The technique which we have adopted for measuring bubble chamber film has sufficient accuracy. Its speed is more than an order of magnitude greater than the conventional methods of cloud chamber data analysis, but we are still far short of being able to analyze all of the interesting physics which exist in the bubble chamber film. We are currently working on the development of a type of mechanical flying spot scanner which promises to provide considerably higher speed.

*Length Measurement of Migrating Salmon by Paired Underwater Cameras**†

WILLIAM FRANCIS THOMPSON
and
DAN WILEY CLANCY,
Fisheries Research Institute,
University of Washington,
Seattle, Wash.

ABSTRACT: *To provide accurate information for the management of commercial salmon fisheries, certain basic data on the habits and numbers of the fish must be obtained. Because of the large numbers of fish involved, visual methods of counting are not of sufficient accuracy. Cameras mounted on towers had inherent problems. This paper discusses use of an underwater camera system to produce stereo pairs of photographs to obtain data.*

THE purpose of management of the red salmon fisheries in Bristol Bay, is to allow a sufficient number of fish to escape the fishery, to spawn and to maintain the catch at its highest possible permanent level. To determine what this number should be, there is but one available method, the use of historical records. To be usable, these must be accurate statistics of the year-by-year runs and their escapements, with sufficient biological data to interpret the record thus obtained. The equipment described in this paper is designed to provide such data.

These red salmon are anadromous, feeding in the open sea, breeding far up the river systems of our Pacific Coast, laying their eggs in the gravel of lake shores, or in the bed of streams from which the emerging young can reach lakes in which to feed and grow for a period before going to sea. The adults return when four to six years old, to spawn once and die.

If the returning adults were all of the same age, it would be easy to compare the number of spawners of the parent generation with the new generation which returns and contributes to catch and escapement in a later year. For these fish return to their own streams, in fact to the particular gravels in which they were born. But to secure these basic statistics has been a difficult task, in the multitude of streams, for the five species of salmon. And to make the task far more difficult, the returning generation comes back in successive installments, over three years of overlapping generations. The different species move together, and the sexes differ in size and appearance. Counts of migrants must be supplemented by biological sampling to determine species, age and sex.

Counts of fish taken are secured from records of the commercial catch. There is no major difficulty in so doing.

Counts of the remainder of each run—the

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† This paper is contribution 54, College of Fisheries, Univ. of Washington.

FIG. 1. Underwater photograph of male red salmon on their spawning migration up the Wood River, Alaska.

escapement—must be secured in the river, or later after the fish have distributed themselves over the wide-spread spawning grounds of rivers, creeks and lake shore. Until accurate figures of this escapement are secured to add to the figures of the catch, and thus arrive at the total run, and until these are divided according to species and according to the year of birth, there can be no real study made of the relation of the number of spawners and the later returns—the basic problem of fish management.

Counts of the escapement were formerly made either by the building of weirs in the rivers, or by later surveys of the spawning grounds by foot or by air. The weirs interfered with the normal passage of fish and frequently were not fish-tight, or were not used properly. The spawning ground surveys have been shown to include only a fraction, sometimes less than 10 per cent, of the fish known to enter a system. Such methods are inaccurate and very expensive, necessitating crews working for months in the remote interior lakes.

New methods, first used by the Fisheries Research Institute in 1951, are now being used in the Wood River, Nushagak Bay, Alaska. Red salmon pass up the rivers along each bank, in a band usually 25 or 30 feet wide at most, at about the six to eight foot depth contour, when the stream is deep enough. Since all the fish entering a river system must pass through an entrance the width of that stream, it is thus a logical step to count the fish there, where they can all be seen as they pass, and where they can be sampled for biological data in proportion to their numbers. This has been done in those streams on which the Fisheries Research Institute has been working, under contract to either the salmon packing industry or to the government. Figure 2. (Gilbert, John MSS, 1955: Mathisen, Ole MSS, 1957.)

To do the necessary counting, towers made from metal scaffolding are erected on both sides of the stream, some 30 feet in height, overlooking the salmon as they pass over contrasting backgrounds laid on the bed of the stream. Since their numbers are so great, (some nine million having been recorded within three weeks in one river system) and since they pass day and night, the numbers are at times beyond the ability of an observer to tally visually by ordinary methods. It has thus been necessary to develop some automatic method of recording their numbers. To do this cameras are used on top of the towers, a picture being taken at time intervals by electronic flash. The count of fish on the film, multiplied by a pre-determined factor, gives the total number of fish passing. The factor is determined by continuous visual counting over certain periods, for comparison with the counts on the photographs taken over the same periods. The fish are thus not interfered with in any way, or delayed. The electronic flash does not disturb their passage. In fact, during the important parts of the runs, the fish are oblivious to all around them.

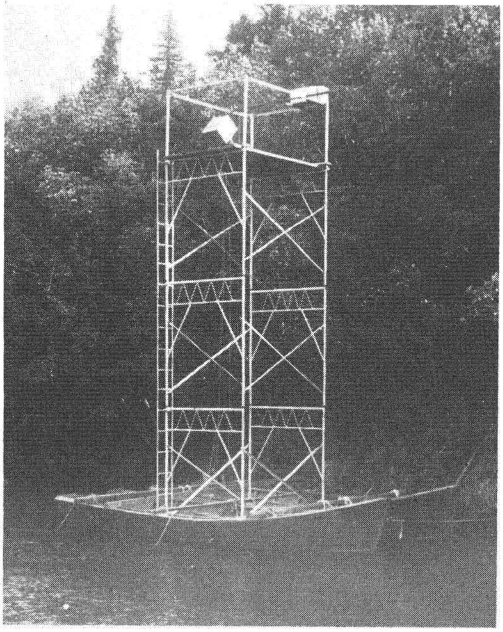


FIG. 2. Fish counting towers in the Wood River.

But as has been said, the catch and the escapement are not all of the same species or age, but may be of several species which may each have originated in not less than three spawning years. So it is necessary to examine the passing migrants by some system of sampling. The age is related to the size, so that once the size frequency of the red salmon is known, the distribution of numbers among the age groups can be determined with a minimum of work and difficulty. The distribution of age according to size is ascertained in the commercial catch, and this can then be applied to the size sampling of the escapement, since both come from the same run, selection by the nets being solely for size, not age.

To determine the size frequencies, underwater cameras are used, and these not only yield the needed biological data but may possibly be adaptable to supplant counts from the towers. They avoid the somewhat disturbing effect of the surface water ripples, of the rain and the wind. They can give the length of the passing fish by the use of paired cameras, by triangulation.

The photographs are made by electronic flash, and give the sharp definition needed for triangulation. Figure 1. There is a great deal of ambient light during the daytime and the flash light is diffused by suspended particles. So the photographs are somewhat lacking in contrast; this must then be built up by the use of proper films, lights, exposures, and if needed, in printing. The detail is, in the end, excellent. In addition to length, it is possible to distinguish the species, morphological characters such as size of scales or body depth, the greater length of snout which identifies the male, and scars, gill net marks, etc.

To determine length by triangulation, simultaneous pictures are taken by a pair of cameras mounted in underwater boxes on the ends of a stout, aluminum beam, the base for triangulation. Figure 3.

In use, the equipment is lowered over the side of a boat so that the pointer arm, shown in Figure 3, projects into the column of passing fish so that the photographs are then taken from the depth at which the fish are passing. Bridles from the end of the pointer arm and the upstream end of the base beam are attached to an anchor upstream at such distance as allows the equipment to be shifted toward and away from the fish, as appears best. The boat is anchored separately, to allow for its free movement. A generator in the boat or ashore provides current for operation of the cameras and for the flash lamps.

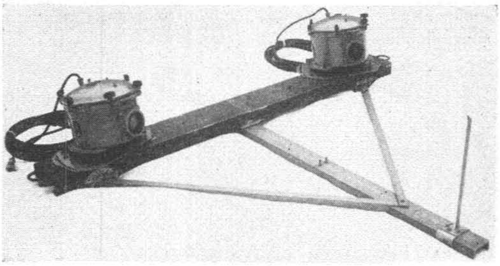


FIG. 3. Underwater cameras and triangulation device.

As fish are seen to pass near the pointer, which is in a known position in the camera fields of vision, a button is pressed to take the pictures. It is expected that this can be done, if desired, by use of a light sensitive cell, placed so as the beam will be broken by the fish. At present the equipment is made to operate visually and only during daylight, but there is no reason why it could not be used automatically and at night, if modified for that purpose.

The cameras are synchronized with two electronic flash lamps, mounted on the frame back of the cameras. As a fish passes through the overlapping fields of vision of the cameras, and is photographed, its position in each field is shown by the distance of its image from that of the pointer, so placed on a rod projecting from the base beam as to appear in each camera field. The accompanying photograph and diagram show the essentials of this apparatus, which has been dubbed a "phototriangle." See Figure 3 and 4.

The steps in determining the length of a fish by the graphical method of phototriangulation are as follows (see Figure 4):

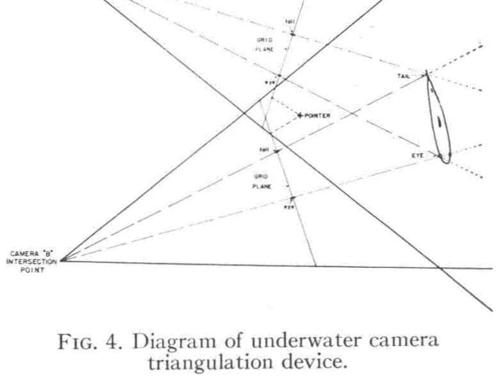


FIG. 4. Diagram of underwater camera triangulation device.

1. Charts of the field of the two cameras are drawn on a reduced scale and are represented by heavy lines.
2. A grid divided into $\frac{1}{4}$ inch horizontal units is placed at right angles to the field at a known distance from the camera, the same in both cameras, and photographed.
3. Simultaneous pictures of a fish are taken by the two cameras.
4. Negatives of the fish are laid exactly over the corresponding grid negatives and using the tip of the pointer as a point of reference, measurements are made and are plotted on the grid line as "eye" and "tail" (the center of the eye and the fork of the tail).
5. Lines (represented here by dotted lines) are then drawn that pass through the intersection points and the points on the grid line that indicate the tail and eye of the fish.
6. Where the lines cross in the overlapping camera fields is the actual position on the graph of the center of the eye and the fork of the tail.
7. A measurement of the fish is then obtained by measuring between the two points.

Certain problems have been met in using this equipment.

A.

There has been inevitably considerable variation in a number of things, among which the following may have an effect: the position of the camera within the underwater box, of the film in the camera as related to the axis of the lens, the film resolution, diffusion of light within the film, the effect of temperature, and the setting of the boxes on the base beam, all of which change the position of the image or the outline of the frame on the negative in one camera as compared to the other. It might be also desirable at times to change focus, or change lenses, or replace the port in the underwater case. And however well made the equipment may be with precision in bolts and their holes, alterations constantly occur as the result of handling, of striking objects and of difficult adjustments. To overcome these, the pointer mentioned in the preceding paragraph is placed so that it can be made to appear in both pictures to establish a point of comparison. From it measurements can be taken to the desired points on the fish, and the relative position of the latter in the two photographs thus determined.

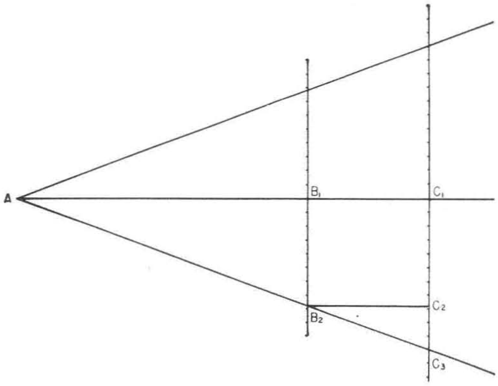


FIG. 5. Underwater triangulation. Diagram of use of two scales to determine intersection point back of camera lens.

The points chosen are the center of the eye and the fork of the tail. The center of the eye is chosen because the length of the nose varies in the male with the approach of spawning, finally becoming larger, long and hooked. The position of the center of the eye with regard to the pointer gives the angle from which the eye is viewed by the camera; the familiar process of triangulation then gives us its position in space.

B.

There is a marked distortion of the field in the negative, due to the undetermined indices of refraction of materials in the window and lenses, and their surfaces.

This is overcome by photographing a grid, using each camera in its box, under water. The grid is made of carefully drawn, equally spaced white lines on a black background. Since the negative images of the grid, the fish and the pointers, are subject to the same degree of distortion, the distance of the point on the fish to the tip of the pointer can be accurately stated in terms of grid divisions by comparing the negatives, hence ultimately in terms of angles to the base line.

C.

To determine the length of the base line and the above angles, it is necessary to determine the point of apparent intersection of the base line with the lines which pass through points on the fish, in their varying distance from the camera. The point of their intersection near the lens and film plane is determined as shown on the accompanying diagram. Figure 5. To do this two graduated scales are photographed together at a known distance, B_1C_1, apart, each at a right angle to the axis of the lens, in planes B_1B_2 and C_1C_2.

When the negative or photograph of the two scales is examined, certain points on the two scale images are seen to coincide in position, and lines drawn through them on the drafting board can be projected to an intersection point A, about 2 inches behind the lens. The distance AC_1 can also be determined by comparing the similar triangles AC_1C_3 and $B_2C_2C_3$.

It may be possible to determine the refractive indices of the lens and port window in the box and calculate the position of A, but it seems more practical to determine the effect of each combination, which may vary with each camera and box and with every repair or alteration of the equipment as well as aberrations due to the optical glass and lens structure.

The lens is focussed at six feet and retained permanently in that position.

D.

To assure that the grid and scale planes are at right angles to the lens, a mirror is placed at the grid center, in its plane, and reflects crossed lines on the lens surface, back into and through the lens to a ground glass at the film plane.

E.

The cameras are adjusted until the two fields are in proper alignment. This can most readily be done by setting the cameras on a plate or plates which swing on the same hinge or on two hinges on the same axis parallel with the base line. They must then be elevated so that the horizontal mid lines of the two fields are in line, or their vertical edges are parallel. If this is not done the bases of the cameras must be tilted to compensate, or an error will appear in the measurements, an error which gave much trouble until its cause was discovered.

For testing, fish models were made from sheet metal, placed in various positions, photographed, and their lengths calculated. In the apparatus, as at present used, the error is less than .25 inches in an 18 inch fish.

"Beattie Varitron," Model S-2 cameras were used. The lenses are "P. Angenieux" (France) Retrofocus Type R-1, 35 mm. E.F., f: 2.5. Their magazines contain 100 feet of 35 mm. film, sufficient for 800 frames, and of a high-speed type because of the diminished light and the need for relatively small stops to give depth of field. Figure 6.

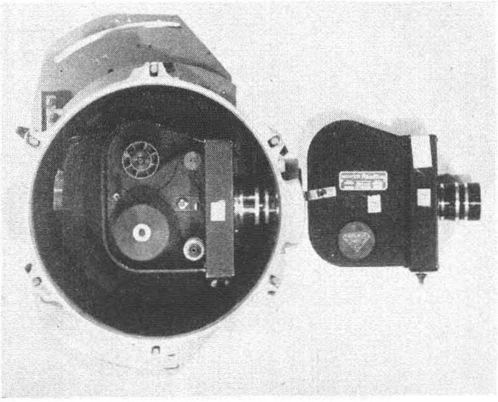


FIG. 6. Interior of underwater camera cases (with camera set alongside and near the case).

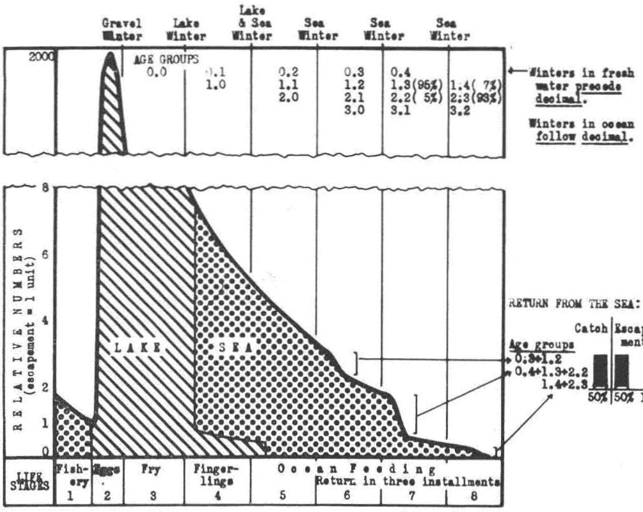
The light used is a custom-made electronic flash, which is in process of alteration to incorporate recent advances in transistors, hence is not described here. It is hoped that commercial models will be available for use, using batteries rather than a generator as at present.

Future uses of this equipment are many. If it can be made sufficiently simple and automatic in performance with batteries, and with time lapse equipment added, it can be installed at many points with a minimum of service, to give statistics at each lake entrance. It can be modified for study and enumeration of the small downstream migrants, but such use will require nets to concentrate them on a plane such as will allow photographs at short distances, with a relatively shallow depth of field.

The apparatus is defective in that it needs relatively clear water in which to operate, such as is usually found in outlets of lakes inhabited by red salmon. To overcome this, there is badly needed a series of experiments in semi-turbid water, since there is a chance that usable photographs can be secured even under such conditions, either of the fish or its shadow.

To understand the need for equipment of this kind, there should be some discussion of the fundamental problems it may help to solve.

In the attached diagram (Figure 7) there are shown eight stages in the life of the salmon, numbered at the base. Each period of life, usually a year, is ended by an event, shown as a vertical line labelled at the top of the diagram, such as a winter in the lake. Across these stages of life runs a survival curve, theoretical in form, to illustrate numbers of individuals passing through each of these stages.



Survival Curve of Red Salmon of the Nushagak System (Data for 1957 from Koe mss.)

FIG. 7. Red Salmon. Survival curve and life history diagram.

Relatively few adults return to begin a new generation. Of these roughly half of their numbers are shown as removed by the catch (stage 1). By those which escape, a great number of eggs are deposited in the beds (stage 2). The emerging fry leave the gravel to enter upon periods of lake life (stages 3 and 4) during which we know little of what happens to the survival curve, except that the major mortality in the life span occurs there. Frankly, we do not understand the process of compensation which tends to increase poor spawnings to average or at times even more than average abundance. It would appear that a reduction in the number of eggs and young, results in lower mortalities, caused perhaps by what the speculative scientist calls "density dependent factors" such as food available per individual, or perhaps by space limitations for successful spawning ground. Whatever these factors may be, they obscure or destroy the direct dependency of abundance upon number of spawners which the public and fisherman take for granted. We are faced with a problem in fundamental biology as to the nature of the resiliency which enables a species to survive under adversity. Understanding these mortalities which ultimately determine the yield and understanding, thereby to manage our resources scientifically so as to allow a commercial fishery to continue indefinitely, awaits accurate records and analysis of what happens during the now unrecorded years in the lake.

Then, abruptly, in stages 4 and 5 the young fish appear, in two age installments in successive years, at the lake entrance on their way to the sea. We seek to secure an index to their abundance, by sampling with fyke nets, but to do so is difficult and the results doubtful. We badly need a photographic method, such as we have described above, to enumerate and study biologically for age, etc. the vast hordes of young that go to sea in the spring.

Then follow years in the sea where the history is just as unknown, and from it comes the ultimate return which we are now attempting to analyze and record with some semblance of accuracy, shown in stages 6, 7, and 8.

It is plain that we must multiply our recording devices, not only to obtain separate records for the individual lake units, but for each of the stages as they pass through their successive environments. Such records are needed, first to understand; second to forecast; and third to adapt ourselves to what we cannot remedy. Only when we have reliable counts and indices to pin down the time and place of occurrence of variations in mortalities and survivals, will we be able to pin point the causes of those mortalities. One must known where and when to look in order to see those things which happen, and to determine causes.

There is no "royal road" to learning these facts vital to management of our fisheries. Can we take a high percentage of the adults, trusting to the supposed and unmeasured "density connected factors" to make good our removals? Or are all the surplus eggs and young needed for survival of the species? Can we detect or foretell disasters to our salmon, and protect them accordingly? The answer is not in speculation, but in accurate records and their analysis by use of such equipment as we can devise and have here described. It lies in multiplication of such points and times of observation as have been indicated in our graphs, a multiplication which can only take place if equipment is devised which is accurate, cheap to make and saving of labor, and if it is diversified in form to meet the varied conditions under which it must be used.

To create such instruments requires time, money and scientific knowledge of the fish themselves.

*The Accuracy of Human Bone Composition Determination from Roentgenograms**

PAUL T. BAKER
and
HARALD SCHRAER,
Biophysics Laboratory,
The Pennsylvania State University
and
RICHARD G. YALMAN
Chemistry Dept., Antioch College

ABSTRACT: *Several techniques have been developed to determine bone mineral content in living subjects. This paper describes and compares three common techniques, two of which involve photogrammetric methods.*

THERE has been a recent and rapid rise of interest in roentgenogrammetric techniques for determining bone mineral content in living subjects. Documentation is so recent that when queried two years ago about the feasibility of a film technique for estimating bone mineral in man, the chief of the medical research division for a large x-ray film producer replied that he seriously doubted such a technique could be developed.

Despite numerous publications, none have demonstrated by direct comparison the relationship between the roentgenological answers and bone compositions for human material.

The most common techniques break down into three basic categories:

1. the first method is the comparison of the passage of light through bone images on x-ray film with a standard index image appearing on the same film;
2. the second is quantitative determination of the silver salt of an image on an exposed x-ray film; and finally
3. a direct measurement of the radiation passing through the exposed anatomical site, using detectors other than films such as tubes and scintillation counters.

Of these three techniques the first is the oldest and most widely used. In its simplest form a light beam is passed through the film at a predetermined location, and the light intensity is compared to a step wedge of some material which is x-rayed on the same film. Efforts to validate the results obtained with such a technique have been meager. Mainland ('57) found that the results obtained on an os calcis film could be reproduced on the same film, but that results from a densitometer analysis of a second os calcis film introduced larger errors. Most of the between-film error appears to be a location problem. Slight differences in positioning from one exposure to the next produce significant differences in the film opacity.

More recent investigations have solved the location problem by using a tracing densitometer (Balz, *et al.* '57, Lackman '55, Omnell

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† Presented as part of the Society's symposium "Photogrammetry in Science" in conjunction with the 125th meeting of the American Association for the Advancement of Science, Sheraton-Park Hotel, Washington, D. C., December 29, 1958.