AN ABSTRACT OF THE THESIS OF

Tirso S. Poblete Arellano for the degree of Master of Science in the Department of Fisheries and Wildlife presented on November 26, 1985

Title: Life History of Rainbow Trout and Considerations for Introducting Steelhead Into Southern Chile

Abstract approved: Redacted for Privacy

Howard F. Horton

Two hundred-fifty-nine rainbow trout were captured in Rupanco Lake, Puyehue Lake, Rahue River, Pilmaiquen River, and Bueno River, southern Chile, between December 1981 and March 1984. Length frequency distributions, sex ratios, maturity, scale features, life history patterns from scale analyses, age and growth of the rainbow trout collected were studied. Most fish were obtained come from Rupanco Lake and Rahue River. Fork length (FL) ranged from 12 to 80 cm and weight varied from 21 to 7500 g. More females than males were collected particularly in Rupanco Lake and Rahue River. Spawning checks were observed in fish over 48 cm FL (1300 g body weight) with ages of III, IV, and V years old at capture. Scale analyses revealed that fish from 12.3 to 58.9 cm FL and ages of I^+ to V^+ had spent 2 or 3 years in streams or rivers before migration. About 15 to 20 circuli were formed on the scales of rainbow trout in their first 2 or 3 years of growth prior to migration. All scales showed a well marked increment in the number of circuli formed immediately after the fish were presumed to have entered the lake or estuary. Thereafter, the number of circuli appear to diminish with age.

Two types of migrants were recognized and estimated lengths for 2nd and 3rd year migrants varied among study areas. The fork lengths of 2nd and 3rd year migrants were estimated to be 27.0 to 38.8 cm and 52.3 to 61.0 cm, respectively. Second year migrants were more dominant than 3rd year migrants. From circuli growth patterns, it appears that rainbow trout in the study area constitute resident populations particularly in the lakes. Observational growth data were fitted to the Von Bertalanffy growth model. Highest growth rates and asymptotic lengths were found in Puyehue Lake and Rupanco Lake. Validation of estimated at ages I to V was attempted for fish sampled from each study area. Highest variability in life history patterns and age composition was found in fish collected from Rupanco Lake. Ten age types were recognized which included four patterns for fish spawning for the first time. Finally, the advisability of introducing anadromous rainbow trout into the study area is discussed.

LIFE HISTORY OF RAINBOW TROUT AND CONSIDERATIONS FOR INTRODUCING STEELHEAD INTO SOUTHERN CHILE

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed November 26, 1985

Commencement June 1986

APPROVED:

Redacted for Privacy

Professor of Fisheries in charge of major

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Date thesis is presented: November 26, 1985

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ACKNOWLEDGMENTS

I would like to express my since appreciaton to Dr. Howard F. Horton for his guidance and encouragement to carry out this study.

I also wish to acknowledge Dr. Richard Tubb for his assistance in the different stages of my study, and Dr. Frederick Smith for his financial support through The Tinker Foundation Program during my graduate studies and research.

Sincere thanks are due to Nancy MacHugh, Lisa Van Dyke and Ken Kenaston (Oregon Department of Fish and Wildlife, Corvallis) for their help and assistance.

I would like to express my special thanks to Patricio Pavez for his encouragement an assistance.

Finally, I sincerely thank Jose Nuñez and Ruben Onate for their help and cooperation in the fish sampling.

DEDICATION

I dedicate this thesis to the four most important women in my life: my wife, Edith, my daughters, Monica and Laura, and my mother, Otilia.

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INTRODUCTION

The rainbow trout is the most valuable species for freshwater recreational fishing in southern Chile. In spite of its importance, little is known about the biology of the wild rainbow in the Rupanco Lake area. Accordingly, my study is the first attempt to analyze the life history characteristics of this species based on scale features.

The scale still remains the most popular means of estimating and calculating the age of salmonids. Understanding the process of scale formation may help in interpretating age and other life-history events useful for successful management programs on Chilean trout.

An important goal of my study was to use scale features to search for anadromy patterns in Chilean rainbow trout. Migration patterns have not been studied in these southern fish even though Wetzlar (1979) stated that rainbow trout go to the ocean and return to spawn to natal streams in Chile. These patterns have been described in sea-run rainbow trout (steelhead) on the western coast of the United States (Shapovalov and Taft 1954).

On the west coast of USA, the stocks of steelhead are economically important because they support recreational fisheries as well as Indian commercial fisheries, and fisheries are managed to accommodate the steelhead migration patterns.

In southern Chile, wild rainbow trout have also become a major attraction for the recreational fishermen. The importance to the tourist industry emphasizes the need to address the question of anadromy in Chilean Salmo as a means to improve the current management of this specie.

On the other hand, there have been attempts to culture anadromous salmon (Oncorhynchus) in the south of Chile (Brown 1983). If naturalized populations of rainbow trout are anadromous, they may be more logical candidates for commercial ocean ranching than the introduced species of Oncorhynchus.

Lately, sea-run rainbow trout have been introduced into the Rupanco Lake study area. Thus, knowledge of the migration patterns of naturalized populations of rainbow trout will make it possible to compare and evaluate the interactions between these migratory and non-migratory varieties.

My study present data which have resulted from the examination, interpretation and measurement of scale samples from 260 rainbow trout caught in two lakes (Rupanco and Puyehue) and three rivers (Rahue, Bueno and Pilmaiquen) located in southern Chile.

This research represents the preliminary part of a comprehensive investigation of the life history and management needs for the wild rainbow trout in Region X of southern Chile. My main objective was to determine if introduced rainbow trout populations in southern Chile have developed and anadromous life history pattern.

In order to achieve this objective the following sub-objectives were set:

A. To study the characters of Chilean rainbow trout scales in relation to growth, spawning and migration checks.
    1. To estimate the age structure of rainbow trout collected in lakes and river of my study area.
    2. To determine if the ages of rainbow trout estimated from scales and length frequency analyses differ significantly.
    3. To determine if growth rates in rainbow trout differ significantly among lake and river systems in the study area.
    4. To determine age of maturity of Chilean rainbow from analyses of spawning checks on scales.

B. To determine if Chilean rainbow trout have zones of ocean growth in their scales.
    1. To identify the proportion of trout with freshwater and freshwater-marine life history patterns on their scales.

C. To determine by scale analyses if rainbow trout populations in the study area display distinctly different life history patterns.
    1. To determine the relationship of scale features to rainbow trout life history patterns.

D. To develop management recommendations regarding the advisability of introducing anadromous rainbow trout (steelhead) into southern Chile.

REVIEW OF LITERATURE

Since 1874, the endemic range of rainbow trout (Salmo gairdneri Richardson) has been extended through introduction to include eastern North America and the continents of Africa, Asia, Australia, Europe and South America (MacCrimmon 1971).

Rainbow trout were first described by Richardson in 1836 (MacCrimmon 1971) and since that time, various specific names have been given to local forms, generally based on phenotypic differences.

An important life history attribute of coastal rainbow trout is the occurrence of anadromous steelhead populations throughout the range of the resident rainbow trout, often inhabiting the same streams (Behnke 1979). This author indicated that all anadromous steelhead trout and all resident rainbow trout did not arise from two distinct evolutionary lines but rather the two ecological forms have given independently to each other in various times and places.

Resident rainbow trout populations spend all their life in freshwater and migrate within inland waters which include streams, medium and large rivers and lakes.

Steelhead trout typically spend one to three years in freshwater before smolting and migrating to the ocean. After one to three years of ocean life steelhead return to spawn in their natal stream. There are two patterns which can be divided into Spring-Summer and Fall-Winter runs. In the Spring-Summer run, the fish enter freshwater with immature gonads and spawn in the following season. In the Fall-Winter run, fish enter freshwater with sexual products in various stages of development but spawn within the same season (Shapovalov and Taft 1954; Withler 1965).

In terms of habitat requirements, the major environmental factors affecting survival and controlling production and growth in rainbow trout are: flow, physical habitat and energy (Reiser and Bjornn 1979; Bottom et al. 1985). In terms of dissolved oxygen requirements the levels recommended for spawning and migration activities are at least 80% of saturation with temporary levels no lower than 5.0 mg/l (Reiser and Bjornn 1979). Other environmental factors such as alkalinity, mineralization and pH affect the success of natural reproduction of these fishes (MacCrimmon 1971).

The environmental factors considered to be of primary importance in the survival of introduced populations are favorable water temperature and precipitation. The presence of suitable spawning grounds, coupled with seasonal water temperatures below 13°C, are essential for the establishment of self-sustaining populations (MacCrimmon 1971).

Rainbow trout were first brought to Chile in 1905 from Germany and distributed in waters south of Santiago (McClane 1965). Although, other salmonid species were introduced in Chile between 1905 and 1913 only the brown trout (*Salmo trutta*) and the rainbow trout species have achieved acclimatization in Chilean waters (Campos 1970; Arenas 1978). Lately, the introduction of the sea-run rainbow trout (steelhead) into the Rupanco Lake area (43° S) has shown good results (H. Horton, Department of Fisheries and Wildlife, Oregon State University, Corvallis, pers. comm. 1984).

Currently, the present naturalized range of rainbow trout is more or less continuous between Coquimbo (30° S) and the south of Tierra del Fuego (51° S) with an isolated population in the Loa River, Antofagasta Province (23° S) (Fig. 1) (MacCrimmon 1971; Wetzlar 1979).

In Chile, the rainbow trout is the most valuable species for inland recreational fisheries. The fishery regulation establishes a fishing season which extends from the 15th of November to the 16th of April for Region I to X. The fishing season for Region XI and XII extends from the 15th of September to the 1st of April. Also, a fishing season for some particular lakes located in Region XI extends from the 31st of October to the 1st of April. There is no size limit and the regulations establish that only three fishes or a maximum weight of 15 kg will be allowed in the daily catch. On the other hand, the fishing regulations establish that only artificial bait with a single hook may be used. The maximum weight of the sinker is 100 g and the sport fisheries must be conducted with a fishing rod and each fisherman may not fish with more than one fishing pole (Anonymous 1983). These existing fishery regulations remain as a management tool

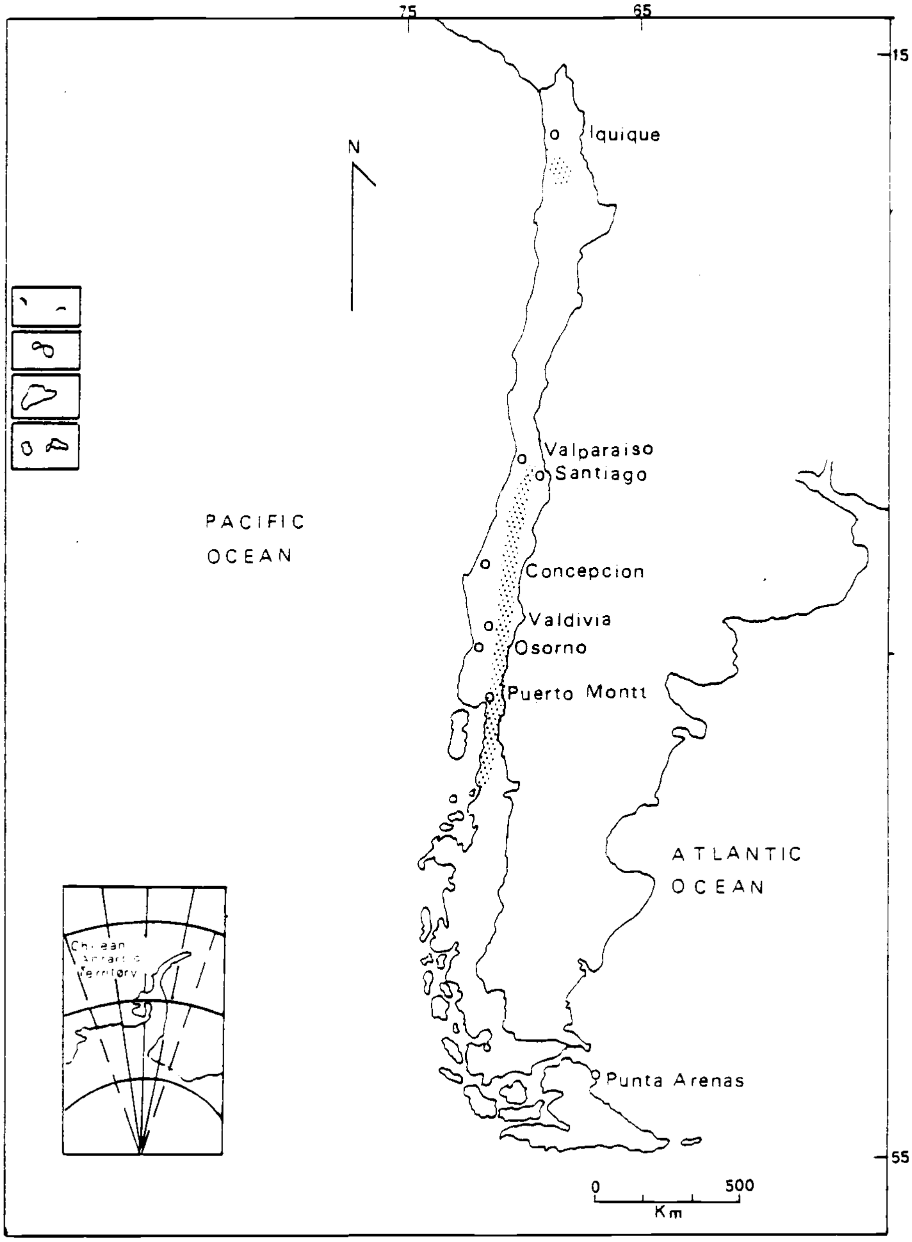

Figure 1. Naturalized distribution of Salmo gairdneri in Chile described by MacCrimmon (1971). Distribution is shown in shaded area.

of limited effectiveness because they are based on an incomplete knowledge of the life history of rainbow trout.

A few studies have been made on the life history of salmonids in the south of Chile. Burns (1972) analyzed the importance of freshwater crabs (Aegla) as a food item in the diet and growth rate of rainbow and brown trout. He suggested that the growth rate of Chilean trout sampled from waters containing Aegla was rapid, assuming that the abundant crab population probably contributes significantly to the large fish size attained. Arenas (1978) studied the seasonal variation of the food items in the diet of wild rainbow trout in Rinihue Lake and San Pedro River. Basic food consisted of Trichopthera, Aeglidae, and Pisces. In addition, secondary food consisted of terrestrial Coleoptera and a diversity of authocthonous and allocthonous items. This author found that the diet varied seasonally and with the size of the fish and no differences in diet occurred between sexes. In the same geographical area, Wetzlar (1979) described the effects of the acclimatization of rainbow and brown trout on the Chilean native fishes and on the formation of ecological niche by the introduced salmonids in the new environment. He studied feeding patterns, growth and age, meristics, morphometric parameters and parasites. He concluded that the acclimatized rainbow and brown trout in Chilean freshwaters constitute phenotypic variations caused by biological factors. Therefore, these species have great variability in growth, color patterns, feeding, fecundity and time of spawning in the different locations studied.

Zama and Cardenas (1983) made biological observations of wild brown trout in the Aysen and Salto Rivers. They analyzed scale samples in order to investigate age structures and migration patterns. These authors determined that 15 circuli were formed on the scales of brown trout during each of the first and second year in freshwater. All scales showed a sudden, well marked increase in number of circuli and in width of radius when the fish are presummed to have entered the fiord; but thereafter, annual increments diminished each year. The total length at smolt migration of the second- and third-year migrants were estimated to be about 12 and 17 cm, respectively. Brown trout migrate to the fiord and appear to become mature at the end of their third or fourth year of life at 40 to 50 cm total length.

Growth and age of rainbow trout were studied by Wetzlar (1979) in the Rinihue Lake area. This author fitted data to the Von Bertalanffy growth model and found that growth in length increases rapidly in the first 2 or 3 years and the asymptotic growth is reached at about 4 to 5 years. Age-length relationships for some particular areas showed that a 2-year old fish is 70.7 cm in length (Rinihue Lake), 4-year old fish are 83 cm in length (Ranco Lake) and 2-year old fish are 71.6 cm in length (Llanquihue Lake).

Growth-weight relationships have been studied by Burns (1972) in 200 Chilean rainbow trout collected in rivers and lakes of central and southern Chile. The best trout growth was found in Maule Lake were rainbow trout 2 years old weighed 2.2 kg, 3-year olds were 2.8 kg and, 4-year olds were 4.3 kg.

In terms of rainbow trout scale features, these usually have relatively uniformly spaced circuli and annuli which sometimes are difficult to detect. Circuli are moderately spaced near the focus and then the distance between them widens with age. Burns (1972) postulated that after an initial period of moderate growth, rainbow trout find an abundant supply of food which allows them to grow at a more rapid rate and that water temperatures do not inhibit growth for an extended period in winter.

Scale features of steelhead trout were described by Mosher (1969) who stated that many of the circuli in freshwater growth are continued around the scales into the posterior field. In addition, a few of the ocean circuli may continue into the clear field as weak circular striations but radial striations do not occur. Steelhead trout scales are large and may show one or more spawning checks.

Studies from otolith analyses have been made by McKern *et al.* (1974) who described otoliths and determined that the absence of changes in density in the freshwater growth of otoliths from hatchery-reared steelhead and the presence of these changes in the otoliths from wild steelhead were useful characteristics to separate these stocks. In addition, Rybock *et al.* (1974) studied the diameter of otolith nuclei as a means to separate juvenile steelhead trout from juvenile rainbow trout.

Most of the studies about growth, age and migration patterns from scale analyses have been made on the west coast of United States. In steelhead trout the growth rate is much greater in the ocean than in freshwater and the ocean growth determines the size of fish at maturity. Most steelhead trout return from the ocean to freshwater as mature adults at an age of 3, 4, or 5 years (Sumner 1945; Maher and Larkin 1954; Chapman 1957; Narver 1969).

Detailed life history patterns of steelhead trout are described by Shapovalov and Taft (1954). In addition, Withler (1965) studied the variability in life history of steelhead along the Pacific Coast. This latter author indicated that timing of initial stream entry from marine water showed little variations, the incidence of repeat spawning decreased from south to north and mean fork lengths were greater in northern areas where the fish spent more years in both freshwater and saltwater.

MATERIAL AND METHODS

My study area was located in southern Chile (40° 30' S and 72° 30' W) and includes the drainage area of the Bueno River which includes Ranco, Puyehue and Rupanco Lakes (Fig. 2). These araucanian lakes receive a considerable influx of water from the Andean mountain chain. Their water levels are correlated with an abundant supply of water from mountain streams in the spring which originates from the melting ice and snow in the mountains. Ample precipitation during this season also contributes to the supply of water (Thomasson 1963).

Most of the wild rainbow trout sampled were caught in Rupanco Lake (224.1 km^2) and its outlet, the Rahue River. This lake is located at 40° 50' S, 73° 30' W at 117 m above sea level. The drainage into this lake comes directly from 57 Andean streams and the Rahue River is the outlet. The watershed is characterized by granitic rocks which are low in calcium and the streams of the region have pH concentration ranging from 6.5 to 7.5 (Vila et al. 1978). Rupanco Lake has a maximum depth of 150 m and the temperature in the euphotic zone ranges from 10 to 18° C with an oxygen content between 9 to 11 mg/l (Donoso 1984). The Rahue River originates at Rupanco Lake (226 km^2) and flows NW about 150 km to its confluence with the Bueno River about 90 km from the Pacific Ocean.

Fish samples were also taken in the Pilmaiquen River (upper dam area). This river originates at Puyehue Lake (153.3 km^2) and flows NW about 25 km to Pilmaiquen Dam, a hydroelectric facility about 15 m high with no fish-passage facilities. From Pilmaiquen Dam, the Pilmaiquen River flows NW about 100 km to the Bueno River, which then flows about 125 km to the Pacific Ocean.

Another sample station was located in the Bueno River which originates at Ranco Lake (423 km^2) and flows about 200 km to the Pacific Ocean. The sample sites are shown in Fig. 2.

Between November 1981 and March 1984, sample fishes were caught by hook and line and by surface gill nets in Rupanco Lake. In the sample sites located in the rivers, the fishes were caught using hook and line, surface gill nets, and beach seines. Moreover, information was obtained through creel census data from anglers in Rupanco Lake.

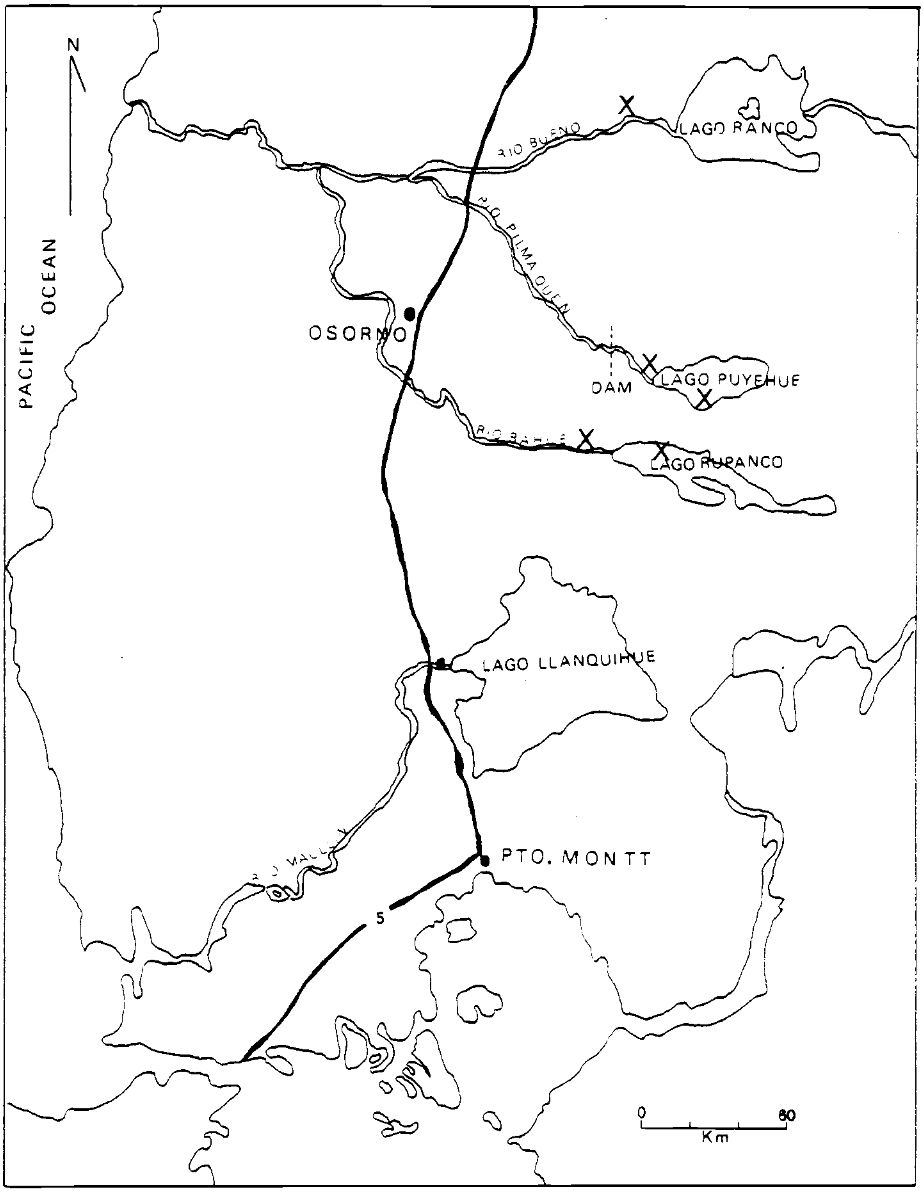

Figure 2. Study areas in which rainbow trout were collected in southern Chile during 1981-1894. Sample sites are indicated (X).

For each fish caught, weight, sex and fork length were recorded. Also, scale samples were taken from an area between the lateral line and the insertion of the dorsal fin.

Ages of fish were determined by counting annuli on scales and by length-frequency distributions. Fishes were divided into 1-cm length intervals. Average body length and corresponding average scale radius length of all groups were used to compute regression of body length on scale length. Body length at the annulus was back-calculated using the Frazer-Lee method (Carlander 1982). Also, the length-weight relationship was established (Ricker 1975).

Age structure estimation was determined using the polymodal graphical curve analysis (Harding 1949).

Asymptotic length was determined using the graphical method of Ford (1933) and Walford (1949). Finally, a growth curve was established using the Von Bertalanffy model (1938) in which the parameters L_{inf} , t_o and K were computed.

In this thesis, I present data which have resulted from the examination, interpretation and measurement of scales and otoliths from 260 rainbow trout captured in my study area located in southern Chile (Table 1).

Table 1. Sample size and sexes of rainbow collected in the study area in southern Chile during 1981-1984.

Sampling area	Sample size	Males	Female
Rupanco Lake	120	46	74
Rahue River	74	34	40
Puyehue Lake	27	4	23
Pilmaiquen River	12	5	7
Bueno River	26	19	7

Scale Analyses Procedures

Scale samples were collected and preserved dry in coin envelopes on which other pertinent data were recorded. For reading procedures, the scales were cleaned and mounted between glass microscope slides or had their sculptured features impressed in laminated plastic (cellulose acetate). This latter method required the use of heat (100° C) and pressure (5,000 psi) exerted via a scale press (Tesh 1971).

Adult and juvenile scales were read and measured twice using a Bausch & Lomb scale projector with a magnification of 150 x. Measurements to annuli were taken from the focus to the outside of the annulus at the last constricted circulus or to the point where abrupt new growth was evident. All distances were recorded to the nearest millimeter. All radial measurements were made on the anterior field of the scale at a fixed angle from the anterior-posterior axis of each scale (Chapman 1957; Peterson 1978).

Age was designated in the manner used by McKern et al. (1974) for sea-run rainbow trout. These authors designed the number of freshwater and ocean annuli separated by a slash. For instance, a 2/2 steelhead trout would have spent two winters in freshwater and two winters in the ocean. Completed spawning migration, identified by the presence of spawning checks, were designated by "s". These spawning checks on the scale were recognized by marginal absorption of the scale produced as the spawning time approaches.

The following information from scale readings was recorded: estimated age at capture, distance from the focus to each annuli, number of circuli per annulus, total scale radius, spawning checks and migration checks.

The scale growth pattern recognition, identification and terminology of scale marks were made following the criteria given by Peck (1970) and Jearld (1983).

Identification of Scale Marks

Circulus: a concentric ridge around the focus, or central clear area on the upper surface of the anterior field of the scale.

Check: an interruption in the regular pattern of circuli, appearing as crowded, narrow, and/or incomplete circuli.

Annulus: a check that was considered to have formed during the winter. It is a concentric zone, band or mark, which is correlated with a yearly event.

False annulus: a check that formed at a time other than during the time of annulus formation.

Plus growth or marginal increment: the zone of circuli beyond the last check. This plus growth indicates whether a check was complete or not.

Migration checks were identified using the criteria given by Koo (1962) who established that this check is characterized by circuli that are much wider than those developed in freshwater and this difference creates a demarcation between the freshwater and saltwater growth. Furthermore, this author indicated that migration checks are easily recognized on scales of adults that originate from early season smolt migrants. However, in scales of middle and late season smolt migrants, the change from freshwater to marine growth is more gradual because of the presence of plus growth such that the exchange may be so gradual as not to be apparent to the inexperienced eye. In adults which come from the very late migrants, there is more or less an abrupt change from freshwater to marine water. In this case the migration check seems to be a true annulus and differentiation between the two may be difficult.

Otoliths Analysis Procedures

A total of 89 otoliths of adults and juveniles were obtained by splitting the head and using a pair of pointed tweezers to extract the ear stones (McKern *et al.* 1974). The otoliths were preserved in a media containing 50% glycerin and 50% ethanol.

In order to describe the otolith characteristics, the terminology used by Kim and Koo (1963) was used. Moreover, measurements and examination were made following the methodology described by McKern *et al.* (1974).

Otolith Nomenclature

Hyaline nucleus: the small oval center of the otolith which appears dark with a narrow opaque ring around the border.

Metamorphic check: a narrow hyaline ring delineating the nucleus.

Opaque rings: the uninterrupted oval opaque zones formed during summer growth in freshwater.

Hyaline rings: the uninterrupted oval hyaline zones formed during winter growth in freshwater.

Plus growth: a narrow opaque zone of freshwater growth formed after the last hyaline ring.

Metamorphic check: a narrow hyaline zone delineating plus growth.

Opaque bands: opaque zones formed during summer growth in saltwater which are interrupted by notches in the anterior and posterior regions of the otolith.

Hyaline bands: hyaline zones formed during winter growth in saltwater which are interrupted by notches in the anterior and posterior regions of the otolith.

In order to describe the life history patterns observed in rainbow trout from scale and otolith analyses, the following terms from Shapovalov and Taft (1954) were used:

Juvenile: fish which is sexually immature.

Adult: fish which has matured sexually after one or more summers of sea life.

Grilse: adult fish which has matured sexually after only one summer of sea life.

Resident fish: Fish which is an offspring of parents that spawned without having been to sea and which itself has not been to sea.

Sea-run fish: fish which has entered a stream to spawn after one or more summer of sea life.

Stream fish: fish which has not been to sea, irrespective of its parent-age or sexual maturity.

Ripening fish: fish whose sexual products are developing preparatory to spawning.

<u>**Fall-run fish**</u>: fish which enters a stream at any time from the late summer through the following spring and will spawn sometime during that same period.

<u>**Spring-run fish**</u>: fish which enters a stream in the spring or early summer, but will not spawn until the following fall, winter, or spring.

<u>**Maiden fish**</u>: fish, whether male or female, which has not spawned.

<u>**Ripe fish**</u>: fish which is ready for spawning.

Data Analysis

Linear regression analyses were used in order to establish the relationship of scale radius to fish length. After that, back-calculation procedures were applied following the Frazer-Lee method (in Carlander 1982) whose formula is:

$$l_n = a + \frac{(L-a)}{S} \cdot s_n$$

where:

L = fish length at capture

S = total scale radius at capture

l_n = calculated fish length at age n

s_n = scale measurement for annulus n

a = constant calculated from regression line

The growth equation of rainbow trout in the study area was determined according to the Von Bertalanffy model (1938) using the formula:

$$L_t = L_{inf} \, [1-e^{-k(t-t_o)}]$$

where:

L_t = length at time t

L_{inf} = asymptotic length

k = growth coefficient

t = time

t_o = hypothetical growth in which the fish would have an age o if its growth had always been as described by this model.

Weight-length relationships were estimated according to Ricker (1975) and the formula is:

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

where:

W = weight

L = length

a = proportionally constant of the length-weight relationship

b = exponent of length-weight relationship

Allometry or isometry in growth was determined by estimating b-values for fish collected in Rupanco Lake and Rahue River.

RESULTS

Length-frequency Distributions

A total of 259 rainbow trout were analyzed and number, fork length (FL), body weight, and sex ratio for fish in each study area are shown in Appendices I, II, III, IV, and V.

Fork length of the fish examined in this study ranged from 12 to 80 cm and body weight varied from 21 to 7500 g. The first approximation of the population structure of rainbow trout was made through a length-frequency distribution analysis in which fish were divided into 1-cm length intervals.

For the fish collected in Rupanco Lake, two modes were observed (Fig. 3-A). The dominant mode occurred at the interval between 30 and 67 cm and a minor mode was found at 15 to 25 cm. A difference in size was observed between sexes, with females tending to be larger than males. As is shown in Fig. 3-A, this size difference is highly marked in fish > 45 cm. In the fish collected from Rupanco Lake, fork length ranged between 15 to 70 cm and body weight varied between 50 and 4,020 g (Appendix I).

For Rahue River, the fish sampled showed one mode between 10 and 35 cm (Fig. 3-B). No consistent size difference was observed between sexes, although males tended to be larger than females. In this sample site, fork length ranged between 12 and 62 cm and body weight varied from 21 to 1850 g (Appendix II).

Length-frequency distribution of rainbow trout collected in Puyehue Lake is shown in Fig. 3-C. Size composition was relatively uniform so that no dominant modes were observed. Females tended to be larger than males > 55 cm. In this study area, fork length ranged between 26 and 80 cm and body weight varied from 800 to 7500 g (Appendix III).

For Pilmaiquen River, most of collected fish were grouped between 20 to 30 cm (Fig. 3-D). Fork length varied between 19 and 76 cm and body weight ranged from 65 to 3200 g (Appendix IV).

Size composition for fish collected in Bueno River is shown in Fig 3-E. A mode occurred between 15 to 30 cm FL. Fork length ranged

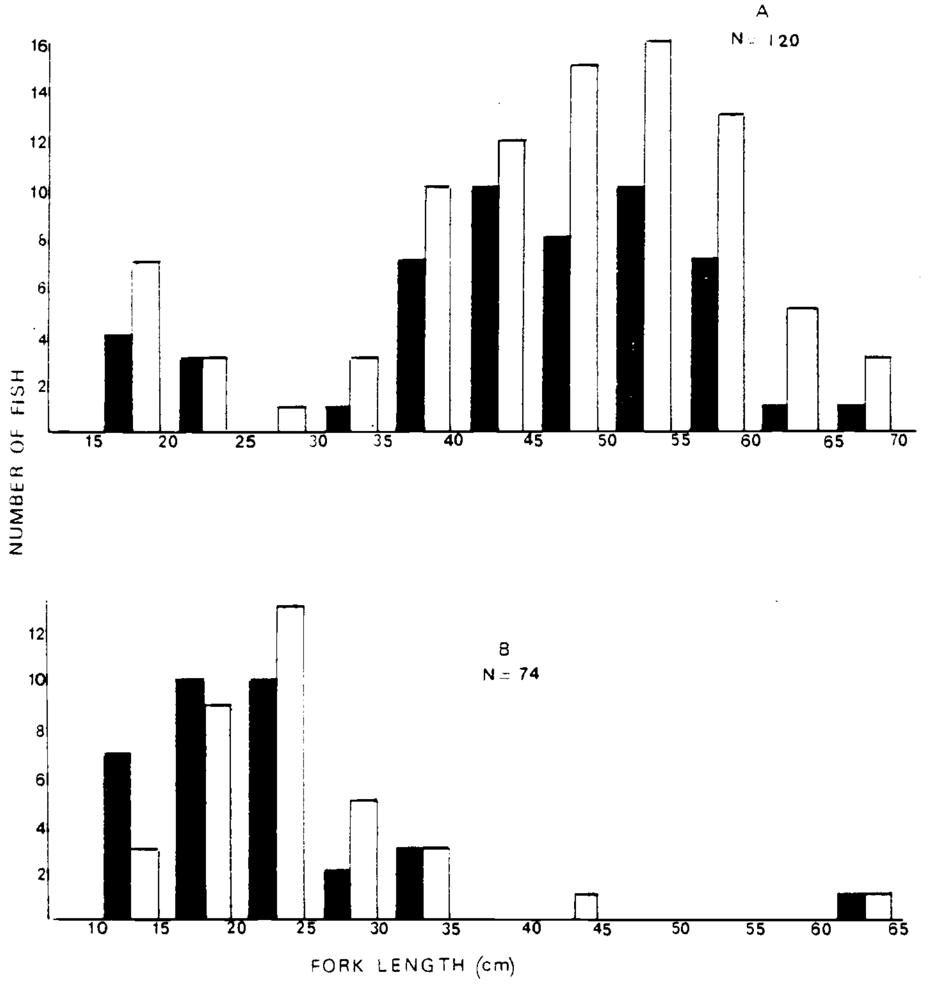

Figure 3-A,B. Fork length composition of males (dark bar) and females (open bar) of rainbow trout collected in (A) Rupanco Lake and (B) Rahue River, Chile.

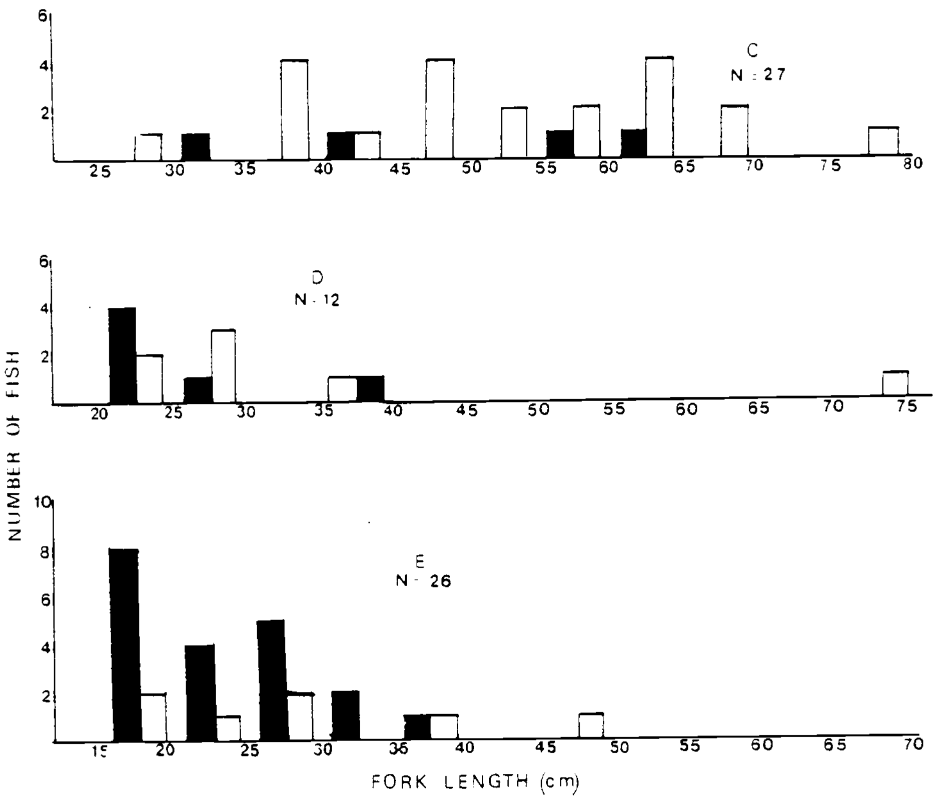

Figure 3-C,D,E. Fork length composition of males (dark bar) and females (open bar) of rainbow trout collected from (C) Puyehue Lake, (D) Pilmaiquen River and (E) Bueno River, Chile.

between 14 to 47 cm and body weight varied between 36 to 860 g (Appendix V).

Weight-length relationships between fork length in centimeters and body weight in grams of all fish obtained from the five study areas are plotted in Fig. 4. Table 2 summarizes the sample size (N), constant (a), exponent (b) and correlation coefficient (r) for females and males from Rupanco Lake and Rahue River. The values of (b) were tested to evaluate isometry and growth differences between females and males collected from both study areas.

Table 2. Summarized data from weight-length relationships for females and males of fish collected from Rupanco Lake and Rahue River, Chile.

Sample site	Sex	N	a	b	r
A. Rupanco Lake	Females	62	0.01	3.03	0.98
	Males	41	0.01	3.04	0.98
B. Rahue River	Females	39	0.02	2.74	0.99
	Males	35	0.02	2.84	0.98

In the fish sampled from Rupanco Lake, slope b did not differ from 3 at the $P \leq 0.1\%$ level of significance which indicates that females and males display isometric growth (Appendices VI and VII). In addition, both females and males did not show a significant growth difference (Appendix VIII).

In fish sampled from Rahue River, slope b is significantly different from 3 at the $P \leq 0.1\%$ level of significance so that females and males have allometric growth (Appendices IX and X). Moreover, there is no significant growth difference between females and males (Appendix XI).

The values for (b) obtained from the other study areas were not tested between sexes because of the small sample size. Males and females were then grouped and Table 3 shows the sample size (N), constant (a), exponent (b) and correlation coefficient (r) for fish from Puyehue Lake, Pilmaiquen River and Bueno River.

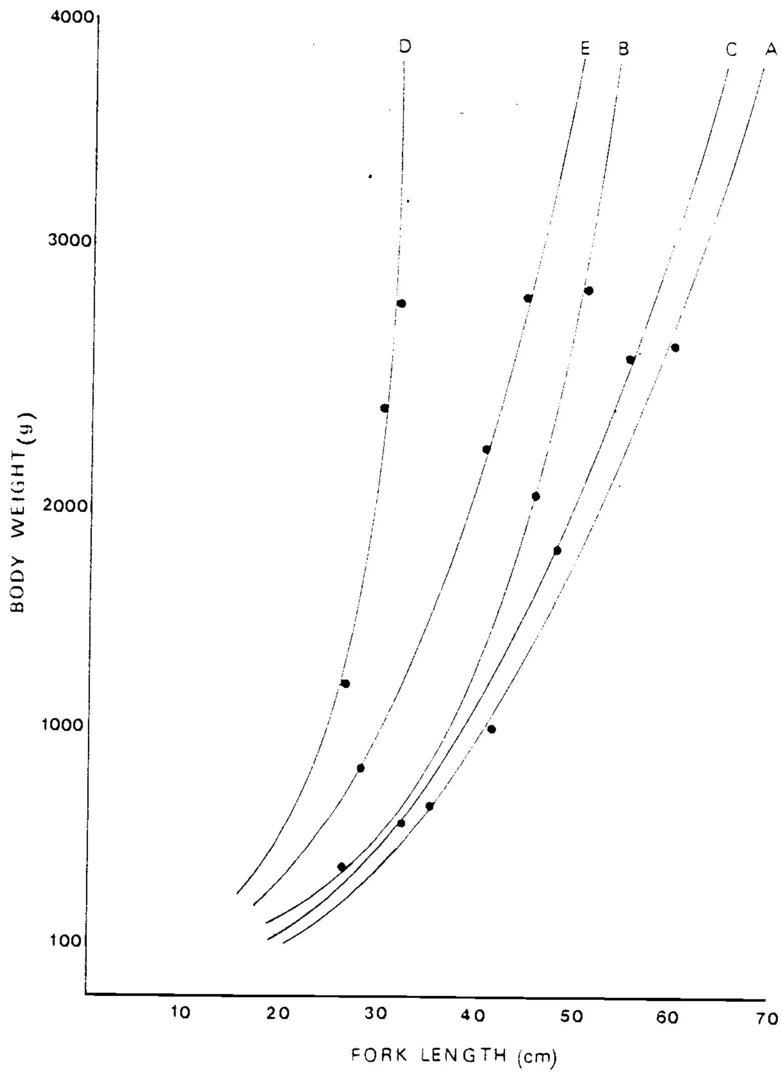

Figure 4. Length-body weight relationships of rainbow trout collected from (A) Rupanco Lake, (B) Rahue River, (C) Puyehue Lake, (D) Pilmaiquen River, and (E) Bueno River, Chile.

Table 3. Summarized data from weight-length relationships for rainbow trout collected from Puyehue Lake, Pilmaiquen River, and Bueno River, Chile.

Sample site	N	a	b	r
C. Puyehue Lake	27	0.100	2.52	0.87
D. Pilmaiquen River	12	0.030	2.70	0.91
E. Bueno River	26	0.040	2.59	0.97

According to these data, the relationships of body weight to fork length differ among fishes from the respective study areas. Significant growth differences between sexes were not found in fish sampled from Rupanco Lake and Rahue River even though growth was isometric in rainbow trout from Rupanco Lake and allometric in fish collected from Rahue River.

To help clarify the population structure of rainbow trout from Rupanco Lake and Rahue River, a graphical analysis of the polymodal frequency distribution was made using probability paper. The other fish collections were not considered in this analysis because of their small sample size.

In fish obtained from Rupanco Lake, four model groups were estimated by straight lines (Fig. 5) which were normalized in Fig. 6. Size interval, fish number, model length and standard deviation for each model group is shown in Table 4.

In fish collected from Rahue River, three model groups were observed from size frequency curves (Fig. 7). Normalized straight lines are shown in Fig. 8. Size interval, fish number, model length and standard deviation are shown in Table 5.

The modal lengths obtained from these graphical analyses indicate fish lengths at successive ages which may be compared to lengths derived from age determination modes from scales in order to validate the scale analysis methods.

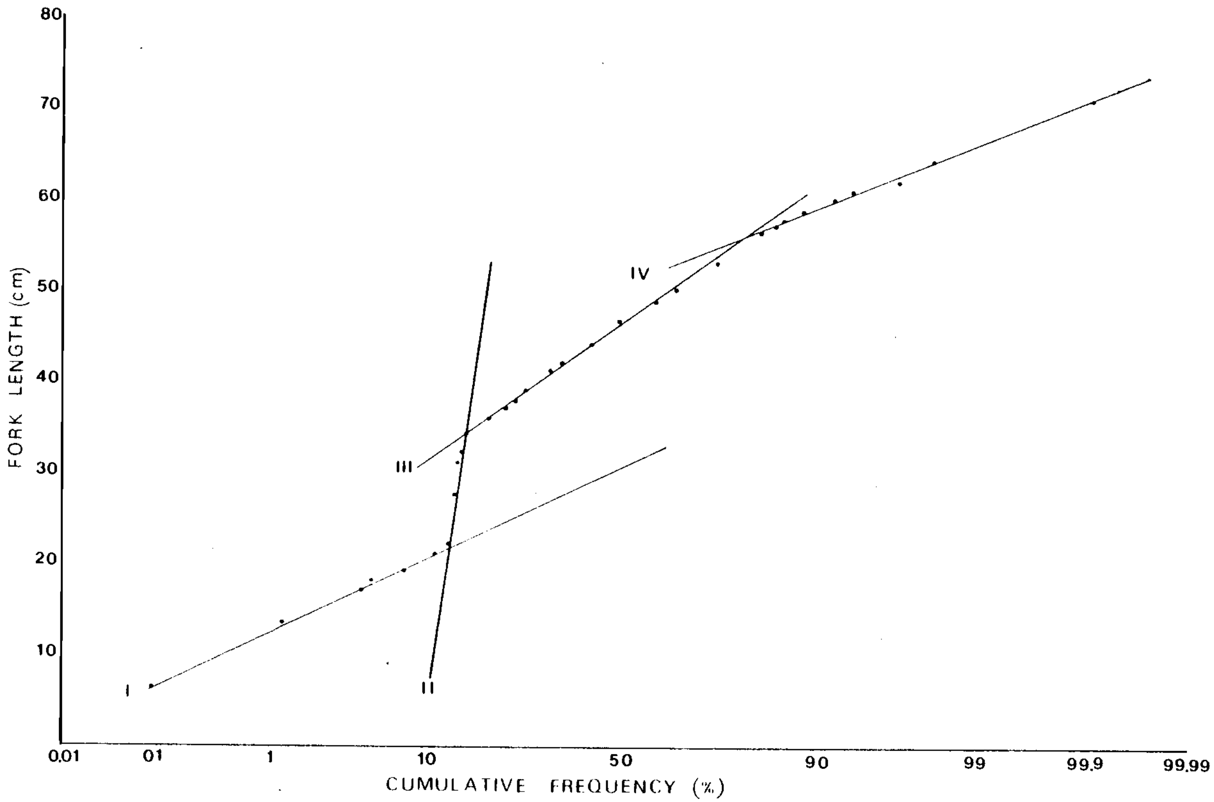

Figure 5. Graphical analysis of polymodal distribution of fish collected from Rupanco Lake, Chile. Modal groups are indicated in roman numbers.

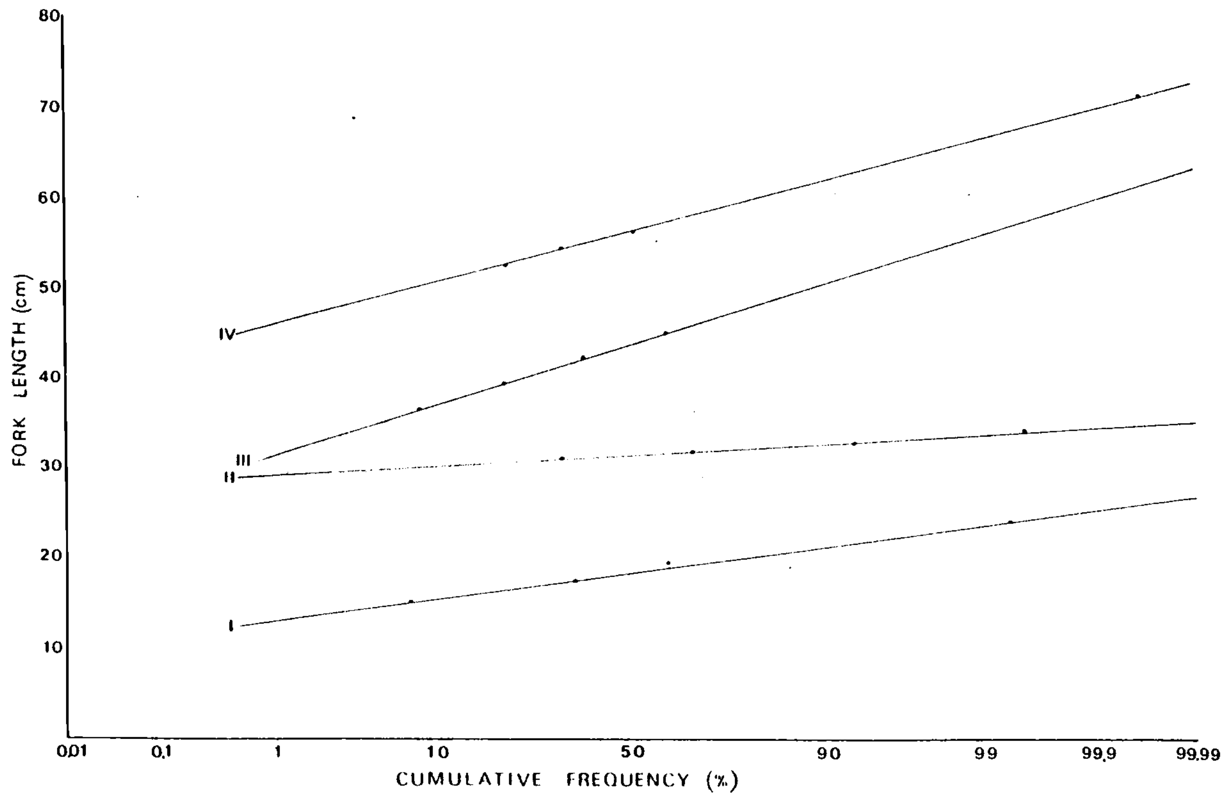

Figure 6. Normalized straight lines of modal groups determined from graphical analysis of polymodal distribution of rainbow trout lengths collected from Rapanco Lake, Chile.

Table 4. Summarized data from modal groups of rainbow trout lengths obtained by graphical analysis of fish sampled from Rupanco Lake, Chile

Modal group	Size interval (cm)	Modal length (cm)	Standard deviation (s)	Fish number	%
I	15-22	18.0	2.05	15	12.5
II	31-34	31.0	0.50	3	2.5
III	36-51	43.1	5.35	60	50.0
IV	52-71	56.1	4.35	42	35.0

Table 5. Summarized data from modal groups of rainbow trout lengths obtained by graphical analysis of fish sampled from Rahue River, Chile.

Modal group	Size interval (cm)	Modal length (cm)	Standard deviation (s)	Fish number	%
I	12-24	16.1	2.25	48	64.8
II	25-44	29.0	4.25	23	31.1
III	47-62	49.5	6.00	3	4.05

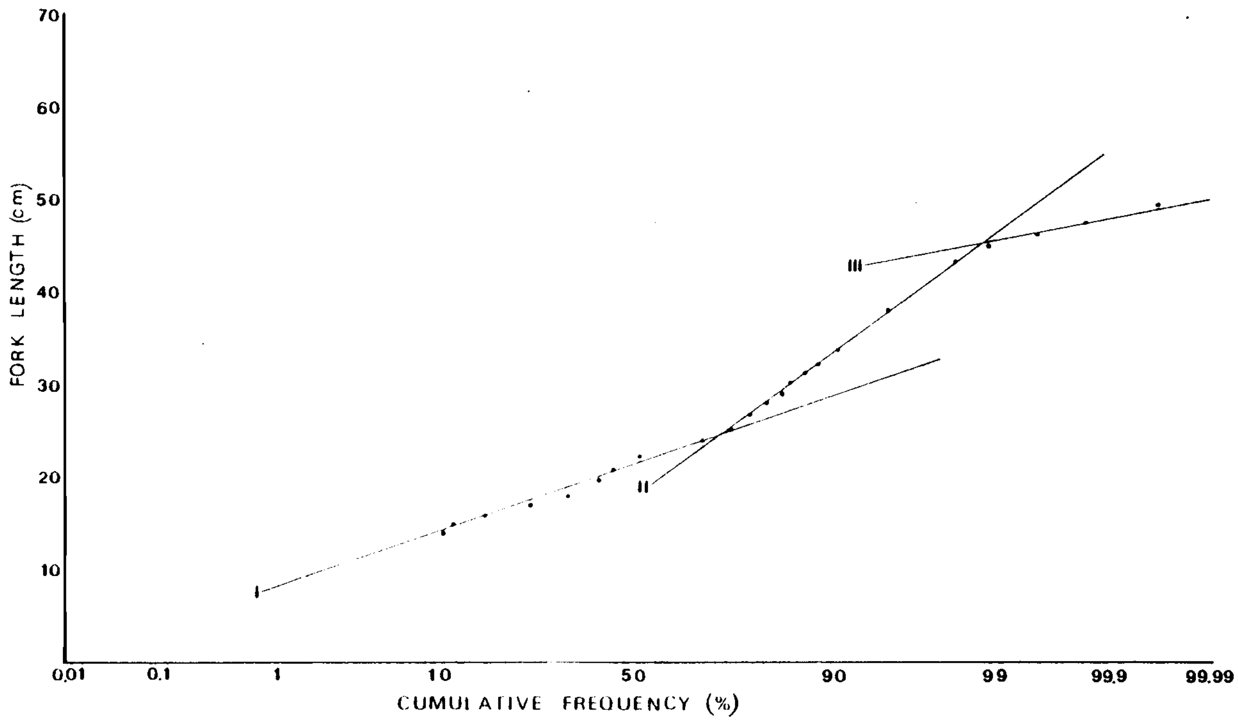

Figure 7. Graphical analysis of polymodal distribution of fish collected from Rahue River, Chile. Modal groups are indicated in roman numbers.

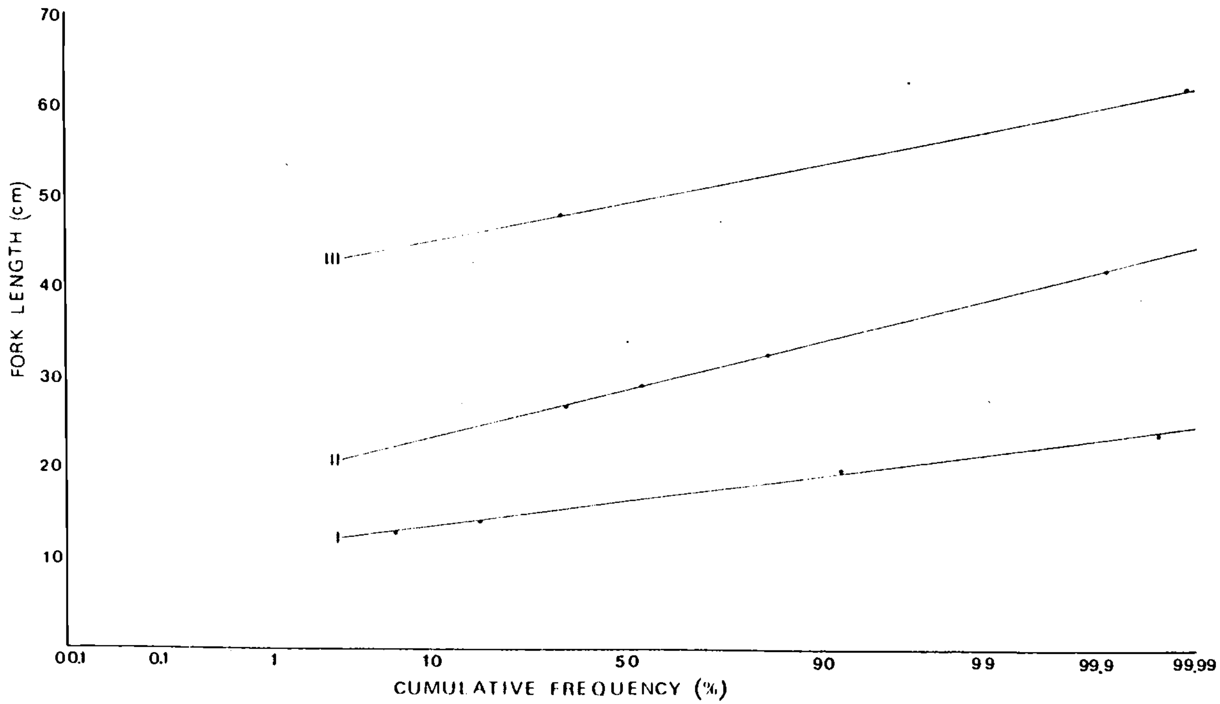

Figure 8. Normalized straight lines of modal groups determined from graphical analysis of polymodal distributions of rainbow trout lengths collected from Rahue River, Chile.

Scale and Otolith Analyses

A representative comparison of aging structures on fish scales and otoliths from specimens collected in each of the study areas is shown in Figs. 9, 10, 11, 12, and 13.

Scales of rainbow trout showed two growth patterns in which spaces between circuli were different. In the first pattern, the circuli tended to be thin and closely spaced. This circuli feature appeared during the first, second and third year of growth and before the transition period associated with migration. After migration, a second growth pattern was observed in which circuli tended to be wider and more spaced. Both the first and the second growth patterns showed complete and broken circuli. Other features such as annuli and spawning checks were also identified on the scales.

In otoliths, light and dark zones that corresponded to opaque and hyaline rings were observed before migration. After migration, light and dark zones identified as opaque and hyaline bands were also observed.

In rainbow trout for which age determination was made by counting annuli, year classes ranged from one (I^+) to five (V^+) years. These year classes were designated by the terminology proposed by Maher and Larkin (1954) in order to describe events in the life history of the fish sampled. Hence, 10 different age types ranging from 1/1 to 3/1s2 were observed (Table 6). Mean length and mean weight for each age type is summarized in Table 7.

Three age types were recognized before migration and nine age types occurred after migration, including four patterns for fish making their first spawning. In addition, two groups of migrants were identified--those which spend two years in freshwater (second year migrant) and those which spend three years in freshwater before migration (third year migrant) (Table 6).

In Rahue, Pilmaiquen, and Bueno Rivers, fishes with age type 1/1 and 2/1 were more numerous than those in Rupanco Lake and Puyehue Lake. In Rupanco Lake, fish showed a great variety of age types dominated by 2/1 (30.7%); and the percentage of fish with post-migration circuli (54.2%) was a little higher than those with

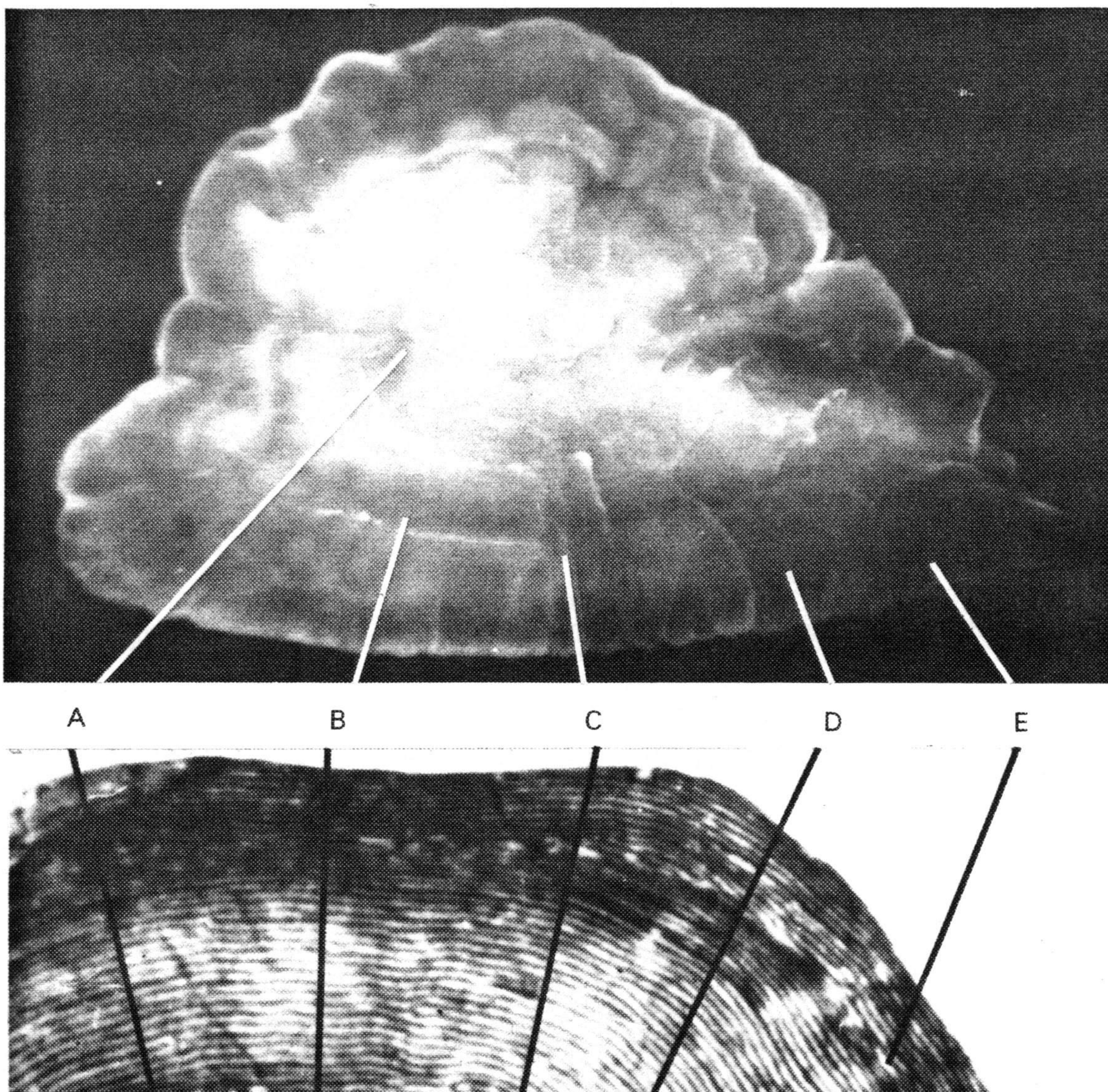

Figure 9. Photomicrographs of an otolith and a scale of a rainbow trout from Rupanco Lake, Chile. Features shown are: (A) annulus 1/ , (B) annulus 2/ , (C) migration check, (D) annulus /1, and (E) spawning check /2s (magnification 15 diameters).

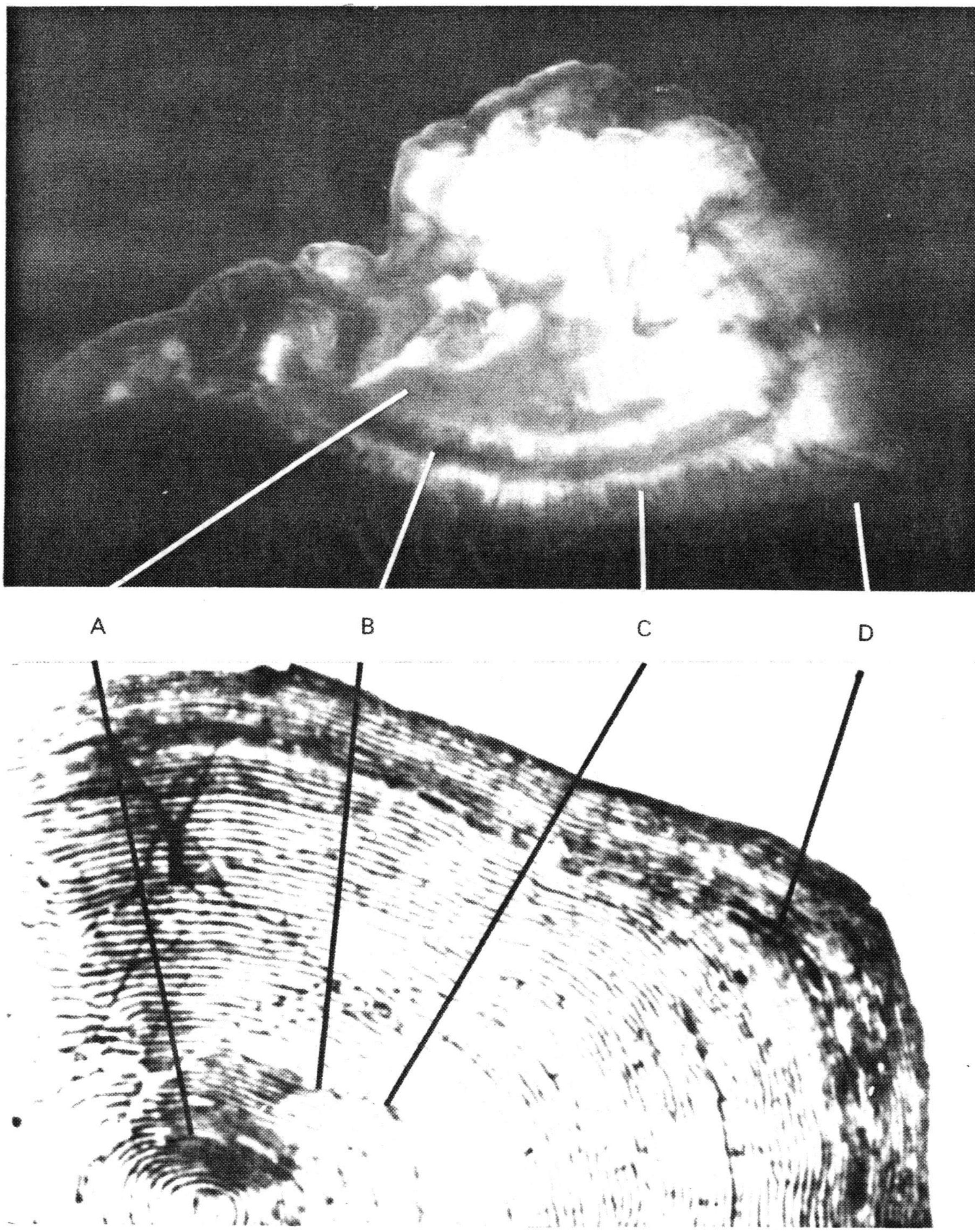

Figure 10. Photomicrographs of an otolith and a scale of a rainbow trout from Rahue River, Chile. Features shown are: (A) annulus 1/ , (B) annulus 2/ , (C) migration check, and (D) spawning check /1s (magnification 15 diameters).

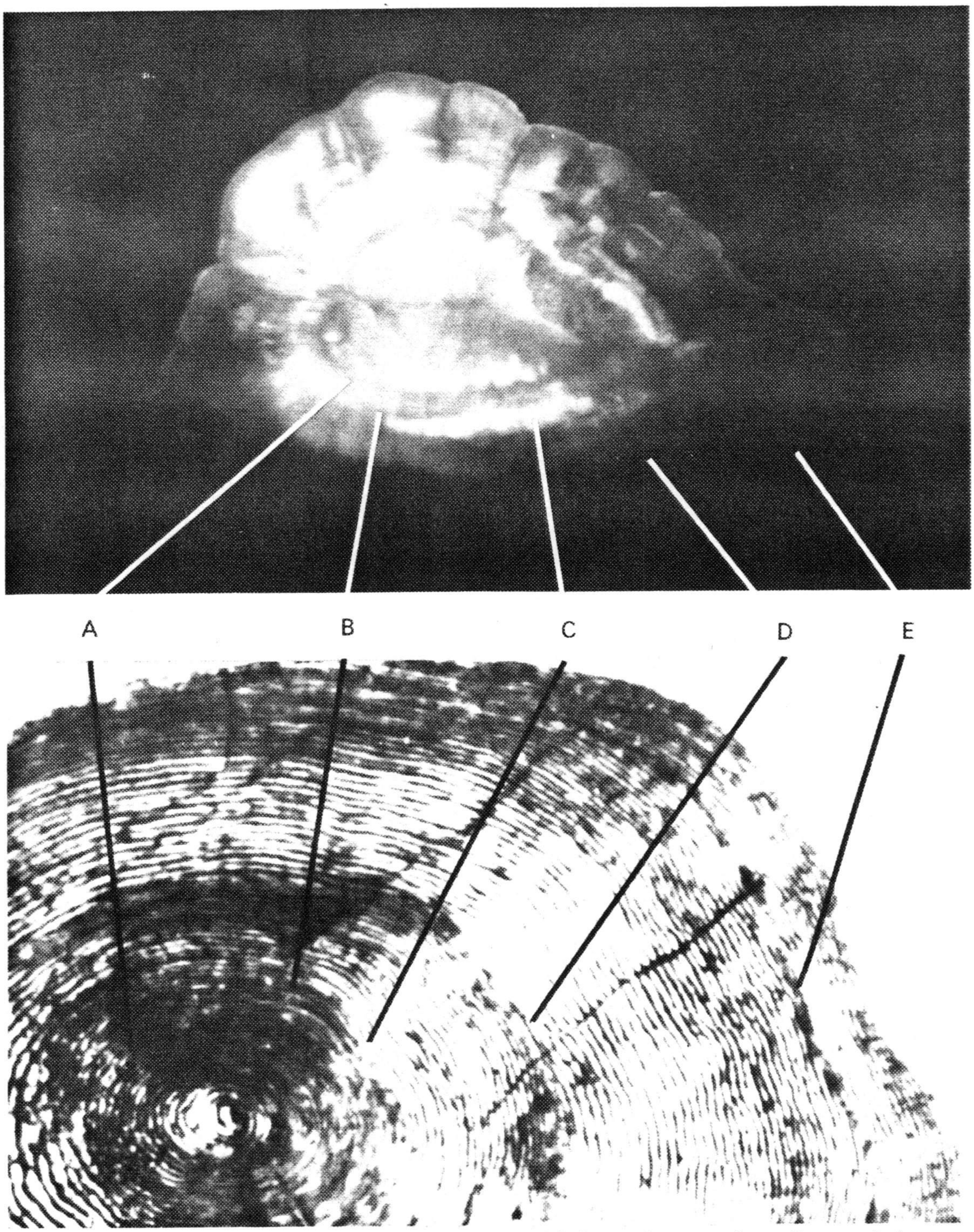

Figure 11. Photomicrographs of an otolith and a scale of a rainbow trout from Puyehue Lake, Chile. Features shown are: (A) annulus 1/ , (B) annulus 2/ , (C) migration check, (D) annulus /1, and (E) annulus /2 (magnification 15 diameters).

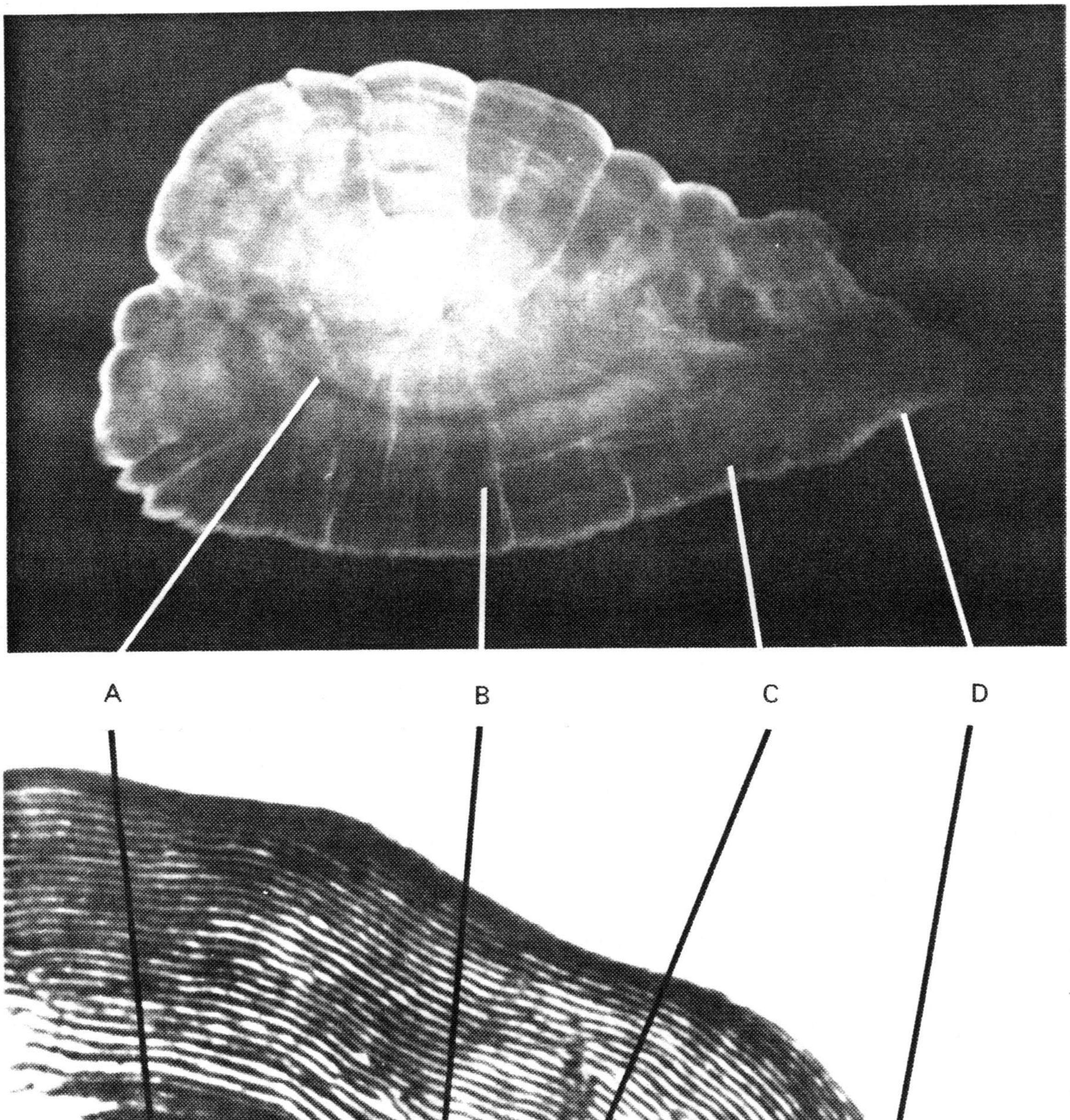

Figure 12. Photomicrographs of an otolith and a scale of a rainbow trout from Pilmaiquen River, Chile. Features shown are: (A) annulus 1/ , (B) annulus 2/ , (C) migration check, and (D) annulus /1 (magnification 15 diameters).

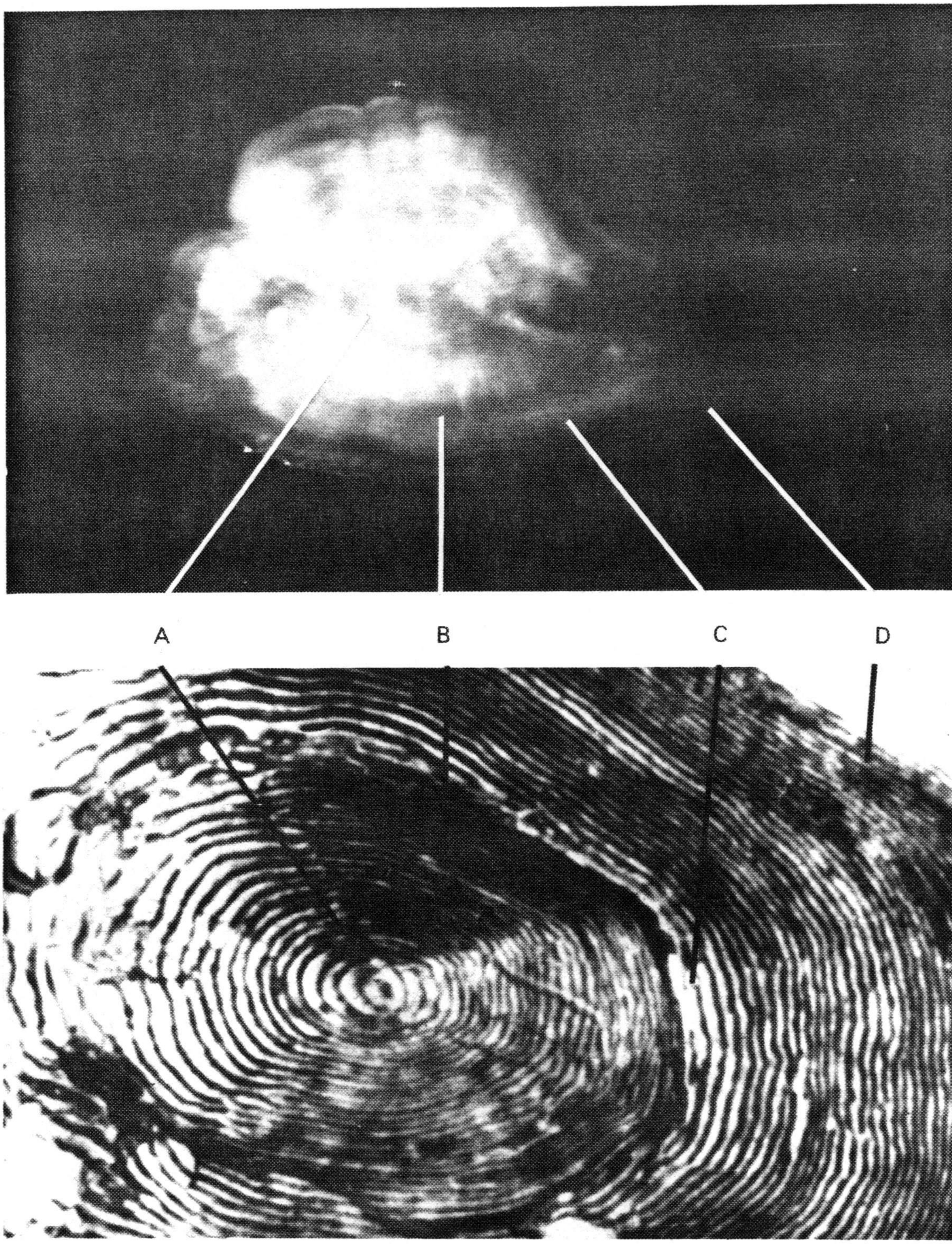

Figure 13. Photomicrographs of an otolith and a scale of a rainbow trout from Bueno River, Chile. Features shown are: (A) annulus 1/ , (B) annulus 2/ , (C) migration check, and (D) annulus /1 (magnification 15 diameters).

Table 6. Composition of age types as determined from scales of rainbow trout collected in southern Chile, 1981-1984.

		Rupanco Lake		Rahue River		Puyehue Lake		Pilmaiquen River		Bueno River	
Number annuli	Age type	N	%	N	%	N	%	N	%	N	%
I	1/1	5	4.4	15	28.8			3	30	10	43.4
Second Year Migrant											
II	2/1	35	30.7	34	65.4	4	14.8	5	50	11	47.8
III	2/2	25	21.9	1	1.9	10	37.0	1	10	2	8.6
IV	2/3	6	5.2			3	11.1	1	10		
III	2/1s2	2	1.8	1	1.9						
IV	2/2s3	6	5.2			7	25.9				
V	2/2s4	3	2.6			3	11.1				
Third Year Migrant											
III	3/1	12	10.5	1	1.9						
IV	3/2	16	14.0								
IV	3/1s2	4	3.5								

Table 7. Mean length (m.l.) and mean weight (m.w.) of rainbow trout in southern Chile during 1981-1984 in relation to age type.

	Rupanco Lake		Rahue River		Puyehue Lake		Pilmaiquen River		Bueno River	
Age type	m.l. (cm)	m.w. (g)	m.l. (cm)	m.w. (g)	m.l. (cm)	m.w. (g)	m.l. (cm)	m.w. (g)	m.l. (cm)	m.w. (g)
1/1	19.9	88.3	19.0	98.3			22.0	131.0	20.1	135.2
Second Year Migrant										
2/1	38.8	771.3	32.2	337.3	39.0	976.6	27.0	250.8	30.7	254.6
2/2	51.4	1540.2	47.0	1100.0	46.4	1660.0	36.0	550.0	41.0	730.0
2/3	55.0	1950.3			58.3	2316.6	76.0	3200.0		
2/1s2	48.5	1337.5	62.0	1850.0						
2/2s3	59.6	2725.0			60.2	3060.7				
2/2s4	61.0	2843.0			65.3	3850.0				
Third Year Migrant										
3/1	52.3	1524.1	61.0	1270.0						
3/2	52.4	1604.2								
3/1s2	55.0	2150.0								

pre-migration circuli (45.6%). In addition, most of second and third year migrants were found in Rupanco Lake (Table 6).

In fish sampled from Puyehue Lake, the dominant age type was 2/2 (37%) which corresponds to a second year migrant (Table 6).

In all samples, fish in their second (II^+) year class were immature with no previous spawning marks on their scales. Spawning checks were observed on the scales of fish that were three (III^+), four (IV^+) and five (V^+) years old at capture (Table 6).

Table 7 summarizes the estimated mean length and mean weight for each age group. Fish which grew two years before they migrated reached a length ranging between 27.0 to 38.8 cm and weighed 251 to 977 g. Third year migrants reached lengths of 52.3 to 61 cm FL and weighed 1270 to 1524 g.

First spawning was observed in fish with lengths between 48.5 and 62 cm FL and weights between 1338 to 2843 g.

Between 12 and 22 circuli were formed on the scales during the first and second year for second year migrants (Table 8). A similar range was observed for third year migrants during their first three years. Fish which migrated in their second year had a large increment in number of circuli during their third year of growth. Afterward, the number of circuli diminished with age. For third year migrants, the observed pattern was similar so that an increase in the number of circuli was identified in the fourth year of growth. Apparently, rainbow trout begin to grow rapidly after migration.

According to my observations, the growth rate of rainbow trout scales did not slow with age indicating environmental changes. Compared to scales showing a typical sea growth (steelhead trout), the circuli of some scales I collected were closely spaced during one to three years after migration or the difference between growth annuli and resting zones was not clear. These effects are probably caused by migrations and life history patterns which occurred only in freshwater. Rainbow trout could migrate seasonally from streams to the lakes or from rivers to estuaries without migrating to the ocean. These probable migration patterns within freshwater explain why circuli formed after migration were sometimes close together and did

Table 8. Mean number of circuli in each year of growth (Cn) on the scales of rainbow trout from Rupanco Lake (RL), Rahue River (RR), Puyehue Lake (PL), Pilmaiquen River (PR), and Bueno River (BR), Chile during 1981-1984.

Age type	C_1					C_2					C_3				
	RL	RR	PL	PR	BR	RL	RR	PL	PR	BR	RL	RR	PL	PR	BR
1/1	17.3	18.3		15.2	12.7										
2/1	13.1	14.5	14.7	12.7	11.4	21.4	20.3	22.1	23.1	15.3					
2/2	11.8	13.0	10.2	13.0	11.1	23.5	21.0	14.3	20.0	24.7	38.2	32.0	32.0	38.0	35.4
2/3	14.2		10.7	18.0		19.5		25.3	12.0		20.1		18.3	42.0	
2/1s2	18.0	17.0				27.2	19.0				36.7	38.0			
2/2s3	10.3		15.4			14.3		19.7			46.2		40.3		
2/2s4	18.4		15.8			22.1		24.8			37.2		35.3		
TOTAL MEAN	14.7	15.7	13.4	14.7	11.8	20.5	20.1	21.4	18.1	20.0	35.7	35.0	31.5	40.0	35.4
3/1	13.4	18.0				15.7	20.0				14.3	22.0			
3/2	12.3					24.6					20.6				
3/1s2	10.1					23.2					22.3				
TOTAL MEAN	11.9	18.0				21.1	20.0				19.0	22.0			

Table 8. Continued

Age type	C_4					C_5				
	RL	RR	PL	PR	BR	RL	RR	PL	PR	BR
1/1										
2/1										
2/2										
2/3	31.1		14.1	20						
2/1s2										
2/2s3	24.1		30.2							
2/2s4	28.1		23.8			18.7		14.0		
TOTAL MEAN	27.8		22.7	20		18.7		14.0		
3/1										
3/2	36.3									
3/1s2	34.2									
TOTAL MEAN	35.4									

not present a uniform growth pattern. Hence, transitional growth periods were unclear.

Age and Growth Parameters

For making back-calculations of growth in rainbow trout, it was necessary first to determine the relationship between growth of scales and otoliths on length of the fish. For this purpose a plot of fork length on total scale radius and a plot of otolith length on fork length for each collected sample was made (Fig. 14 and 15). The respective linear regression equations, number of observations and correlation coefficients are summarized in Tables 9 and 10. According to these results, the relationship between fork length and scale radius or otolith length are linear but not directly proportional.

Back-calculation of length at previous age was performed by the Lee-Fraser formula using a-values obtained from the fork length-scale radius relationship (Table 9). Use of this formula requires the assumption that the fish-scale relationship is proportional and linear (Tesch 1971).

Average annual growth was determined by back-calculating lengths from scale radius measurements. Mean calculated length at previous age in relation to the estimated age of rainbow trout captured at each sample site is shown in Appendices XII, XIII, XIV, XV and XVI.

Lee's phenomenon (Lee 1920) and its reverse can be detected in the estimated figures. Hence, estimated length for each estimated age group may be less or more than the true values, especially for fish at age II from Rahue River and at age III from Puyehue Lake and Pilmaiquen River (Appendices XIII, XIV, and XV).

At the end of the first year, rainbow trout from Rupanco Lake appeared to be larger than any first year fish from the other areas. The second best first year growth was observed in Puyehue Lake. Rainbow trout from the three rivers seemed to be small in their first year of growth and terminal lengths were relatively similar.

At the end of the second year, longest lengths were reached by rainbow trout from Rupanco Lake and Bueno River. Fish from Pilmaiquen River appeared to be smaller than those from other rivers.

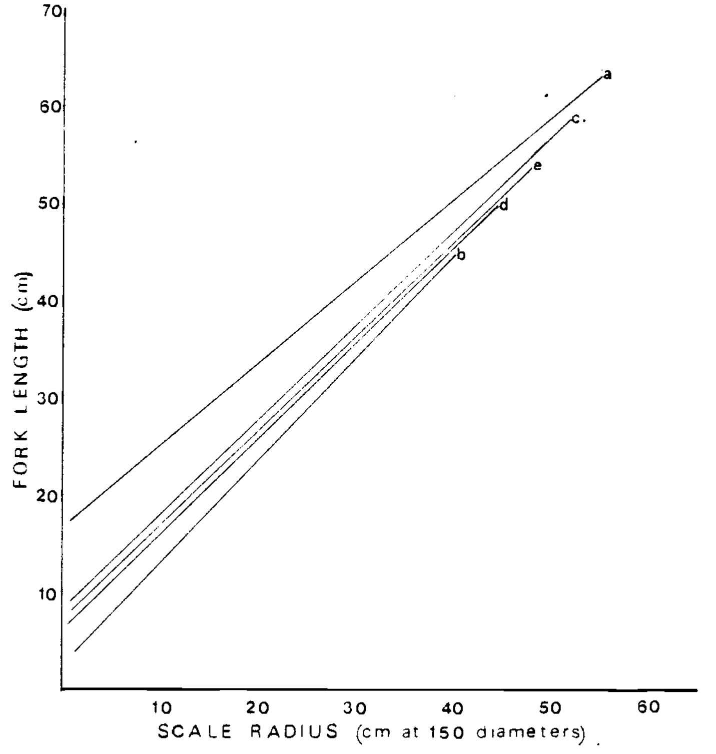

Figure 14. Regression lines of rainbow trout fork length (y) on total scale radius (x) at 150 diameters; (a) Rupanco Lake, (b) Rahue River, (c) Puyehue Lake, (d) Pilmaiquen River, and (e) Bueno River in southern Chile, 1981-1984.

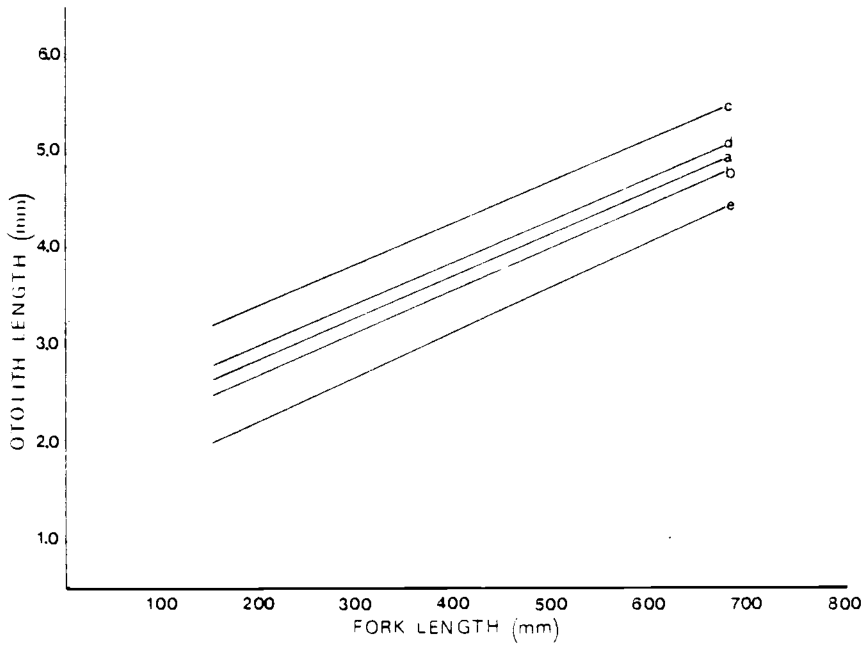

Figure 15. Regression lines of rainbow trout otolith length (y) on fork length (x); (a) Rupanco Lake, (b) Rahue River, (c) Puyehue Lake, (d) Pilmaiquen River, and (e) Bueno River in southern Chile, 1981-1984.

Table 9. Linear regression of fork length (y) on total scale radius (x) at 150 diameters for rainbow trout collected in southern Chile, 1981-1984.

Sample Site	Equation	r	N
A. Rupanco Lake	y = 15.37 + 0.86 (x)	0.84	120
B. Rahue River	y = 3.03 + 1.12 (x)	0.91	74
C. Puyehue Lake	y = 8.89 + 1.09 (x)	0.85	27
D. Pilmaiquen River	y = 5.92 + 1.01 (x)	0.91	12
E. Bueno River	y = 6.90 + 0.93 (x)	0.91	26

Table 10. Linear regression of otolith length (y) on fork length (x) for rainbow trout collected in southern Chile, 1981-1984.

Sample Site	Equation	r	Observations
A. Rupanco Lake	y = 2.01 + 0.01 (x)	0.83	41
B. Rahue River	y = 1.85 + 0.01 (x)	0.86	27
C. Puyehue Lake	y = 2.59 + 0.0047 (x)	0.95	7
D. Pilmaiquen River	y = 2.19 + 0.01 (x)	0.54	10
E. Bueno River	y = 1.33 + 0.01 (x)	0.83	9

Annual length increased markedly from the second to the third year of growth, particularly for rainbow trout from Rupanco Lake, Puyehue Lake and Pilmaiquen River. These noticeable increases were not observed in fish from Rahue River and Bueno River. Fish in these study areas, reached a similar length at the end of their third year of growth (Appendices XIII and XVI). At the end of their third, fourth and fifth year of growth, rainbow trout from Puyehue Lake seemed to be larger than those from Rupanco Lake (Appendices XII and XIV).

In order to establish a growth curve for rainbow trout from each study area, back calculated mean lengths were fitted to the Ford-Walford and the Von Bertalanffy growth models.

The Von Bertalanffy growth model is based on physiological growth hypotheses and postulates that length at any time t is given by the expression:

$$L_t = L_{inf}\ (1-e^{-k(t-t_o)}) \qquad (1)$$

where parameters L_{inf}, k, and t_o were calculated using the Ford-Walford linear transformation.

For length data at intervals of equal unit time, expression (1) is transformed to:

$$L_t + T = L_{inf}\ (1-e^{-k(t+T-t_o)})$$

$$L_t + T - L_t = L_{inf} \cdot e^{-K(t-to)} \cdot (1 - e^{-kT})$$

$$L_t + T - L_t = (L_{inf} - L_t)\ (1 - e^{-kT})$$

For T = 1

$$L_t + 1 = L_{inf}\ (1-e^{-k}) + L_t \cdot e^{-k}$$

This lattest expression corresponds to the Ford-Walford transformation which can be solved linearly using regression analyses in which:

$b = e^{-k}$ (slope)

$a = L_{inf}\ (1-e^{-k})$ (intercept which equals hypothetical length at age 0

L_{inf} (asymtotic length) was obtained from the Walford plot by the projection of the axis L_{t+1} or L_t to the interception point between the regression line and the bisecting line ($L_{t+1} = L_t$).

Parameter t_o indicates the hypothetical time at which the fish would have been zero size if it had always grown according to Von Bertalanffy model. Parameter t_o was calculated following the expression given by Gulland (1971) using parameters L_{inf} and k whose values were obtained from Ford-Walford transformation. The expression is:

$$t_o = t + \frac{1}{k} L_n \frac{L_{inf}-L_t}{L_{inf}}$$

The estimated t_o was the mean of all calculated t_o for all the age groups. In order to apply this method, calculated mean lengths were used. The figures for each sample site are shown in Appendices XII, XIII, XIV, XV, and XVI.

Table 11 summarizes the linear equations obtained from the mean length regression analyses. In Fig. 16 (A-B-C-D-E), plots of length (L_t) on the length increment (L_{t+1}) are shown.

Table 11. Linear regression of mean length increment per unit time (L_t+1) on mean length (L_t) for rainbow trout in southern Chile, 1981-1984.

Sample Site	Equation	r
A. Rupanco Lake	$L_t + 1 = 13.47 + 0.87\ L_t$	0.93
B. Rahue River	$L_t + 1 = 12.62 + 0.85\ L_t$	0.99
C. Puyehue Lake	$L_t + 1 = 16.87 + 0.82\ L_t$	0.88
D. Pilmaiquen River	$L_t + 1 = 15.80 + 0.80\ L_t$	0.84
E. Bueno River	$L_t + 1 = 20.85 + 0.47\ L_t$	0.98

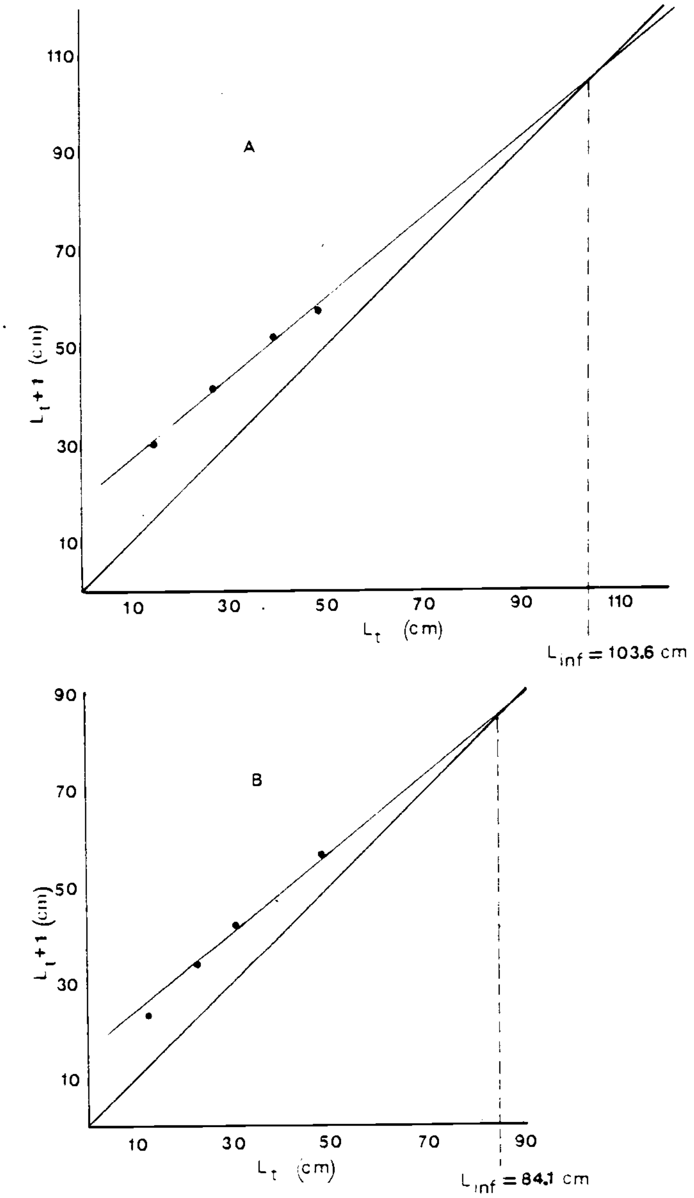

Figure 16-A,B. Ford-Walford plot for estimated lengths of rainbow trout sampled from (A) Rupanco Lake and (B) Rahue River in southern Chile, 1981-1984.

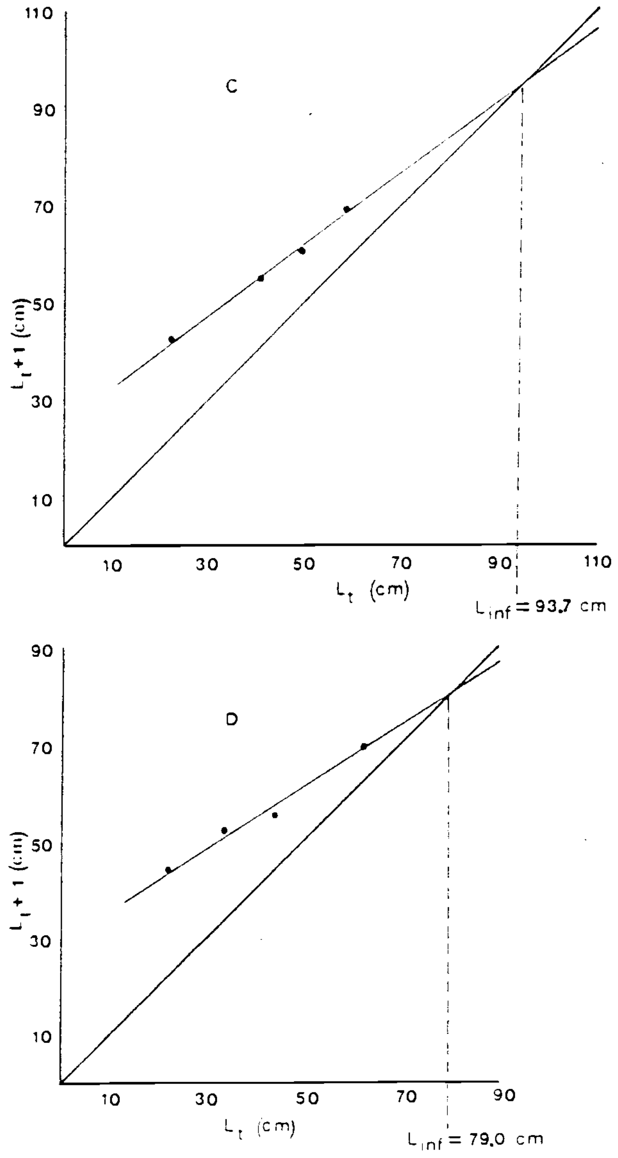

Figure 16-C,D. Ford-Walford plot for estimated lengths of rainbow trout sampled from (C) Puyehue Lake and (D) Pilmaiquen River in southern Chile, 1981-1984.

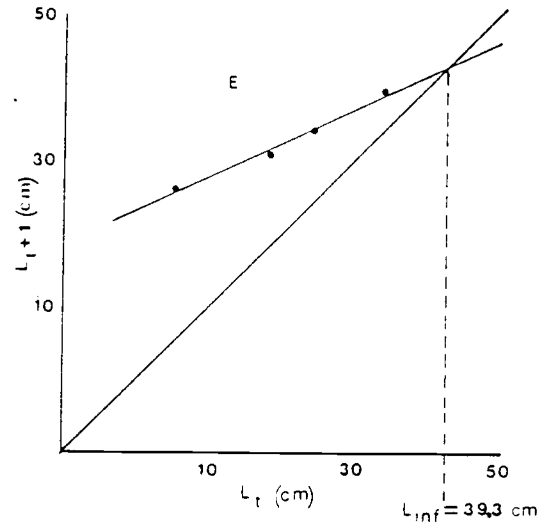

Figure 16-E. Ford-Walford plot for estimated lengths of rainbow trout sampled from (E) Bueno River in southern Chile, 1981-1984.

Table 12 summarizes parameters L_{inf}, K and t_0 calculated in order to fit data to the Von Bertalanffy model. In addition, calculated mean lengths from scale analyses and predicted lengths from growth models are also compared. In general, no great differences between these two calculated lengths were observed, so I postulate that the observational growth data from scale radius analyses appears to fit in the Von Bertalanffy growth model.

Highest L_{inf} values were obtained in rainbow trout from Rupanco Lake (103.6 cm) and Puyehue Lake (93.7 cm). Lowest L_{inf} value was found in rainbow trout from Bueno River (39.3 cm) (Table 12).

Growth curves of rainbow trout collected in each sample site, are shown in Fig. 17. Apparently fish from Rupanco Lake and Puyehue Lake had a faster growth rate than did fish from the rivers. Also, growth rates tended to decrease in older ages such as 7 and 8 years (Fig. 17).

The slowest growth rate was observed in fish collected from the Bueno River, and growth rate diminished at earlier ages such as 3 and 4 years old (Fig. 17).

Steelhead Trout Introduction In The Study Area

Since March 1982, sea-run rainbow trout have been introduced into Rupanco Lake. Shipments, totaling 600,000 eyed eggs have been received from the Alsea River Trout Hatchery (Oregon, USA). These steelhead trout have been reared at the Rupanco Lake Hatchery facilities and released into a tributary of Rupanco Lake (Huillin Creek).

The first release was made in January-April 1983. Some 100,000 smolts were released at a mean length of 18.5 cm and a mean weight of 72 g. In August 1984, steelhead trout spawners were reported to home to Huillin Creek. A sample of these fish had lengths ranging between 56 to 67 cm FL and weighed 1950 to 3700 g.

A scale of a steelhead trout which returned to Huillin Creek is shown in Fig. 18.

Table 12. Summarized data of estimated parameters and comparisons between calculated mean lengths as determined from scale analysis and predicted lengths from growth models of rainbow trout in southern Chile, 1981-1984.

Age	Calculated mean length at previous age	Standard deviation	Number fish	L_∞ K t_0	Predicted length from growth model
A	$\bar{x}$ (cm)	S	N	(cm, a^{-1}, a)	(cm)
Rupanco Lake					
1	19.9	0.4	5		19.9
2	26.2	1.9	35		30.8
3	42.6	1.7	39	103.6	40.2
4	49.2	0.4	32	0.139	48.5
5	56.1	1.2	3	-0.530	55.6
Rahue River					
1	12.3	0.8	15	84.1	12.3
2	23.1	6.8	34	0.162	23.1
3	32.3	5.1	3	0.023	32.2
Puyehue Lake					
1	14.3	0.5			14.5
2	20.6	1.3	2		28.8
3	44.0	4.7	9	93.7	40.5
4	51.3	1.8	10	0.198	50.1
5	58.9	0.7	3	0.147	57.9
Pilmaiquen River					
1	12.8	1.4	3		12.6
2	19.9	2.5	5	79.0	25.8
3	40.0	10.5	1	0.223	36.5
4	45.6		1	0.221	45.0
Bueno River					
1	11.7	1.0	10	39.3	12.2
2	26.3	0.3	11	0.755	26.5
3	33.1	3.4	2	0.510	33.3

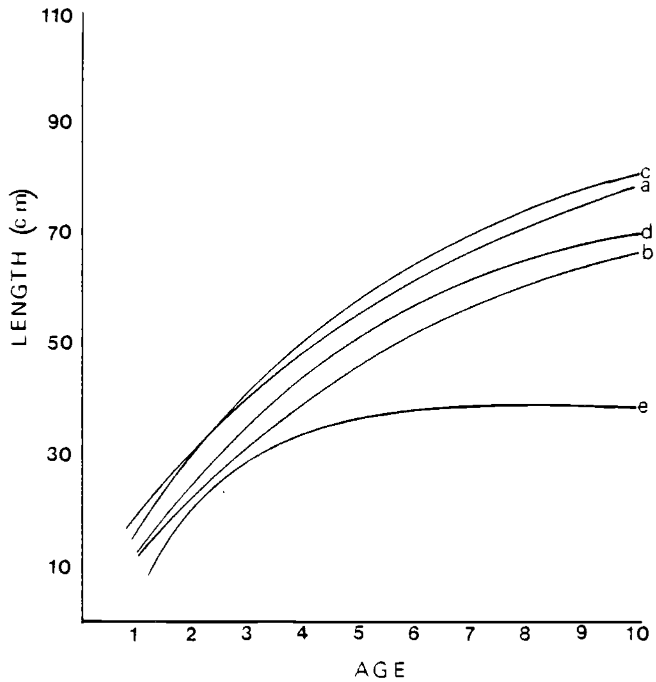

Figure 17. Growth curves for rainbow trout sampled in (a) Rupanco Lake, (b) Rahue River, (c) Puyehue Lake, (d) Pilmaiquen River, and (e) Bueno River in southern Chile, 1981-1984.

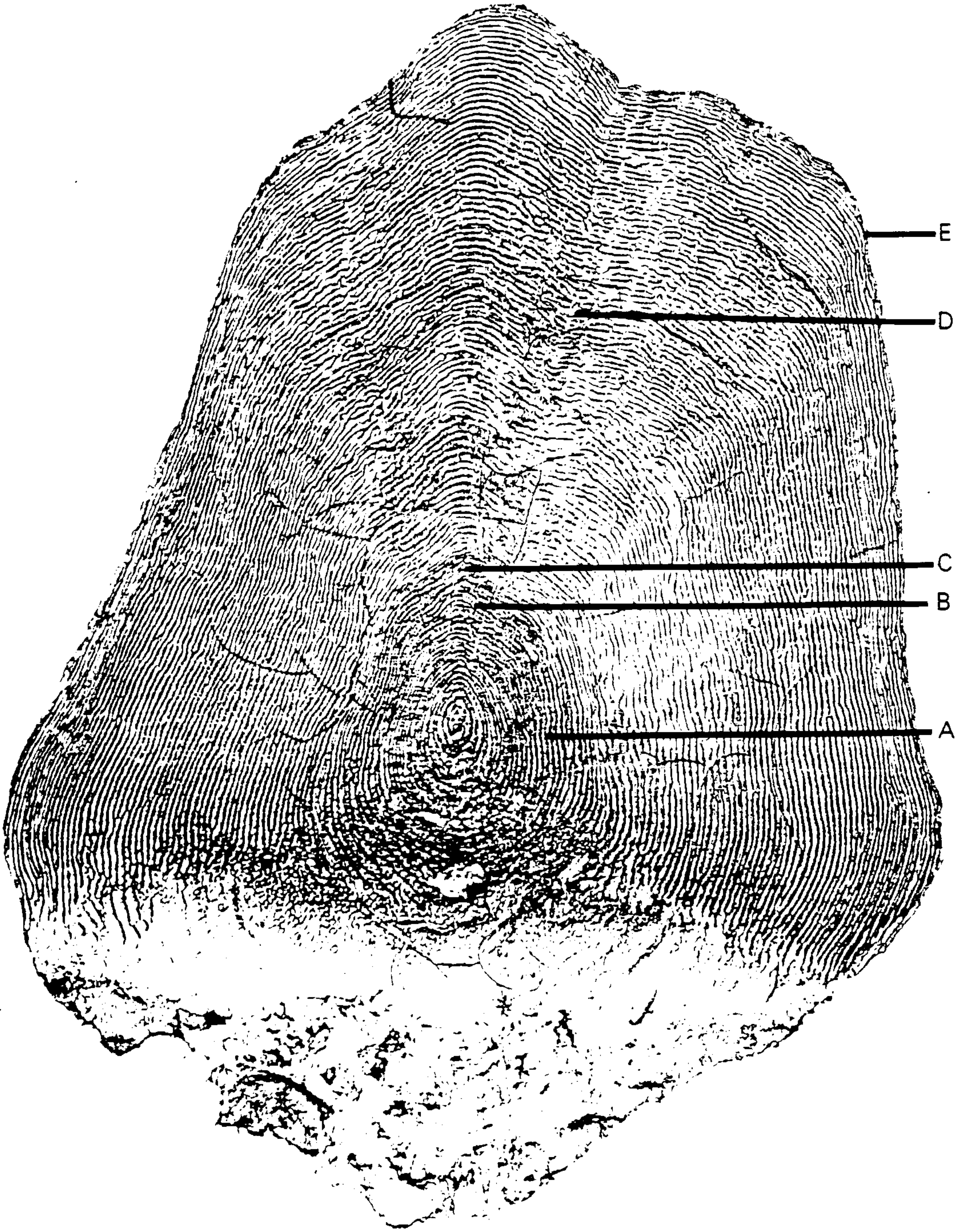

Figure 18. Scale of steelhead trout which returned to Huillin Creek in southern Chile in August, 1984, showing (A) freshwater annulus 1/ , (B) plus growth, (C) migration check, (D) ocean growth circuli and (E) ocean annulus /1 (magnification 27 diameters).

DISCUSSION

Both resident and sea-run rainbow trout can be recognized as one species, Salmo gairdneri (Behnke 1979). Despite the native range of rainbow trout being confined to Western North America, naturalized populations have been established through introductions in many countries in both hemispheres (MacCrimmon 1971).

In Chile, rainbow trout were first introduced from Germany during 1905 to 1913 and distributed in waters south of Santiago. The present naturalized range is relatively continuous between 31° S and 53° S (MacCrimmon 1971; Wetzlar 1979). Presumably, rainbow trout in Chile have developed different life history patterns than their ancestral stocks, so that the overall goal of my study was to reveal the life history characteristics of patterns in rainbow trout inhabiting the Rupanco and Puyehue Lake areas.

Sex Ratios and Maturity

Spawning of rainbow trout occurs in late winter or early spring in Western North America (Shapovalov and Taft 1954; Withler 1965; Dodge and MacCrimmon 1971), and in early winter to spring (June to December) in Chile (Wetzlar 1979). Dodge and MacCrimmon (1971) stated that upstream movement to the spawning grounds is stimulated by a temporary rise of water level or temperature. In my study, the catches of rainbow trout in Rupanco Lake were more abundant during September through December. In these months there was an increase in the temperature of the surface layers of 2 to 4° C and the isopleth of water temperatures in the surface layers fluctuated between 12° and 18° C (Donoso 1984).

Female rainbow trout were more abundant than the males in my study, particularly in Rupanco Lake and Rahue River from September through May. The sex ratio of rainbow trout (19-66 cm FL) sampled in Rupanco Lake and Rahue River was about 65% females in the catches made during September through May. Hobbs (1937) observed an excess of females over males in the spawning runs of lake-living rainbow trout in New Zealand waters. On the spawning grounds, however, it is known that sex ratios tend to be even (Shapovalov and Taft 1954; Chapman 1957; Withler 1965).

In natural steelhead runs, females predominate over males (Maher and Larkin 1954). These authors also observed that in older fish or fish which have spent extra years in salt water, females make up a greater portion of the total for each age group and the sex ratios inclusive of all age groups are about 60% females month by month. Withler (1965) postulated that the slightly greater number of females present in rainbow trout populations is due to their greater survival following first spawning and to the possibility that males deteriorate physically to a greater extent than females as spawning approaches. A higher survival of females after first spawning would explain, in part, the greater number of females captured in Rupanco Lake and Rahue River during September through May.

In Western North America, rainbow trout reach maturity in their second to fifth year, and usually in their third or fourth year. Fork length attained at maturity ranges from 47 to 88 cm and weigh ranges from 3.5 to 4.1 kg (Maher and Larkin 1954). In Rupanco Lake, rainbow trout first spawned at lengths which varied between 48.5 to 62 cm and weights which ranged from 1.3 to 2.8 kg. In addition, spawning checks were observed in fish at three, four and five years of age at capture (Table 6). In Puyehue Lake, rainbow trout first spawned at lengths of from 60.2 to 65.3 cm and weighs of from 3.1 to 3.9 kg.

It is known that fish size is an important factor in determining the age at first spawning (Shapovalov and Taft 1954). According to my results, rainbow trout from southern Chile would tend to maintain similar ages and lengths at maturity as their ancestral stocks in Western North America. In hatchery-reared rainbow trout, the fish generally reach maturity at early ages and spawn for the first time at a fork length of about 28 cm FL (Kato 1975).

Growth and Age

Relationships between fork length and body weight showed an isometric growth in fish sampled from Rupanco Lake and an allometric growth for fish from Rahue River. This particular growth difference could be explained because they are different populations and presumably their nutritional condition is different (Ricker 1975). Another explanation could be related to samples sizes. In Rahue River, the fish sampled were composed predominantly of juvenile sizes in which changes in ratios of linear measurements may be higher than those of adults which compose the majority of fish sampled from Rupanco Lake. In any case, both females and males from Rupanco Lake and Rahue River did not show significant growth differences which allowed me to treat the composite sample and to compare growth rates of body weight to total length among the study areas. Apparently, growth rate of body weight to the fork length was higher in Rupanco Lake than any other study area. Factors such as food availability, the fish sample collected in other study areas, nutritional stages, size composition and sampling dates could be affecting these observed results.

Frequency-distribution Analysis

For the population structure analysis, a first approximation was made using histogarms in which fish were divided into 1 cm intervals. In these modal groups the breakdown of the polymodal structure was difficult because the modes overlap for fish of different ages. Hence, a graphical analyses using probability paper (Harding 1949) was applied in order to estimate the age structure of the rainbow trout sampled in a clearly visible manner. This analysis was only carried out for fish sampled from Rupanco Lake and Rahue River. I did not consider the other fish collected because of the small sample sizes.

Four modal groups were determined in fish sampled from Rupanco Lake (Fig. 5, Table 4). The greatest percentage of fish was found in modal group III (50%) in which the size interval ranged between 36 to 51 cm with 41.3 cm being the modal length. Only 2.5% of the fish belonged to modal group II whose size interval fluctuated between 31 to 34 cm with 31 cm being the modal length.

In rainbow trout collected from Rahue River, three modal groups were determined (Fig. 7; Table 5). Most of fish were grouped in modal group I (64.8%) whose size interval ranged from 12 to 24 cm with 16.1

cm being the model length. The lowest percentage corresponded to modal group III (4.05%) in which the size interval fluctuated between 47 and 62 cm with 49.5 cm being the modal length.

A comparison between modal lengths for each group and mean lengths derived from scale analyses, showed that in fish sampled from Rupanco Lake both lengths tended to be similar at estimated ages I, II and III. Length differences between the two systems of analysis were observed at proposed age IV. In general, I believe that the first three ages can be verified from this comparison. In fish collected from Rahue River, verification of age could only be proposed for groups I and II because at proposed age III both length groups differed significantly. Unfortunately, not all ages could be verified using this comparison. One of the factors which might be affecting this analysis is the fact that some mean lengths at previous age determined by scale analyses showed Lee's phenomenon and its reverse. This phenomenon can occur by size selectivity mortality of fast growing or slow growing fish in a population and non-random sampling (Lee 1920).

Despite these difficulties it is important to attempt to validate all age groups because use of inaccurate ages has caused serious errors in the management and understanding of fish populations (Beamish and McFarlane 1983). According to Casselman (1983) validation of age and growth studies should become routine. This author proposes that fluorescent markers and tag-recapture data are the most useful; however, indirect tests such as fitting growth models (e.g. Von Bertalanffy) can be helpful.

In my study, I have attempted to validate lengths at ages I to V from fish of unknown ages using the Von Bertalanffy growth model. This comparison is shown in Table 12 in which both calculated mean length at previous age determined by scale analyses and predicted length from growth models tended to be relatively similar in all age groups for each study area.

Growth Curves

Growth curves were estimated from information obtained in scale analyses. By using the Walford-Ford plot and the Von Bertalanffy model, growth parameters were determined and compared among study areas.

Highest growth rates and asymptotic length values were found in rainbow trout collected from Rupanco Lake and Puyehue Lake. Substantially smaller growth rates were observed in fish from Bueno River and Pilmaiquen River.

The fastest rainbow trout growth was found in Puyehue Lake, where rainbows 2 years old were 977 g, 3-year-olds were 1,600 g, 4-year-olds were 3,060 g and 5-year-olds were 3,850 g. The second best rainbow trout growth was reached in Rupanco Lake, where rainbows 2 years old were 771 g, 3-year-olds were 1,540 g and 4-year-olds were 2,150 g.

In rivers, rainbow trout achieved the best growth in Rahue River, where 2-year-olds were 337 g and 3-year-olds were 1,406 g. The lowest growth rate was reached in Pilmaiquen River where rainbows 2 years old were 251 g and 3-year-olds were 550 g.

According to these results, rainbow trout grow better in lakes than rivers. These fish growth differences among my study areas probably occurred because each body of water has different secondary production (potential food for fishes) and physical habitat. In fact, lakes in general have higher secondary production than rivers and physical habitat is relatively more stable (Wetzel 1975).

In Puyehue Lake and Rupanco Lake, rainbow trout reached the fastest growth presumably due to the availability of freshwater crabs (Aegla) and fishes such as Galaxia maculatus and the presence of a more suitable physical habitat. Burns (1972) observed that growth rates of Chilean rainbow trout from waters containing Aegla were rapid, suggesting that the abundant crab populations probably contribute to the large size attained by rainbow trout. In addition, Arenas (1978) stated that Galaxias maculatus, which is an important food item for rainbows, behave differently in lakes than in rivers in that they form large schools which concentrate in littoral and sublittoral zones for a long time. Hence, these schools are more available to rainbow trout in lakes than in rivers. In rivers, G. maculatus tend to form schools which move constantly and are composed of a limited number of individuals.

Scale Features and Life History Patterns

Scales of rainbow trout showed two growth circuli patterns. Although no reference is available regarding the annual formation of circuli on rainbow trout scales from Chile, the number of circuli is useful as an index for age determination (Clutter and Witesel 1956). Rainbow trout in my study had about 10 and 20 circuli in the first and second year of growth, respectively, before migration. A similar circuli number was determined for the first year's growth in fish which migrated in their third year.

No great differences were found in the number of circuli on scales during the first two or three years of growth in fish samples collected in each of my study areas. It seems that rainbow trout form 12 to 16 circuli on their scales during one year in freshwater life even though the range and mode of circulus number may vary within populations. Mosher (1969) described that in the freshwater zone of steelhead scales, 30 or more circuli may be completed. Approximately the same number of circuli were counted on rainbow trout scales before migration in their second year of growth. In scales from fishes which migrated in their third year of growth, about 50 circuli were completed before migration.

It is important to point out the increase in the number of circuli in the third and fourth year of growth which occurred in second year and third year migrants, respectively. Afterward, the number of circuli diminished with age.

Two types of migrants were recognized: rainbow trout which migrated in their second year of growth (second year migrant) and in their third year of growth (third year migrant). Estimated lengths for second and third year migrants are variable among each study area. Longest length for a second year migrant was found in Puyehue Lake (39 cm) and shortest length occurred in Pilmaiquen River (27 cm). For third year migrants, longest length was observed in Rahue River (61 cm) and shortest length occurred in Rupanco Lake (52 cm). Second year migrants were predominant in all fish sampled and third year migrants were only found in rainbow trout collected from Rupanco Lake and Rahue River.

In terms of migration patterns, circuli growth was not as uniform as that found on scales showing typical sea growth as found on steelhead trout scales. According to my observations made from scales, I believe that rainbow trout in my study areas migrate only within freshwater and they do not go to the ocean. Hence, our naturalized rainbow trout must be recognized as resident populations particularly in lakes. Eventually, rainbow trout from rivers may migrate to estuarine areas. Rainbow trout from Pilmaiquen and Puyehue River do not have any chance to migrate to the estuary because of the dam facilities. I would assume that these river fish tend to migrate into Puyehue Lake and the lake fish would migrate into streams. In rainbow trout from Rupanco Lake, migration patterns could occur from the 57 tributaries which surround the lake (Donoso 1984). These streams would offer a suitable habitat for spawning grounds and smolt growth before migration to the lake. After migration, rainbow trout would grow rapidly in the lakes where food availability is greater than in tributaries.

In North America, rainbow trout migratory patterns within freshwater have been studied in the Great Lakes by Biette et al. (1981). These authors determined that rainbow trout entering into the Great Lakes tributaries, comprised a discrete stock because of the great variability in timing of spawning migrations and life history patterns shown by the fish in each tributary. If I apply this concept to the rainbow trout populations in Rupanco Lake, I would say that the great variety of age types and life history patterns exhibited by the fish I collected would be because these rainbows came from discrete stocks which "home" to the tributaries surrounding Rupanco Lake. Hence, future studies of rainbow trout populations from Rupanco Lake and Puyehue Lake would need to examine the life history patterns available in each tributary in order to determine if these fish constitute discrete stocks. If this hypothesis was accepted, current fishery regulations which cover wide geographical areas would need to be modified in order to manage these fish as discrete stocks confined to small geographical zones.

On the other hand, my study of life history patterns was conducted from scale analyses and only a comparison between scale and otolith gross features was attempted. I would suggest that in future rainbow trout population studies, the use of otoliths might be intensified because they offer some advantages over scales. These advantages are: (1) they do not show false annuli, (2) they are protected from damage, (3) they do not show reabsorption in spawning periods and (4) they do not have regenerated nuclei (Kim and Koo 1963; McKern and Horton 1974).

Steelhead Introduction In The Study Area

In Chile, ten salmonid species have been introduced in which rainbow trout and brown trout have established naturalized populations (Wetzlar 1979). Lately, the introduction of Pacific salmon for experimental and commercial purposes has been carried out by private companies and federal agencies. Results of these introductions are still in evaluation (Brown 1983).

Since March 1982, attempts to introduce sea-run rainbow trout on my study area have been made by a cooperative research between the Department of Fisheries and Wildlife at Oregon State University and the Department of Aquaculture and Food at the Professional Institute of Osorno. So far, 600,000 eyed eggs of winter steelhead spawners have been received from the Alsea River Trout Hatchery and they have been reared at The Rupanco Lake hatchery facilities.

From scale analyses of returning spawners, ocean growth was observed so that these fish seem to maintain the characteristic anadromy pattern in southern Chilean waters. It is not possible to evaluate the success of the steelhead introduction because complete data are not available even though some of the returning spawners tend to reach large size (67 cm FL -- weight 3,700 g). These first returning spawners came from the eyed eggs of winter steelhead spawners from the Alsea River stock (Oregon, USA). These eggs were shipped to Chile by air and they were incubated in March 1982 (late summer) in the Rupanco Lake hatchery facilities. Smolts at 18.5 cm FL and 72 g mean weight were released into Huillin Creek (Rupanco Lake tributary) from January until April 1983 (middle summer-early fall). In August 1984 (spring), returning spawners were reported "homing" to their natal stream.

Scale features showed freshwater circuli patterns in which one freshwater annulus was formed in June-July 1983 (winter). After that, plus growth before migration was observed. The ocean entrance point was determined on the scale as a migration check and I would assume that "Chilean" steelhead trout migrated to the ocean in August-September 1983 (spring). Then, it spent one summer (December through February 1984) and one winter (May through July 1984) in the southern Pacific Ocean. Ocean growth circuli patterns were observed and a first ocean annulus formed in winter 1984. After ocean residence, the steelhead migrated upstream and returned for spawning in August 1984 (spring). Returning spawners were captured in a trap which was set in Huillin Creek where the smolts were released.

According to these preliminary scale analyses, introduced steelhead would reach maturity at age II^+ after remaining approximately one year in freshwater (stream or lake) and migrating to the ocean in the spring.

A similar life history pattern has been observed in 1-salt winter steelhead from the Alsea River stock. In fact, eyed eggs shipped to Chile corresponded to winter steelhead spawners. According to K. Kenaston (Oregon Department of Fish and Wildlife, Corvallis, pers. comm. 1984) the return cohort age of winter steelhead trout from the Alsea River is formed approximately by 1-salt (2%), 2-salt (80%), and 3-salt (18%) fish. Hence, I would assume that the first steelhead group released in Chile behaved as winter steelhead of 1-salt return age.

In terms of migration patterns, "Chilean" steelhead in the southern hemisphere would migrate in the spring (September through December) into the ocean after one year of freshwater residence. In the Alsea River (U.S.A., north hemisphere), seaward migration also occurs in the spring (mid-April to mid-May) even although fish migrate seaward after two or more years of stream residence (Wagner et al. 1963). Therefore, if I compare the migratory pattern between the "Chilean" steelhead stock in the south hemisphere and their ancestral stock from the Alsea River in the north hemisphere, I would say that they have the same smolt migration and seaward timing (spring), but in reverse months, and they display a difference in time of freshwater residence. This latest difference could be explained because of the reversal of factors such as photoperiod and temperature produced by the change of hemisphere. These parameters which influence the smoltification processes are reversed and could affect age, size and freshwater residence of the steelhead smolts from the Alsea River in their life history behavior in Southern Chile.

According to my results with naturalized rainbow trout, these fish would constitute resident populations with migratory patterns from stream to lakes or rivers to estuaries. The introduction of anadromous rainbow trout should be beneficial for resident rainbow trout populations because crossbreeding of closely related stocks often results in "hybrid vigor". Interracial crosses between steelhead and non-migratory rainbow trout developed at the University of Washington resulted in hybrids that grew faster than steelhead. In addition, hybrids seem to retain the steelhead characteristics of migrating to the sea, where they grow rapidly (Donaldson and Joyner 1983). Also, Reisenbichler and McIntyre (1977) have demonstrated that steelhead trout matings derived from hatchery fish and wild fish showed the fastest growth rate.

In my study area, there has been a general decline of naturalized rainbow trout populations over the last years probably due to overfishing, limited effectiveness of fishery regulations, and degradation of spawning and rearing grounds in streams by improper logging activities, road construction, and pollution. Therefore, introduction of steelhead would seem advisable in order to supplement naturalized rainbow trout stocks and improve fishing. Since the steelhead is such an important sport fish, possessing a great angling history, its introduction in my study area would attract more recreational fishermen. This situation would have beneficial effects in the economical and social development of this Chilean region.

However, it is known that the introduction of artificially propagated salmonids into natural stream or lake systems may affect naturalized salmonid stocks or other native fishes through competition for food and space resources. Genetic structure of wild population may be altered by interbreeding of introduced fish and wild fish in natural spawning grounds, and introduced fish may transmit and disseminate infectious and contagious diseases on naturalized salmonid populations and native fishes (Laurent 1972; Reisenbichler and McIntyre 1977; Conroy 1981). Some possible undesirable results of mixing naturalized rainbow trout with steelhead could be the reduction in average size of returning adults, changes in behavior such as a loss of wildness or aggressiveness, changes in timing of upstream migrations, and reduction in the number of smolts produced (Barnhart, 1977, Reisenbichler and McIntyre 1977). In addition, introduction of exotic fishes can cause changes in natural communities through increases in competitive interactions which can affect abundance and survival of native fishes (Laurent 1972; Li and Moyle 1981). These latest authors stated that the introduction of new species into aquatic communities to increase fish production is a management technique that often has created problems due to the inability to correctly predict impacts in the natural community. Considering a program developed by entomologist specializing in the study of biological control systems, Li and Moyle (1981) have proposed a modification of that program for use in fisheries management. This modified program suggests "rules" and criteria which might be considered for introducing exotic fishes in the aquatic system.

Finally, it should be clear from the foregoing discussion that the steelhead trout introduction in my study area could cause beneficial or deleterious effects on the naturalized rainbow populations and native fishes. Therefore, I would recommend anadromous rainbow introduction come under careful evaluation in order to avoid undesired changes in the natural community.

SUMMARY AND CONCLUSIONS

1. Female rainbow trout collected in my study were more abundant than males particularly in Rupanco Lake and Rahue River from September through May. Higher survival of females after first spawning would explain the greater number of females captured in these study areas.
2. From spawning check analyses, it is assumed that rainbow trout from my study area tend to maintain similar ages and lengths at maturity as their ancestral stocks in Western North America.
3. Growth of body weight and fork length differed among the fish sampled. Factors such as food availability, fish sample size, different populations, nutritional stages, size composition or sampling dates could have affected these growth differences.
4. A comparison between modal length for each modal group obtained from graphical analyses and mean lengths determined from scales, showed that both lengths tended to be similar at earlier proposed ages.
5. Observational growth data seems to fit the Von Bertalanffy growth model and validation of lengths at ages I to V showed that calculated mean length at previous age from scales analyses were similar to the predicted length from growth models.
6. Highest growth rates and asymtotic length values were found in rainbow trout collected from Rupanco Lake and Puyehue Lake. Lowest growth rates were determined in rainbows from Bueno River and Pilmaiquen River.
7. Scales of rainbow trout showed two circuli patterns in which spaces between circuli were different.
8. Rainbow trout scales presently studied had about 15 and 20 circuli in the first and second year, respectively, of growth before migration. A similar circuli number was observed for the first three year's growth in fish which migrate in their third year of life.
9. No great differences were found in the number of circuli during the first two or three years growth in fish collected in each

study area. In addition, there is a noticeable increment in circuli number from the third year and fourth year of growth which occurred in second and third year migrants, respectively. Afterward, the number of circuli diminished with age.

10. Two types of migrants were recognized, the second year migrant and third year migrant. Estimated lengths in these migrants was variable among each study area. Second year migrants were predominant in all fish sampled and third year migrants were found only in Rupanco Lake and Rahue River.
11. According to my observations of circuli growth patterns, I believe that naturalized rainbow trout in my study areas constitute a resident populations particularly in the lakes.
12. Highest variability in life history patterns and age types were found in rainbow trout from Rupanco Lake.
13. Preliminary scale analyses of introduced steelhead in my study area, showed that they may reach maturity at age II^+, and after remaining one year in freshwater, they migrate to the ocean as smolts. This first group of introduced steelhead in southern Chile, behaved as winter steelhead and returned at 1-salt age.
14. It appears advisable to introduce anadromous rainbow in my study area in order to increase rainbow trout stocks. However, a careful evaluation of this introduction must be made in order to avoid undesirable results which can affect native fishes and naturalized wild rainbow trout populations.

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APPENDICES

APPENDIX I

Number, fork length, body weight and sex of rainbow trout collected in Rupanco Lake, Chile.

Date	Sex	Number	Fork length (cm)	Body weight (g)
December 1981	Male	5	44-53	1000-1250
	Female	10	52-67	1650-2600
February 1982	Male	1	44	800
	Female	1	55	1975
April 1982	Male			
	Female	1	44	1200
May 1982	Male			
	Female	1	70	4020
September 1982	Male	8	42-52	830-1750
	Female	10	49-58	1450-2650
October 1982	Male	3	21-62	290-1980
	Female	7	46-48	1150-1625
December 1982	Male	8	17-54	50-1940
	Female	13	19-62	70-2200
April 1983	Male	3	39-57	950-3125
	Female	4	36-60	800-3000
May 1983	Male	13	35-59	850-3275
	Female	17	32-66	600-3700
December 1983	Male			
	Female	1	67	3500
January 1984	Male			
	Female	1	55	1820
March 1984	Male	6	15-39	47-825
	Female	7	16-47	46-875
TOTAL AND RANGE		120	15-70	50-4020

APPENDIX II

Number, fork length, body weight and sex of rainbow trout collected in Rahue River, Chile.

Date	Sex	Number	Fork length (cm)	Body weight (g)
February 1982	Male	12	13-34	26-420
	Female	8	12-27	21-230
April 1982	Male	5	17-29	70-310
	Female	1	17	80
May 1982	Male	6	16-29	42-272
	Female	3	18-19	65-66
June 1982	Male	2	21-33	90-415
	Female	7	19-32	70-363
August 1982	Male	1	62	1850
	Female	3	26-61	170-1270
October 1982	Male			
	Female	8	17-35	50-470
November 1982	Male	1	35	470
	Female			
May 1983	Male	1	20	90
	Female	1	27	270
November 1983	Male	7	20-24	85-136
	Female	8	19-27	74-201
TOTAL AND RANGE		74	12-62	21-1850

APPENDIX III

Number, fork length, body weight and sex of rainbow trout collected in Puyehue Lake, Chile.

Date	Sex	Number	Fork length (cm)	Body weight (g)
March 1982	Male	1	41	1080
	Female			
May 1982	Male			
	Female	1	80	7500
June 1983	Male	2	35-64	800-4250
	Female	2	40-69	900-5000
March 1983	Male	1	56	2400
	Female	20	26-69	800-3800
TOTAL AND RANGE		27	26-80	800-7500

APPENDIX IV

Number, fork length, body weight and sex of rainbow trout collected in Pilmaiquen River, Chile.

Date	Sex	Number	Fork length (cm)	Body weight (g)
February 1982	Male	1	21	109
	Female			
May 1982	Male	1	25	230
	Female	3	19-36	65-550
September 1982	Male	3	20-42	80-980
	Female	3	28-29	260-270
December 1982	Male			
	Female	1	76	3200
TOTAL AND RANGE		12	19-76	65-3200

APPENDIX V

Number, fork length, body weight and sex of rainbow trout collected in Bueno River, Chile.

Date	Sex	Number	Fork length (cm)	Body weight (g)
February 1982	Male	1	14	36
	Female			
May 1982	Male	8	17-35	90-600
	Female			
August 1982	Male			
	Female	1	28	270
October 1982	Male	3	24-28	160-250
	Female	1	47	860
November 1982	Male	1	27	195
	Female			
December 1982	Male			
	Female	1	33	330
June 1984	Male	6	16-36	50-475
	Female	4	19-39	70-675
TOTAL AND RANGE		26	14-47	36-860

APPENDIX VI

Weight-length relationship and isometry testing for females from Rupanco Lake, Chile.

a) model: $W_i = a\ L_i^{\ b}$

where: a = coefficient of proportion

b = regression coefficient

b) linearization

$$Ln(W) = ln(a) + b\ ln(L)$$

c) sums squares

sum (x)	= 230.20	sum (y^2)	= 420.36
sum (y)	= 420.36	mean dependent	= 6.78
sum (xy)	= 1,584.20	mean independent	= 3.71
sum (x^2)	= 861.54	sample size	= 62

d) parameters of weight-length relationships:

a = 0.0116785

b = 3.03

r = 0.979

$s^2 y/x$ = 0.04686 (estimator of variance for regression model)

$s^2 b_1$ = 0.005738 (estimator of variance for the slope)

e) Hypothesis testing for isometry ($b^1 = 3$)

--hypothesis

Ho: $b_i = 3$

Ha: $b_i \neq 3$

--test statistic (two side)

$t = b' - b_1/sb_1$

--reject Ho if t > 1.671 for 0.1% level of significant and 60 d.f.

--computations

$t = 0.03/0.075733 = 0.3960$

--decision

Ho cannot be rejected at 0.1%

--conclusion: slope is not significantly different from 3 at 0.1% level of significance so that Ho is accepted.

APPENDIX VII

Weight-length relationship and isometry testing for males from Rupanco Lake.

a) model: $W_i = a\ L_i^{\ b}$

where: a = coefficient of proportion

b = regression coefficient

b) linearization

$Ln(W) = ln(a) + b\ ln(L)$

c) sums squares

sum (x)	= 152.291	sum (y^2)	= 1,974.51
sum (y)	= 281.06	mean dependent	= 6.86
sum (xy)	= 1,063.28	mean indpendent	= 3.73
sum (x^2)	= 575.22	sample size	= 41

d) parameters of weight-length relationships:

a = 0.011220644

b = 3.04

r = 0.979

s^2y/x = 0.372102564 (estimator of variance for regression model)

s^2b_1 = 0.075319 (estimator of variance for the slope)

e) Hypothesis testing for isometry ($b^1 = 3$)

--hypothesis

Ho: $b_i = 3$

Ha: $b_i \neq 3$

--test statistic (two side)

$t = b' - b_1/sb_1$

--reject Ho if t > 1.683 for 0.1% level of significant and 39 d.f.

--computations

$t = 0.04/0.2744439 = 0.145749$

--Decision

Ho cannot be rejected at 0.1%

--conclusion: slope is not significantly different from 3 at 0.1% level of significance so that Ho is accepted.

APPENDIX VIII

Comparison of b-values (slopes) between females and males from Rupanco Lake.

a) Full model (two separates slopes, two separate intercepts)

for females $y = -4.50 + 3.03 (x)$

for males $y = -4.50 + 3.04 (x)$

From ANOVA:

SSE = 4.70360 (error sum of squares)

D.F. = 99 (degree of freedom)

R^2 = 0.9624 (coefficient of determination)

b) Reduced model (two separates slopes, two separate intercepts)

for females $y = -4.47 + 3.03374 (x)$

for males $y = -4.46 + 3.03374 (x)$

From ANOVA:

SSE = 4.70481 (error sum of squares)

D.F. = 100 (degree of freedom)

R^2 = 0.9624 (coefficient of determination)

c) General linear hypothesis test

--hypothesis:

Ho : slopes are same (or reduced model is just as good as full model

Ha : slopes are not same (or reduced model is not as good as full model

--test statsitic

$F = SSE_R - SSE_F \div DF_R - DF_F / SSE_F \div DF_F$

reject Ho if F > 3.89334 (0.95; 1,99)

--computation

$F = 4.70481 - 4.70360 \div 1/4.70360 \div 99$

--decision

Ho cannot be rejected

--conclusion: F - ratio for testing equality of slopes is F = 0.00254 with corresponding P-value of 0.8736 so that slopes are the same

APPENDIX IX

Weight-length relationship and isometry testing for females from Rahue River.

a) model: $W_i = a\ L_i^{\ b}$

where: a = coefficient of proportion

b = regression coefficient

b) linearization

$Ln(W) = ln(a) + b\ ln(L)$

c) sums squares

sum (x) =	123.15	sum (y^2) =	989.86
sum (y) =	193.25	mean dependent =	4.96
sum (xy) =	621.75	mean indpendent =	3.16
sum (x^2) =	393.08	sample size =	39

d) parameters of weight-length relationships:

a = 0.024972

b = 2.74

r = 0.989

$s^2 y/x$ = 0.019665675 (estimator of variance for regression model)

$s^2 b_i$ = 0.0046709682 (estimator of variance for the slope)

e) Hypothesis testing for isometry ($b^i = 3$)

--hypothesis

Ho: $b_i = 3$

Ha: $b_i \neq 3$

--test statistic (two side)

$t = b' - b_1/sb_1$

--reject Ho if t > 1.688 for 0.1% level of significant and 37 d.f.

--computations

$t = 0.26/0.06834448 = 3.8$

--Decision

Ho can be rejected at 0.1%

--conclusion: slope is significantly different from 3 at 0.1% level of significance so that H_1 is accepted.

APPENDIX X

Weight-length relationship and isometry testing for males from Rahue River.

a) model: $W_i = a\ L_i^{\ b}$

where: a = coefficient of proportion

b = regression coefficient

b) linearization

$Ln(W) = ln(a) + b\ ln(L)$

c) sums squares

sum (x)	=	106.25	sum (y^2)	=	794.08
sum (y)	=	163.18	mean dependent	=	4.66
sum (xy)	=	506.72	mean indpendent	=	3.04
sum (x^2)	=	326.55	sample size	=	35

d) parameters of weight-length relationships:

a = 0.0019254

b = 3.84

r = 0.984

s^2y/x = 0.033720 (estimator of variance for regression model)

s^2b_i = 0.00842129 (estimator of variance for the slope)

e) Hypothesis testing for isometry ($b^i = 3$)

--hypothesis

Ho: $b_i = 3$

Ha: $b_i \neq 3$

--test statistic (two side)

$t = b' - b_1/sb_1$

--reject Ho if $t > 1.693$ for 0.1% level of significant and 33 d.f.

--computations

$t = 0.16/0.091768 = 1.74$

--decision

Ho can be rejected at 0.1%

--conclusion: slope is significantly different from 3 at 0.1%

level of significance so that H_1 is accepted.

APPENDIX XI

Comparison of b-values (slopes) between females and males from Rahue River.

a) Full model (two separates slopes, two separate intercepts)

for females $y = -3.693584 + 2.739019\ (x)$

for males $y = -3.945416 + 2.835481\ (x)$

From ANOVA:

SSE = 1.84365 (error sum of squares)

D.F. = 70.0 (degree of freedom)

R^2 = 0.9726 (coefficient of determination)

b) Reduced model (two separates slopes, two separate intercepts)

for females $y = -3.842068 + 2.78604\ (x)$

for males $y = -3.795332 + 2.78604\ (x)$

From ANOVA:

SSE = 1.86274 (error sum of squares)

D.F. = 71 (degree of freedom)

R^2 = 0.9723 (coefficient of determination)

c) General linear hypothesis test

--hypothesis:

Ho : slopes are same (or reduced model is just as good as full model

Ha : slopes are not same (or reduced model is not as good as full model

--test statistic

$F = SSE_R - SSE_F \div DF_R - DF_F/SSE_F \div DF_F$

reject Ho if F > 4.014 (0.95; 1,71)

--computation

$F = 1.86274 - 1.84365 \div 1/1.84365/70 = 0.7246$

--decision

Ho cannot be rejected

--Conclusion: F - ratio for testing equality of slopes is F = 0.00254 with corresponding P-value of 0.8736 so that slopes are the same

APPENDIX XII

Back calculated mean length of rainbow trout sampled from Rupanco Lake in southern Chile, 1981-1984.

Estimated age at capture	Calculated length at previous age					Fish number
	1	2	3	4	5	
I	19.3					5
II	20.4	28.9				35
III	20.0	25.7	44.4			39
IV	19.7	24.9	41.1	48.9		32
V	19.9	25.1	42.2	49.5	56.1	3
$\bar{x}$	19.9	26.2	42.6	49.2	56.1	
s	0.40	1.9	1.7	0.4	1.2	

APPENDIX XIII

Back calculated mean length of rainbow trout sampled from Rahue River in southern Chile, 1981-1984.

Estimated age at capture	Calculated length at previous age			Fish number
	1	2	3	
I	13.2			15
II	11.9	27.9		34
III	11.8	18.3	32.3	3
$\bar{x}$	12.3	23.1	32.3	
s	0.78	6.8	5.1	

APPENDIX XIV

Back calculated mean length of rainbow trout sampled from Puyehue Lake in southern Chile, 1981-1984.

Estimated age at capture	Calculated length at previous age					Fish number
	1	2	3	4	5	
I						
II	14.0	20.5				3
III	14.1	19.6	45.9			9
IV	15.1	22.5	47.4	52.5		10
V	14.1	19.8	38.6	50.0	58.9	3
$\overline{x}$	14.3	20.6	44.0	51.3	58.9	
s	0.52	1.32	4.7	1.76	0.7	

APPENDIX XV

Back calculated mean length of rainbow trout sampled from Pilmaiquen River in southern Chile, 1981-1984.

Estimated age at capture	Calculated length at previous age				Fish number
	1	2	3	4	
I	14.9				3
II	12.3	21.6			5
III	11.7	21.0	47.3		1
IV	12.3	170	32.5	45.6	1
$\overline{x}$	12.8	19.9	40.0	45.6	
s	1.4	2.5	10.5		

APPENDIX XVI

Back calculated mean length of rainbow trout sampled from Bueno River in southern Chile, 1981-1984.

Estimated age at capture	Calculated length at previous age			Fish number
	1	2	3	
I	12.7			10
II	11.8	26.5		11
III	10.6	26.0	33.1	2
$\bar{x}$	11.7	26.3	33.1	
s	1.03	0.35	3.4	