4.4 CHANGES IN ABUNDANCE OF SOME SPECIES OF ANIMALS AROUND SUNSET IN OPEN WATER

Type Date Place	Hourly* Sampling Interval p.m.	Numbers and Weights (mgms.) in Size-Groups 1	2	3	4	5	6	7	8	9	10		Total Wgt	Total Nos.	Maximum Size-Group
Caenis sp. (mayfly mymph)	(1)		16 3.52	12 9.36	6 10.80	6 23.40	2 12.80						59.88	42	
271064	(2)	7 .77	424 93.28	407 317.46	132 237.60	9 35.10							684.21	979	(6)
	(3)		3661 805.42	2858 2229.24	931 1722.35	128 506.88							5263.89	7578	
R.I. D.P.2 Sixth Creek Drift	(4)	10 1.10	1993 438.46	1404 1095.12	425 765.00	65 253.50							2553.18	3897	
Atalophlebia albiterminata (mayfly nymph)	(1)		2 .56										.56	2	
	(2)		28 7.84	12 10.56	3 7.20	2 7.60	1 5.90						39.10	46	
as above	(3)	3 .60	55 15.40	46 40.48	26 98.40	13 98.80	9 76.60	76.30	1 13.00	1 18.50		1(11) 31.00	471.18	196	(14)
	(4)	2 .40	31 8.68	46 40.48	22 52.80	19 72.20	6 35.40	3 26.10	7 91.00	1 18.50			345.56	157	
Dinotoperla evansi (stonefly nymph)	(1)	13 1.04	21 7.14	9 7.65	3 4.65								20.48	46	
060765	(2)	27 2.16	50 17.00	70 59.50	12 18.60	3 8.10							105.36	162	(14)
	(3)	45 3.60	134 45.56	199 169.15	107 165.85	9 23.30	7 35.00	1 9.00					452.46	502	
R.I. D.P.2 Sixth Creek Drift	(4)	21 1.68	79 26.86	133 113.05	83 128.65	19 51.30	3 15.00	1 9.00					345.54	339	

* Sunset occurs at the end of interval (1)

TABLE 4.4 (Contd.)

Type Date Place	Hourly Sampling Interval p.m.	Numbers and Weights (mgms.) in Size-Groups										Total		Maximum Size-Group
		1	2	3	4	5	6	7	8	9	10	Wgt.	Nos.	
Olinga feredayi (cased caddis larva)	(1)	8 2.08	1 .79									2.87	9	
as above	(2)	70 18.20	14 11.06	2 3.10								32.36	86	(7)
	(3)	257 66.82	158 124.82	20 31.00								222.64	435	
	(4)	172 44.72	117 92.43	18 27.90								165.05	307	
Deleatidium sp. (mayfly nymph)	(1)	1 .06	3 1.02	34 31.28	8 14.40							46.76	46	
" "	(2)	-	74 25.16	617 567.64	104 187.20							780.00	795	(6)
250365	(3)	7 .42	319 108.46	786 723.12	64 115.20							947.20	1176	
R.I. P.P. 9 Sixth Creek Drift	(4)	-	120 40.80	550 506.80	58 104.00							651.20	728	
Stratiomyidae (Diptera larva)	(1)	1 .05										.05	1	
as above	(2)		3 .45	3 2.37	1 1.60		1 4.70					9.12	8	
	(3)		3 .45	13 10.27	4 6.40		5 23.50	2 13.60	2 19.60			73.82	29	(18)
	(4)		5 .75	17 13.43	9 14.40	3 9.80	4 18.80					57.18	38	

TABLE 4.4 (Contd.)

Type Date Place	Hourly Sampling Interval p.m.	Number and Weights (mgms.) in size groups											Total		Maximum Size-Group
		1	2	3	4	5	6	7	8	9	10		Wgt.	Nos.	
Gomphidae (Dragonfly larva) 190165 R.I. PP 9 Sixth Creek Drift	(1)													0	(21)
	(2)	1 .70	1 1.50	2 5.60									7.80	4	
	(3)		1 1.50	3 8.40	3 13.20	1 12.50	2 38.40	1 28.00	1 40.00			1(17) 230.00	372.00	13	
	(4)		1 1.50	3 8.40	1 4.40	1 12.50							27.80	6	
Hydropsyche sp. (caddis larva) as above	(1)													0	(14)
	(2)			2 3.75		1 4.50	1 6.60						14.85	4	
	(3)			1 1.25	1 2.40		1 6.60		2 26.00		1 23.00		59.25	6	
	(4)					1 4.50							4.50	1	
Rivissessor pattisoni (operculate snail) 060365 R.I. P.P. 9 Sixth Creek Drift	(1)	189 68.04	12 20.40	3 12.90									101.34	204	(5)
	(2)	108 38.88	12 20.40	1 4.30	1 7.90								71.48	122	
	(3)	77 27.72	9 15.30										43.02	86	
	(4)	70 25.20	7 11.90										37.10	77	

TABLE 4.4 (Contd.)

Type Date Place	Hourly Sampling Interval p.m.	Numbers and Weights (mgms) in size groups											Total		Maximum size-group
		1	2	3	4	5	6	7	8	9	10		Wgt.	Nos.	
Chironomidae (Diptera larva) 031264 R.I. D.P.2 Sixth Creek Drift	(1)	2 .08	31 4.65	24 8.16	11 6.60	7 7.00							26.49	75	(10)
	(2)	5 .20	30 4.50	22 7.48	19 11.40	1 1.00							24.58	77	
	(3)	4 .14	23 3.15	22 7.48	14 8.40	4 1.40							24.89	68	
	(4)		13 1.95	15 5.10	9 5.40								12.45	37	
Chiltonia subtenuis (amphipod-scud) 180265 Myponga Reservoir Still-water sampling by pump	(1) 6.27-6.47			1 1.00									1.00	1	(7)
	(2) 7.27-7.47	9 .45	86 28.38	144 144.0	27 58.0								230.88	266	
	(3) 8.27-8.47	8 .40	111 36.63	239 239.00	25 53.75		← At lower densities in other catches the highest numbers occurred in the catch for this interval.						329.78	383	
	(4) 9.27-9.47	-	152 50.16	292 292.00	63 135.45								477.61	507	
Paratya australiense (decapod - shrimp) as above	(1)												0	0	(23)
	(2) as above	0	0	1 .25	5 3.50	12 21.00	10 32.00	5 27.00	1 9.00			1(15) 94.00	186.75	35	
	(3)	0	4 .22	5 1.25	11 7.70	26 45.50	33 105.60	29 156.60	9 81.00	3 43.50		1(18) 190.00	631.37	121	
	(4)	1 .01	1 .06	1 .25	15 10.50	16 28.00	8 25.60	2 10.80		1 14.50		1(15) 94.00	183.72	46	

since the measurements of velocity for the flow through the nets could also be used to estimate the total flow. At sites where the water was swift and shallow the vertical profile of velocity was almost uniform. After the experiment described in section 4.2.4 samplings were made at this type of site.

However at the Run-in of P.5 there was about one foot of water in a channel wide enough for one net. Catches at this site in nets set at 0.2, 0.6 and 0.8 of the depth were made on three occasions (Table 4.5). On 271163 when the total flow was smallest the values of q decreased with depth in the ideal form. (the average of q at 0.2 and 0.8 of the depth is equivalent to q at 0.6). When the total flow was greater the vertical profile of q became more uniform. When many animals are emerging from the bed of the stream after sunset, as during the sampling on 191065, their density might be expected to be lowest at the centre and surface of a large fast moving volume of water. Before sunset there is no evidence of this tendency in the samples on 080564. On 271163 the highest density after sunset occurred near the surface presumably because the velocities at the lower depths were lower. On the three occasions the density of the catch at 0.6 of the depth is very close to at least the maximum density at one of the other positions.

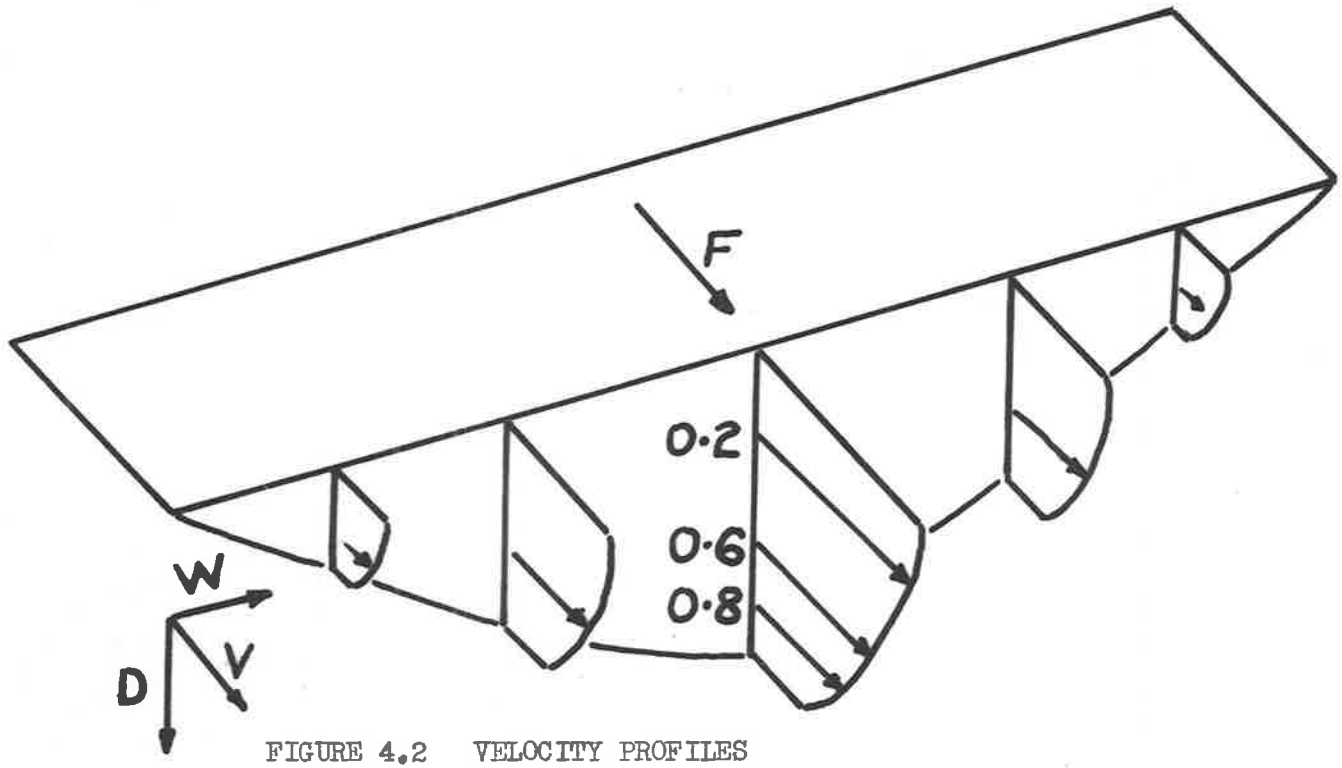


FIGURE 4.2 VELOCITY PROFILES

F = FLOW V = VELOCITY

W = WIDTH D = DEPTH

TABLE 4.5 CATCHES FROM DRIFT SAMPLING AT DIFFERENT DEPTHS

Date	Place	Total Flow (l/hr)	Sunset	Sampling Interval	qn (q)	Depth of net	Numbers and Weights (mgms) in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)		Total Nos	Total Wgts	Density (Nos/qn)
271163	R.I.P5	142,890	7.11pm	7.40-8.40 pm	24,900 (27,234)	0.2	39 2.99	124 41.62	59 39.99	19 28.00	12 35.90	2 9.70	3 27.00		1 23.50			259	208.70	.0104
	Total Depth 28 cms				21,040 (21,038)	0.6	24 2.87	93 29.09	56 37.05	24 24.75	7 13.40	1 5.80		1 5.00				206	117.96	.0098
					15,750 (15,752)	0.8	5 .33	53 19.42	36 24.11	7 9.60	6 15.10	3 12.20		1 2.50				111	83.26	.0071
080564	R.I.P5	226,530	5.27pm	4.30-5.30 pm	25,500 (28,350)	0.2	29 2.87	14 4.21	3 2.05									46	9.13	.0018
	Total Depth 27 cms				26,700 (30,807)	0.6	25 3.29	17 5.85	3 2.55		1 1.00				1 3.20			47	15.89	.0018
					25,800 (28,913)	0.8	24 2.12	10 3.16	6 5.09	1 0.60								41	9.97	.0016
191065	R.I.P5	176,990	6.33pm	7.33-8.33 pm	26,400 (30,105)	0.2	494 129.40	1116 438.53	833 713.86	197 349.80	161 447.30	50 252.70	3 27.00	2 22.80	1 18.50		1(16)	2858	2409.90	.108
	Total Depth 25 cms				25,000 (27,338)	0.6	736 192.79	1347 569.41	843 722.05	196 351.65	156 437.00	54 270.00	15 128.80	3 32.60	1 18.50			3351	2722.80	.134
					25,900 (29,027)	0.8	858 224.96	1387 635.21	803 710.69	200 356.70	181 501.70	65 326.80	8 68.90	1 13.00	3 71.00	1 31.00	1(12) 39.00	3508	2975.86	.136

4.2.3 Changes in the drift density at different total flows

Just after floods during the late winter, and early spring many nymphs of a species of Plecoptera (Dinotoperla evansi) were observed in rivulets around the rearing ponds and on logs and concrete walls in strongly flowing water. As the stream fell and cleared the stonefly nymphs vanished. These observations suggested that the drift of these nymphs was high during floods and a normal part of their life cycle. The nymphs were the most numerous food found in the stomachs of trout in Sixth Creek during the spring when the fish grew most rapidly.

The annual changes in the density and sizes of the nymphs of D. evansi in drift catches are shown in Table 4.6. Very few nymphs were found in the drift or Bottom Samples during the summer. The animals appeared to spend the summer as eggs, resistant to exposure to the air, which are laid by adults in the spring. Many very small nymphs appeared in the stream when the flow increased in the autumn each year. The nymphs live on stones in running water.

The changes in the drift of these nymphs, and also the other animals in the stream, at different total flows were therefore of interest.

The peak flow of a flood occurred about 4.30 am on 170965. Drift samples (20-minute sampling interval) were taken in each of the 3 hours after sunset on 170965, 180965 and 210965 as the flood waters abated. Details and results of the samplings are shown in Table 4.7. The maximum rate of drift occurred in the second hour after sunset, as usual, (interval (2) - nets 3 and 2) on each date. The densities of

TABLE 4.6 Changes in the density and size composition of nymphs of Dinotoperla evansi (Plecoptera) in the drift. The maximum size-group of (emerging) nymphs, in the spring, is (14).

Date Place	Sampling Interval	Numbers in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)		Total Nos.	Density (10^4 (Nos/litres)
060365 RI PP9	(1)	2	1							3	
	(2)	11	3	2	1					17	9.0
	(3)	1								1	
	(4)	2		1	2					5	
220465 RI R28	(1)	5	6							11	
	(2)	21	24	2						47	15.8
	(3)	16	18	3						34	
	(4)	6	28	2	1					37	
080564 RI P5	(1)	22	8							30	
	(2)	29	73	20						122	
	(3)	13	58	35	7	1				144	
	(4)	35	65	21	3	1				125	46.8
060765 RI DP2	(1)	13	21	9	3					46	
	(2)	27	50	70	12	3				162	
	(3)	45	134	199	107	9	7	1		502	223.6
	(4)	21	79	133	83	19	3	1		339	
310864 RI DP2	(1)	1	6	1	1	1				10	
	(2)	2	13	7	3	3	2	4		34	
	(3)	1	17	17	11	20	23	4		93	32.7
	(4)		10	6	8	8	22	4		58	
271064 RI DP2	(1)		1	1	1	2				5	
	(2)	1	4	20	22	11	20			78	
	(3)	1	4	22	26	29	79	5	1(11)	167	54.9
	(4)		7	9	12	11	32	4		75	
031264 RI DP2	(1)									0	
	(2)		2	2						4	
	(3)		2			1	3	1		7	2.5
	(4)						3			3	

Sampling intervals (1)-(4) are for the hour before and the 3 hours after sunset on each date.

TABLE 4.7 DRIFT SAMPLING AT 3 DIFFERENT TOTAL FLOWS AFTER A FLOOD IN SIXTH CREEK

PLACE: R.I. DP2 No moonlight on dates below	NET	Sampling Interval	Numbers and Weights in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(10)		Total Wgt. (mgms)	Total Nos.
170965														
Total flow 931,104 litres/hr.	3	(1) 6.28-6.48	479 83.07	1009 331.02	165 154.44	51 86.80	1 2.70	1 8.80					666.83	1706
Sunset 6.08 p.m.	3	(2) 7.28-7.48	490 109.01	1443 514.02	663 559.22	554 880.80	278 752.10	40 197.30		1 3.85		1(30) 80.00	3096.30	3470
net 3 q = 46122 litres/hour qn = 10130 litres/20mins	2	(2) 7.28-7.48	741 150.83	1353 460.15	804 694.05	550 860.80	300 809.00	58 290.90	3 24.20	1 2.50			3292.43	3810
net 2 q = 54489 litre/hr qn = 9970 litre/20 mins	3	(3) 8.28-8.48	449 100.68	993 348.15	348 298.86	169 263.10	72 22.97	14 62.80	1 6.80				1113.36	1986
180965														
Total flow 774,936litres/hr	3	(1) 6.29-6.49	216 42.15	298 111.21	44 38.88	8 12.05	4 10.80	1 3.80					218.89	571
Sunset 6.09 p.m.	3	(2) 7.29-7.49	389 88.05	1111 330.75	379 314.70	143 222.75	62 168.50	15 76.80			1 24.00		1225.55	2100
net 3 q = 38565 litre/hr qn = 9780 litre/20mins	2	(2) 7.29-7.49	478 99.35	1418 422.58	331 273.38	137 214.50	59 163.20	19 92.30	4 46.80	1 9.80			1321.91	2447
net 2 q = 45720 litre/hr. qn = 10130 litre/20mins	3	(3) 8.29-8.49	280 63.63	752 233.53	182 156.28	59 93.25	24 65.20	4 20.00	1 1.90				633.79	1302
210965														
Total flow 546,714litre/hr	3	(1) 6.31-6.51	142 26.24	170 29.23	24 68.36	2 29.23	3.15	1	5.00				131.98	339
Sunset 6.11 p.m.	3	(2) 7.31-7.51	166 34.52	720 200.70	148 120.59	32 58.75	31 87.10	14 70.00	1 9.00		1 53.00		633.66	1113
net 3 q = 31323 litres/hr qn = 8970 litres/20mins	2	(2) 7.31-7.51	158 32.04	1001 280.16	237 204.47	24 38.35	20 55.10	7		1 13.00			656.23	1448
net 2 q = 38226 litres/hr qn = 9730 litres/20mins	3	(3) 8.31-8.51	98 20.01	490 140.54	108 88.26	19 30.35	9 26.40	3 16.60		1 13.00	1 17.00		352.16	729

Table 4.8 Numbers and densities of the species in the catches shown in Table 4.7 (density as Nos./litre)

	Dinotoperla evansi	Caenis sp.	Atalophlebia albiterminata	Olinga feredayi	Rivissessor sp.	Total
170965 Q = 931,104 litres/hour. Net 3 q = 46122 l./hr. Net 2 q = l./hr. qn = 10130 l./20mins. qn = 9970 l./20mins						
(1) Net 3	586 .0578	757 .0747	12 .0012	319 .0315	20 .0020	1706 .1684
(2) Net 3	1885 .1861	936 .0924	20 .0020	597 .05893	10 .0010	3470 .3425
(2) Net 2	1995 .2001	1101 .1104	21 .0021	659 .0061	10 .0010	3810 .3821
(3) Net 3	779 .0769	623 .0615	14 .0014	546 .0539	4 .0004	1986 .1961
180965 Q = 774,936 l./hr. Net 3 q = 38565 l./hr. Net 2 q = 45720 l./hr. qn = 9780 l./20mins qn = 10130 l./20mins						
(1) Net 3	102 .0104	265 .0271	4 .0004	188 .0192	4 .0004	571 .0584
(2) Net 3	484 .0495	1162 .1188	13 .0013	430 .0440	5 .0005	2100 .2147
(2) Net 2	497 .0491	1446 .1427	10 .0010	458 .0452	17 .0017	2447 .2416
(3) Net 3	236 .0241	726 .0742	3 .0003	320 .0327	7 .0007	1302 .1331
210965 Q = 546,714 l./hr. Net 3 q = 31323 l./hr. Net 2 q = 38226 l./hr. qn = 8970 l./20mins. qn = 9730 l./20mins.						
(1) Net 3	73 .0081	147 .0164	1 .0001	99 .0110	14 .0016	339 .0378
(2) Net 3	181 .0202	747 .0833	6 .0007	162 .0181	9 .0010	1113 .1241
(2) Net 2	184 .0189	1068 .1098	7 .0007	167 .0172	15 .0015	1448 .1488
(3) Net 3	102 .0114	502 .0560	5 .0006	110 .0123	4 .0004	729 .0813

the total catches were greatest at the highest flow (Figure 4.3). This result was also true for the plecopteran nymphs (Figure 4.3) which were the most abundant animal at the highest flow and for Olinga feredayi (cased caddis larva) and Atalophlebia albiterminata (mayfly nymph) - Table 4.8. However nymphs of Caenis sp. (mayfly nymph), which were the most numerous animals in the catches at the lower flows, were densest at the intermediate flow. There was no indication from the changes in the drift on each date, or from the appearance of the animals in the samples, that they had been forcibly removed from the substrate, or injured.

4.2.4 Drift at different places

To establish the sampling of drift food on a routine basis it was necessary to know whether the rate of drift varied along the study section. Needham (1930) concluded that pools in streams acted as catch basins for animals swept down from the stickles above them. Muller (1954) found great variations in the drift rate at different positions in the stream and at different times of the year. He did not meter the flow through the drift nets or, at that time, account for diurnal changes. Tanaka (1960) estimated the apparent flow of water through single drift nets which he set at two places in a stream. But he did not use these values to explain differences in the drift. Waters (1962b) stated that "the drift rates fluctuate along the course of the stream, depending on the relative size and occurrence of pools and riffles". The data for this statement was not published but presumably, from his other work, the flows through the nets were not metered and the catches were measured volumetrically.

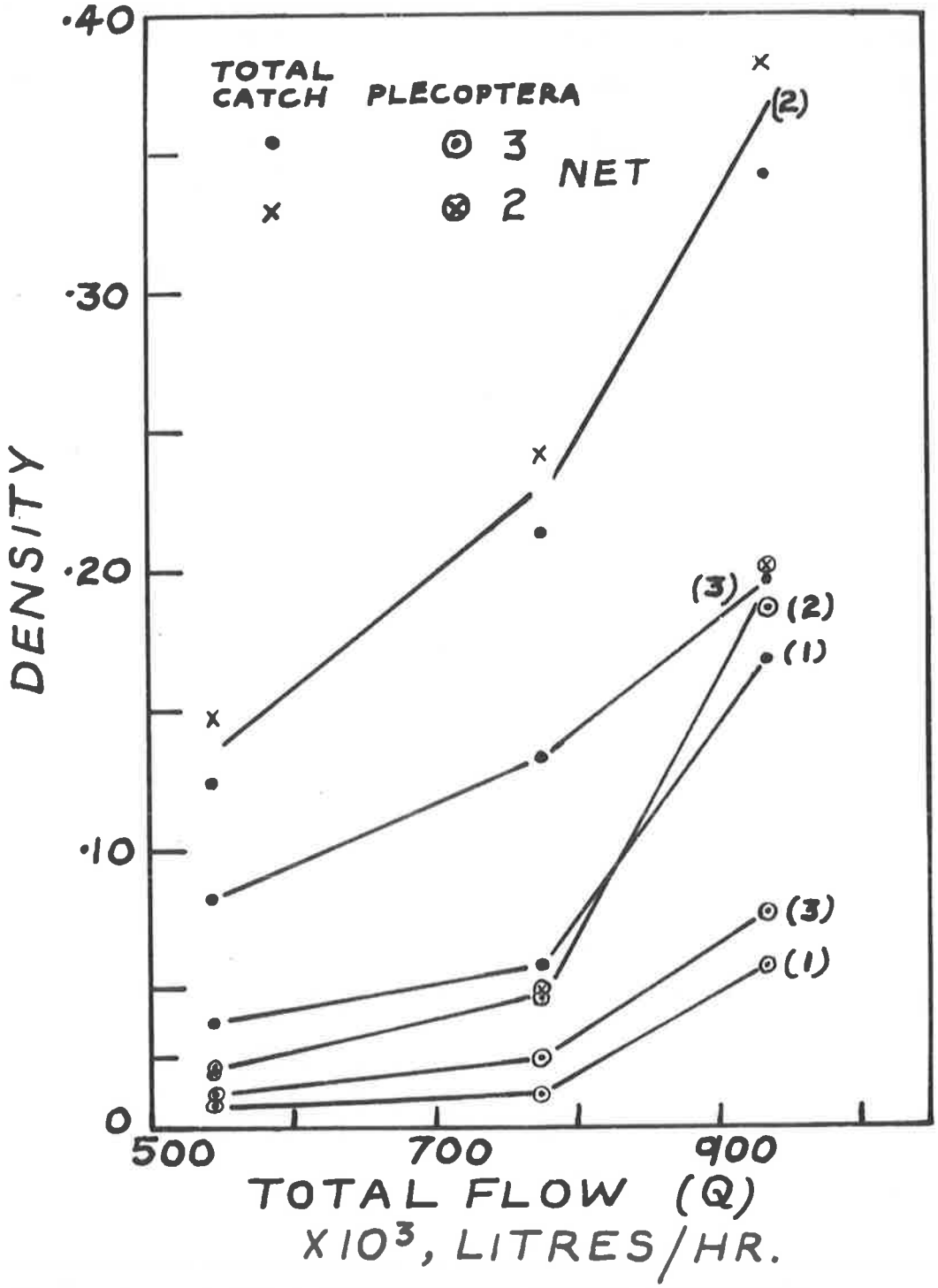


FIGURE 4.3 GRAPH OF THE DENSITIES FOR THE TOTAL CATCH FOR PLECOPTERAN NYMPHS ON TOTAL FLOW

The drift rate in the study section was estimated between 200264 and 020464 at 9 of the places where bars had been set across the stream earlier (the 10th at the Run-out of DP2 was not covered by an appreciable flow of water). The lengths of Stickle immediately above the bars varied greatly (Table 4.9). Since the total flow was small at this time of the year the velocity of the current through the pools was very small and large differences in the drift rates were expected.

Samples were taken over one hour starting one hour after sunset. Nets were set at 0.6 of the depths above the bars. The catches are shown in Table 4.10 (Copepoda and Daphnidae are not included). The initial plot of the total number in each catch on the flow through the net (qn) showed considerable additional variability (Figure 4.4). However the scatter could not be explained by the nature of the stream above the sampling site. Instead differences in the velocity profile of the cross-section of the stream at each site were found to be the most probable cause. At the Run-ins (RI) of P5, P2, R28, DP4 and DP5 the stream was very narrow, the current relatively strong, and there was little slack water around the net(s). The differences in the catches at these places were largely caused by differences in the value of qn. Using the points for these places as a trend reference, the catches in nets 2 and 3 at the RI P3, net 2 at RI DP1 and net 2 at RI PP9, in comparison, were much higher. At RI P10 the catch for net 2 was below this trend. The flow through the nets on the sides at these places was very small. A large part of the rather high catches in these side nets appeared to

Table 4.9 Types of water immediately upstream from the food sampling sites in Table 4.10

Sampling Site	Types of water upstream to and including the next pool (lengths in feet)
RI P5	RI(30), S16(10), PP7(18), S17(13), R17(14), PP8(15); P6(51).
RI P3	S12(76); DP2(131).
RI DP1	R11(20), S7(21), PP3(13), S8(19); SP9(31).
RI P2	SP5(60).
RIP10	SP18(40).
RI PP9	S28(25), R32(34); SP15(43).
RI R28	S25(20), P7(32).
RI DP4	S36(10), R45(13), S37(10), R46(22); SP20(100).
RI DP5	R49(25); SP22(86).

Data from the survey of the study section in November and December 1963.

RI = Run-in, S = Stickle (Riffle), R = Run, PP = Pocket Pool,

SP = Shallow Pool, P = Pool, DP = Deep Pool.

TABLE 4.10 CATCHES OF DRIFT ANIMALS AT DIFFERENT PLACES ALONG SIXTH CREEK

Date	Place	Q Total Flow (litres/hr)	Sunset pm	Water temperature °C	qn, (q) litres/hr.	Net	Numbers and Weights (mgms) Size Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)				Total Nos	Total Wgts	Density (Nos/qn)
200264	RI P5	29,710	7.07	20.1	5850 (5850)	n_1	5 .55	56 17.93	48 42.63	31 57.02	1 3.40			1 2.20						142	123.73	.024
090364	RI P3	54,430	6.43	18.7	1750 (1750)	n_1	27 6.20	29 17.26	36 35.45	10 18.00	1 4.50	1 29.00								104	110.41	.0937
					4,740 (4,740)	n_2	104 28.63	75 36.43	73 82.07	33 67.40	3 10.20	1 1.40								289	226.13	.0390
					18,050 (18,050)	n_3	57 13.12	88 41.92	162 168.93	58 124.51	5 46.20				1 3.20					371	397.88	.0115
					2,780 (2,780)	n_4	58 16.48	36 16.98	50 52.02	17 37.50	1 3.40		2 45.00							164	171.38	.0374
130364	RI DP1	52,250	6.37	18.3	460 (460)	n_1	11 2.08	14 5.16	19 19.06	17 45.00	2 6.80									63	78.10	.137
					12,890 (12,890)	n_2	40 7.78	92 54.11	119 108.95	75 135.82	18 66.80	2 6.10		1 13.00						347	392.56	.0154
					428 (428)	n_3	9 2.06	18 11.68	32 29.31	19 34.20	6 20.90	1 4.70								85	102.85	.199
	RI P2				31,000 (43,070)	n_1	44 7.22	138 56.37	196 184.39	91 173.95	10 32.90	7 44.10	2 43.20	1 35.00			1(12) 108.00	2(19) 760.00		492	1445.13	.0163
250364	RI P10	112,390	6.20	17.3	1,296 (1,296)	n_1	8 1.25	22 5.43	6 6.30	9 16.01	1 3.40									46	32.29	.0355
					14,380 (14,380)	n_2	5 .67	29 8.16	23 21.16	13 24.00	3 7.20									73	61.19	.0132
					5,738 (5,738)	n_3	8 1.08	37 11.92	18 16.29	8 14.40										71	43.69	.0124

TABLE 4.10 (Contd.)

Date	Place	Q Total Flow (litres /hr.	Sunset pm	Water temperature °C	qn (q) litres /hr.	Net	Numbers and Weights (mgms) Size Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)				Total Nos	Total Wgts	Density* (Nos/qn)
	RI PP9				24,700 (26,730)	n_1	55 13.88	135 52.75	105 103.03	56 106.35	6 31.60	3 15.30					1(11) 12.00	1(18) 41.00	1(20) 41.00	363	460.91	.0141
					30,300 (45,547)	n_2	46 8.30	331 110.46	221 215.56	95 168.74	16 49.50	4 12.20	4 31.70				1(14) 165.00			718	761.46	.0178
					2,297 (2,297)	n_3	23 3.29	100 25.72	35 31.46	16 28.20	4 14.10	1 1.40		1 9.80						180	114.08	.0784
260364	RI R28	127,550	6.18	18.3	27,250 (32,206)	n_1	47 12.24	136 44.46	115 106.67	40 69.42	7 21.70	8 96.10					1(12) 4.30			354	354.89	.0126
					19,548 (19,548)	n_2	13 2.07	85 28.15	110 106.62	45 78.41	1 2.70									254	217.95	.0130
020464	RI DP4	54,330	6.09	17.0	20,680 (20,680	n_1	11 1.84	126 35.17	98 87.94	61 100.49	8 30.40	1 1.35								305	257.19	.0148
	RI DP5				24,300 25,970)	n_1	59 8.14	177 53.20	64 62.37	48 87.58	15 41.70	2 16.00	3 10.60				1(16) 9.80			369	289.39	.0133

* Density is calculated using corrected numbers where appropriate, see text.

be a measure of the nett movement of the animals at right angles to the flow. In the case of RIs P3, DP1 and PP9 into, and at RI P10 out of, the centre of the current. For RIs P5, P2, R28, DP4 and DP5 the nett movement across the current is close to zero most probably because movements in and out of the current are equal in magnitude. At RI P3, DP1 and PP9 the stream was narrowing and the current quickening before flowing on into the still water. At RI P10 the stream was already widening, deepening, and the current slowing in the pool.

Therefore the following corrections were made. For RI P3 the catches for net 1 and net 4 were subtracted from those for nets 2 and 3 respectively. For RI DP1 the catches for both net 1 and net 3 were subtracted from that for net 2 and for RI PP9 the catch for net 3 from that for net 2. In the case of RI P10 the catches for net 1 and net 3 were added to that of net 2 (Table 4.11). A replot of the data (omitting catches in the side-nets mentioned above) is shown in Figure 4.5. The points now show a consistent trend.

Table 4.11 Results of corrections applied to certain of the catches shown in Table 4.10

Place	Net	Corrected Nos	Corrected Weights
RI DP1	N_2	199	211.61
RI P10	N_2	190	137.17
RI PP9	N_2	538	647.38
RI P3	N_2	185	115.72
	N_3	207	226.50

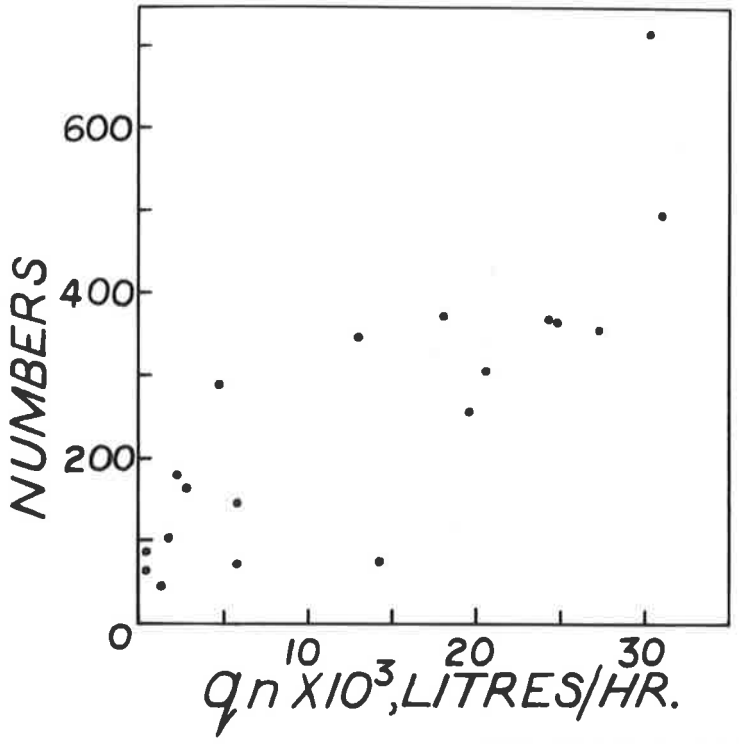


FIGURE 4.4 GRAPH OF THE TOTAL NUMBERS IN DRIFT CATCHES (TABLE 4.10) ON THE ACTUAL FLOW (qn) THROUGH THE SAMPLING NET

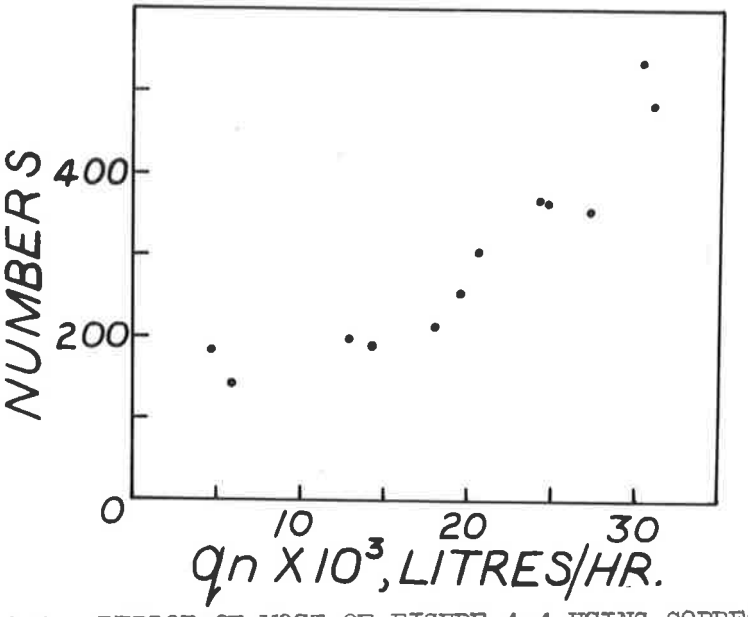


FIGURE 4.5 REPLOT OF MOST OF FIGURE 4.4 USING CORRECTED CATCH NUMBERS

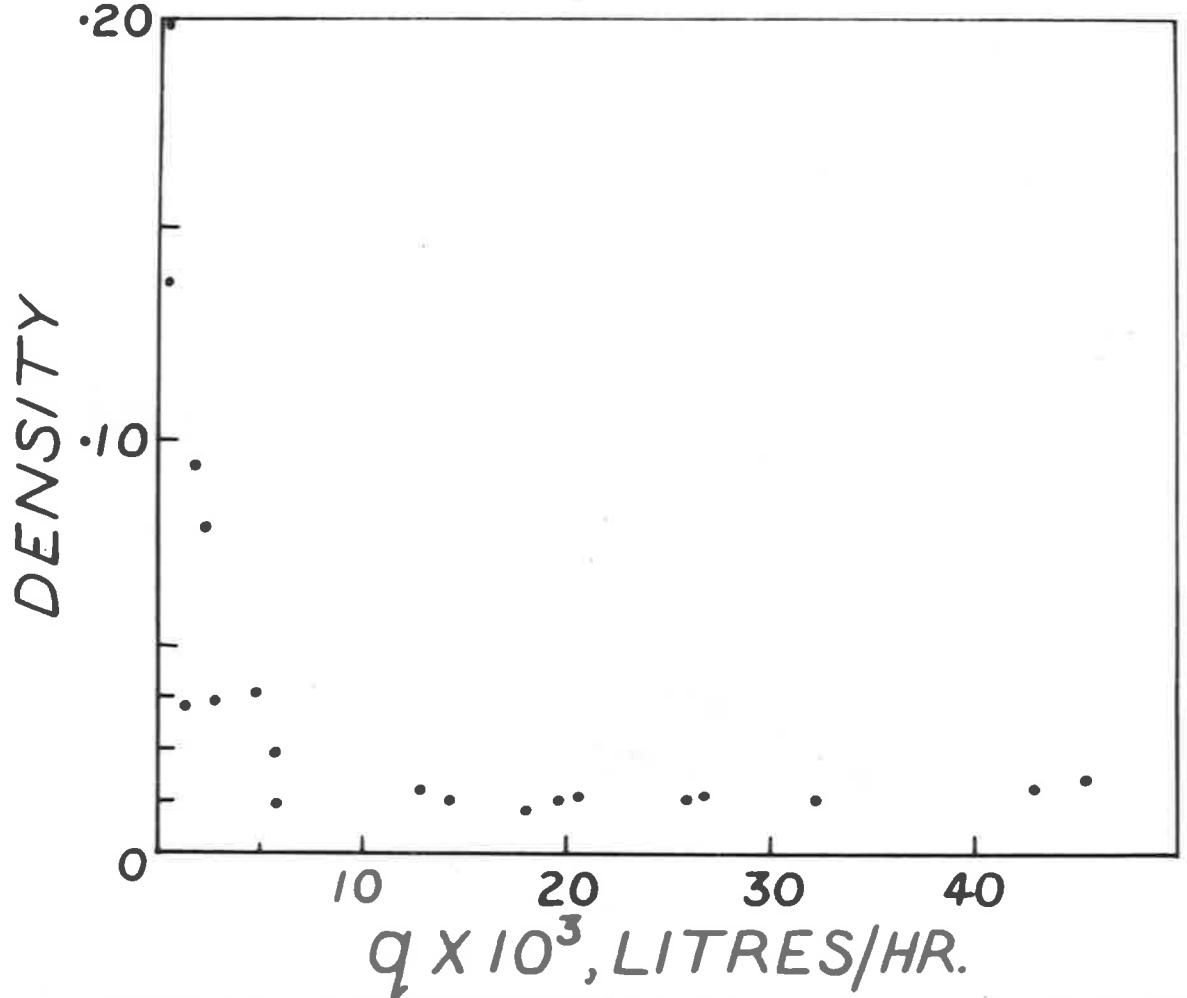


FIGURE 4.6 GRAPH OF DENSITIES OF DRIFT CATCHES AT DIFFERENT PLACES ON THE APPARENT FLOWS THROUGH THE NETS (q)

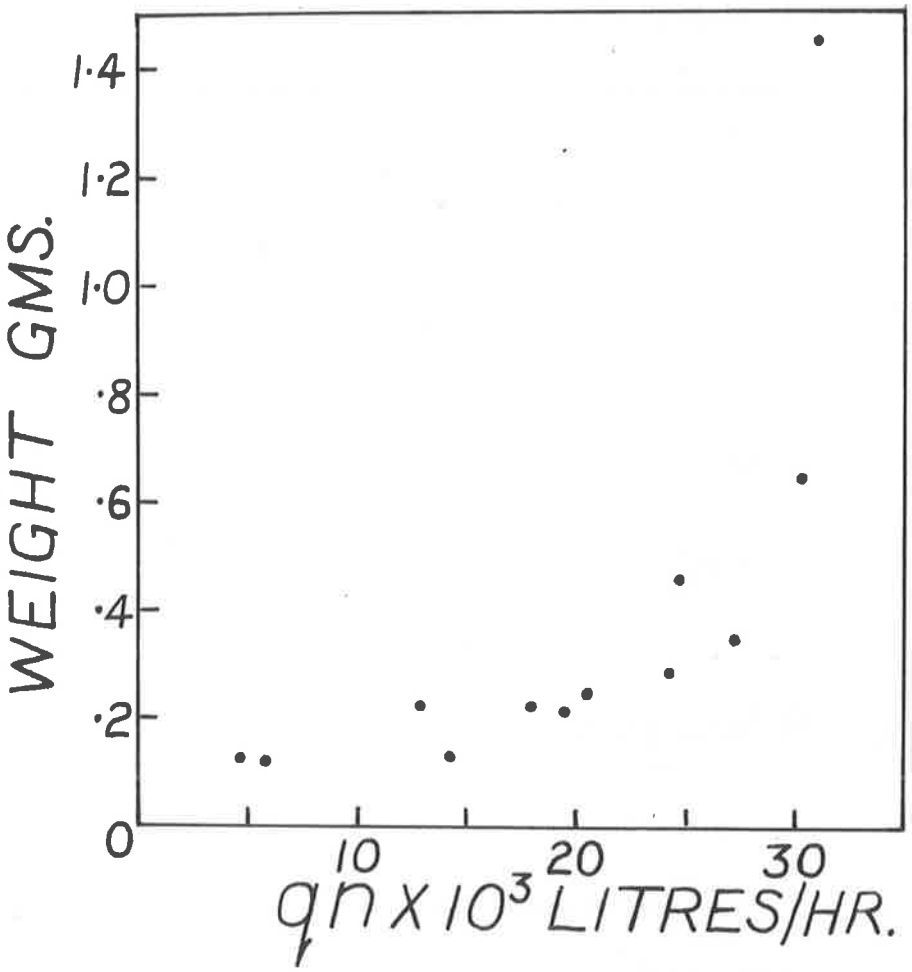


FIGURE 4.7 GRAPH OF THE TOTAL WEIGHTS OF DRIFT CATCHES AT DIFFERENT PLACES ON THE ACTUAL FLOWS THROUGH THE NETS (q_n)

TABLE 4.12 SPECIES COMPOSITION OF THE DRIFT SAMPLE FROM RI P2, 130364

SIZE GROUP	Caenis	Deleatidium	Atalophlebia	Hydropsyche	Chironomidae pupae	Stratiomyidae	Gomphidae	Corduliidae	Zygoptera	Others
(1)	21			1					1	Ameria (1) 4, (3) 1
(2)	34	45	9	1	1	2	4	1	1	Rivisessor (1) 6, (2) 4
(3)	10	168	4	5	1	1	1	1		Hydroptilidae (2) 32
(4)		73	5	6		2		1	1	Rhycophilidae (4) 1
(5)	1	6	1		1	1				Chironomidae (2) 1 larvae)
(6)			2		1	3		1		Sphenedae (1) 2, (2) 2, (3) 1
(7)							1	1		
(8)								1		Empididae (3) 1
(9)										Limnophilidae (4) 1
(10)										Olinga (1) 5, (4) 1
								1 (12)		Ostracoda (1) 2, (2) 1
										Hydracarina (1) 2
Total	66	292	21	13	4	11	6	9	3	67
										Total 492

The plot of density (total numbers/qn, using corrected numbers where appropriate, last column Table 4.10) on the apparent flow through the net is shown in Figure 4.6.

Henceforth in the study sites with characteristics necessitating corrections of the catches were avoided, or modified by restricting the flow to the width of a single net.

At the higher flows larger items, a few of which (Corduliidae and Gomphidae - dragonfly nymphs) were particularly large, occurred in the catches (Table 4.12). The plot of total weight of catches on qn illustrates the ability of higher flows to carry heavy items along the stream (Figure 4.7). (An alternative explanation that these large heavy items only occur in catches from nets with high values of qn because they have a very low frequency of occurrence is unlikely because none of the other catches contained them). This phenomenon is of particular interest because the fish, especially the larger ones, occupy feeding positions in running water similar to those where the nets with high values of q were set.

4.2.5 The drift into, through and out of a pool

A common observation is that trout living in a pool in a stream feed in the current both at the Run-in and Run-out of the pool. This suggests that the drift out of a pool may be of the same magnitude as, and independent of, the con-current drift into the pool.

On 201264 nets were set at the Run-in and Run-out of P5 (Map 6). The scheme of the sampling and the results of the experiment are shown in Table 4.13. Net 1 and net 2 were alternately set at the

Upper. A drift sampling net set at the Run-in of D.P. 2 when the Sixth Creek was flowing strongly (170865.)

Lower. A net set at the Run-in of P.P.9 when the flow was small (250365).





Run-in and Run-out, respectively, in 6, 20-minute, periods around sunset. Since the total flow was fairly high there was an appreciable current through the pool. So a larger net (opening 20 cms deep by 50 cms wide) of the same material was set at the Run-in with net 2 at the Run-out at the same time in 3 other, 20 minute, periods. The sampling interval was 19 minutes because 1 minute was needed to change the nets at the end of each 20 minute period.

The smooth curve of the trend in the densities (based on qn) of the catches with time is shown in Figure 4.8. The density for net 2 is slightly higher than that for net 3, set in the same period, on the ascending part of the curve and lower on the descending limb because net 2 was set and retrieved 1 minute later in the same period. The density for net 3 is based on a qn (multiplied by 4) read from the calibration curve for the smaller nets using the value of q (from measurements of velocity at 9 points at the net position) for net 3 divided by 4. Although net 3 filtered about 1/3 of the total flow into the pool this removal apparently did not influence the catch made by net 2 set at the same time at the Run-out.

The densities of the drift into and out of the pool are (about) the same but the animals coming into the pool do not (immediately) form the drift out of the pool (see Section 4.2.7).

MAP 6 POOL 5 (P5) - SIXTH CREEK

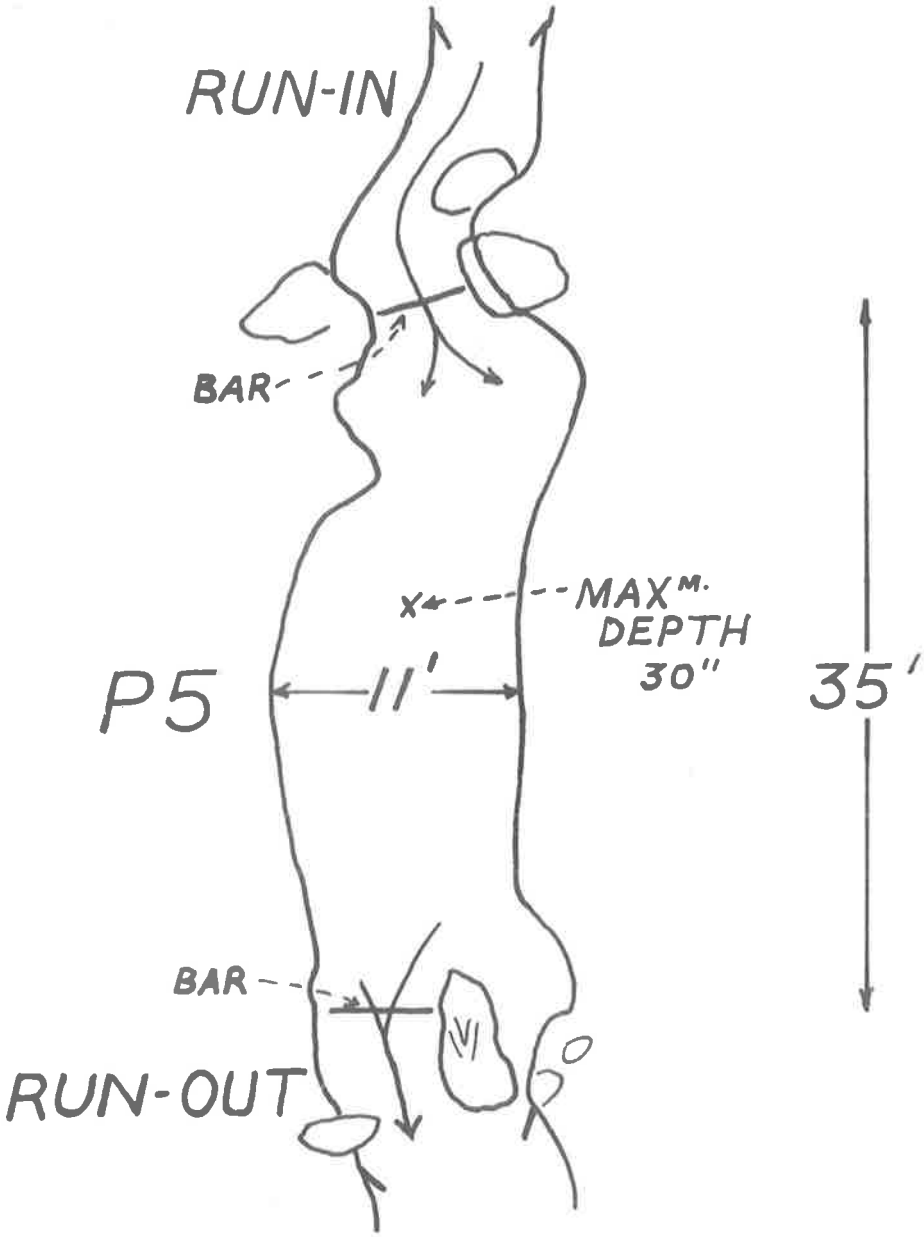


TABLE 4.13 DRIFT CATCHES FROM SAMPLING AT THE RUN-IN AND RUN-OUT OF A POOL

DATE:
201264
PLACE:
P5
SUNSET:
7.28 pm
MOONRISE SET
8.53 pm 5.44 am
(full moon on 19th)

TOTAL FLOW:
326,040 litres/hr.
(no change during sampling)

q : litres per hour

net 1 . 33,872.4
net 2 . 56,026.8
net 3 .131,400

qn:litres per 19 mins

net 1 . 8,835
net 2 . 9,466
net 3 . 34,830

Sampling Interval p.m.	Net	Numbers in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	Total Wgts (mgms)	Nos.	Density (Nos/qn)
(1) 7.28-7.47	1	16	18	8	5	1						23.41	38	.0043
(2) 7.49-8.08	2	11	24	26	14	1	1					39.40	77	.0081
(3) 8.08-8.27	3	62	181	181	88	23	10	2	3	2	1	705.22	553	.0159
(3) 8.09-8.28	2	20	78	75	24	8	4					152.71	209	.0221
(4) 8.28-8.47	1	16	213	192	68	21	4	2	2			491.07	518	.0586
(5) 8.49-9.08	2	3	340	314	105	40	2	1		1		705.15	806	.0851
(6) 9.08-9.27	3	56	726	649	232	70	7	3	3	3		1544.94	1749	.0502
(6) 9.09-9.28	2	4	189	167	60	24	2					426.55	447	.0172
(7) 9.28-9.47	1	10	122	117	38	18	2	1				271.38	308	.0349
(8) 9.49-10.08	2	14	112	91	28	11	1					202.14	257	.0271
(9) 10.08-10.27	3	22	254	224	74	26	12	3	1			617.85	616	.0177
(9) 10.09-10.28	2	3	60	50	18	9	1			1		172.05	142	.0150

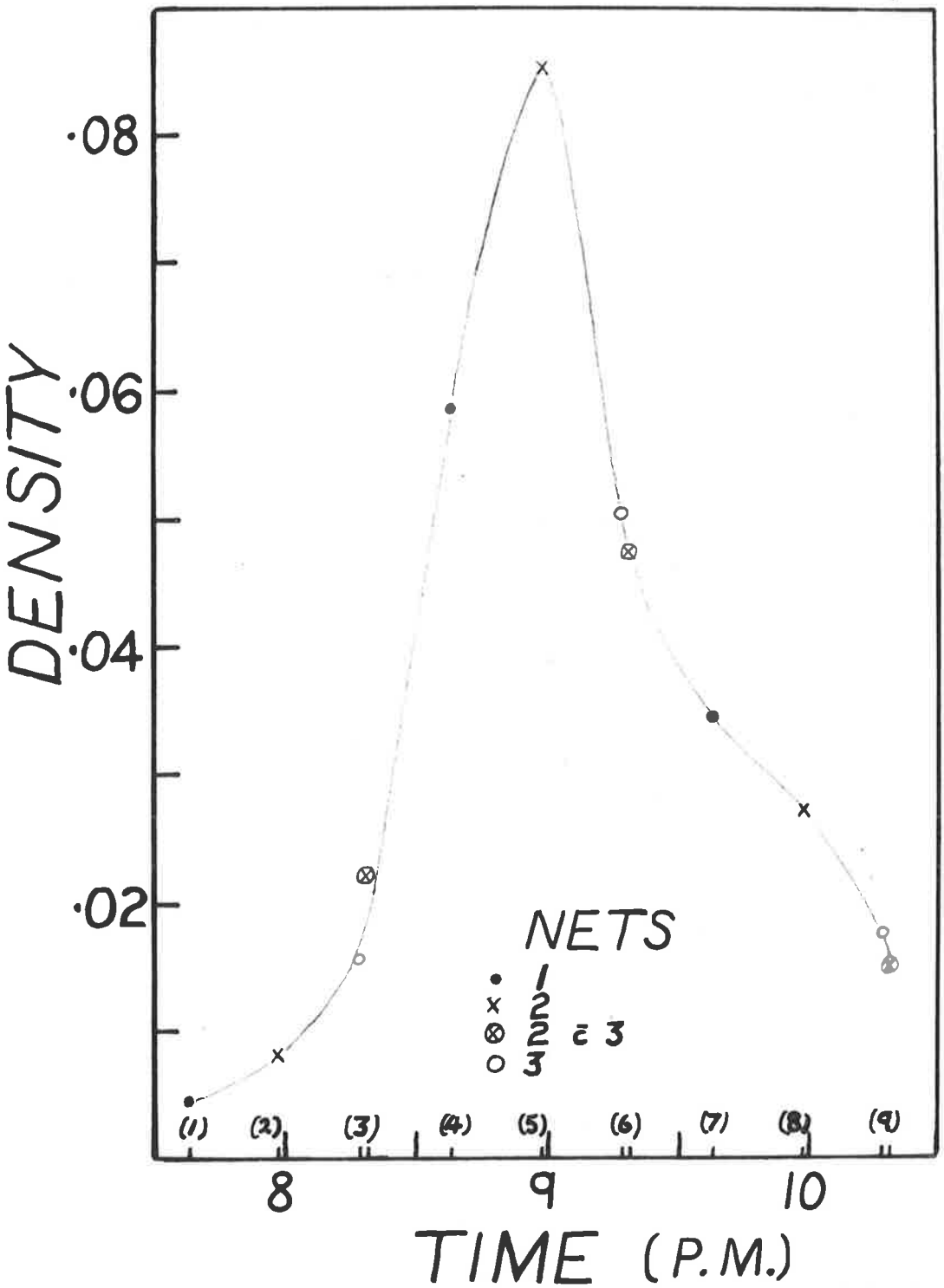


FIGURE 4.8 GRAPH OF THE DENSITIES OF CATCHES IN TABLE 4.13 ON TIMES AROUND SUNSET

4.2.6 Drift down a Stickle

In the spring of 1965 an attempt was made to find out how far the animals in the drift were carried by the current down a Stickle between two pools. From the relatively close spacing of fish along the stream (3.2.2); and the discussion at the close of 4.2.1a; this distance might be expected to be fairly short.

The longest Stickle in the study section - S12 - was chosen. On 201065 and 211065 the diminishing flow of the stream was small enough to allow a net of brass mesh (40 meshes/inch) large enough to filter all the flow to be set across the stream. At this time of the year the drift density was high allowing short (10 min.) sampling intervals and the important species of invertebrates were present. A sampling bar was already set at the lower end of the Stickle (site RI P3) and 3 more bars were set above this site during the previous winter. The positions of the bars are shown (somewhat diagrammatically for clarity) on Map 7. The lowest bar (4) was set just above the constriction of the stream before it ran on into P3 and the other bars (3, 2, and 1) similarly just above the other 3 narrower parts of the stickle. At bars 1, 2 and 3 the stream was further constricted with stone walls, and a metal deflector at bar 1, so that all the flow would pass through the large stop net (opening 40" wide by 8" deep).

On 201065 the drift was sampled in the usual way at bar 1 near the top of the stickle and at bar 4 55' downstream. The sampling details and results are shown in Table 4.14. The density of the drift was somewhat higher at the top end of the stickle.

MAP 7 - STICKLE 12 (S12) - SIXTH CREEK

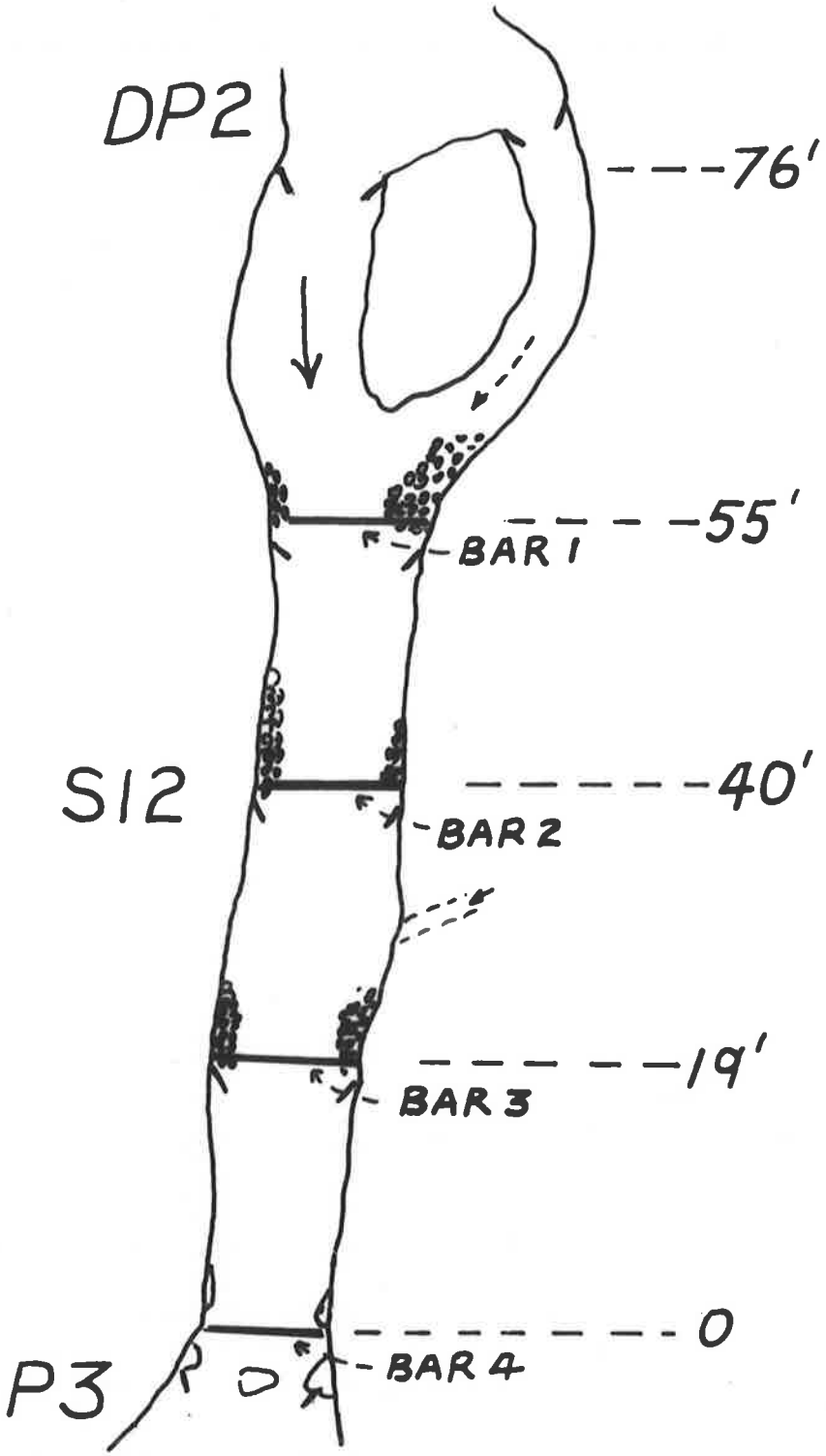


TABLE 4.14 DRIFT CATCHES FROM SAMPLING NEAR THE LOWER AND UPPER ENDS OF A STICKLE

		Sampling Interval p.m.	Numbers in Size-Groups											Total		Density (Nos/qn)
			1	2	3	4	5	6	7	8	9	10			Wgts (mgms)	Nos.	
Date 201065	For Net 1 at Top of Stickle	(3) 8.14-8.24	173	437	261	45	7	2		1			1(17)	1(19)	976.39	928	.183
Place S12	q = 45720 litres/hour	(5) 8.44-8.54	161	371	214	31	4	2			1				346.22	784	.155
Sunset 6.34 pm	qn = 5060 litres/10 mins	(7) 9.14-9.24	140	323	160	14	5	1		1	1				378.29	645	.128
no moon	For Net II at Bottom of Stickle	(1) 7.29-7.39	154	319	102	40	15	2		1		1			494.21	634	.127
Total Flow (Q) 257,587 litres/hour		(2) 7.59-8.09	184	465	193	51	10	3							515.11	906	.181
	q = 42707 litres/hour	(4) 8.29-8.39	179	361	128	31	11	3	1	1					426.88	715	.143
	qn = 5000 litres/10 mins	(6) 8.59-9.09	96	326	128	33	16	1							367.68	600	.120
Date 211065	For Net II at Bottom of Stickle	(1) 7.30-7.40	258	324	122	43	14	1					1(12)	1(17)	690.93	764	.153
Place S12		(2) 8.00-8.10	220	362	87	32	7	3	1				1(16)		567.68	713	.143

TABLE 4.14 (Contd.)

		Sampling Interval p.m.	Numbers in Size-Groups											Total		Density
			1	2	3	4	5	6	7	8	9	10		Wgts (mgms)	Nos.	(Nos/qn)
Sunset 6.35pm no moon	q = 41443 litres/hour	(4) 8.30-8.40	173	349	73	26	12					1		329.66	634	.127
Total flow(Q) 214,757 litres/hour	qn = 4980 litres/10 mins	(6) 9.00-9.10	73	192	29	17	3							167.51	314	.063
at Bar 1 7.40-8.10 pm at Bar 2 8.10-8.40 pm at Bar 3 8.40-9.10 pm	STOP NET															

On 211065 the samplings were repeated at bar 4 during the same intervals of time after sunset. In addition the large stop net was set at bar 1 during interval (2), at bar 2 during interval (4), and at bar 3 during interval (6). The stop net was set, from a plank lain across the stream at least 10 minutes before the sampling with the small net was started at the lowest bar.

The degree of reduction of the catches on the second day, in comparison to those on the first day, should therefore give estimates of the percentage of animals moving over bars 1, 2 and 3 which were carried on to pass over bar 4.

The density of the catch in net 2 was higher on the second day for interval (1). The densities for catches in net 2 on the first date were therefore multiplied by the ratio of the catch density for interval (1) on 211065 to the density for the same interval on 201065 - (Table 4.15). This assumes that the same proportional increase occurred in intervals (2), (4) and (6). The densities for intervals (2), (4) and (6) on 211065 were then subtracted from the corresponding (corrected) densities on 201065 and then these differences were divided by the latter densities and multiplied by 100. The values thus obtained were the percentage reductions in catches over bar 4 on the second date when the stop net was set varying distances upstream from bar 4 (Table 4.16).

The percentage reduction for the total catch is lower for interval (4) when the stop net was set at bar 2 than in the previous interval (2) when it was at the furtherest bar up the Stickle. The obvious explanation for this irregularity at first seemed to be that

Table 4.15 Numbers and densities of most of the species present in the drift catches shown in Table 4.14

Date Sampling Interval Net	SPECIES						Total
	Dinotoperla evansi	Caenis sp.	Deleatidium sp.	Atalophlebia albiterminata	Olinga feredayi	Rest	
201065							
(3) Net 1	56 .0111	503 .0994	97 .0192	17 .0034	227 .0449	28 .0055	928 .1834
(5) Net 1	40 .0079	424 .0838	67 .0132	20 .0040	218 .0431	15 .0030	784 .1549
(7) Net 1	23 .0045	322 .0636	52 .0103	12 .0024	205 .0405	31 .0061	645 .1275
201065							
(1) Net 2	62 .0124	221 .0442	37 .0074	18 .0036	254 .0508	42 .0084	634 .1268
(2) Net 2	55 .0110 .0132	495 .0990 .1062	43 .0086 .0147	26 .0052 .0078	253 .0506 .0632	34 .0068 .0078	906 .1812 .2183
(4) Net 2	31 .0062 .0074	350 .0700 .0751	26 .0052 .0089	15 .0030 .0045	267 .0534 .0667	26 .0052 .0060	715 .1430 .1723
(6) Net 2	29 .0058 .0070	316 .0632 .0678	27 .0054 .0092	8 .0016 .0024	198 .0396 .0495	22 .0044 .0050	600 .1200 .1446
211065							
(1) Net 2	74 .0149	236 .0474	63 .0127	27 .0054	316 .0635	48 .0096	764 .1528
(2) Net 2	50 .0100 .0031	321 .0645 .0417	37 .0074 .0073	16 .0032 .0046	259 .0520 .0112	30 .0060 .0018	713 .1432 .0751
(4) Net 2	40 .0080 .0014	316 .0635 .0116	20 .0040 .0049	9 .0018 .0027	234 .0470 .0198	15 .0030 .0030	634 .1273 .0450
(6) Net 2	21 .0042 .0027	151 .0303 .0374	13 .0026 .0066	6 .0012 .0012	110 .0221 .0274	13 .0026 .0024	314 .0631 .0815
Correction Factor	1.1984	1.0722	1.7095	1.5056	1.2490	1.1475	1.2050

Table 4.15 (Contd.)

In each cell the uppermost number is the absolute number of animals and below this is the density based on qn. For net 2 on 201065 the lowermost number, for intervals (2), (4) and (6), is the density multiplied by the correction factor in the last row. The correction factor is the ratio of the density for net 2 on 211065 in sampling interval (1) to the density for net 2 on 201065 in the same interval. The lowermost number for net 2, intervals (2), (4) and (6) on 211065 is the difference between the corrected density for net 2 on 201065 and the density for net 2 on 211065.

Table 4.16 The percentage number of animals of different species in the drift that were carried by the current to the lower end of S12 from 3 distances upstream

Distance Upstream from Bar 4	Dinotoperla evansi	Caenis sp.	Deleatidium sp.	Atalophlebia albiterminata	Olinga feredayi	Rest	Total
55'	23.8	39.3	49.7	59.0	17.7	22.8	34.4
40'	18.8	15.5	54.8	60.0	29.7	49.5	26.1
19'	39.3	55.3	71.7	50.0	55.3	48.3	56.4

The difference in density between catches on 201065 and 211065, shown as the lowermost numbers for net 2 in intervals (2), (4) and (6) on 211065 in Table 4.15, have been divided by the corrected density for net 2 in the corresponding intervals on 201065 and then multiplied by 100.

the stop net was not set correctly at bar 2 and some of the water was not filtered. However the values for the species which were most abundant in the catches show that this trend did not occur in all cases (Figure 4.9). Table 4.16a gives the relative numbers (%) of the predominant species in the catches shown in Table 4.15. For Cacnis sp., which shows the largest discrepancy for sampling interval (4), the relative number has almost the same value on the two dates.

The catch in a drift net is a measure of the movement of animals down the stream in the current and also of movements into and out of the current. If all the animals which are picked up by the current down a Stickle, were to be carried to the lower end of the Stickle the density of the drift there would be very much greater than at the upper end. Since this has been shown not to be the case the majority of the animals must either drift a very short distance or the majority of the animals must drift from near the upper end of the Stickle. In any case the drift density at any point along the stream is the nett result of the numbers of animals moving out from cover varying distances upstream, and being picked up by the current, and the distance they drift before moving out of the current.

The answer to this complicated problem may then reside in changes in the behaviour of the animals with time through sampling intervals (2), (4) and (6), the extent of which is different for each species.

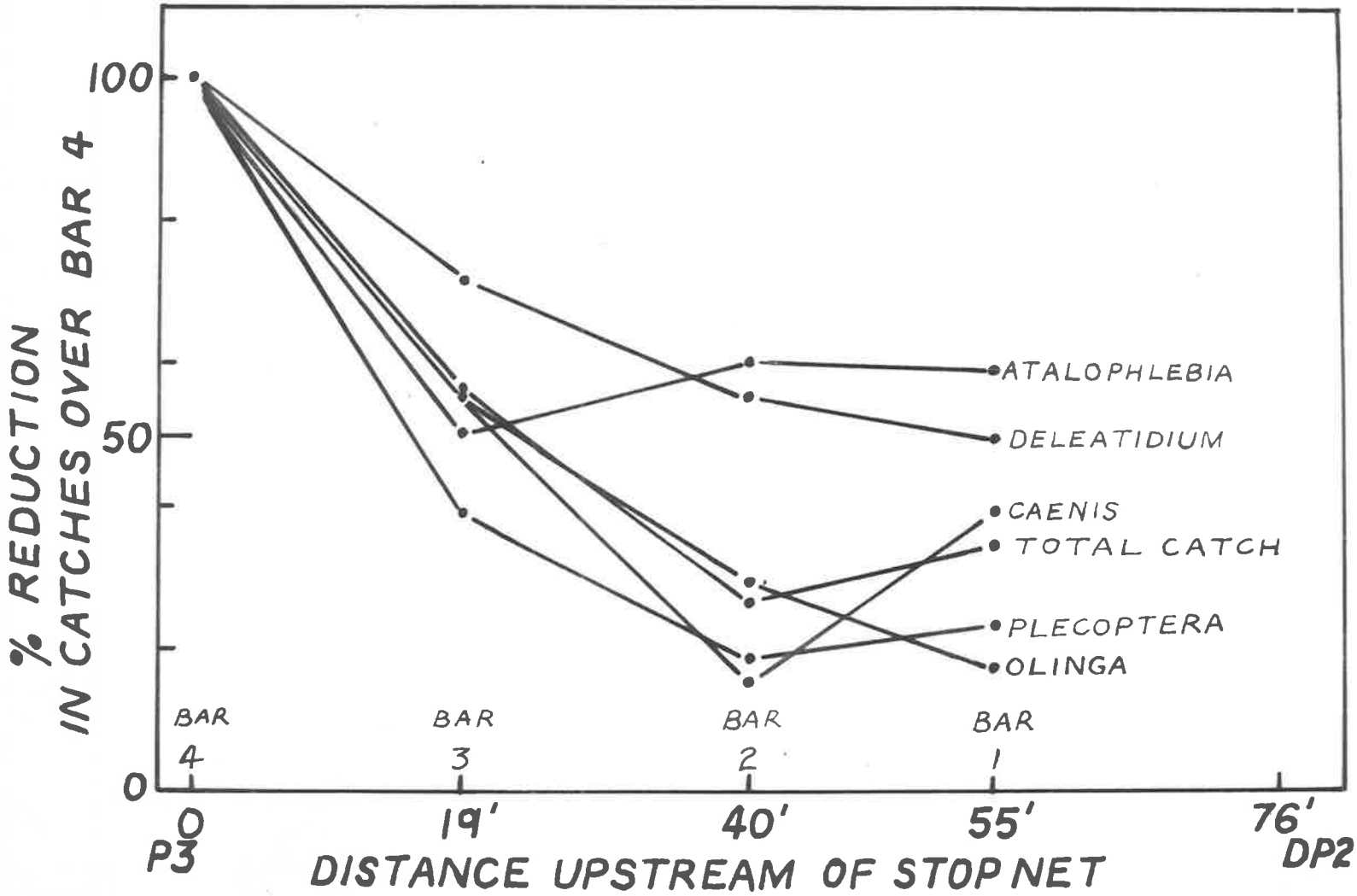


FIGURE 4.9 THE DISTANCES WHICH ANIMALS OF DIFFERENT SPECIES DRIFTED DOWN A STICKLE. THE ORDINATE, CORRESPONDING TO A DISTANCE, IS THE % NUMBER WHICH DRIFTED AT LEAST THIS DISTANCE.

Table 4.16a % occurrence in the catches of the species shown in Table 4.15

Date Sampling Interval Net	Dinotoperla	Caenis	Deleatidium	Atalophlebia	Olinga	Rest
201065 (3) Net 1	6.0	54.2	10.5	1.8	24.5	3.0
(5) Net 1	5.1	54.1	8.5	2.6	27.8	1.9
(7) Net 1	3.6	49.9	8.1	1.9	31.8	4.8
201065 (1) Net 2	9.8	34.9	5.8	2.8	40.1	6.6
(2) Net 2	6.1	54.6	4.7	2.9	27.9	3.8
(4) Net 2	4.3	49.0	3.6	2.1	37.3	3.6
(6) Net 2	4.8	52.7	4.5	1.3	33.0	3.7
211065 (1) Net 2	9.7	30.9	8.2	3.5	41.4	6.3
(2) Net 2	7.0	45.0	5.2	2.2	36.3	4.2
(4) Net 2	6.3	49.8	3.2	1.4	36.9	2.4
(6) Net 2	6.7	48.1	4.1	1.9	35.0	4.1

4.2.7 Comparison of pump catches in "still-water" near the Run-out and Run-in of a long Deep Pool

In previous sections of 4.2 drift catches into and out of a pool and at the upper and lower ends of a Stickle have been compared. There is a further need for a comparison of catches by pumping in still-water near the Run-in and Run-out of a long Deep Pool. The routine samplings by pumping in Sixth Creek (4.3.2) were made near the Run-out of a long Deep Pool (DP3) where it was thought that the catches would be most likely to measure the changes in activity of animals in still-water around sunset. A feature common to all of these samplings was the unusually small catch for the 20-minute sampling interval in the first hour after sunset.

Pump samples were taken therefore near the Run-out of DP2 on 271065 and near the Run-in on 281065 in the hour before and the 3 hours after sunset (20 minute samples). DP2 is an even longer pool (the longest in the study section) than DP3. The sampling sites at DP2 are shown in Map 8. The total flow was small - 90,000 litres/hour - at these dates and the current passing the pump inlet at both sites (9" up from the bed of the pool) was slight. Details and results of the samplings are shown in Table 4.17.

A comparison of the numbers (since the amount of water filtered at each site was the same - 3250 litres/20 mins.) shows (Figure 4.10) that the catch at the Run-in was about 7 X the catch at the Run-out for interval (2). In the first interval, (1), the catch at the Run-in was 4 X greater and for intervals (3) and (4) about 1.1 X greater.

MAP 8 DEEP POOL 2 (DP2) - SIXTH CREEK

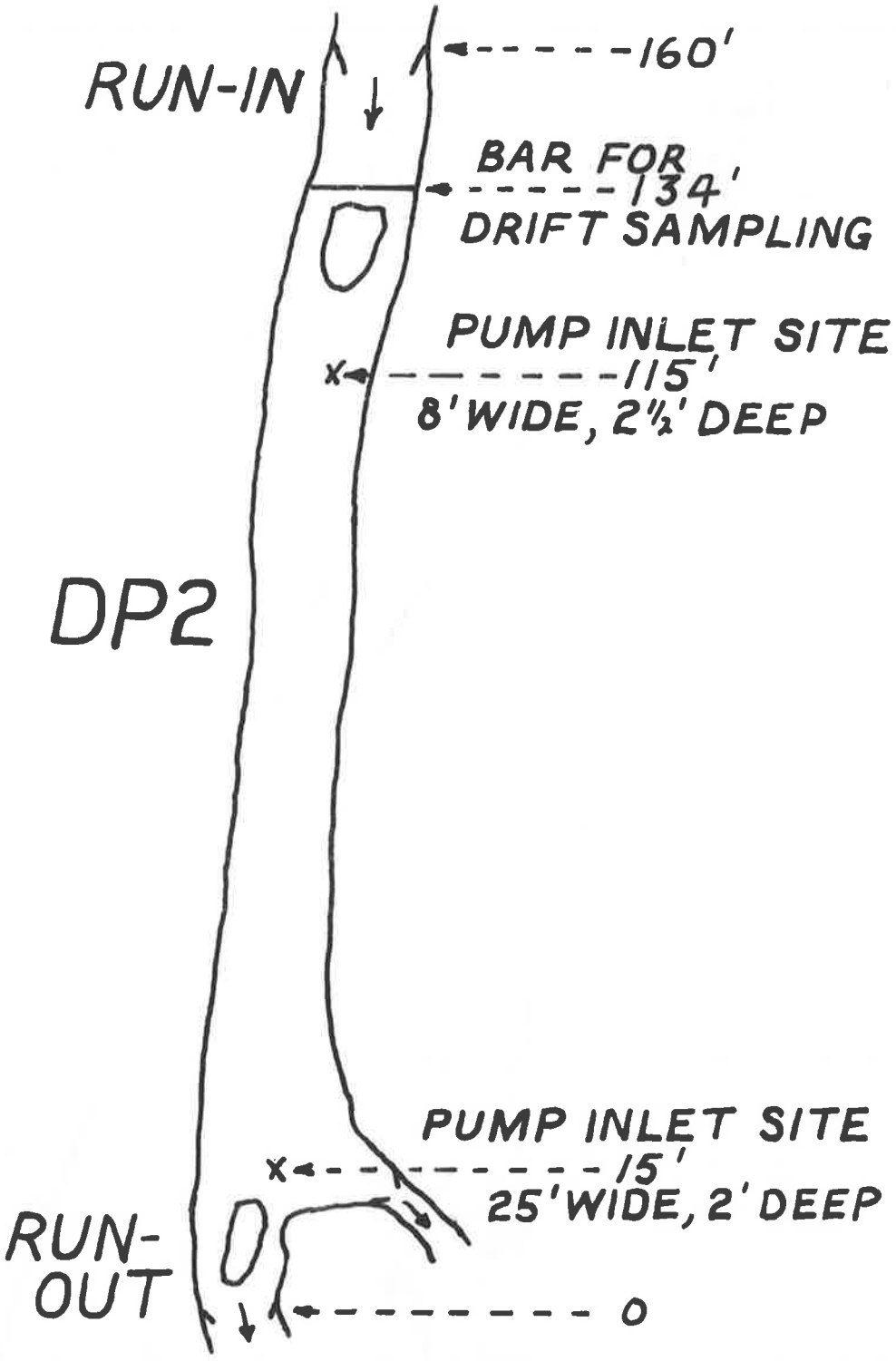


TABLE 4.17 PUMP SAMPLES FROM THE RUN-OUT AND RUN-IN OF DP2

		Sampling Interval	Numbers and weights (mgms) in size groups								Total	
			1	2	3	4	5	6	7	8	Nos.	Wgts
Date: 271065 Sunset: 6.40 pm Moonrise: 6.56 am Moonset: 9.30 pm	Place: Run-out of DP2	(1) 6.00-6.20	5 1.19	4 4.98	1 .34						10	6.51
		(2) 7.00-7.20	16 3.37	11 8.05		1 1.80					28	13.22
		(3) 8.00-8.20	423 51.10	274 83.02	108 94.28	19 31.75	3 9.20				827	269.35
		(4) 9.00-9.20	228 32.64	195 65.92	95 83.20	17 29.45	1 2.70				536	213.01
Date: 281065 Sunset: 6.41 pm Moonrise: 7.36 am Moonset 10.31 pm	Place: Run-in of DP2	(1) 6.01-6.21	36 10.91	6 4.44							42	15.35
		(2) 7.01-7.21	141 31.52	46 24.57	13 11.96	4 7.20					204	75.25
		(3) 8.01-8.21	546 89.87	239 124.30	79 72.52	30 34.31	1 2.70				895	323.70
		(4) 9.01-9.21	341 63.39	186 112.98	42 37.99	13 19.55	1 2.70			1 13.00	584	249.61

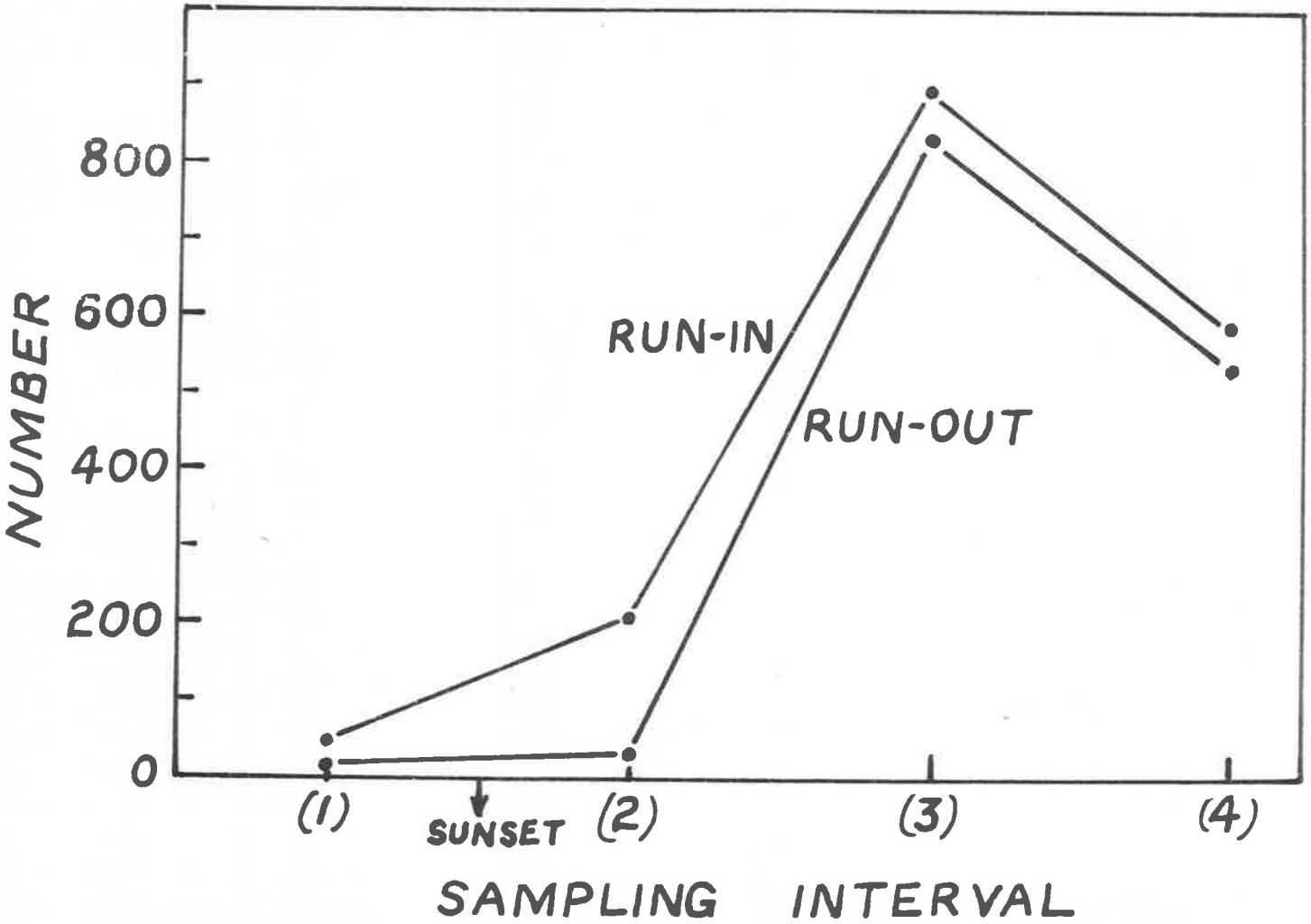


FIGURE 4.10 GRAPH OF NUMBERS OF ANIMALS IN THE PUMP CATCHES (TABLE 4.17) AT DIFFERENT SAMPLING INTERVALS

Thus the reduced catch for interval (2) just after sunset not only occurs in the summer and autumn when the routine pump sampling was undertaken (see 4.3.2) but also in the spring.

The pump catch at the Run-out was primarily a reflection of the drift into the pool. Table 4.18 shows that the order of decreasing ability to swim (drift) through the pool of the species of Deleatidium, Caenis, Dinotoperla, Atalophlebia, Olinga and Rivissessor was also the order of importance which they came to assume in the catches at the Run-out in comparison with that at the Run-in in the last sampling interval. The catch at the Run-in was higher than that at the Run-out since some of the animals settled out in between, or were eaten by trout, and was composed of small items only since only one of the larger items occurring in the drift was able to reach the pump sampler at the Run-in in the slackening flow there.

4.2.8 Comparison of net and pump samples from running water

Nets and filters in general retain a decreasing proportion of animals in the consecutively smaller size groups below a certain size. Thus the catches made by the drift sampling net and the pump filter certainly do not include all of the smaller animals which were in the water that they filtered. Most of the animals are much smaller in both width than in length. Entanglement of appendages, the tendency of the animals to cling to the mesh and the tendency for the sample to collect in a mass at the lower end of the net, or filter, reduce the loss of animals whose body width is smaller than the width

Table 4.18 The % occurrence of animals of different species in the pump catches, shown in Table 4.17, at the Run-in (R.I.) and Run-out (R.O.) of Deep Pool 2. The last row gives the ratio of the % numbers for each species at the two places in the last sampling interval.

Sampling Interval	Place	Caenis	Rivissessor	Olinga	Dinotoperla	Deleatidium	Atalophlebia
(1)	R.I.	7.1	47.6	26.2	0	0	0
	R.O.	0	20.0	60.0	0	0	0
(2)	R.I.	30.4	17.6	29.9	5.4	6.9	2.0
	R.O.	7.1	10.7	53.6	0	3.6	0
(3)	R.I.	49.7	1.2	33.7	3.0	6.6	3.6
	R.O.	76.5	0.1	6.9	3.5	10.6	1.1
(4)	R.I.	37.3	1.7	47.8	3.4	5.0	3.3
	R.O.	62.1	0.4	15.3	4.3	14.6	2.2
	R.O./R.I.	1.7	0.2	0.3	1.3	2.9	0.7

of the mesh opening. The filter used with the pump had a smaller mesh (40 meshes/inch) than the bag of the drift net (34 meshes/inch).

The two techniques of sampling may also give catch densities from the same volume of (running) water that are different because of the difference in the way the water is sampled. Thus animals could probably crawl out of a drift net when the current was small but this seems most unlikely from the inlet of the pump (1" dia. with filter) in which the flow was very rapid (3250 cms/sec.). While the net is a "passive" sampler the currents generated around the inlet of the pump may result in a higher catch.

To compare the two methods the net and pump were set alternately in S12 on 231165 around sunset. The net was set at 0.8 of the depth (14 cms) and the pump inlet at the midpoint (by depth and width) of the net position. The speed of the current at the pump inlet was 31.2 cm/sec. which is equivalent to a value of q = 9360 litres/20 mins for a net position (50 cms x 5 cms) with a uniform speed of flow of 31.2 cm/sec. through it. The value of q for the net itself was almost the same - 9,210 litres/20 mins. Details and results of the samplings are shown in Table 4.19. A plot of the catch densities reveals that the pump catches were about 2-3 x those made by the drift net (Figure 4.11). At least some of the difference appeared to be caused by the pump filter, with its smaller openings, catching more items of the smaller size-groups. Also the snail Rivissessor sp. was noticeably more numerous in the pump catches. This animal cannot swim (unlike most of the other

TABLE 4.19 CATCHES FROM SAMPLING WITH NET AND PUMP IN RUNNING WATER

	Sampler N = net P = pump	Sampling Interval p.m.	Numbers in size-groups (1)	(2)	(3)	(4)	(5)	(6)	Total Wgts. (mgms)	Nos.	Density (Nos/litre)
Date: 231165 Place: S12 Sunset: 7.07 p.m. Moonrise: 4.51 a.m. Moonset: 7.14 p.m. Total flow 91,678 litres/hour net: q = 27,630 litres/hour qn = 8,370 litres/20mins pump: 3250 litres/20mins pumped	N	(1) 6.27-6.47	103	67	11	1(26)			198.34	182	.0218
	P	(2) 6.57-7.17	107	64	16	9			186.42	196	.0603
	N	(3) 7.27-7.47	135	113	31	6	1		193.12	286	.0342
	P	(4) 7.57-8.17	145	100	24	7	1		157.97	277	.0852
	N	(5) 8.27-8.47	124	165	55	18	2	1	239.37	365	.0435
	P	(6) 8.57-9.17	161	94	24	8	1		170.63	388	.0889
	N	(7) 9.27-8.47	104	169	40	10		4	217.70	327	.0391

Table 4.20 Corrections applied to the catches in Table 4.19 to show the sources of the difference between pump and net catches

Correction	Density of catch in sampling interval (Nos./litre)							Sampler
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	
None		.0603		.0852		.0889		pump
	.0218		.0342		.0435		.0391	net
Minus items in size-group (1) (and smaller)		.0274		.0406		.0394		pump
	.0094		.0180		.0287		.0267	net
Minus items in size-groups (2), (1) (and smaller)		.0077		.0098		.0101		pump
	.0014		.0045		.0091		.0065	net
Minus items in size-groups (2), (1) (and smaller) and Rivissessor in larger size-groups		.00092		.0080		.0083		pump
	.00096		.0038		.0087		.0060	net

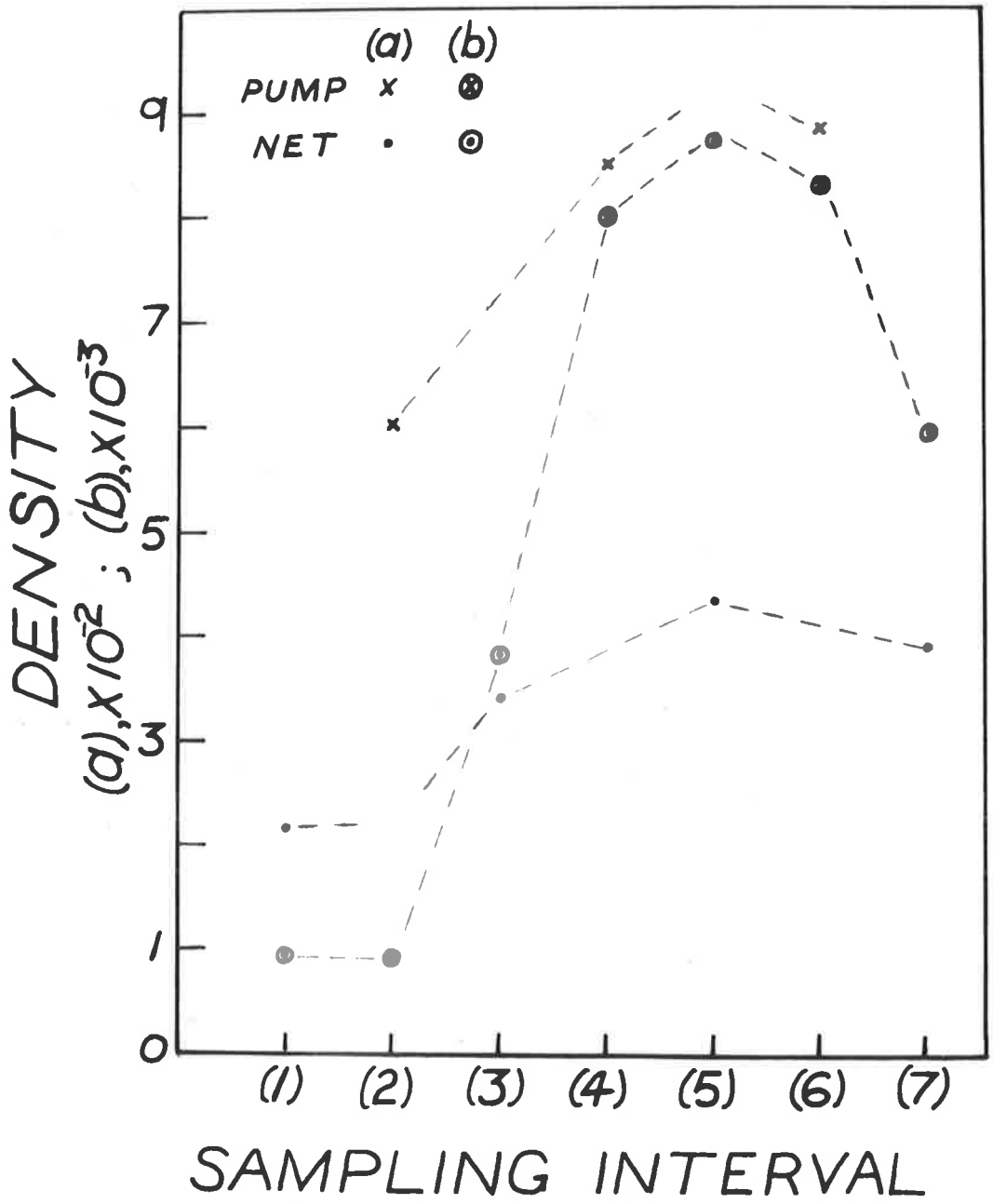


FIGURE 4.11 GRAPH OF THE DENSITIES FOR THE CATCHES, (A) SHOWN IN TABLE 4.19, AND FOR THESE CATCHES, (B) AFTER THE CORRECTIONS SHOWN IN TABLE 4.20, AT DIFFERENT SAMPLING INTERVALS

animals in the drift) and occurs in the drift net catches in lower numbers than might be expected from its great abundance in the creek. Snails were very numerous on the surface of stones near the pump inlet and perhaps were forcibly removed by the current generated close to the pump inlet which was about 1" off the bottom of the stream.

When these differences were eliminated (Table 4.20) the densities of catches of animals in size-group (3) and greater, excluding the snails, for the two samplers show a consistent trend. (Figure 4.11). The curve is steep after sunset because most of the drift before sunset consists of very small items and Rivissessor sp. drifts more just before than after sunset (Table 4.4).

4.3 General food sampling

4.3.1 Changes in the accessibility of animals in running water around sunset in Sixth Creek

Table 4.21 shows the results of samplings made in addition to those for specific purposes the data for which were given earlier. These additional samplings were made to get a fuller description of seasonal changes in the food accessible to the trout in running water. When the total flow of the Creek was high during the winter and spring it was only possible to use the bar which had been set at the Run-in of D.P.2. A maximum of 5 nets could be set at the same time across the stream at this site during abatement of the flow between floods. When 5 nets were actually set (271064 and 031264) the density of the drift was found to vary across the stream. The density was lowest on the sides and highest near the centre of the stream where the current was strongest.

Estimates of the maximum daily drift during the second hour after sunset were available for 24 different times of the year (Figure 4.2). The densities, from 10 minute, 20 minute, and hourly samplings centred on the time of the maximum drift rate during the second hour after sunset, are not strictly comparable. Since the drift rate rises to a maximum and then decreases the shortest interval gives the highest density. The difference in the densities given by intervals of different duration, centred on the time for the peak drift rate depends on the magnitude of the rise above daytime values. Since the latter varies considerably no one correction can be applied to make the densities comparable. For example on 041264 the density for a 20 minute interval was 1.254 X larger than the density for the hourly interval, and on 201264, 1.184 X.

It is apparent from Figure 4.2 that the magnitude of the total drift and the density of the drift are positively correlated with the total flow (Q) of the stream. This correlation has two components. The seasonal increase in the abundance of food animals in the bottom fauna through the winter and spring and the changes in the accessibility of these animals caused by day to day changes in the flow. The importance of the latter phenomenon was described in section 4.2.3.

The density of the drift is high in the late winter-spring period and to a lesser extent again in the late summer-early autumn. The low density for the catch made at the end of August was the result of one practical problem of sampling during the winter. The actual

TABLE 4.21 CATCHES OF ACCESSIBLE FOOD AROUND SUNSET IN SIXTH CREEK. DENSITY AS NUMBER PER LITRE

	NET	Hourly Sampling Interval	Numbers and Weights in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)			Total catch Wgt (mgms)	Nos	Density
080564 R.I. P5	1	(1) 10-30.11-30 a.m.	17	15	2												
S.R.6.59am. S.S.5.27pm			2.00	4.84	1.97										8.81	34	.0013
M.R.2.24am. M.S.3.27pm	1	(2) 1230-1.30 p.m.	15	8		1											
Q: 226,530 l./hr			1.15	3.01		.60									4.76	24	.0009
q: 30,807 l./hr	1	(3) 2.30-3.30 p.m.	26	11	2	1											
qn: 26,700 l./hr			2.43	3.88	2.04	.60									8.95	41	.0015
	1	(4) 4.30-5.30 p.m.	25	17	3		1				1						
			3.29	5.85	2.55		1.00				3.20				15.89	47	.0018
	1	(5) 5.30-6.30 p.m.	37	126	67	2			1								
			3.21	38.12	55.69	8.50			6.80						112.32	233	.0087
	1	(6) 6.30-7.30 p.m.	19	174	60	9	4	1	2								
			2.45	49.15	49.89	17.05	13.60	4.70	17.40						154.24	269	.0101
	1	(7) 7.30-8.30 pm	41	173	39	6	2		1	1							
			4.21	38.47	33.48	11.45	6.50		6.80	9.80					110.71	263	.0099
060765 R.I. DP2	3	(1) 4.17-5.17 p.m.	37	37	16	3											
S.R.7.24am S.S.5.17pm			7.13	21.60	37.75	4.65									71.13	93	.0042
M.R.12.24pm M.S.12.08am	3	(2) 5.17-6.17 p.m.	230	219	106	22	6										
Q: 263,320 l./hr			40.60	81.25	123.85	48.40	15.92								310.02	583	.0260
q_2: 25,200 l./hr																	

TABLE 4.21 (Contd.)

	NET	Hourly Sampling Interval	Numbers and Weights in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)			Total catch Wgts. (mgms)	Nos	Density
qn_2 : 23,900 l./hr.	2	(3) 6.17-7.17 p.m.	485 94.00	843 327.78	272 282.27	119 " 219.55	24 74.80	6 30.00							1028.40	1749	.0732
q_3 : 22,780 l./hr	3	(3)	471 94.01	754 285.90	283 269.01	119 " 188.55	10 27.40	7 " 35.00	1 " 9.00						908.87	1645	.0734
qn_3 : 22,400 l./hr.	3	(4) 7.17-8.17 p.m.	337 64.99	529 " 204.59	196 " 208.55	94 " 148.45	25 66.0	3 15.00	1 9.00						716.58	1185	.0529
310864 R.I. DP2	3	(1) " 12.55-1.55 p.m.	10 2.61	26 9.33	11 9.63	1 1.20	2 2.00								24.77	50	.0018
S.R.6.37am S.S.5.55pm	3	(2) " 2.55-3.55	31 " 7.65	22 7.37	17 " 15.39	2 3.00				1 9.80					43.21	73	.0026
M.R.1.20am M.S.11.37am	3	(3) " 3.55-4.55	14 2.78	20 6.50	14 12.81	3 " 5.55				1 " 2.50					30.14	52	.0018
Q : 1,227,600 l./hr	3	(4) " " 4.55-5.55	14 3.20	15 6.89	12 11.80	2 " 2.75	1 2.70		1 1.90			1 55.00			84.24	46	.0016
q_2 : 68,310 l./hr	3	(5) " 5.55-6.55	19 3.79	124 37.46	45 " 35.89	5 " 7.85	4 " 17.40	3 15.90	4 " 36.00						154.29	204	.0072
qn_2 : 24,500 l./hr	2	(6) " 6.55-7.55	23 5.17	334 86.90	107 91.63	30 " 54.02	18 " 50.60	31 " 185.50	9 " 73.80		1 " 18.50				566.12	553	.0226
q_3 : 60,610 l./hr	3	(6)	15 3.44	245 62.19	101 83.03	20 38.20	29 104.00	24 " 145.90	7 " 93.40			1 4.00			534.16	442	.0156
qn_3 : 28,400 l./hr	4	(6)	13 2.60	162 41.14	92 59.12	8 " 14.06	9 " 41.30	12 69.70	16 " 131.20	1 " 16.50					375.62	293	.0097
q_4 : 43,870 l./hr																	
qn_4 : 30,150 l./hr																	

TABLE 4.21 (Contd.)

	NET	Hourly Sampling Interval	Numbers and Weights in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)			Total catch Wgts. (mgms)	Nos	Density
	3	(7) 7.55-8.55	7 2.76	175 43.76	66 54.68	17 29.80	13 34.22	22 110.00	5 44.70				1(12) 85.00		404.92	306	.0108
271064 R.I. DP2 S.R.5.19am S.S.6.41pm M.R.12.08am M.S.10.18am	3	(1) 3.40-4.40 p.m.	5 1.44	27 11.80	24 25.33	14 23.20	3 8.80	2 10.00							80.47	75	.0025
	3	(2) 4.40-5.40	4 1.03	28 10.46	27 24.53	14 28.53	11 42.90	1 4.70		1 2.50					114.65	86	.0028
Q :1,004,750 l./hr.	3	(3) 5.40-6.40	8 2.22	30 11.66	17 19.70	10 14.75	9 29.80	2 12.80		1 67.00			1(32) 95.00		282.93	78	.0026
q_1 : 38,647 l./hr qn_1 : 29,400 l./hr	3	(4) 6.40-7.40	17 2.90	481 118.33	451 360.68	166 294.70	22 72.40	23 114.60		1 10.00					973.61	1161	.0382
q_2 : 46,634 l./hr qn_2 : 30,400 l./hr	1	(5) 7.40-8.40	23 4.86	2546 579.14	2182 1728.22	857 1567.60	180 684.10	56 306.40	15 141.50	6 71.60		2 77.00			5160.42	5867	.1996
q_3 : 47,595 l./hr qn_3 : 30,400 l./hr	2	(5)	8 1.76	4145 923.15	3055 2400.44	723 291.10	186 656.10	92 514.60	14 127.20	9 143.80	4 91.00				5578.15	8244	.2712
q_4 : 32,804 l./hr qn_4 : 27,500 l./hr	3	(5)	5 1.11	3736 831.62	2942 2309.05	1013 1893.15	200 750.48	99 548.10	15 142.50	1 13.00	2 58.50		2(11) 69.00		6616.51	8015	.2637
q_5 : 23,285 l./hr qn_5 : 22,800 l./hr	4	(5)	1 .25	3405 760.27	2491 1953.38	593 1077.65	143 524.60	50 256.00	7 59.30	5 83.00	2 37.00	2 77.00	2(11) 97.00		4925.45	6701	.2437
	5	(5)	1 .26	2466 548.68	1822 1427.14	437 804.55	104 385.70	38 191.50	6 52.80	2 29.00	2 18.50	1 53.00	1(11) 100.00		3610.93	4882	.2141
	3	(6) 8.40-9.40	18 3.01	2050 459.75	1480 1169.14	479 883.10	100 370.10	43 217.60	9 88.10	7 91.00	1 18.50				3360.78	4186	.1377

TABLE 4.21 (Contd.)

	NET	Hourly Sampling Interval	Numbers and Weights in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)			Total catch Wgts. (gms)	Nos	Density
031264 R.I. DP2																	
S.R. 4.55am S.S.7.16pm	3	(1) 3.15-4.15 p.m.	9 2.66	64 19.30	71 41.41	15 10.80	1 4.40								78.57	160	.0056
M.R.4.21am M.S.6.31pm	3	(2) 5.15-6.15	21 4.20	60 17.33	50 28.46	19 15.00	2 2.00								66.99	152	.0053
Q : 568,926 l./hr	3	(3) 6.15.7.15	13 3.10	76 25.98	45 24.72	13 10.20	7 7.00						1(13) 35.00		106.00	155	.0054
q_1 : 23,175 l./hr	3	(4) 7.15-8.15	15 3.74	97 38.09	115 81.13	31 34.80	1 1.00				1 20.00				178.76	280	.0098
qn_1 : 22,700 l./hr	1	(5) 8.15-9.15	11 3.26	354 85.07	402 315.24	127 231.95	20 73.50	2 18.40	1 8.70						736.12	917	.0404
q_2 : 30,184 l./hr	2	(5)	2 1.00	481 116.35	538 415.61	124 229.50	17 55.70	16 25.90	1 9.80		1 13.00				866.96	1170	.0442
qn_2 : 26,450 l./hr	3	(5)	6 1.16	758 175.28	521 400.46	140 250.80	26 18.32	11 64.30	2 17.70	1 9.80					937.82	1466	.0513
q_3 : 35,618 l./hr	4	(5)	15 2.78	539 128.70	507 394.54	179 329.75	18 67.10	6 35.70	2 18.80						977.57	1266	.0476
qn_3 : 28,600 l./hr	5	(5)	14 2.06	454 105.37	415 313.61	126 210.00	15 53.00	7 45.20	1 1.90	2 30.50			1(11) 66.00		827.64	1034	.0433
q_4 : 30,724 l./hr	3	(6) 9.15-10.15	5 .68	351 85.90	307 239.27	93 165.00	18 62.90	14 87.20							640.95	788	.0276
qn_4 : 26,600 l./hr																	
q_5 : 25,200 l./hr																	
qn_5 : 23,900 l./hr																	

TABLE 4.21 (Contd.)

	NET	Hourly Sampling Interval	Numbers and Weights in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)			Total catch Wgts. (mgms)	Nos.	Density
190165 R.I. PP9 S.R.5.22am S.S.7.31pm M.R.9.11 pm M.S.6.48am Q : 141,375 l./hr q_1 : 34,571 l./hr qn_1 : 28,300 l./hr	1	(1) 4.31-5.31 p.m.	166 60.60	6 4.92	21 26.11	8 26.15									177.78	201	.0071
	1	(2) 5.31-6.31	103 37.80	14 15.50	12 23.28	5 9.00									85.58	134	.0047
	1	(3) 6.31-7.31	123 45.65	34 47.88	22 28.91	6 29.10	2 6.10						1(14) 50.50		208.64	188	.0066
	1	(4) 7.31-8.31	85 31.79	86 37.10	206 185.13	20 43.10	8 32.45	1 6.60							330.37	406	.0143
	1	(5) 8.31-9.31	63 17.08	198 81.95	216 197.14	54 107.80	25 94.70	3 24.10	3 63.40	5 54.00	2 58.00	1 23.00	1(11) 31.00	1(17) 230.00	968.58	571	.0202
	1	(6) 9.31-10.31	26 9.13	94 41.40	143 128.94	42 79.55	6 24.30	1 12.50		1 9.80			1(15) 51.00	1(17) 70.00	428.62	315	.0111
040265 R.I. PP9 S.R.5.38am S.S.7.21pm M.R.7.38pm M.S.9.04pm* Q : 56,984 l./hr q_1 : 22,500 l./hr qn_1 : 22,250 l./hr	1	(1) 4.21-5.21 p.m.	44 14.25	33 19.07	26 22.31	3 5.40									61.03	106	.0048
	1	(2) 5.21-6.21	72 24.33	40 29.76	25 23.92	4 13.10									91.01	141	.0063
	1	(3) 6.21-7.21	166 55.78	72 50.17	36 42.19	11 22.00	2 15.00								185.14	287	.0129
	1	(4) 7.21-8.21	115 30.16	439 153.67	242 215.37	18 28.80		1 1.40	1 14.00						553.70	8.6	.0367
	1	(5) 8.21-9.21	94 26.20	609 226.03	639 579.30	70 131.15	2 7.70			1 13.00	2 80.00				1063.38	1417	.0637

TABLE 4.21 (Contd.)

	NET	Hourly Sampling Interval	Numbers and Weights in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)			Total catch Wgts. (mgms)	Nos.	Density
	1	(6) 9.21-10.21	184 51.69	718 272.73	468 428.70	43 92.92	4 14.10	1 1.40	1 9.40	1 13.00					883.94	1420*	.0638
060365 R.I. PP9 S.R.6.07am S.S.6.47pm M.R.8.31am M.S.8.34pm Q : 30,336 l./hr q_1 : 18,945 l./hr qn_1 : 18,945 l./hr	1	(1) 3.47-4.47 p.m.	194 50.33	97 44.29	93 103.49	25 46.40	1 1.70						1(14) 43.00		289.21	411	.0217
	1	(2) 4.47-5.47	222 52.17	104 51.27	94 97.91	17 29.50	1 4.50								235.95	438	.0231
	1	(3) 5.47-6.47	494 103.25	88 44.65	83 82.32	12 21.60		1 6.60							250.42	678	.0358
	1	(4) 6.47-7.47	1174 159.79	693 221.84	896 815.88	69 127.65	3 12.18	1 4.70							1352.16	2835	.1496
	1	(5) 7.47-8.47	1115 154.01	906 284.82	784 720.78	103 203.45	13 23.52	11 50.20	4 36.90		1 2.70		1(11) 28.00	1(22) 50.00	1571.48	2940	.1552
	1	(6) 8.47-9.47	1035 142.88	488 171.22	611 557.22	70 130.60	4 10.20	5 10.30	2 15.50						1057.92	2215	.1169
250365 R.I. PP9 S.R.6.22am S.S.6.21pm M.R.11.35pm M.S.1.45pm	1	(1) 3.21-4.20 p.m.	135 42.11	64 69.95	32 59.86	14 31.10	1 3.80								206.82	246	.0082
	1	(2) 4.21-5.21	196 61.42	63 75.75	48 98.74	15 27.00	1 4.50								267.31	323	.0108
	1	(3) 5.21-6.21	143 45.01	50 58.67	45 75.07	9 22.30									201.05	247	.0083
	1	(4) 6.21-7.21	665 155.80	392 313.23	666 653.57	112 205.60	2 7.60	5 64.70		1 30.00					1432.10	1844	.0617

TABLE 4.21 (Contd.,)

	NET	Hourly Sampling Interval	Numbers and Weights in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)			Total catch Wgts. (mgms)	Nos.	Density
Q : 66,409 l./hr		(5)	340	824	895	121 "	16	12	2	2	2		1(11)				
q_1 : 41,704 l./hr	1	7.21-8.21	82.41	300.07	856.43	245.85	58.00	96.70	13.60	19.60	16.70		23.00		1712.36	2216	.0741
qn : 29,900 l./hr		(6)	275 "	469	617	92	13	7			1		1(12)	(15)			
	1	8.21-9.21	68.05	181.98	577.73	183.80	42.40	37.20			2.70		195.00	160.00	1448.86	1476	.0494
220465 R.I. R28		(1)	79	34 "	14	6											
S.R.6.44am S.S.5.44pm	1	3.44-4.44 p.m.	72.66	39.65	43.66	27.00									135.47	133	.0045
M.R.10.16pm M.S.12.28pm		(2)"	70 "	43	15	5 "											
	1	4.44-5.44	22.50	53.26	34.09	14.50									134.35	133	.0045
Q : 178,994 l./hr		(3)	121	275 "	175	69"	2	3									
q_1 : 55,508 l./hr	1	5.44-6.44	30.90	127.15	145.36	145.36	141.00	6.90	17.70						469.09	607	.0204
qn_1 : 29,750 l./hr		(4)	153	586	224	162	32	13				1					
	1	6.44-7.44	28.86	177.16	223.08	297.90	113.90	75.70				53.00			779.56	1171	.0394
		(5)	97 "	548	181	87" "	20	7	1				1(24)				
	1	7.44-8.44	20.55	168.21	173.44	175.75	66.00	38.90	8.70				60.00		711.55	942	.0317

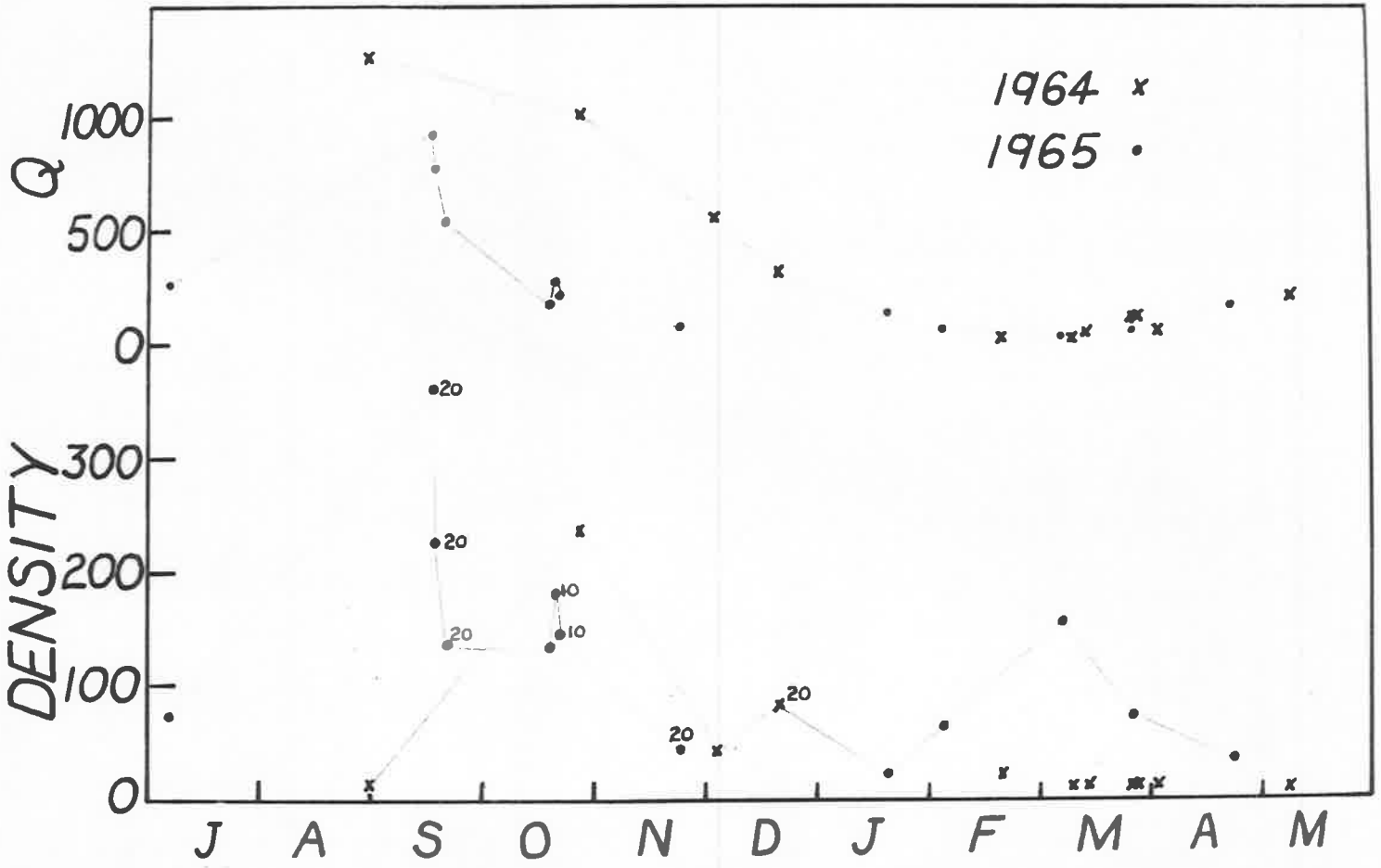


FIGURE 4.12 DENSITY OF DRIFT (NOS./ 10^3 LITRES) DURING THE SECOND HOUR AFTER SUNSET, AND TOTAL FLOW (Q X 10^3 LITRES), AT DIFFERENT TIMES OF THE YEAR. SAMPLING INTERVALS LESS THAN 60 MINS. INDICATED BY 20 OR 10.

amount of water filtered by the nets was markedly reduced by clogging with a dark brown alga which coated the stones in the creek at this time of the year. Not only is the total number of drifting animals greater during the spring when the total flow is high but their weight is also greater than at other times of the year since larger animals, principally the stonefly - Dinotoperla evansi, are present in the drift. The smaller peak in the drift, of shorter duration, during the summer-autumn period of low water was only encompassed by the catches made during 1965. The peak in the growth (in weight) of the fish (Table 3.32) occurred earlier in the summer of 1963-64 and the condition of the fish declined in early March. During 1964-65 the increase in condition occurred later starting in late February and remaining high during March until it fell in April. The values of Lgr, correlated with the condition of the trout, were higher in the first season. The cycle of increase and decrease in the production of animals in the Summer bloom of algae probably occurred earlier in 1963-64. The flow of the stream reached a low level before December 1963, whereas in 1964-65 the flow was still high through December 1964 because of the spring rains in 1964 (Figure 2.9).

Table 4.22 shows some of the catches of Bottom Fauna from stones and algae which were taken just above the drift sampling sites. In Table 4.23 comparisons are made between drift and Bottom Fauna catches. Species which were important because of their size (e.g. the large dragonfly nymphs Corduliidae, Gomphidae, Aeschnae), numbers (e.g. the very small mayfly nymphs; Caenis, Deleatidium), or other reasons - principally high accessibility (e.g. the pulmonate snail

TABLE 4.22 CATCHES OF BOTTOM FAUNA ABOVE DRIFT SAMPLING SITES IN SIXTH CREEK

St. = stickle Alg. = algae

Date	Place	Type of Sample	Numbers in size-groups																Total Nos (wgt.mgms)
			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)							
230264	RI P5	St.	96	151	148	68	19	2	2	3	1	1	2(12)							491 (1009.38)
"	"	"	77	156	159	96	23	3	1		2		1(12)	1(14)	1(16)	2(17)	1(22)			522 (1400.64)
"	"	Alg.	271	289	93	91	13	7	4			3	2(12)	1(15)						774 (1333.33
100364	RI P3	St.	183	292	236	78	22	7	8	1	6		1(13)	1(18)	1(20)					836 (1987.11)
"	RO DP2	Alg.	196	1110	199	124	67	15	12	11	2	5	1(11)	1(12)	2(14) 1(15)	1(17)	2(18)	1(19)	1(30)	1752 (4356.29)
240364	RI P2	St.	416	651	574	326	61	24	12	9	2	4	3(11)	1(14) 1(13)	1(15)	3(16)	5(17)	1(18)	1(19)	2095 (5566.59)
"	SP 5	Alg.	338	682	93	82	31	18	4	12	9	2	4(11)	1(12)	2(13)	1(15)				1282 (3233.15)
020466	RI R28	St.	393	504	336	71	8	3	8	5	1		3(12)	2(15)	2(16)					1336
"	"	St.	456	662	326	131	49	19	30	7	1		1(12)	1(15)	1(17)	1(21)	1(22)			1666
"	P7	Alg.	762	2342	123	59	25	8	6	6	1	2	4(11)	2(12)	1(13)	1(15)				3343
"	RI PP9	St.	543	993	518	243	32	13	12	3	2	2	2(11)	2(12)	4(13)	2(15)	6(16)	1(17) 1(18)	1(20) 1(25)	2381
"	RI P10	St.	256	545	194	73	28	17	4	3	1		2(16)	2(17)						1125
180564	RI P5	St.	307	983	757	204	61	12	31	3		2	2(13)	2(14)	1(18)					2365

TABLE 4.22 (Contd.)

Date	Place	Type of Sample	Numbers in size-groups																Total nos
			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)							
150964	RI DP2	St.	71	134	97	79	39	14	3	5		1							443
051164	RI DP2	St.	26	161	245	232	49	16	6			6	5(11)	1(15)	1(17)				748
041264	RI DP2	St.	75	425	352	295	72	15	4	2			1(11)	1(14)	1(15)	1(26)	1(27)		1245

(Lenameria tenuistriata) are shown. The number of animals of each species in the catches is given as a percentage of the total number and also shown are the median size and maximum size present for each species. It is not relevant to calculate mean sizes (or weights) because the size-frequency distribution for each species is usually highly skewed.

A discussion of the relevance of the composition of these catches will be given at the end of the next section after catches from still-water are shown.

4.3.2 Changes in the accessibility of animals in "still-water" around sunset in Sixth Creek

The reasons for these samplings and the novel technique used have been given in section 4.1.2. The results of the 4 samplings around sunset on each of 8 dates during the summer 1964-65 and autumn 1965 are shown in Table 4.24.

The still-water catches showed the same increase in numbers after sunset as did the drift catches (the tendency for the change in numbers not to be so rapid during interval (2) has been considered in section 4.2.7). A comparison of the average values of absolute light intensity and the rate of change of intensity during the 4 sampling intervals over the period (Table 4.25) with the catch numbers shows that the animals are more active for a given rate of change of light intensity when the absolute light intensity is lower. The same feature was shown by the drift catches. Also the presence of moonlight had a similar inhibiting influence on the movements of the animals after sunset.

TABLE 4.23 COMPARISON OF SPECIES AND SIZE COMPOSITION OF THE CATCHES OF ACCESSIBLE FOOD (DRIFT DURING THE SECOND HOUR AFTER SUNSET) AND BOTTOM FAUNA FROM IMMEDIATELY UPSTREAM

Date	Type of Sample	Corduliidae* Gomphidae**	Ameria* Rivissessor**	Atalophlebia	Corixidae* Stratiomyiidae**	Aeschnae* Zygoptera**	Hydropsyche* Hydrobiosis**	Deleatidium	Caenis	Oliga* Hydroptilidae**	Chironomidae* Simuliidae**	Dinotoperla	Sphenedae	Nos.
Maximum Size-group		(23)* (21)**	(17)* (5)**	(14)	(3)* (18)**	(43)* (19)**	(14)* (14)**	(6)	(6)	(7)* (4)**	(10)* (6)**	(14)	(9)	
210264 (RIP5)	D.	(1) (2) (3)	.7** – (2)	4.2 (3) (4)			.7* – (3)	42.3 (3) (5)	25.4 (3) (4)	.7* 23.2** – – (2) (2)	.7** – (2)	.7 – (2)		1 4 2
230264	St.	.2* 1.3** – (10) (5) (17)	.1* 20.9** – (2) (3) (5)	.5 (4) (6)			.4* (5) (9)	11.7 (4) (6)	11.3 (3) (4)	23.5* 2.9** (2) (2) (5) (4)	2.0* 2.5** (3) (3) (4) (4)	.2 – (3)	11.3 (4) (9)	1 0 1 3
230264	Alg.	2.1* (4) (5)	.3* 27,9** – (3) (6) (5)	.3 – (4)	1.0** (10) (15)	.8** – (7)		.1 – (3)	38.0 (1) (4)	3.0* 19.6** (2) – (4) (2)	2.3* (5) (7)			7 7 4
090364 (RIP3)	D.	.1* – (2)	11.2* 16.3** (2) (1) (7) (3)	.9 (3) (4)	.5* – (3)		.4* (3) (5)	50.2 (3) (5)	15.2 (2) (4)	1.9** – (2)	.3* (3) (6)	.1 – (2)	.2 (3) (4)	9 2 8
100364	St.	.5** (15) (20)	4.7* 40.2** (2) (2) (7) (4)		.2** – (7)		13.3* .1** (4) – (9) (7)	12.0 (3) (5)	1.6 (2) (3)	10.9* .3** (1) – (4) (2)	7.9* (5) (4)		1.7 (3) (7)	8 3 6
100364	Alg.	3.3* (6) (14)	8.3* 21.5** (2) (2) (9) (5)	.5 (5) (8)	2.8* .9** – (8) (3) (19)	1.4** (2) (4)		2.4 (3) (6)	41.8 (2) (5)	11.7** – (2)	5.0* (3) (7)		.1 1 (3)	1 7 5 2

TABLE 4.23 (Contd.)

Date	Type of Sample	Corduliidae* Gomphidae **	Ameria* Rivissessor **	Atalophlebia	Corixidae* Stratiomyiidae**	Aeschnae* Zygoptera**	Hydropsyche* Hydrobiosis**	Deleatidium	Caenis	Olinga* Hydroptilidae**	Chironomidae* Simuliidae**	Dinotoperla	Sphenedae	Nos.
130364 (RIP2)	D	1.8* 1.2** (6) (2) (19) (7)	1.0* 2.0** (1) (1) (3) (2)	4.3 (3) (6)	2.2** (4) (6)	.6** (2) (4)	2.6* .2** (3) - (4) (4)	59.3 (3) (5)	13.4 (2) (5)	1.2* 6.5** (1) - (4) (2)	.2* - (2)		1.0 (2) (3)	4 9 2
240364	St	1.0** (15) (19)	.05* 35.8** - (2) (5) (5)		.2** (5) (10)		3.8* .5** (5) (3) (9) (8)	26.5 (3) (5)	.1 - (2)	7.3* 3.2** (1) - (5) (2)	8.5* .3** (2) (3) (4) (4)		7.1 (3) (8)	2 0 9
240364	Alg.	6.3* 1.0** (3) (2) (15) (3)	12.6** (2) (5)	2.1 (5) (13)		.1* .4** - (2) (16) (5)		3.1 (3) (5)	47.1 (2) (5)	.4* 8.3** - - (1) (2)	11.9* (2) (6)		.3 - (2)	5 1 2 8 2
260364 (RIP28)	D	.2* - (3)	.5* 4.8** - (1) (2) (3)	3.0 (3) (5)	.2* 4.8** - (3) (3) (6)	.2* .2** - - (2) (2)	.2* - (3)	48.7 (3) (4)	14.0 (2) (3)	1.3* 12.5** (1) - (2) (2)	.5* 1.8** - (2) (6) (4)	1.8 (1) (5)	.4 - (2)	6 0 8
020464	St	.1* .3** (9) (13) (15) (17)	29.6** (2) (5)		.2** (4) (5)	.1* - (22)	4.7* .2** (5) - (8) -	10.8 (3) (5)	4.8 - (2)	16.9* 5.3** - - (2) (2)	6.5* 5.0** (2) (2) (6) (3)	1.6 - (2)	3.2 (4) (9)	3 0 0 2
020464	Alg	1.4* 1.0** (2) (2) (15) (7)	.03* 1.3** - (2) (2) (5)	.2 (5) (8)		.4** (4) (6)	.03* - (3)	1.3 (3) (5)	80.9 (2) (5)	.4* 3.9** - - (2) (2)	4.1* .1** (3) - (6) (3)	.06 - (6)	.06 - (2)	3 3 4 3
250364 (RIPP9)	D	.1* 1.4** - (2) (14) (3)	.8* 4.5** (2) (1) (3) (5)	2.2 (4) (7)	4.8** (4) (18)	.1* .3** - - (2) (3)	.7* (3) (7)	39.7 (3) (5)	28.3 (2) (4)	1.5* 10.0** (1) - (3) (2)	1.3* (3) (6)	.9 (1) (2)	.2 - (4)	1 2 6 1

TABLE 4.23 (Contd.)

Date	Type of Sample	Corduliidae* Gomphidae**	Ameria* Rivisses-sor **	Atalo-phlebia	Corixidae* Stratio-myiidae**	Aeschnae* Zygoptera**	Hydropsyche* Hydrobiosis**	Delea-tidium	Caenis	Olinga* Hydrop-tilidae**	Chironomidae* Simuliidae**	Dinoto-perla	Sphe-nedae	Nos.
020464	St.	.04* .8** (5) (17)	25.0** (2) (4)		.6** (4) (6)	.2* (20) (25)	1.3* (2) (8)	18.0 (3) (5)	25.4 (2) (3)	13.9* .7** (2) (2) (5) (3)	1.9* .3** (3) (2) (4) (3)	4.5 (1) (3)	1.8 (5) (9)	2 3 8 1
080564 (RIP5)	D	.4* - (5)		.7 - (7)	.7** - (6)	.4** - (5)			47.6 (2) (3)	3.7* - (2)		42.4 (2) (5)		2 6 9
180564	St.	.3* .4** (10) (4) (18) (14)	.1* 6.3** - (2) (13) (4)		.04* .3** - (4) (3) (7)				6.1 (2) (3)	7.6* (1) (3)	.5* (4) (7)	75.4 (3) (7)	1.7 (4) (8)	2 3 6 5
310864 (RIDP2)	D	.2* .6** - (4) (5) (6)	.1* .1** - - (7) (1)	4.7 (3) (9)	.2* .5** - (4) (3) (7)				64.8 (2) (3)	3.1* (4) (6)	.2* - (4)	20.3 (5) (8)	.2 - (2)	1 2 8 8
150964	St.			.2 - (10)	.5** - (4)		.5* - (8)		23.5 (2) (4)	8.4* (2) (5)	15.1* (4) (8)	27.8 (2) (7)	1.8 (4) (6)	4 4 3
271064 (RIDP2)	D	.4* (5) (17)	.05** (2) (4)	2.3 (3) (11)	.3** (5) (10)				94.1 (2) (5)	.2* (2) (4)	.1* (4) (5)	2.4 (5) (11)	.01 - (2)	8 2 4 4

TABLE 4.23 (Contd.)

Date	Type of Sample	Corduliidae* Gomphidae**	Ameria* Rivisses-sor **	Atalo-phlebia	Corixidae* Stratio-myiidae**	Aeschnae* Zygoptera**	Hydropsyche* Hydropiosis**	Delea-tidium	Caenis	Olinga* Hydrop-tilidae**	Chironomidae* Simuliidae**	Dinoto-perla	Sphe-nedae	Nos.
051164	St.	.5** (13) (17)	48.8** (3) (5)	1.3 (3) (10)				.1 - (5)	5.8 (3) (4)	5.7* (3) (5)	25.4* (3) (7)	7.8 (5) (11)	.8 - (3)	7 4 8
031264 (RIDP2)	D.	.1** - (6)	.1** - (2)	7.4 (3) (7)	.4** (2) (8)		.1* - (3)		79.5 (2) (4)		4.6* (3) (6) .5** (3) (5)	.5 (6) (7)		1 4 6 6
041264	St.	.2** (11) (14)	49.9** (3) (5)	.2 - (3)		.2* - (27)	.7* (3) (5)		3.5 (3) (5)	1.3* (4) (5)	24.0* (2) (6) 10.9** (3) (4)	5.2 (5) (7)	1.1 (5) (8)	1 2 4 5

D. = drift St. = Bottom Fauna from Stickle
Alg. = Bottom Fauna from algae

(1) relative number (%) in the catch
(2) median size-group
(3) largest size-group present

} indices shown

TABLE 4.24 CATCHES FROM SAMPLING "STILL-WATER" IN SIXTH CREEK

	Sampling Interval (20 mins)	Water Temp-erature °C	Moon-light	Numbers and Weights in size-groups									Total catch		
				(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)		Wgt. (mgms)	No	Density
081264	(1)	17¼	ON (new moon)	2 .86	18 4.53	3 4.98	1 0.60						10.97	24	.0074
Sunrise Sunset 4.55am - 7.21 pm	(2)	17¼	ON	45 3.54	106 16.79	27 10.08	13 9.00		1 1.40				42.81	192	.0591
Moonrise Moonset 8.01 am - 10.46 pm	(3)	16½	ON	20 3.02	205 41.97	131 69.72	50 58.20	2 4.80					177.71	408	.1255
	(4)	16	ON	8 1.27	142 29.62	100 58.30	36 49.20	5 10.40	2 11.80		1 4.50		163.09	294	.0905
050165	(1)	21½	ON (new moon)	51 18.36	1 .15	2 1.13							19.64	54	.0166
5.08 am - 7.34 pm	(2)	20½	ON	16 5.32	21 3.22	13 6.34	2 1.20						16.08	52	.0160
6.50 am - 9.24 pm	(3)	19½	ON	72 13.10	89 26.50	81 51.30	24 42.80	4 16.00	2 7.30				157.00	272	.0837
	(4)	18½	OFF*	62 10.57	87 21.70	113 85.35	30 43.40	3 9.00	1 12.50	1 19.20			201.72	297*	.0914
200165	(1)	17½	OFF (full moon)	27 7.14	7 5.45	6 4.78							17.37	40	.0123
5.23 am - 7.30 pm	(2)	17¼	OFF	34 13.10	8 1.46	4 1.94	2 2.40						17.90	49	.0151
	(3)	16½	OFF	139 10.42	63 17.52	23 17.19	19 9.72	1 3.40				1(13) 108.00	176.25	246	.0757
9.50 pm - 8.01 am	(4)	16	ON*	56 7,92	28 9.18	11 7.97	2 3.60		1 1.40				30.07	98*	.0302

TABLE 4.24 CATCHES FROM SAMPLING "STILL-WATER" IN SIXTH CREEK. (Contd.)

	Sampling Interval (20 mins)	Water Temp-erature °C	Moon-light	Numbers and Weights in size-groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)		Total Catch Wgt. (mgms)	Nos.	Density
050265	(1)	20½	ON (new moon)	145 41.48	19 5.83	5 3.44	1 1.80						52.55	170	.0523
5.39am - 7.20 pm	(2)	20	ON	329 53.38	70 16.95	9 9.02	7 12.60	1 3.40	2 1.20				96.55	418	.1286
	(3)	19½	ON	597 100.33	229 68.19	122 121.92	42 81.00	7 7.00	6 8.40	2 43.70		1(9) 50.00	480.54	1006	.3095
8.37 am - 9.33 pm	(4)	19	OFF*	327 71.21	139 40.53	69 66.22	36 63.00	9 32.70	4 5.60	1 24.50	1 28.00	1(12) 85.00	416.76	587*	.1806
200265	(1)	22¼	OFF (full moon)	16 3.26	23 7.70	6 4.04	1 1.80						16.80	46	.0142
5.54am - 7.05 pm	(2)	21¾	OFF	501 56.81	107 37.33	53 39.57	6 11.40	1 4.40		1 24.50			174.01	669	.2058
9.51 pm - 10.05 am	(3)	21	OFF	1782 195.53	122.3 413.17	596 541.07	100 181.80	2 10.60	2 30.10	1 1.90			1374.17	3706	1.1403
	(4)	20½	OFF	876 107.73	354 118.89	141 126.38	5 9.00	1 1.00					363.00	1377	.4237
070365	(1)	21	ON (new moon)	10 1.73	1 .34	1 .92	1 1.80						4.79	13	.0040
	(2)	20½	ON	93 10.87	3 .52	6 4.36	3 5.40						21.15	105	.0323
	(3)	20½	ON	373 42.45	178 56.32	70 62.20	7 16.10	1 2.70					179.77	628	.1932

TABLE 4.24 (Contd.)

	Sampling Interval (20 mins)	Water Temperature °C	Moonlight	Numbers and Weights in size-groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Total Catch Wgt. (mgms)	Nos.	Density
	(4)	20¼	OFF*	241 28.95	128 56.79	26 24.64	4 10.70					121.08	399*	.1228
210365	(1)	16½	OFF	6 .92	1 .15	1 .92						1.99	8	.0025
6.19 am - 6.26 pm	(2)		OFF											
8.51 pm - 9.53 am	(3)	16	OFF	621 69.80	191 47.06	60 52.14	32 54.60	3 11.70				235.30	907	.2791
	(4)	16	ON*	293 33.52	66 15.99	18 15.59	2 3.60					68.70	379*	.1166
230465	(1)	15	OFF (full moon)	1 .08	3 2.19							2.27	4	.0012
6.45 am - 5.43 pm	(2)	14½	OFF	16 1.57	5 1.39							2.96	21	.0065
11.10pm - 1.15 pm	(3)	14¼	OFF	61 7.08	79 18.70	31 28.40	16 29.40					83.58	187	.0575
	(4)	14	OFF	47 5.29	99 23.36	18 16.56	9 16.20	6 21.60				83.01	179	.0551

Sampling intervals (1)-(4) centred in the hour before and the first 3 hours after sunset.

The increase and then decline in the numbers in the catches was correlated with the bloom of green algae in December which subsequently provided shelter and food for animals until the end of February when it started to die and break up. The growth of this algae is in turn correlated with an interaction between the total flow of the stream and the number of hours of day-light (Figure 4.13). The algae appeared in the stream in the spring after late flooding subsided. Massive growth however did not occur until December when the flow dropped markedly and the day-length was nearly maximal. With decreasing daylight in late February-early March this algae started to die, and in the shallower water-types was broken up and carried away by the increasing flow.

At first the catches were obviously influenced by the drift of animals from the stones of Stickles into the pool. Later however when the flow of the creek was at a low level there was some surprising evidence that the catches in the so-called still-water near the Run-out of the long Deep Pool were more dependent on the production of animals in the algae of running water than in the algae surrounding the sampler in the Deep Pool. The catch in the second sampling interval at each date was peculiarly low. This phenomenon was shown earlier in section 4.2.7 to result from the movement of animals from running water through a pool. It will be shown later that this did not occur in catches made in true still-water (a dam and a reservoir). Also the algae in the Deep Pool, and to a lesser extent in shallower pools, persisted through March and into April until the rains came. Both the catches from still-water and running

Table 4.25 Changes in the light intensity around sunset for the 20-minute sampling intervals

	20-MINUTE SAMPLING INTERVAL				
	(1)	S U N S E T	(2)	(3)	(4)
Absolute Light Intensity (Lux)	1060		97.2	2.21	0.048
Relative* Rate of Change of Light Intensity (Lux/20 mins.)	1.71		3.28	4.07	2.68

* difference between log Lux values

(Average values for 12 dates during summer and autumn)

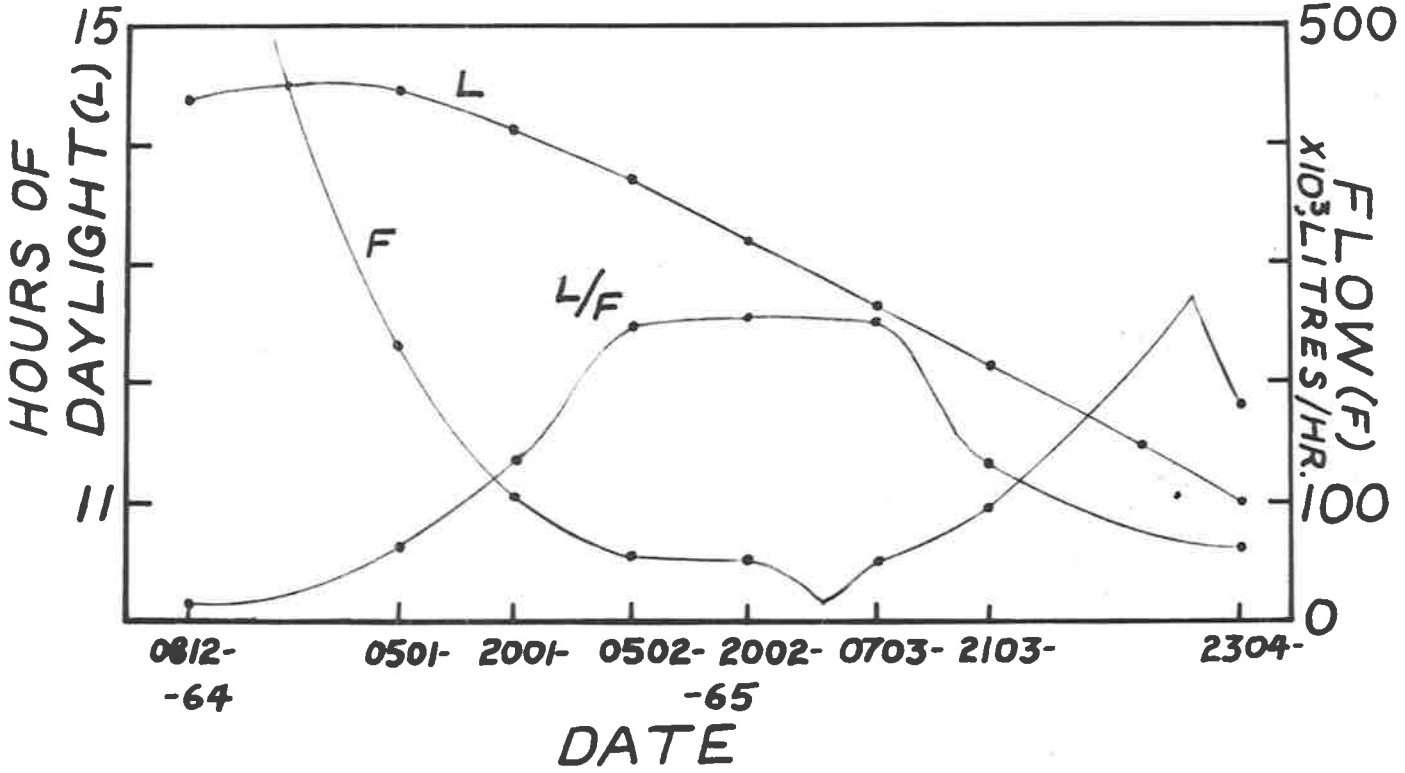


FIGURE 4.13 CHANGES IN THE HOURS OF DAYLIGHT AND TOTAL FLOW OVER THE SAMPLING PERIOD; DECEMBER 1964 TO APRIL 1965.

water exhibited a maximum in numbers during late Febriary - early March when the algae in the running water was disappearing (Table 4.26). The condition of the trout improved at the end of February. It would seem that as the algae broke up in running water the animals in it were forced to move out of it and became accessible to both fish and samplers. It is difficult to clarify these changes further by considering individual species of food animals because most of the species of animals in Sixth Creek could live in either running water or still-water habitats on stones or in algae (e.g. Table 4.23). Usually however their relative numbers were greater in catches from one or the other habitat. This flexibility does seem to be necessary from the mechanics of the drift phenomenon and from the likelihood of little or no flow in streams in S.A. during the summer.

The relative numbers (%) and sizes of different species of animals in the "still-water catches are shown in Table 4.27. The catches were dominated by the tiny mayfly nymph, Caenis, and to a lesser extent by the nymph, Deleatidium. Deleatidium is able to swim rapidly and primarily occurs under stones in stickles. It was numerous in drift catches. Large animals were even more poorly represented in these catches than in the drift catches. The predatory dragon fly nymph, Corduliidae, which lives mainly in the algae (although under stones in stickles at large sizes throughout the year) was numerous in the Deep Pool but only occurred in the catches while the growing individuals were small (peak density in early February).

Table 4.26 Comparison of the density of animals in drift and still-water catches

	DENSITY (Number* per 1000 litres)					
	"Drift"			"Still-water"		
PERIOD→	(1)	(2)	(3)	(1)	(2)	(3)
031264	6.0	19.6-26.7	15.1			
081264				12.6	56.3	44.3
050165				4.6	34.2	46.8**
190165	8.3	9.1	6.9			
200165				1.8	16.6	4.0
040265	11.8	30.3	23.1			
050265				5.9	55.4	37.2
200265				18.8	215.7	45.2
060365	51.0	44.0	36.5			
070365				2.8	24.0	9.2
210365				0	29.2	6.2
250365	25.9	27.9	24.3			
220465	8.0	12.3	9.8			
230465				0	11.5	10.2

* Number excluding size-groups (1) and (2) and all Rivissessor. Periods (1), (2) and (3) are for the first, second and third hour after sunset respectively.

** Moonset in period (2).

60 - minute sampling interval for drift.

20 - minute sampling interval for still-water.

Unfortunately the labour involved in sorting samples allowed only a few samples of algae to be taken in 1964-65 from positions in Deep Pools (Table 4.28). This algae was almost completely dominated by the small operculate snail, Rivissessor, and the hymph, Caenis, which was exceedingly numerous in size-groups (1) and (2). The algae in different parts of the Deep Pools appeared to vary considerably in the animals present in it. The algal matt floating near the surface, and exposed to considerable heating from the sun, contained enormous numbers of Rivissessor while the weed in the Run-out appeared to have a greater variety of species and sizes of animals than the algae a short distance further up the pool near the sampler. The large highly accessible animals, the pulmonate snail, Ameria, the damselfly nymph Zygoptera, and the dipteran larva, Stratiomyiidae did not occur in the catches and, although noticeable in the algal samples from above drift sites during the previous summer (Table 4.23), were almost completely absent from the stream during the summer of 1964-65.

Although the density of aquatic animals accessible to the trout in Sixth Creek has been shown to be high usually, and at times extremely so, the great majority of the individual items were very small. It is then not difficult to picture why the growth of the fish was very poor except at a small size. The growth of the multitude of small fish was as high as, or better then, the growth of fish of the same age in other places where the larger fish grew much more rapidly than in Sixth Creek.

TABLE 4.27 SPECIES COMPOSITION OF THE CATCHES IN TABLE 4.24 FOR SAMPLING INTERVAL (3)

Date	Corduliidae* Gomphidae**	Ameria* Rivisses-sor**	Atalo-phlebia	Corixidae* Stratio-myidae**	Aeschnae* Zygoptera**	Hydropsyche* Hydrobiosis**	Deleati-dium	Caenis	Olinga* Hydrop-tilidae**	Chironomidae* Simuliidae**	Pinoto-perla	Nos.
081264	(1) (2) (3)	.2** - (1)	1.7 (2) (5)					53.9 (2) (4)		42.4* (3) (5)		4 0 8
050165	.4* - (1) 1.1** - (5)	8.1** (1) (2)	1.1 (4) (6)				17.6 (3) (4)	39.7 (2) (5)		29.0* - (2) .7** - (2)	.4 - (2)	2 7 2
200165	2.0* - (1) .4** - (13)	7.7** - (1)	.4 - (4)				11.8 (4) (5)	66.7 (1) (4)	1.2* (2) (3) .8** - (2)	6.9* (2) (4)		2 4 6
050265	4.8* (2) (9) .3** (4) (7)	12.7** - (1)	1.1 (2) (3)	.1* - (1)		.1* - (2)	13.4 (2) (4)	55.1 (1) (4)	.7* (2) (3) 7.1** (1) (3)	4.2* (3) (6)		1 0 0 6
200265	.8* (2) (6)	.03** - (4)	.5 (1) (4)			.03* - (3)	52.7 (2) (4)	34.0 (1) (4)	.5* (1) (3) 8.9** (1) (3)	2.1* (1) (5)	.03 - (3)	3 7 0 6
190265 (Bottom sample from Algae	1.5* (4) (13)	86.6** (2) (5)					1.6 (4) (4)	6.0 (3) (4)	1.3* (3) (5) 2.8** (3) (3)			1 9 0
070365	.6* (2) (4) .2** - (1)		2.9 (2) (3)				30.6 (2) (4)	58.8 (1) (3)	.3* - (1) 4.1** (1) (2)	2.1* (2) (3)		9 6 2 8

TABLE 4.27 (Contd.)

Date	Corduliidae* Gomphidae**	Ameria* Rivisses-sor **	Atalo-phlebia	Corixidae* Strati-myidae**	Aeschnae* Zygoptera**	Hydropsyche* Hydrobiosis**	Deleati-dium	Caenis	Olinga* Hydrop-tilidae**	Chironomidae* Simuliidae**	Dinoto-perla	Nos.
210565	.8* (1) (3)		2.3 (2) (5)			.1** - (5)	8.8 (3) (5)	81.4 (1) (3)	.3* 3.4** - - (2) (2)	2.4* .1** (3) - (4) (2)	.1 - (2)	9 0 7
230465			.5 - (4)			.5* - (3)	27.3 (3) (4)	63.6 (2) (2)	2.7* .5** (1) - (2) (3)	2.7* - (2)	2.1 (1) (2)	1 8 7

(1) % occurr. . in catch

(2) median size-group in catch

(3) maximum size-group in catch

Table 4.28 Catches of Bottom Fauna from algae in Deep Pools in Sixth Creek

Date	Place	Numbers in Size-Groups											Total
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)		Nos.
150165	DP2	293	161	54	130	48							686
190265	DP2	884	469	286	233	26	7	2	1			1(13)	1909
080365	DP3	402 ⁂	512 ⁂	107	12	12	6	4	4		2		1061
260365	DP3	124 ⁂	730 ⁂	650	272	18	10	6	3	3			1816
270465	DP3	73 ⁂	75 ⁂	334	489	61	8	3	15	2	5	I(I2)	1066

⁂ Nymphs of Caenis very numerous in (1) and (2) - not counted.

The numbers of larger animals in communities are always less than the number of smaller ones either of the same species, because of mortality, or of different species, because they occupy different niches in the food chains (the Pyramid of Numbers, Elton (1927), from herbivores to predators). It did appear however that there was an unusual absence of certain species of animals of larger size in Sixth Creek which were known to be common in other streams in S.A. where the older trout grew better. Also among the species of animals which were present in Sixth Creek those that did grow ultimately to a large size appeared to be inaccessible to the fish except while they were very small.

It is postulated that this situation in Sixth Creek has been brought about by the trout selectively eliminating, or reducing to very low numbers, certain species of indigenous aquatic animals which are (or were) large and/or highly accessible to them. It is not suggested that the biomass of aquatic animals has been reduced in toto for there was an abundance of food potentially available to the trout during the study although the species found were either inaccessible if large, or very small if accessible. As a corollary then to the reduction, or elimination, of certain species one may postulate a compensatory increase in the abundance of other species. Changes in the relative abundance of species in an aquatic community does seem to be a consequence of the introduction of trout to any water where there has never been any predation by such a voracious fish. Among streams in S.A. these changes may be expected to have been extreme in Sixth Creek. The Torrens River - Sixth Creek system

has been heavily stocked since the early 1950s, the larger older fish, which suppress the numbers of small fish, have been selectively cropped by intensive fishing, and the trout are almost continuously distributed along the creek.

This is of course a problem peculiar to streams in countries such as Australia where trout are not indigenous. Butcher (1945) has considered the influence of the introduced trout upon native fish in Victoria. A consequence of changes in the food supply, in the direction described above, is a deterioration in the growth rate of the fish. Percival (1932), in N.Z., and Nicholls (1957), in Tasmania, have both discussed allegations of decreases in the growth rate of the trout. No one has sampled both the food and trout in a stream from the time of the first releases of the fish and the opportunities for doing so now are very few. That changes in the density of Salmonids, and other fish, can cause changes in the biomass of the bottom fauna is well known in streams where the fish are indigenous, or have been established for a long time, (e.g. Ruggles, 1959). In a few cases it has been possible to infer, fairly convincingly, that fish have caused changes in the composition of the food species (Blegvad, 1926, for plaice; Robertson, 1947, for trout; Brooks and Dodson, 1965, for herring; and Reif and Tappa, 1966, for smelt).

In the next section samples of food animals from other places in S.A., where the trout grew better than in Sixth Creek, will be given as a basis for the inference that the food situation in this Creek has been brought about by the predation of a dense trout population.

Of course the food situation in Sixth Creek was not quite as grim as appeared from the samplings for the trout is a more efficient "sampler" than the mechanical devices used. For example the trout ranges closer to the sources of accessible food, the bed of the stream and masses of algae. And it samples larger volumes of water per unit time by moving from side to side in the current and by patrolling a "beat" in still-water. Also there are other sources of accessible food which were not sampled. There are the imagines of aquatic insects flying just above the water surface, while mating and laying their eggs, and terrestrial animals which fall onto the water.

One of the obstacles to the full exploration of the relationship between the trout and its food is the great diversity of creatures which it eats. A study of the ecology of the trout tends to expand into a study of the ecology of the whole community of aquatic animals. The sampling of the food animals necessitates the consideration of individual species since their behaviour varies. The complete sampling of the food supply obviously requires several radically different methods. Although the majority of the species of aquatic animals could be, and were, sampled as a whole in Sixth Creek there were some other species (which were extremely important sources of food elsewhere) whose mode of life excluded them from the catches.

Consideration will be given to other sources of accessible food for the trout in the next sections and in section 4.3.4 to the actual numbers, species, and sizes of animals which the trout ate in Sixth Creek and other places.

4.3.3 Estimates of accessible food and Bottom Fauna in other places

Catches of accessible animals and Bottom Fauna were made in the latter half of the summer of 1964-65 in the Myponga Reservoir, the Light River, Bulls Creek, a dam near Delamere, and the Torrens River (Table 4.29).

The catches made by pumping in the two true still-waters (as opposed to pools in streams) showed conclusively that there is a large increase in the numbers of aquatic invertebrates moving in open water after sunset and hence in the amount of food accessible to the trout. It is therefore possible to conclude that the increase in the drift after sunset in running water is basically a consequence of the earlier evolution of a form of behavioural protection from predators, the movement of animals from cover into open still-water only after sunset.

The drift of aquatic invertebrates in streams, which is known to occur in Europe, North America and Japan, definitely occurs in streams in South Australia also.

The fish in all the places which have been sampled displayed a wide range of growth rates, the highest being in the Myponga Reservoir and the lowest in Sixth Creek (Table 3.21). The samples from the places introduced in this section therefore should provide a basis for the development of the explanation proposed in the last section for the poor growth of the trout in Sixth Creek. But first a short description of these other places is appropriate.

TABLE 4.29 RESULTS OF SAMPLING FOR ACCESSIBLE FOOD AND BOTTOM FAUNA IN OTHER PLACES

LIGHT RIVER. 260165 S.R.5.29am S.S.7.28 pm MR.12.24am MS.2.18 pm	Sampling Interval	Numbers and Weights in Size-Groups														Total catch		
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)					Wgts. (mgms)	Nos.	Density
Running water (drift net) Q : 30,9 2 1,/hr.	(1)		12 5.16	25 23.47	21 34.00	11 24.30	1 4.90		3 13.00							104.83	73	.0045
	(2)	4 .36	14 5.80	20 19.57	24 38.55	12 23.10					1 55.00					142.38	75	.0046
q(= qn) 16,200 litres/hour	(3)	4 .32	15 7.26	31 30.32	15 28.80	12 34.00	3 15.40		2 26.00	1 18.00						160.10	83	.0051
	(4)	10 1.22	29 13.05	72 74.28	74 130.70	28 104.70	8 49.40	4 33.60	5 95.00			1(12) 41.00				542.95	231	.0143
	(5) 8.28-9.28 pm	10 1.66	39 16.40	70 65.47	41 91.20	30 116.60	13 91.30	8 75.20	12 150.00	8 144.00	3 110.00					861.85	234	.0144
	(6)	8 1.08	26 9.39	37 31.47	25 54.55	11 51.00	6 39.60	4 37.60	2 26.00	3 50.50		1(12) 108.00	1(14) 74.00			483.19	124	.0077
Still-water (pump)	(1)			2 2.00	1 2.15											4.15	3	.0009
	(2)	22 2.22	34 6.31	40 54.50	3 5.50											68.53	99	.0305
	(3) 8.48-9.08 pm	21 2.09	39 12.89	75 84.29	29 66.70	7 30.80	3 9.60	11 12.40	8 72.00	1 14.50		1(12) 41.00	1(13) 57.00			403.27	196	.0603
	(4)	14 1.25	33 14.84	39 39.25	24 49.20	1 4.50		4 18.10	1 9.00			1(12) 41.00	1(15) 94.00			271.14	118	.0363
Bottom Fauna from Stickle (1) (Stones)		5 .45	38 16.50	74 60.92	53 76.90	22 59.50	10 39.60	7 65.80	3 39.00	6 108.00	1 23.00	3(11) 28.00				517.67	222	
Bottom Fauna from Pool (2) (Algae - Cladophora sp.)		27 7.69	238 84.18	149 151.42	60 153.55	20 90.90	4 12.80	9 53.40	10 115.60	1 49.00		1(11) 29.00	1(13) 57.00	1(14) 74.00		878.54	521	

TABLE 4.29 (Contd.)

BULLS CREEK. 280165 SR5.30am SS7.26pm MR1.33am MS4.12pm	Sampling Interval	Numbers and Weights in Size-Groups														Total Catch		
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)					Wgts (mgms)	Nos.	Density
Running water	(1)	3 .67	11 3.83	1 .34	5 4.90	1 1.70										11.44	21	.0015
Q = 25,313 l./hr.	(2)	7 .50	5 1.86	5 2.96	1 .70	1 3.80										9.82	19	.0010
q(= qn) = 18,338 litres/hour	(3)	4 .57	15 7.50	4 1.85	3 1.90	4 12.30		1 6.80								30.92	31	.0017
	(4)	12 1.13	28 7.40	50 57.68	14 24.05	5 24.05	5 52.70	2 33.90	2 48.00	1 4.20	1 33.50					286.61	120	.0065
excluding Copepoda, Daphnidae	(5) 8.26-9.26 p.m.	13 2.85	56 16.63	64 58.01	39 65.90	13 43.92	12 70.80	3 26.80	4 28.20		2 46.00	1(11) 5.00	1(12) 34.50	2(13) 84.00		482.61	210	.0115
	(6)	12 2.08	46 16.30	57 47.54	33 51.40	11 36.00	8 42.70	2 17.40	3 34.70	1 2.70	3 69.00	1(12) 34.50	1(13) 42.00			396.37	178	.0097
Still-water	(1)	6 .57	5 1.11		2 3.00	1 1.70										6.38	14	.0043
	(1)				4 4.80	6 23.40	8 51.20									79.40	18	.0055
	(2)	65 3.91	94 22.48	28 17.56	10 10.40	2 5.40	1 2.20									61.95	200	.0615
(excluding small forms above)	(3) 8.46-9.06 pm	9 2.05	81 22.84	70 41.93	55 69.80	25 45.30	10 62.70	1 8.70	2 15.50	1 18.00		1(12) 41.00				327.82	255	.0785
	(4)	14 2.76	38 11.94	45 26.01	30 34.80	11 27.85	8 46.20	4 32.90	1 13.00		1 23.00					218.46	152	.0468
Bottom Fauna from Stickle (1) (stones)		31 7.38	54 37.09	66 98.56	114 260.80	11 47.70	1 6.60	31 290.00		2 260.00	2 36.00	8(11) 184.00	4(12) 112.00	1(14) 74.00	1(35) 130.00	1310.13	326	
Bottom Fauna from Pool (2) (Plant Detritus)		31 11.34	61 59.09	387 475.87	164 332.90	48 212.25	43 247.00	26 214.15	7 84.60	1 18.50		1(14) 74.00				1729.40	769	

TABLE 4.29 (Contd.)

Myponga Reservoir 180265 SR5.52am SS7.07pm MR8.51pm MS7.56am	Sampling Interval	Numbers and Weights in Size-Groups												Total catch		
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)			Wgts. (mgms)	Nos.	Density
Still-water	(1)		2 1.86	32 47.50										49.36	34	.0105
	(2)	9 .45	107 47.34	254 307.75	32 61.55	12 21.00	10 32.00	5 27.00	1 9.00			1(15) 94.00		600.09	431	.1326
(excluded very many Daphnidae and Copepoda)	(3) 8.27-8.47	9 .85	132 45.35	281 291.37	40 68.65	26 45.50	33 105.60	31 181.60	9 81.00	4 88.50		1(18) 190.00		1098.42	566	.1742
	(4)	4 .96	179 67.74	322 331.12	80 148.35	16 28.00	8 25.60	2 10.80		1 14.50		1(15) 94.00		721.07	613	.1886
Bottom Fauna from Plant Detritus on (1) Mud and Sand		11 .55	137 45.21	79 81.50	2 4.30	6 12.65	5 16.00	1 21.50						181.71	241	
Bottom Fauna from Mud and (2) Sand		1 .15	13 4.26	27 35.53	2 4.30									44.24	43	
Bottom Fauna from Plant Detritus on Mud and Sand(3) (250264)		15 1.33	169 110.57	151 186.80	287 201.35	54 79.25	38 123.80	80 441.85	46 432.00	36 522.00		1(11) 55.00		2153.95	887	

TABLE 4.29 (Contd.)

	Sampling Interval	Numbers and Weights in Size-Groups (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)			Total catch Wgts.	Nos.	Density
Delamere Dam 210265 Stillwater SR.5.55am SS.7.03pm MR.10.22pm MS.1107am	(1)		2 .55	2 1.92	2 2.40									4.87	6	.0018
	(2)		14 4.52	15 14.84	11 21.15									40.51	40	.0123
	(3) 8.23-8.45 pm		30 11.05	26 23.91	12 22.00	2 7.30	1 4.90	2 8.01	2 12.35			1(13) 35.00		124.47	76	.0234
(excluded many Copepoda and Daphnidae)	(4)	3 .31	19 6.92	29 28.79	14 28.80	1 1.00	1 4.90	18 63.00		1 3.20				136.92	86	.0265
Bottom Fauna from Potomogeton Sp. (1) (Rooted Emergent Plant)		2 .19	19 6.85	12 11.92	8 14.35	9 14.77		2 31.50	1 9.80		1 17.00	1(12) 30.00		136.38	55	
Bottom Fauna on Mud	(2)	2 .44	8 2.58	9 9.50	15 26.15	1 1.00	2 9.80	2 14.00	1 9.80		1(12) 30.00	1(18) 95.00		198.27	42	
Torrens River 170265 Still-water SR.5.51am SS.7.08pm MR.8.18pm MS.6.46 am	(1)	5 1.13	5 1.98		1 1.80			1 1.90						6.81	12	.0037
	(2)	174 16.88	45 10.32	18 12.08	4 6.50									45.78	241	.0742
	(3) 8.28-8.48 pm	108 11.27	109 34.73	84 83.45	13 22.10	3 12.20	1 1.40							165.15	318	.0978
	(4)	53 5.27	66 18.38	22 20.88	2 3.60									48.13	143	.0440
Bottom Fauna from Cladophora sp. (algae) in pool (1)		395 72.35	183 130.11	169 201.39	115 286.40	29 160.00	1 1.40							850.64	892	
Bottom Fauna on silt and stones in pool (2)		9 4.05	53 41.65	173 253.11	10 10.16	1 14.00								322.97	246	

Density as number per litre.

60-minute (running water) and 20-minute (still water) sampling intervals centred in hours around sunset.

The reservoir filled with water for the first time during the winter of 1963 (the rain of one winter is sufficient). The Rainbow trout, whose high growth rate was given in Table 3.21, were stocked in the previous year. The reservoir also contained Brown trout which previously lived in the Myponga Creek the valley of which was inundated. These trout were more difficult to catch. The scales of a few very large Brown trout showed the same evidence of rapid growth as the scales of the Rainbow trout but this growth was in addition to earlier lower stream growth. The high growth rate and condition of the fish during their second year when they were first caught (early 1964) resulted from an abundance of aquatic invertebrates, species which apparently lived in the creek before-hand, in food chains derived from the decomposing submerged terrestrial vegetation.

When a reservoir fills for the first time the terrestrial vegetation submerged dies. This matter and energy is eaten by detritus feeders and broken down by bacteria and passes into food chains of a rapidly formed community of animals. When the water is drawn down (e.g. in the next summer usually) some regrowth of vegetation occurs on the exposed soil. However this is less abundant than formerly so that there is commonly a dramatic reduction in the amount of animal production within a year or so of the first filling unless the reservoir is so large that a number of wet seasons are needed to fill it completely (e.g. Lake Eucumbene in N.S.W.). This plant source of matter and energy is to some extent replaced by phytoplankton in the open water and emergent aquatic plants in the littoral zone.

However the zooplankton sustained by the phytoplankton are too small for a large fish like trout to feed efficiently upon them and their numbers are low during the winter. In reservoirs, and particularly in hydro-electric storages, the annual cycle of draw-down and refill is usually so large in magnitude that the growth of rooted aquatic plants in the shallow littoral zone is prevented. Wave action also tends to remove the top-soil from the shores. The food situation in later years may also be worsened by the presence of a large biomass of trout that developed in the first few years of abundance of food and the careless introduction of Redfin perch (Perca fluviatilis) which multiply rapidly in still-waters. The older reservoirs in S.A. are unproductive and only a few large old trout and numerous perch are caught. These are important problems in Australia where so many water-storages are created by man. Frey (1965) mentions investigations in the U.S.S.R. on the decline in the productivity of reservoirs during the first few years and Grimds and Nilsson (1965) describe the aging of Swedish reservoirs.

The Light River has been heavily stocked with Rainbow trout since the early 1950's. There is however much shallow water not inhabited by them because of the severity of the climate during the summer. The stream flows through country largely cleared of native vegetation and extensively used for sheep grazing and grain crops. Like most of the streams in S.A. the Light River is alkaline (pH = 8.1 on 270365) but it is also undrinkably saline. There are extensive beds of filamentous green algae, Enteromorpha sp., and Nitella sp.

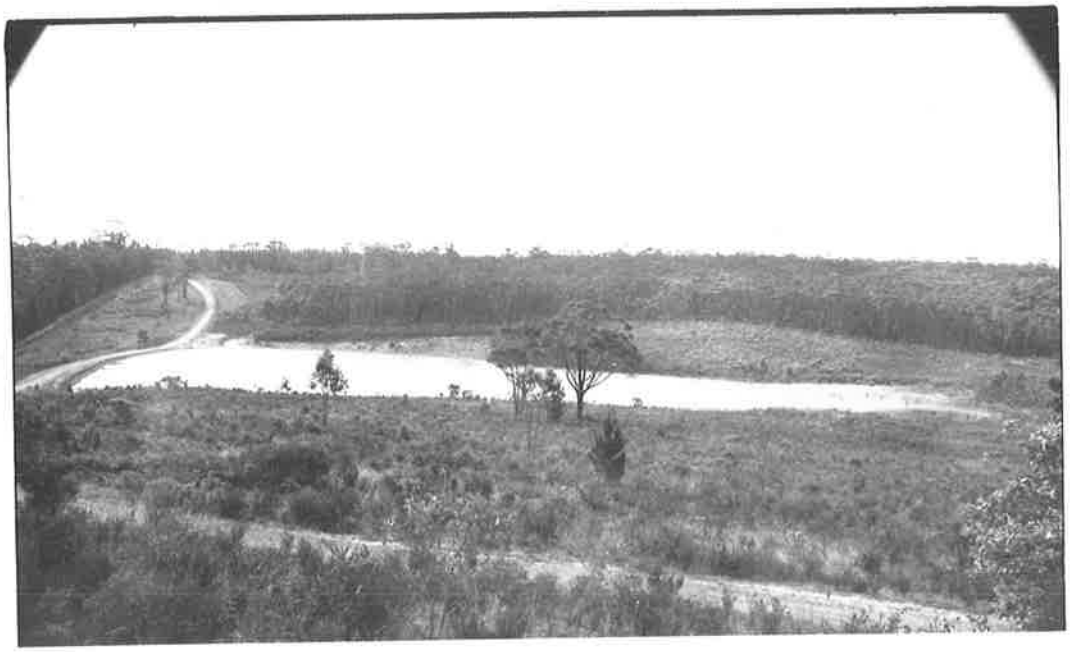
The samplings were made within short distances, upstream and down, of pools containing trout.

Bulls Creek is a small stream well-shaded by trees with a lower (but reliable) flow than Sixth Creek. It has however more frequent long, deep(er) pools which the trout live in. But there are more stretches of very shallow water, uninhabitated by the trout, than in Sixth Creek. Brown trout were established at least by the early 1930's and until the early 1950's the Creek contained many old large trout. Since then intensive fishing has reduced the average size of the fish considerably and the Creek has also been unnecessarily stocked in most years. The surrounding watershed is nearly completely cleared and is used for sheep grazing. Dairy cattle given indiscriminant access to the stream are destroying the banks, and hence pools, in many places. The water is alkaline (pH = 8.0, 290365). Filamentous green algae grows during the summer in sunlit stretches and a considerable amount of plant materal (leaves and tree branches) falls into the water.

The large dam near Delamere is situated in the gully of a non-perenial tributary of Deep Creek. There was no summer draw-down by man. Its small watershed is covered with native eucalypt forest and scrub. The pH of the water was 7.5 on 220165. There were no aquatic plants but a large amount of rotting plant material lay in the shallower water at the top end of the dam. The dam was stocked with 500 each of Brown and Rainbow fry $1\frac{1}{2}$ years after it was built and sampled when the fish were 1+ (early 1965). The fish grew well until

Upper. Delamere Dam (220166).

Lower. Myponga Reservoir (180265).





their second summer (when they were ripening to spawn) and then there was no further detectable growth. The Brown trout were very difficult to catch. Four fish were transferred in the January of their second year to a small dam filled by runoff from shed roofs (pH = 7.0 on 220165). A Rainbow trout was caught in this dam on 100465, 3 months later, which was 41.0 cms long and its weight (1025 gms) was about 4 times that of fish of the same age (1+) in the larger dam. The fish contained 34½ grams of fresh Isidorella subinflata, a large (size groups (12)-(18)) highly accessible pulmonate snail.

The Torrens River was sampled, by pump, in a large pool about ¼ mile below the Sixth Creek. During the summer the river is used as a channel to Adelaide for water pumped over the hills from the Murray River to the east. The large flow (30 million gallons per day) did not allow drift sampling in the narrow stream-course. The fish (both Brown and Rainbow) grew better than in Sixth Creek but not as well as those in other streams.

In the Light River and Bulls Creek the drift samples were taken at the lower end of stony Stickles which were about 40' in length in both places. In the Light River the small pools at the head and lower end of the stickle did not contain fish whereas in Bulls Creek they did. In both places the small flow had to be constricted over the bar which was set in the bed of the stream to support the sampling net. The pump samples in these two streams were taken from the pools into which the Stickles ran.

The densities of animals from the drift and pump catches in these places (Table 4.29) were not greater than the densities from catches at comparable dates in Sixth Creek (Tables 4.21 and 4.24) and were nearly all smaller. However it was obvious from the weights of the catches and the size-frequency distributions that, except for the Torrens River the sizes of the animals in the catches were larger. Table 4.30 shows the relative numbers and sizes of different species of animals in these catches from other places. It is particularly evident in comparison with similar tables (4.23 and 4.27) for Sixth Creek catches that the catches from other places were dominated by species which were unknown, or uncommon, in the catches from Sixth Creek. These species were characteristically not only highly accessible but also accessible to sizes approaching, or including their maximum, and in most cases quite large, sizes in the Bottom Fauna. The highly accessible animals - Corixidae (water boatmen), Zygoptera (damselfly nymphs), Hydropsyche and Hydrobiosis (caddis larvae), simuliidae (midge larvae) - for example were uncommon in Sixth Creek. The most important species of food animals in these other places were the small amphipod (Gammaridae), Austrochiltonia subtenuis, the large decapod shrimp, Paratya australiense, and the crayfish (yabby), Cherax destructor.

Austrochiltonia ("scuds") were found in drift samples from Sixth Creek on 4 occasions (8 individuals) in sizes from (2) to (8) and in the stomach of 5 Sixth Creek trout in sizes from (3) to (9). Dendy (1944) says that gammarids swim actively rather than hide when

TABLE 4.30 COMPARISON OF THE SPECIES AND SIZE COMPOSITION OF THE CATCHES IN TABLE 4.29

Place Date		Paratya	Chiltonia	Corduliidae	Ameria* Rivisses-sor **	Atalo-phlebia	Corixidae	Zygoptera	Hydropsyche* Hydrobiosis**	Deleati-dium	Caenis	Olinga	Chironomidae (larva)	Simuliidae (larva)
Light R. 260165	D	(1) 1.3 (2) - (3) (10)	20.1 (3) (6)	0.4 - (10)			3.8 (3) (8)		35.5* (5) (10)					36.3 (3) (6)
	B (1)		2.7 (4) (5)				0.5 - (3)		37.8* (4) (11)				11.3 (3) (4)	43.7 (4) (6)
	S	16.3 (7) (13)	50.5 (3) (5)				9.2 (3) (3)	0.5 - (7)	19.9* (2) (4)				0.5 - (1)	1.0 - (3)
	B (2)	4.0 (7) (14)	80.0 (2) (5)	0.2 (4)	4.4** (1) (2)		1.5 (3) (3)	0.2 (5) (8)	1.2* (2) (4)				0.4 - (2)	0.4 - (2)
Bulls Creek 280165	D	5.2 (2) (4)				23.3 (4) (8)	1.0 (3)		3.8** (10) (13)	1.4 - (3)	10.5 (4) (5)	5.7 (1) (3)	11.4 (3) (11)	11.9 (3) (5)
	B (1)	0.3 - (14)			6.4** (3) (5)	3.1 (5) (7)			8.3** (10) (12)	4.0 (3) (5)		47.2 (3) (4)	15.6 (3) (5)	0.3 - (5)
	S	2.4 (2) (12)				4.7 (5) (8)	0.8 - (3)		6.7** (3) (9)	0.4 - (3)	9.4 (4) (6)	5.5 (2) (4)	53.1 (3) (8)	11.0 (3) (5)
	B (2)	0.5 (5) (14)			10.9** (2) (5)	26.0 (4) (9)	39.8 (3) (3)		0.4** (5) (8)	2.3 (4) (8)	2.9 (4) (5)	1.6 (4) (5)	2.7 (4) (4)	0.1 - (4)
Myponga Res. 180265	S	21.4 (6) (18)	67.7 (3) (4)				7.2 (3) (3)				1.6 (3) (4)		0.5 - (7)	

TABLE 4.30 (Contd.)

Place Date		Paratya	Chiltonia	Corduliidae	Ameria* Rivissessor **	Atalophlebia	Corixidae	Zygoptera	Hydropsyche* Hydrobiosis**	Deleatidium	Caenis	Olinga	Chironomidae (larva)	Simuliidae (larva)
250264	B (1)	4.1 (6) (6)	92.5 (2) (4)				2.1 (3) (3)				0.4 - (5)			
	B (3)	24.4 (7) (9)	12.3 (3) (5)				11.5 (3) (3)				0.6 (4) (6)		34.9 (4) (11)	
Delamere Dam 210265	S		63.2 (3) (4)	1.3 - (2)				6.6 (6) (13)		1.3 - (7)	3.9 (4) (5)		6.6 (3) (4)	
	B (1)		60.0 (3) (5)	1.8 - (7)			1.8 - (2)	12.7 (7) (12)					14.5 (5) (5)	
	B (2)		54.8 (3) (4)				2.4 - (3)	19.0 (7) (8)			4.8 - (1)		11.9 (4) (5)	
Torrens River 170265	S		30.2 (2) (5)			1.3 - (3)	1.6 - (3)		18.6** (2) (4)	4.4 (3) (5)	34.0 (2) (4)	0.9 - (3)	5.7 (2) (4)	0.3 - (3)
	B (1)		24.3 (2) (4)	0.2 - (4)	4.8* 20.5** (1) (1) (4) (5)	0.2 - (4)	0.3 - (3)			0.2 - (3)	41.1 (1) (5)		0.7 (3) (6)	
	B (2)		0.4 - (3)		7.7** (3) (5)		87.7 (3) (3)				0.4 - (4)	0.4 - (4)		

(1) Relative number (%) in the catch
(2) Median size-group in the catch
(3) Largest size-group in the catch

These indices for drift and still-water catches, taken in the second hour after sunset, are compared with those for the corresponding Bottom Fauna catches.

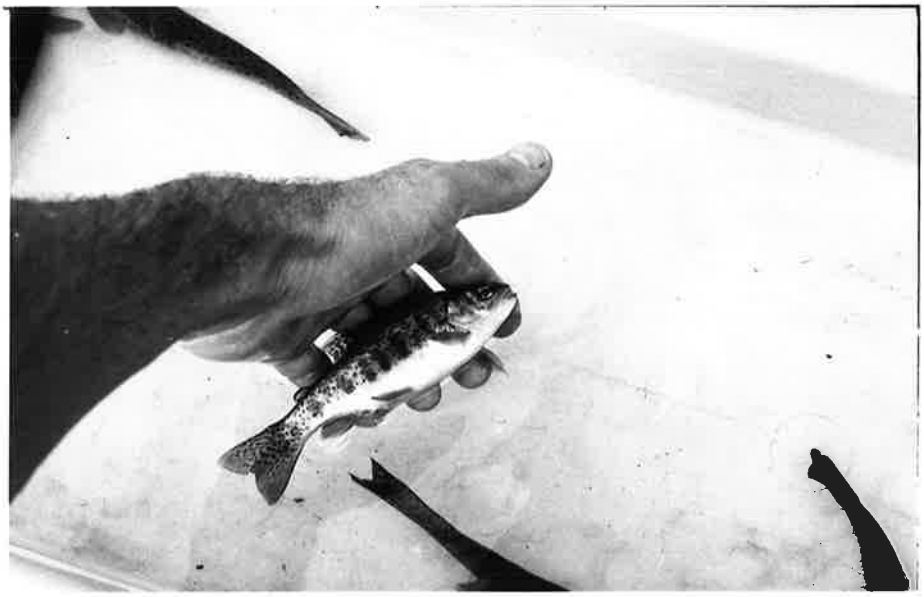
disturbed. The animal is common in many places, and can live under stones in swiftly running water (e.g. in the Torrens River), in filamentous green algae in running water (e.g. in Cladophora sp. in the Broughton River) in beds of Chara or Nitella sp. in still-water (e.g. Light River), or in plant detritus in still-water (e.g. Myponga Reservoir).

The larger shrimp, Paratya, was found only once in the study section in a sample of algae. It occurs in dams on the watershed of Sixth Creek, in adjacent streams such as the Little Para River and Cox's Creek, and is a common animal in freshwater in S.A. Although the samplings showed that its accessibility increased after sunset it is thought that it evaded capture by the pump sampler during the daylight. It can be observed to be capable of rapid evasive swimming when disturbed but is apparently easily captured by trout. For example, a large Brown trout (44.5 cms, 2+) was captured in the Bremer River at 5 p.m. on 231065. The fish was caught while it was feeding actively along a "beat" close to one bank of a pool. It contained 28 fresh Paratya in sizes from (10) to (20).

The yabby, which grows to a very large size in comparison to the other food animals of the trout, is found in all the freshwaters in S.A.; and where the trout have not become numerous can be caught in large numbers by simple baited traps. Except at very small sizes the yabby cannot be expected to be captured by the methods used for other animals since when large it crawls around on the bed of the stream. Its biology and possible methods of estimating its abundance

Upper. A well-conditioned Rainbow trout, age 0+, from Sixth Creek in the late autumn (040565). The other fish in the handling tank are older trout in poor condition which were caught in the same stretch of the creek.

Lower. The Brown trout, mentioned on page 328, which was captured on 231065 in a deep pool of the Bremer River while it was feeding on shrimps. The fish was 44.5 cms. in length, aged 2+, and had spawned (female) in the previous winter. It was one of 68 advanced fingerlings which were carefully stocked in two of the deepest pools in the river at low water on 080664. The fish was caught in one of these pools.





have not been investigated. To get some idea of the numbers and sizes of yabbies in Sixth Creek two wire mesh traps were used. These cylindrical traps (11" length x 7" dia.) were baited with meat. Results of the trappings are shown in Table 4.31 (a) for Sixth Creek and Table 4.31 (b) for other places. The yabby lives in holes in steep banks so that the catches in the Myponga Reservoir on a gently sloping shore underestimate the true numbers which were present. At most times of the year there was only a very few yabbies in Sixth Creek. These were too large for the small trout (mostly less than 30 cms in length) there to swallow (Figure 4.13); an unusual form of a relative shortage of food (Andrewartha and Browning, 1961) whereby the food is in a form which makes it inaccessible to the fish. The yabbies appeared to breed during January in the creek for small individuals, sizes (6)-(7) were found in drift samples during the period January to March. Yabbies were still fairly common in Sixth Creek to the casual observer until about 1958.

Another type of animal for which no sampling method was devised are the small native minnows (Galaxias truttaceous, G. kayi, G. attenuatus, Ellogobius olorum, etc.) Sampling was not needed in Sixth Creek because the enormous numbers of minnows which farmers remember in the creek before 1940 (at which time the trout started dispersing up the creek from the Torrens River) have been completely eliminated by the trout since then. Galaxias spp. can however still be found in the small tributaries of most streams where they can survive stagnation and drought during the summer which the trout

Table 4.31 (a) Catches of Cherax destructor (yabby) in Sixth Creek

Date	Place	Times	Number Caught	Numbers in Size-Groups (mms)								
				(20)	(30)	(40)	(50)	(60)	(70)	(80)	(90)	(100)
05-061164	DP2	2pm 10am	(1) 0 (2) 0									
06-071164	DP2	10am 9am	(1) 0 (2) 1								1	
01-031264	P3 DP1	10am 5.30pm	(1) 0 (2) 2				1		1			
03-041264	P3 DP1	5.30pm 5.30pm	(1) 1 (2) 0						1			
08-111264	DP1 SP9	6pm 12noon	(1) 0 (2) 0									
19-200165	P3 DP2	10.45am 5pm	(1) 1 (2) 1							1	1	
21-220165	SP9 S11	2pm 3.30pm	(1) 2 (2) 0						2			
200265 "	DP3 RIDP3	6.00pm 10pm	(1) 0 (2) 0									
06-070365	DP2 P4	2.30pm 5.15pm	(1) 1 (2) 0						1			
07-080365	P6 DP3	5.30pm 4pm	(1) 5 (2) 7						2 5	3 2		
12-130365	P3 SP9	2pm 10am	(1) 3 (2) 6					1	1 4	1 2		
15-160365	PP3 DP1	3pm 9.30am	(1) 3 (2) 0					2	1			
16-170365	RIDP2 RODP2	11am 6pm	(1) 1 (2) 0						1			
30-020465	R14 SP10	3pm 3pm	(1) 0 (2) 0									
13-140465	SP9 DP2	9.30am 9.30am	(1) 1 (2) 2						1	2		
14-150465	DP1 P4	9.30am 4pm	(1) 0 (2) 0									
01-020366	DP2 SP9	5pm 5pm	(1) 2 (2) 10			1	1	6	2	1		1

(1) and (2) under "number caught" refer to the two traps used.

The yabbies were measured (alive) stretched out on a ruler, from the eye to the end of the segment of the abdomen before the telson and uropods.

Table 4.31 (b) Catches of Cherax destructor (yabby) in other places

Date	Place	Times	Number Caught	Number in Size-Groups								
				(20)	(30)	(40)	(50)	(60)	(70)	(80)	(90)	(100)
071164	Light	11am —	(1) 11			1	3	4	3			
"	River*	6pm	(2) 6			1	2	1	1	1		
221164	"	11am —	(1) 0									
"	"	2.15pm	(2) 4						1	2	1	
"	"	3pm —	(1) 1				1					
"	"	6.15pm	(2) 5				1	3	1			
131264	" ¤	11.30am 3.30pm	(1) 23			1	12	9	1			
"	" ¤	1.30am— 3.30pm	(2) 17				6	8	3			
"	"	3.30 — 6.45pm	(1) 5				3	2				
"	"	3.30 — 7.00pm	(2) 15				9	5	1			
26-	" ¤	3.30pm—	(1) 13				2	3	7		1	
270165	" ¤	7.30am	(2) 13				4	3	6			
28-	Bulls	3.30pm—	(1) 6					2	1	3		
290165	Creek	8.30am	(2) 2					1		1		
170265	Torr-	6.00pm—	(1) 2			1			1			
	ens R.	10pm	(2) 1	1								
180265	Mypon-	5.30pm —	(1) 3						2		1	
	ga Res	10pm	(2) 3							2	1	
Average Weight			(gms)	.22	.90	2.75	6.2	12.0	20.2	35	52	

¤ No trout in pool

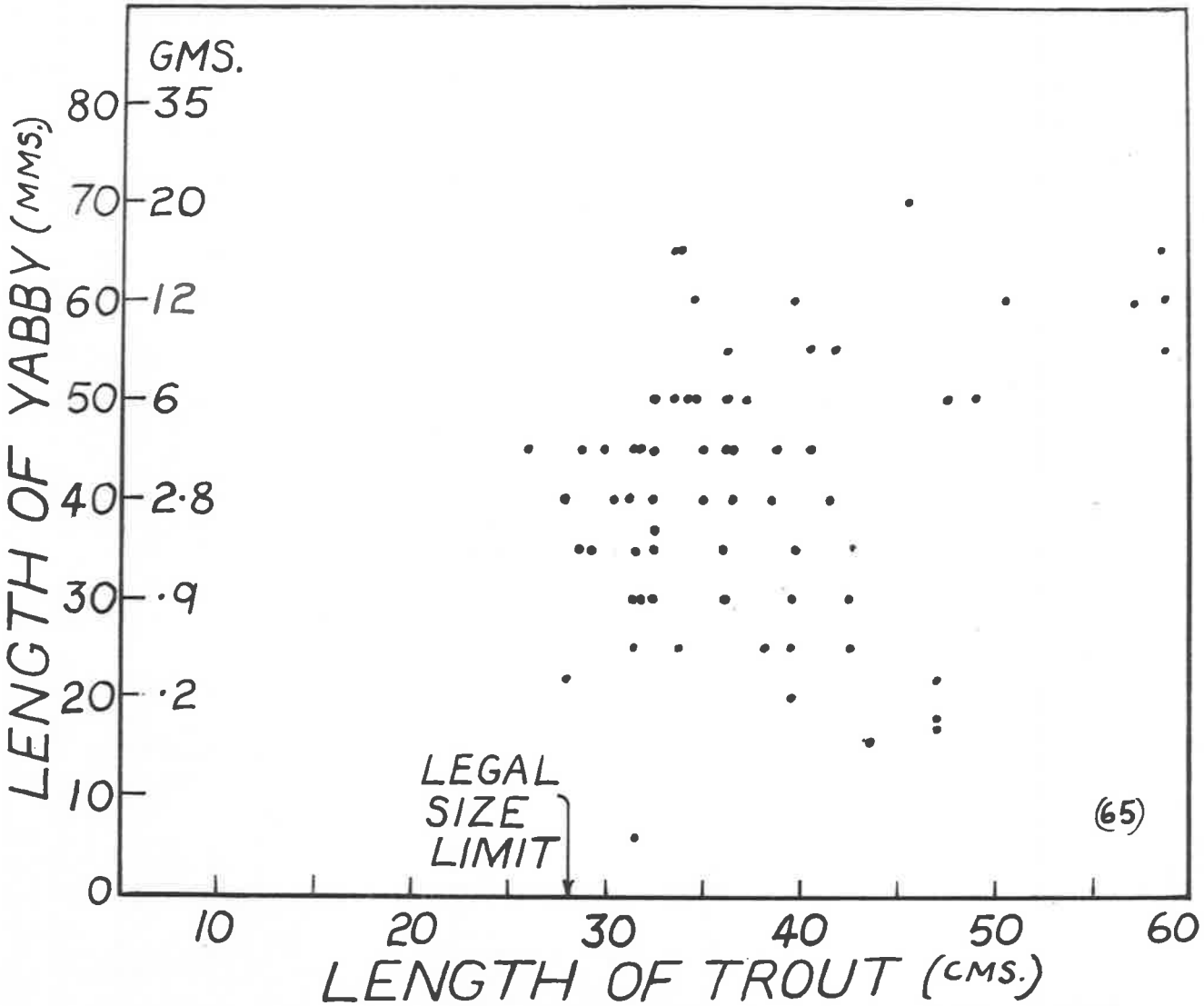


FIGURE 4.14 SIZES OF CHERAX DESTRUCTOR (YABBY) FOUND IN THE STOMACHS OF TROUT OF DIFFERENT SIZES

cannot do. For example Galaxias kayi still survives in the small tributary that enters Sixth Creek at the upper ford shown on Map 5. Galaxias attenuatus ("land-locked" susspecies) is fairly common in the Light River and the Little Para River despite the trout because its greater tolerance of high water temperatures and small size allow it to live in places where the larger trout cannot live.

Other animals which appear to be highly vulnerable to predation by trout and which were absent from Sixth Creek were the Whirligig beetle, Gyrinidae, which was numerous on the surface of pools in which there were no trout, and large water beetles, Dytiscidae, which were observed, for example, moving in open water and rising to the surface to breathe (as pulmonate snails, Ameria and Isidorella and dipteran larvae, Stratiomyidae, do) in the tributary of Sixth Creek. Also the tadpoles of frogs, which breed in the spring, were uncommon in Sixth Creek.

The larger animals which remain in Sixth Creek, for example the predatory dragonfly nymphs, Aeschnae, Corduliidae (= Libellulidae), and Gomphidae, apparently manage to persist because they remain inaccessible to the fish under stones in Stickles and in algal beds at least in the larger sizes. They are vulnerable to the numerous trout when they drift and move in open "still" water while small and also when they emerge from the water. With so many small animals for them to eat it is obvious that the trout were keeping their numbers low. Sixth Creek was once a favourite site for the collection of the mudeye, Aeschnae, by anglers for bait. Corduliidae were present in the Myponga Reservoir (see stomachs next section) in the first year

after it filled although they were not so common in the second year, apparently, when it was sampled. Also during the filling of Lake Eucumbene in N.S.W. this animal is reported as an important source of food for the fast-growing trout there. A large dam at Kersbrook was stocked with a few (50) 0+ Brown trout fingerlings during mid-March 1965. None of these fish were caught, or even seen, until early March 1966 when the dam was emptied and 23 were recovered. These fish ranged in length up to 40 cms. and were in excellent condition. While the dam was being emptied large numbers of Corduliidae were seen. Also plentiful were Austrochiltonia, Caenis, Paratya, Ameria, Atalophlebia albiterminata (a large mayfly nymph common in Australia), Corixidae, and nymphs of Zygoptera. Apart from the mud on the bed of the dam there did not appear to be the opportunities for sheltering from the trout that existed in Sixth Creek. The same number of Brown trout (50) was stocked in a much smaller dam nearby (about 1/20 of the capacity of the larger dam). These fish grew rapidly during the first few months (up to 29 cms.) until the next spring after which their growth (as shown by scale samples) was slow although the same species of food animals were found in the stomachs of the few which were captured. Apparently in the small dam the trout were too dense and reduced the numbers of food animals to a low level.

It should be pointed out that there are no known natural lakes or ponds in the Mt. Lofty Ranges. Therefore the animals which live in still-waters, farm dams and reservoirs, made by Man, are species which live in streams where they are adapted to survive similar conditions during the dry period of the year in pools.

Where trout have attained extremely high growth rates in the world their food supply has been dominated by a large, numerous and highly accessible food animal usually a small fish. For example - Lake Titicaca in Peru, a large and prolific native fish, the pejerrey; the rivers of Chile and Argentina, a crab-like crustacean, the Apancora, and a shrimp; Lake Pend Oreille in Idaho, a degenerate land-locked salmon; Lake Purrumbete in Victoria, Galaxias and shrimp; Lake Taupo and other places in N.Z. small native fish, the bully (Gobiomorphus gobioides), the smelt (Retropinna retropinna), and the crayfish (Paranephros planifrons).

4.3.4 Feeding

Stomachs of both Brown and Rainbow trout from Sixth Creek (125) and other places (235) were collected (preserved in 5% formalin) during the seasons 1963-64 and 1964-65. The purpose of examining the contents of these stomachs was to confirm the conclusions of the previous chapter by showing that the fish actually ate the species and sizes of food animals predicted from the consideration of catches of accessible food and Bottom Fauna in Sixth Creek and other places. An examination of the contents of the stomachs of trout should also show how important were other sources of accessible food which were not sampled (aerial adult stages of aquatic insects and terrestrial species), or only crudely (yabbies).

The occurrence of different species of food animals in the stomachs of trout in Australia has been investigated by McKeown (1934, 1934a, 1934b, 1936, 1937, 1955) in N.S.W., by Evans (1937, 1938-39, 1942) in Tasmania, and by Butcher (1945) in Victoria. Butcher (1945) placed considerable emphasis on differences in the relative numbers of different types of food in the stomachs of Brown and Rainbow trout. It was not clear however that equal numbers of stomachs of each species were collected in each of the Victorian streams, results from which were summed for each species. He mentions that Rainbow trout had been unsuccessful in streams where there were Brown trout (and Brown trout streams were not currently stocked with Rainbow trout) so most of the stomachs of Rainbow trout probably came from different streams from where those of Brown trout were collected.

In this study the emphasis has been on comparisons between different places irregardless of whether they contain only Rainbow trout, or only Brown trout, or both. It was concluded that differences in the growth of the fish in these places was largely the result of differences in the species and size composition of the food supplies. In one stream, Sixth Creek, it was clear that the food supply had been considerably altered by the predation of a dense population of fish distributed almost continuously through the stream. How much of the differences between all the streams is due to different intensities of predation by the trout for a varying number of years or to differences in their suitability for different food species is of

course not known. The Brown trout have been established in southern streams for many years. Rainbow trout stocked in Brown trout streams have not persisted except in the Torrens River - Sixth Creek system where they were restocked in large numbers more recently. In other streams where there were no Brown trout, the Light River and Little Para River, recently introduced Rainbow trout have better growth rates than Brown trout in southern streams. In Sixth Creek where the two species competed for a very limited food supply, and living space, no difference was detectable in their growth, or feeding behaviour, although Rainbow trout persisted in a spot for a shorter time than Brown trout. In the larger Torrens River, the older Rainbow trout grew more slowly than the Brown trout. In lakes, Nilsson (1953) has described segregation of trout and char; the more aggressive trout occupy the shallow littoral areas and the char the open water where there is less food. (This behaviour is not shown by the char when the trout are absent).

In the subsequent tables the data has been summed for the two species where they occur together. It has also been necessary to sum the records for fish of different sizes, except in Sixth Creek, (in other places the fish were nearly all larger than the legal size limit - 11 inches), for different seasons, and for different times of day because of the small number of stomachs and the considerable variability between individual fish. Obvious bias resulting from this practice will be pointed out.

There are various methods of recording the contents of the stomachs of trout and other fish (Hynes, 1950). The choice of method has depended on the purpose of the analysis. The relative numbers of the different species present may be used to show the relative accessibilities of the species to the trout, or the weight of the contents may be used in calculations for the relationship between the growth of the fish and its food supply. Following the method used in the food sampling both the number and sizes of individuals of each species of animal in the stomachs were recorded. The small amount of extra work involved in measuring the animals, after the initial sorting into species, adds a considerable amount of extra information. For the food samples the size-frequencies presented a considerably more illuminating picture of the food supply than if just the number, or weight, of each species had been found. Also the numbers of animals of each species in different size-groups may be easily converted to live weights as was done for the food samples. Usually the numbers of all intact animals and also of recognizable fragments (e.g. heads) are recorded. A more definitive record was thus kept in this study because only the numbers of animals which were sufficiently intact to be measured in length were recorded.

Conclusions as to the relative importance of different food species in the diet of the trout, from the relative numbers of species in their stomachs, may be considerably biassed by the different rates of digestion of different types of animals (Hess and Rainwater, 1939;

Ellis, 1958). Animals which are not so rapidly digested will be recorded in relatively higher numbers. Another source of bias is that smaller animals are more rapidly digested than larger ones of the same type because their surface area is larger relative to their mass. This bias was apparent in this study because considerable attention was paid to the sizes of the food animals.

For example the caddis larva, Olinga, lives in a tough cylindrical case apparently undigested by the fish and the opening to the case is blocked by its large heavily chitinized head. The snail, Rivissessor, has a very thick shell and was often found intact in the intestine of trout in Sixth Creek. On the other hand the snail, Ameria, which has a thin shell was found to be well digested in the cardiac (top end) of the stomach of fish. Soft-bodied crustacea such as the shrimp, Paratya, and the scud, Austrochiltonia, are also rapidly digested. Although the trout in Sixth Creek could eat large numbers of the snail, Rivissessor, the food absorbed by the gut before the snails were eliminated must be much less than an equivalent weight of, say, Austrochiltonia. It was very noticeable that the small mayfly nymphs, Caenis and Deleatidium, were fragmented even when they were found in the oesophagus of a trout. Large food items such as the yabby, which also has a heavily chitinized cuticle, may be expected to persist intact in the stomach for a considerably longer time. It is then not so surprising that of the 62 stomachs of fish from the Light River only 2 had recognizable, but extremely well-digested, remains of the soft-bodied Galaxias whereas a high

TABLE 4.32 % OCCURRENCE OF DIFFERENT SIZES OF AQUATIC ANIMALS IN THE STOMACHS OF SIXTH CREEK TROUT OF DIFFERENT SIZES (1.6% OF STOMACHS WITH REMAINS OF CHERAX DESTRUCTOR)

Length of Fish (cms)	% Occurrence in Size-Groups											(No. of fish) Average number of items per stomach
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)-(19)	⩾(20)	
10.0-14.9	0.73	4.00	59.27	25.27	6.73	1.09	0.91	0.55	0.18	1.27	0.00	(28) 39.3
	14.3	50.0	71.4	75.0	50.0	28.6	21.4	14.3	10.7	39.3	0.00	
15.0-19.9	4.32	11.05	16.20	23.06	24.85	14.55	3.91	0.75	0.07	0.96	0.27	(23)
	34.8	65.2	73.9	56.5	56.5	47.8	34.8	26.1	4.3	52.2	4.3	63.3
20.0-24.9	3.33	16.40	26.57	28.18	14.06	5.98	2.59	0.99	0.25	1.42	0.25	(34)
	32.3	64.7	67.6	58.8	52.9	41.2	23.5	29.4	11.8	41.2	8.8	47.7
25.0-29.9	0.00	3.61	12.16	14.23	24.95	25.84	7.73	1.34	1.65	5.88	0.62	(22)
	0.00	40.9	50.0	45.5	68.2	45.5	40.9	31.8	36.4	68.2	9.1	44.1
30.0	0.20	3.55	6.70	15.53	19.39	18.88	18.88	4.67	1.93	10.10	0.20	(18)
	9.6	33.3	83.3	88.9	83.3	83.3	66.7	61.1	50.0	66.7	11.0	54.7

Upper - % number of animals of the specified size in all the stomachs

Lower - % of stomachs containing at least one item of the specified size.

TABLE 4.33 % OCCURRENCE OF DIFFERENT SIZES OF AQUATIC ANIMALS IN THE STOMACHS OF TROUT FROM OTHER PLACES

Place	% Occurrence in Size-Groups											(No. of fish) Average number of items per stomach
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)-(19)	(20)	
Light R.	-	0.15	10.29	25.20	46.39	3.01	0.80	1.20	0.70	9.49	2.76	(58)
	-	1.7	19.0	24.1	32.8	17.2	15.5	10.3	6.9	51.7	44.8	34.3
Myponga Res. Early 1964	0.08	0.17	15.79	41.43	18.51	9.93	5.94	1.19	0.68	3.57	2.72	(18)
	4.8	9.6	77.8	77.8	77.8	61.1	50.0	22.2	22.2	50.0	61.1	65.4
Myponga Res. Late 1964 on	-	0.03	3.33	6.37	40.16	25.13	16.48	6.78	0.16	1.08	0.48	(32)
	-	3.1	25.0	34.4	40.6	59.4	46.9	25.0	3.1	28.1	25.0	98.6
Bulls Cr. Finniss R. Coxs Cr. Scotts Cr. Deep Cr.	-	2.10	12.61	11.13	17.02	8.82	16.81	5.25	1.89	22.27	2.10	(53)
	-	7.5	28.3	28.3	35.8	35.8	26.4	22.6	9.4	39.6	17.0	9.0
Torrens R.	0.67	10.24	29.15	16.30	25.15	7.03	2.67	0.97	1.70	3.39	2.73	(74)
	6.8	18.9	41.9	44.6	32.4	25.7	20.3	12.2	10.8	31.1	28.4	22.3

Upper - % number of animals of the specified size in all the stomachs

Lower - % of stomachs containing at least one item of the specified size.

percentage of the stomachs contained yabbies.

Tables 4.32 and 4.33 give the % frequency of different sizes of aquatic animals in the stomachs of Sixth Creek trout and trout from other places respectively. Two indices are shown, the % frequency of all the animals of each size-group in all the stomachs (upper figure), and the % frequency of stomachs which contained at least one item of a given size. For Sixth Creek trout values are given for fish in different size ranges. All of the smallest fish were caught in the late summer and autumn and most of the largest fish were caught early in the spring (by anglers).

Except for animals larger than size-groups (20) for the smallest fish, the Sixth Creek trout ate animals of all the sizes present in the samples of accessible food. There was only a small tendency for larger fish to contain larger animals. The fish did not however contain animals of different sizes in the same relative numbers as the samples of accessible food. Apparently they ate fewer of the very small animals in the supply accessible to them. The Sixth Creek trout did not contain fewer animals on the average than in other places. There was a greater tendency for trout in other places to contain larger animals, and more of them, than in Sixth Creek particularly in size-groups greater than (20).

Tables 4.34 and 4.35 show the percentage of stomachs of Sixth Creek trout and trout from other places, respectively, which contained at least one individual of the species listed. The trout from other places contained the animals, Cherax, Paratya, Austrochiltonia, Corixidae, Notonectidae, and Dytiscidae (larger species

than in Sixth Creek) much more often than did Sixth Creek trout. Especially noticeable is the absence of yabbies in Sixth Creek trout.

About 10% of the trout killed in the Light River were parasitized by a larval nematode, Eustrongylides (phalacrocoracis?), which was found free in the body cavity and encysted in the muscle. The final host of this parasite is a cormorant. Nematodes were found in the stomach of the Little Pied Cormorant, Microcarbo melanoleucus, which is common on the more isolated stretches of stream in S.A., Victoria, and New South Wales. Besides the fish another intermediate host is likely to be the yabby which both trout and cormorants eat.

Some attention was given to the actual feeding of trout in Sixth Creek after sunset since the sampling of the accessible food animals revealed that their opportunity to get food during a day was greatest then. It was particularly noticeable while food sampling after sunset that fish appeared in the running water as the light intensity decreased. At this time of the day the fish were not easily disturbed from their positions, unlike during day-light hours, even when violently harassed. The efficiency with which the trout can capture very small items in growing darkness may be questioned. Trout, and other salmonids, do feed actively at night perhaps by viewing their prey against the moonlit sky or by detecting the movements of larger prey with pressure receptors. (Hoar, 1942; Pumphrey, 1961; Lagler, et al, 1962; Brett and Groot, 1963).

Table 4.34 % of stomachs of Sixth Creek trout of different sizes with at least one individual of each of the food species listed

Food Species	Length of Fish (cms)				
	10.0-14.9	15.0-19.9	20.0-24.9	25.0-29.9	⩾ 30.0
Cherax			2.9		5.6
Paratya					
Chiltonia	14.3			4.5	5.6
Corduliidae	7.1	8.7	2.9	9.1	16.7
Gomphidae	17.9	21.7	38.2	31.8	16.7
Ameria	17.9	4.4	5.9	18.2	27.8
Rivissessor	14.3	60.0	73.5	54.5	55.6
Atalophlebia		17.4	32.4	4.5	11.1
Corixidae	7.1		5.9	9.1	
Stratiomyiidae	32.1	26.1	26.5	36.4	22.2
Aeschnae	10.7	4.4	11.8	9.1	33.3
Zygoptera				4.5	5.6
Hydropsyche	7.1	8.7	14.7	4.5	16.7
Hydrobiosis					
Deleatidium	50.0	30.4	23.5	4.5	
Caenis	7.1	17.4	29.4	22.7	38.9
Olinga	60.7	82.6	70.6	31.8	61.1
Hydroptilidae	50.0	30.4	5.9	-	11.1
Chironomidae	35.7	26.1	23.5	36.4	27.8
Simuliidae	7.1	8.7	5.9	4.5	
Dinotoperla	3.6	47.8	41.2	40.9	61.1
Sphaeredae	21.4	47.8	14.7		16.7
Dytiscidae		8.7			22.2
Notonectidae					

Table 4.35 % of the stomachs of trout from other places with at least one individual of each of the food species listed

Food Species	Light River	Myponga Res. early 1964	Myponga Res. later	Brown trout streams	Torrens River
Cherax	65.5	55.6	21.9	30.2	29.7
Paratya	41.4	27.8	3.1	22.6	4.1
Chiltonia	36.2	77.8	65.6	13.2	10.8
Corduliidae		33.9	9.4	3.8	4.1
Gomphidae	6.9		6.3		16.2
Ameria		5.6	15.6	11.3	6.8
Rivissessor	1.7			33.9	35.1
Atalophlebia				24.5	4.1
Corixidae	19.0	55.5	25.0	13.2	16.2
Stratiomyiidae	6.9			1.9	4.1
Aeschnae	3.4			5.7	18.9
Zygoptera	8.6	16.7		1.9	
Hydropsyche	6.9			3.8	2.7
Hydrobiosis				1.9	
Deleatidium				3.8	2.7
Caenis				5.7	18.9
Olinga				5.7	41.9
Hydroptilidae	1.7				4.1
Chironomidae	10.3	22.2	53.1	17.0	21.6
Simuliidae	19.0				2.7
Dinotoperla				11.3	33.8
Sphenedae					
Dytiscidae	20.7	38.9	25.0	18.9	17.6
Notonectidae	12.1	44.4	18.8	15.1	-

Brown trout streams are Bulls Creek, Finniss River, Coxs Creek, Scotts Creek and Deep Creek.

Trout were captured during November 1965 and after sunset by electro-fishing. The trout were caught in shallow watertypes in subsection (3) at sunset and thereafter at 60 minute intervals for 3 hours. Care was taken to arrange the fishing gear well before sunset and succeeding short stretches of stream where fished upstream at each time. Only a few minutes were needed to catch the fish at each time. Table 4.36 allows a comparison of the size compositions of the animals in the stomachs of the trout and in drift catches (data has been summed in each case, for two dates). The large items in the stomachs of the trout and the drift catches were nymphs of Gomphidae and Aeschnae. The trout (19.0 to 27 cms) were selecting larger animals in the drift but ate some of the smallest animals accessible to them. Table 4.37 compares the species compositions of the drift catches and the stomach contents. The smallest aquatic species were less numerous in the stomachs than in the drift while the reverse was true of the largest species. Otherwise the frequencies were comparable. While most of the animals in the drift catches were aquatic species and only about 1% of them were emerging forms (the nets were set below the surface of the water), about one-quarter of the animals in the stomachs were aquatic species emerging from the water (these were mainly small chironomids). Only about 5% of the animals in the stomachs were terrestrial species. These were small beetles, hemiptera, and ants.

The trout in different places in S.A. displayed a wide range of growth rates. If it is surprising to consider the magnitude of the difference between the growth of Sixth Creek trout (which is better than that of many trout in the world) and that of the trout in Myponga

TABLE 4.36 COMPARISON OF THE SIZE COMPOSITIONS OF DRIFT CATCHES AND STOMACH CONTENTS OF SIXTH CREEK TROUT IN NOVEMBER (RELATIVE NUMBER IN THE SIZE-CLASSES EXPRESSED AS PERCENTAGES)

	Time of Day (Mid-point of 20 minute sampling interval for drift)	% Numbers in Size-Groups											No. of items	
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)			
DRIFT 171165 Sunset 7.01pm Q = 158968 l./hr qn = 9630 l./hr	Sunset + 30 mins	51.1	33.4	11.0	4.1							1(25) 0.2	509	DRIFT 231165 Sunset 7.07pm Q = 91678 l./hr. qn = 9210 l.hr.
	S.S. + 90 mins	33.5	41.3	16.7	6.8	1.1	0.3	0.1			0.1	1(15),1(50) 0.3	783	
	S.S. + 150 mins	33.0	47.9	13.4	4.7	0.1	0.7					1(11) 0.1	685	
STOMACH CONTENTS 151165 and 301165	Sunset		13.3			20.0	26.7				6.7	3(19),2 (20) 33.3	Aver-age Nos. 3.8	Actual numbers in each stomach 0,2,6,7
	S.S. + 60 mins	5.1	32.9	35.4	15.2	3.8	6.3					1(18) 1.3	15.8	0,0,5,35,39
	S.S. + 120 mins	9.8	51.0	19.6	11.8	3.3		0.7	1.3		0.7	1(14),2 (15) 2.0	25.5	12,16,20,23,30,52
	S.S. + 180 mins	24.6	34.8	22.8	8.0	2.2	2.7	1.3	0.9			1(18),1(15) 1(23),2(30) 1(16),1(27) 3.1	44.8	12,18,20,40,134

Table 4.37 Comparison of the species compositions of drift catches and stomach contents of Sixth Creek trout in November

Species	Drift	Stomach Contents
Caenis	22.9	8.1
Deleatidium	2.4	3.9
Atalophlebia	9.0	8.1
Dinotoperla	0.7	4.5
Rivissessor	25.7	38.5
Olinga	25.1	22.2
Gomphidae	0.1	2.2
Aeschnae	0	0.1
Other aquatic forms	14.1	11.4
Total aquatic	98.9	68.5
Emerging aquatic adults	0.8	26.9
Terrestrials	0.3	4.6

For the individual species and other aquatic forms their number is expressed as a percentage of the total number of aquatic forms. For emerging aquatic adults and terrestrials the number is expressed as a percentage of the total for all items found in drift and stomachs respectively.

Reservoir then it is even more surprising to realize that trout, and other salmonids, are inherently capable of very much greater growth rates. In freshwater the growth of individuals in most populations of trout around the world is very poor. It seems that this situation is caused by a chronic relative shortage of food (Andrewartha and Browning, 1961) which worsens as the fish grow larger.

Some animals (e.g. certain birds) are able to prevent an absolute shortage of food by anticipating their needs and establishing territories of sufficient size to provide more than adequate amounts of food. The food supply of trout appears to differ fundamentally from that of these animals in that they nearly always suffer from some degree of relative shortage of food. Most of the food supply is inaccessible to the trout and when food animals do become accessible to them, the fish are unable to get as much as they can inherently use in a given time because of the density and sizes of the accessible species. This relative shortage of food, whether caused by the trout or not, is not immediately lessened by an increase in the size of territories. Also the trout are unable to regulate their density in a stream by territorialism sufficiently to prevent a long-term deterioration in the amount of accessible food to the low level reached, for example, in Sixth Creek.

It has been pointed out previously that where trout are known to have attained very high growth rates and large sizes their food supply has been characterised by large and highly accessible food species. Usually this situation existed, for a time at least, in remote places (e.g. South America) when trout were introduced

for the first time. Information on the growth rates of fish in these places, and when the introductions occurred in the last century, are confined to lyrical comments in the angling literature (e.g. Patterson; 1961; Scharff, 1963). The official angling record for a Brown trout is 39½ lbs. This fish was caught during the last century (1866) in Scotland and could have been a very old cannibal fish. The record for Rainbow trout in freshwater is 37 lbs for a fish captured in Lake Pend Oreille, Idaho, in 1947. The trout in this lake attain(ed) weights over 30 lbs. by their fourth year of life. Rainbow trout in Lake Purrumbete in Victoria also display very high growth rates (Butcher, 1945) although their growth appears to slow at weights of 15 to 20 lbs after 3 to 4 years of life. Enquiries to official sources in the U.S.A. and Victoria did not reveal more precise estimates. It is a great pity that the growth rates of fish in these places have not been recorded and that for this reason the significance of the usual poor growth of trout has been ignored. Of course both Brown trout and Rainbow trout display their growth potential in many places when (as sea-trout and steel-head trout, respectively), having migrated to the sea at a small size, they return to freshwater to spawn as large fish after a year, or two, of very rapid growth in the sea.

It is possible to "explain" the growth of the fish at a number of levels (see Figure 1.3). At the closest level to the fish the absolute magnitudes of the increments in growth in weight could be related to certain amounts of food which were eaten by the fish during the interval when the growth was made. The only extensive data

available for trout allowing an estimation of this relationship are those given by Pentelow (1939) for young Brown trout kept separately in small tanks. He weighed the fish at weekly intervals, recorded the weight of Gammarus which they ate (they were "fully fed" on 6 days of each week), and measured the minimum and maximum water temperatures on each day. Attempts have been made by Allen (1951) and Horton (1961) to analyse Pentelow's data for the purpose of estimating the amount of food eaten by trout from growth rates obtained by sampling wild populations.

Allen obtained a linear equation relating food eaten (f), as mgms. per gm. of body weight per day to instantaneous growth rate (k) from Pentelow's published data for "fully fed" fish.

$$f = 0.0123 + 4.205k$$

The intercept represents the amount of food, as a proportion of the body weight, needed to maintain a fish at a constant weight each day. The efficiency of conversion of the food in excess of maintenance requirements to growth was $1/4.205 = 0.238$. Allen assumed that the maintenance expenditure per unit of body weight of the fish did not vary with size. It is well-known that the basal metabolism of animals increases with size being approximately proportional to the surface area of the animal or its body weight raised to the 3/4 power (Kleiber, 1961). It follows that relative to the body weight the maintenance expenditure may be expected to decrease exponentially with increase in size. For trout this change has been shown by Brown (1946). Also increase in temperature may be expected to increase maintenance requirements and influence the

efficiency with which food is digested and assimilated for use in maintenance or growth. Allen (1951) realized these shortcomings. Gerking (1962) has pointed out that the use of this equation leads to estimates of the food consumption of the trout which are at least two to three times too great. The energy expended by Pentelow's fish for activity was also likely to be minimal since there was little current through the tanks and they did not have to range widely for food.

Horton's analysis of Pentelow's data incorporated the decrease in maintenance requirements per unit of body weight with increase in size by using formulae provided by Beverton and Holt (1957). The maintenance function on the right-hand-side of his equation was ξW^j where ξ was called the maintenance food coefficient (constant) and j, the weight (W) exponent. ξ and j express the efficiency of conversion of part of the food to use in maintenance and also the relationship between the weight of the fish and its maintenance expenditure. Horton apparently used some of Pentelow's data where fish were kept at approximately constant weight by restricted feeding, so that the food eaten corresponded to maintenance requirements, to estimate ξ and j. The slope of the log-log plot of (dry) weight (gms) of food consumed per day on weight (gms) fish was j (= 0.84) and the intercept ξ (= .00324). Horton then calculated the food which Pentelow's "fully fed" fish "used" for maintenance from this formula and hence, by subtraction, the amount of food "used" for growth. Hence ϵ, the efficiency of utilisation of food, in excess of

maintenance requirements, for growth was found from the slope of the plot of W increment against growth food (ε = 0.93). The plot showed an increasing scatter from the origin. The value of ε seems to be very high. The food consumption was : $f = \xi W^{j} + \frac{k}{\varepsilon}$

A copy of Pentelow's raw data was obtained early in this study and analysed more completely. The fish called "fully fed", Table 4 (in both the raw data and Pentelow's (1939) paper) - the data for early dates were missing - ranged in weight from 2 gms (0+) to about 100 gms (1+). It was obvious that the fish did not grow maximally, in fact not as well as fish in Sixth Creek or the ponds. There were 129 sets of weekly observations (fish No. 1, 3, 8A, 12A and 12B).

For the purpose of obtaining a stochastic equation the data were analysed using a computer program called "multiple linear regression by stepwise orthoganilization" (written by M. Atkinson of the Waite Institute, Adelaide). For this method the assumption must be made that the successive increments in weight for each fish were independent, and that the growth increment for a week was made on the food eaten in that week. The dependent variate in the equation was the weekly increment in weight, g (mgms), while the 3 determining variables used were the amount of food eaten per week, f (gms), the average size of the fish during the week, W (gms), and a temperature sum, T, for the week. There was a wide range of water temperature through the year, from a maximum of 78°F in summer to a minimum of 32°F in winter. If the change in temperature from the minimum to the maximum and from the maximum to the minimum, each day, is assumed to be linear then the

temperature sum of day-degrees for the week is approximately the average of the sums of maxima and minima for the week. (For hour-degrees for the week, x 24).

The computed equation was :

$$\ln \hat{g} = 1.151 + 0.3067 \ln f - 0.1262 \ln W - 0.5471 \ln T.$$

n	= 129	S.E. of the coefficient for 'f'	=.02842
S.D.	= 0.1071	'W'	= .01005
R^2	= 0.752	'T'	= .1166

All the coefficients and the intercept, were, of course, statistically significant. The data were logged to counteract the increase in the variability of g with increase in the magnitude of the variables and also to include the interaction between temperature and weight in influencing the maintenance requirements. The log-log transformation does not influence linear trends but produces linear trends from curvilinear relationships which are exponential. A high correlation between the size of the fish and the food eaten was found not to influence the calculation. About 75% of the variability in the weekly weight increment of the fish was explained by values of variables pertaining to the same week in which the growth was made. It can be concluded therefore that the assumption that the growth in weight made during a week is dependent on the food eaten through the week, is valid. This is relevent in retrospect to section 3.4.1.

Pentelow's other data, for fish fed a "constant ration" and a "maintenance ration", were analysed in a similar way. For fish fed a constant ration Pentelow thought that the growth increments were influenced by changes in maintenance requirements due to temperature changes. The coefficient for temperature in the regression equation was the only one which was significant. The (larger) fish which were fed a maintenance ration showed a significant coefficient for weight only.

Appendices

(1) - The introduction, and subsequent stocking, of trout in streams in South Australia

In Australasia Brown trout were first successfully reared, in Tasmania, from eggs brought from England in 1864 and Rainbow trout, in New Zealand, from California in 1894.

In South Australia "rearing ponds" for trout were built at Thorndon Park Reservoir on June 1881 (no other details - in log book of the Engineering and Water Supply Department). This reservoir was the first that was built to store water for Adelaide. It was filled by water diverted from the Torrens River by a weir at the western end of "The Gorge". John Dunn (the original owner of the Bridgewater flour mill on the banks of Coxs Creek) mentions in the Mount Barker Courier of September 28th 1883 that a "salmon trout" of 22½" was caught at Bridgewater. He apparently liberated fry from Tasmania in Coxs Creek in the late 1870's. (L. Marriott - in the Bulletin of the S.A. Fly Fishers Association for April, 1958). E. Stirling liberated fry from Ballarat, Victoria, in the Angas River late in the 19th century and the Finniss River and Myponga Creek had trout as early as 1908 (C. Malpas - in "Out Fishing" by H.P. Down, 1952).

From 1914 to 1940 trout fry, and some yearlings, were brought by train from the Ballarat Hatchery in small numbers and distributed by enthusiasts - see Table.

In the late 1940's and early 1950's wild fish were trapped and stripped in Coxs Creek (Brown trout) and the Sturt River (Rainbow trout). The eggs were hatched at first privately by C. Malpas and then by him and other members of the S.A.F.F.A. which was formed in 1947.

From 1951 to 1961 Brown and Rainbow trout eggs were obtained from New Zealand, Tasmania, Victoria, and Western Australia and hatched at Ovingham a suburb of Adelaide (Brown trout 241,000 eggs - 82,150 fry released; Rainbow trout 502,000 - 144,500) - see Table. Chlorination of the water supplied to Adelaide led to the erection of a larger hatchery at Milbrook Reservoir by the S.A.F.F.A. In the first year of operation, 1962, the maximum capacity of 200,000 eggs were held.

Few records of the release of fry from the hatchery are available from 1962 onwards. Some of the Brown and Rainbow trout fry from the Milbrook Hatchery were successfully reared to the "advanced fingerling" stage by H. Smith at Sixth Creek in 1962 and 1963. The only fish reared in 1964 were Brown trout stripped from wild fish and reared at Sixth Creek. The pattern of distribution of the fish from 1962 is known to have followed that carried out in earlier years.

Brown trout were, thus, successfully established in most streams in the early years of the century, or earlier, by remarkably small introductions of fry and Rainbow trout in the Sturt River. Dispersal into tributaries occurred as the result of spawning migrations. Since the early 1950's much heavier stocking of Brown trout has been continued in these streams and Rainbow trout have been introduced into

the Light River, Little Para River and streams which already contained Brown trout.

In addition under headings of "experimental plantings" and "private sales", of which there are no specific records, fish have been released in many streams, and dams, which appear suitable in the spring when the fish are available for release.

Table. Known releases of trout fry.

Sources: 1914-1940. From C.W. Malpas, (records of Fisheries and Game Dept., Adelaide).

1951-1960. Records of The S.A. Fly Fishers Association.

B - Brown trout
R - Rainbow trout

Main Streams	Tributaries	1914-1940	1951-1960
Broughton R.		1926,500B; 1934,500B 500R.	
	Gum Cr.	1930,500B	
Wakefield R.			1000R.
Light R.			69,000R.
	Allens Cr.		
	Gilbert R.	1932,500B; 1934,1000B.	
North Para R.			(1947)500B; 250B; 500R.
	Flaxmans Cr.		250B.
	Tanunda Cr.		
	Jacobs Cr.		
	Salt Cr.		
South Para R.		1921,1000B; 1926, 500B.	1000R
Gawler R.		1923,1500B; 1925, 7000B; 1927,2000B; 1935,1000B.	
Little Para R.			3600R.
Torrens R.		1927,1000B; 1934, 1000R; 1937,2200B (yearlings); 1938, 2900B; 1940,550B and before 1914, B.	21000B; 12500R. 1400R (yearlings)
	Cudlee Cr.		
	Sixth Cr.		
	Fifth Cr.		
	Fourth Cr.		
	First Cr.		
	Brownhill Cr. (Milbrook Res.)	1926,2000B; 1927, 3000B.	
Sturt R.		Before 1914, R.	7000R.
	Chambers Cr.		
	Minno Para Cr.	1923,500B	

Main Streams	Tributaries	1914-1940	1951-1960
Onkaparinga River		1923,500B; 1929,500B 1930,150B; 1937,2200B (yearlings); 1938, 1500B; 1940,550B; and before 1914 B.	3000B, 14000R.
	Inverbrackie Cr		
	Oakbank Cr.		
	Lenswood Cr.		
	Yantaringa Cr.		
	Hahndorf Cr.		
	Coxs Cr.	1930,150B; 1938,250B; and before 1914, B.	600R (yearlings)
	Aldgate Cr.		
	Jupiter Cr.		
	Scotts Cr.		
	Dashwood Gulley Cr.		
Pedlers Cr.			
Myponga Cr.		1915,250B; and before 1914, B.	6000B; 2000R.
Carrikalinga Cr.			
Bungula R.			
Yankalilla R.			11000B.
Yattagolinga R.			150B.
Yohoe Cr.			3500B.
Deep Cr.			11,500B.
Boat Harbour Cr.			1500R.
Waitpinga Cr.		1928, 500B.	
Inman R.			
Hindmarsh R.		1914,500B; 1938,250B.	500B; 5000R.
Currency Cr.		1938,200B	3000R.
Black Swamp Cr.			
Finniss R.		1914,500B; 1924,400B; 1925,1000B; 1930, 150B; 1935,1000R, and before 1914, B.	9000B; 5000R.

Main Streams	Tributaries	1914-1940	1951-1960
	Meadows Cr.		
	Blackfellows Cr.		
	Bulls Cr.	1930,500B	2000B
Angas R.		1928,500B; 1932,100B; 1938,300B; 1936,300R; and before 1914 B.	
Bremer R.		1938,300B.	2000B.
	Bryces Cr.		2000B.
	Scotts Cr.		
	Nairne Cr.		2000B.
	Mt.Barker Cr.		2000B.
	Rodwells Cr.		
Reedy Cr.			
Saunders Cr.			
Marne R.		1915,500B.	5000R.
	Somme R.		

Other places : Cygnet R. (Kangaroo Island), 1917,300B; Harriett R. (I.K.), 1917, 400B; Ulooloo (Broughton R. ?), 1000B; Sheringa Dam (Eyre Pen.), 1934, 500B; Yatta Cr. (?), 1938, 500B; Daveys, Deep and Tunkilla Crs. (?) 1938, 250B; Waterfull (Gully?) Cr., 1951-52, 1500B.

(2) - Chemical analysis of Sixth Creek water.

Form 443

ENGINEERING AND WATER SUPPLY DEPARTMENT

WATER ANALYSIS REPORT No. 1558 / 66

DESCRIPTION Sixth Creek

SOURCE ½ mile up stream from Gorge

DATE COLLECTED 8/9/66 RECEIVED

ORIGINATED FOR Lab Records Request For Analyses.

Constituent	Parts per Million	Equivalents per Million
Silica (SiO_2)	9	———
Iron (Fe)	0.20	———
Cations—Calcium (Ca)	26	1.32
Magnesium (Mg)	25	2.04
Sodium (Na)	46	2.00
Potassium (K)		
Carbonate as CO_3	12	0.4
Anions—Bicarbonate (HCO_3)	153	2.5
Sulphate (SO_4)	21	0.44
Chloride (Cl)	70	1.97
Fluoride (F)		
Nitrate (NO_3)	3	0.05
Dissolved Solids calculated	287	———

Other Data		Parts per Million
Hardness as Calcium Carbonate	Total	168
	Carbonate	145
	Noncarbonate	23
Free Carbon Dioxide (CO_2)		-
Sodium to Total Cations Ratio		37 per cent
Conductivity—Micromhos/cm/25°C 537		pH 8.8 units

REMARKS—

Chief Chemist

3/10/ 19 66

Engineer for Water and Sewage Treatment

(3) - Trout Angling in Australia

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