PHOTOGRAPHIC METHOD FOR MEASURING SPACING AND DENSITY WITHIN PELAGIC FISH SCHOOLS AT SEA

Few measurements exist of the spacing and density of fish within schools in the sea (Radakov 1973) although these characters have been well-studied in the laboratory (Breder 1954; Keenleyside 1955; Dambach 1963; Williams 1964; John 1964; Cullen et al. 1965; Hunter 1966; van Olst and Hunter 1970; Symons 1971). The density and spacing of fish within schools under natural conditions must be known if realistic fish abundance estimates are to be made from sonar survey data (Hewitt et al. 1976). This note describes a camera system that photographed fish schools at sea and a method used for estimating the density and interfish spacing from the photographs.

The camera system[1] consisted of an anodized aluminum casing which housed a spring-driven advance 35-mm camera, strobe light, and electrical components. The system was made watertight by creating a vacuum which sealed the acrylic lenses to the casing. Attached to the casing were a depth release with expendable chain ballast, floats, and a signal flag (Figure 1).

Upon immersion, the camera assumed an upright position, closing a mercury switch and starting an electric timer which activated the camera shutter and strobe light simultaneously. The system took 14 photographs per drop at set intervals of 24 or 48 s while sinking at a rate of 10

[1] Designed by Daniel M. Brown, Scripps Institution of Oceanography (SIO) from an idea of John D. Isaacs, SIO. Blueprints are available at the Marine Sciences Development Shop, SIO.

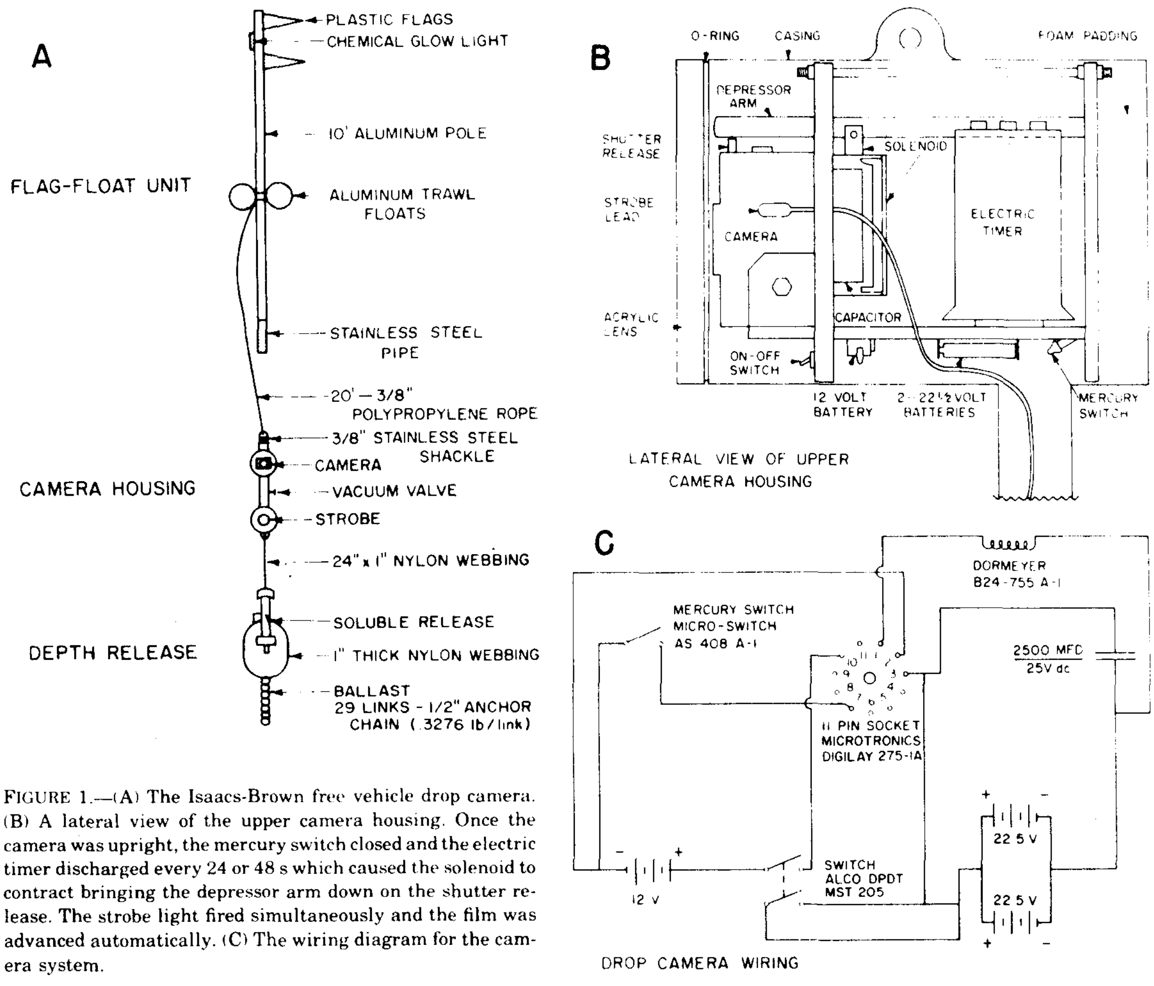

FIGURE 1.—(A) The Isaacs-Brown free vehicle drop camera. (B) A lateral view of the upper camera housing. Once the camera was upright, the mercury switch closed and the electric timer discharged every 24 or 48 s which caused the solenoid to contract bringing the depressor arm down on the shutter release. The strobe light fired simultaneously and the film was advanced automatically. (C) The wiring diagram for the camera system.

m/min. At a preset depth, the ballast was released and the system returned to the surface.

Fish lengths were measured from photographic enlargements with an x-y coordinate reader and only those fish enclosed by a circle of 6 to 10 cm in diameter, drawn centered on the photograph, were counted in order to reduce computer processing time and peripheral photographic distortion. Repeated measurements of a photograph indicated a mean error in individual body length of 3.4% and a maximum error of less than 9.0% for any individual.

To estimate the distances from the camera to the fish it was assumed that all the fish were of the same size, were all oriented perpendicularly to the camera lens, and thus the differences in fish image size were dependent only on the distance from the camera. The distance between any fish and the camera was determined by calculating the ratio of the standard fish size to the 35-mm negative image size and substituting this value into the underwater calibration equation of the camera (Figure 2). The mean standard length of 12.0 cm (s = 1.9 cm) for anchovy in southern California waters (Mais 1974) was used as the standard fish size.

A computer program calculated the lengths of the fish and produced a cumulative percent distribution of their sizes. One would expect the number of fish with small image sizes to increase with distance from the camera lens, but analysis revealed that a distance existed in most photographs at which the numbers of smaller fish failed to increase presumably because the more distant fish were not resolved owing to overlap, water clarity, and loss of lighting. An arbitrary limit was established at that image size by noting a change in slope on the graph of the cumulative percent distribution of fish lengths (Figure 3) and all fish smaller than the limit were not considered.

After establishing the minimum fish image size to be included in the program, a three-dimensional model of the photograph was constructed by calculating a third coordinate, z, based on fish image size and by adjusting the x and y coordinates for distance from the camera. The midpoint of each fish was then determined and a mean distance to the nearest neighbor was calculated by comparison with the midpoints of all the fish. The density of the school was computed by dividing the num-

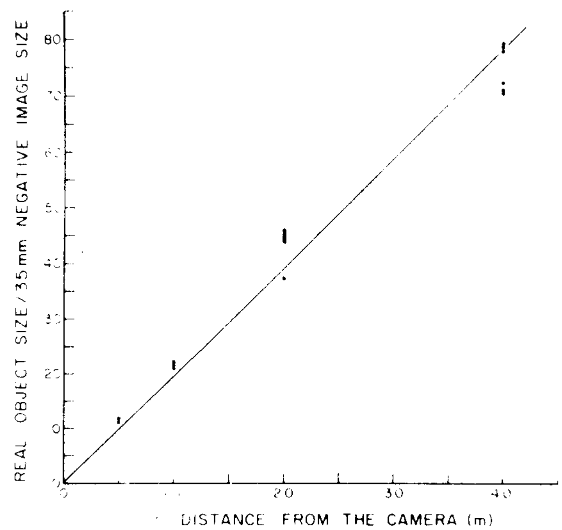

FIGURE 2.—The calibration curve for the Isaacs-Brown free vehicle drop camera. This camera system was calibrated under water by photographing objects of known sizes at fixed distances and the ratio of the real object to negative image size (y) was plotted against distance from the camera (x). The equation for the line is $y = 19.56x$. The distance to a fish was then determined by calculating the ratio of the standard fish size (12 cm) to the 35-mm negative image size of that fish.

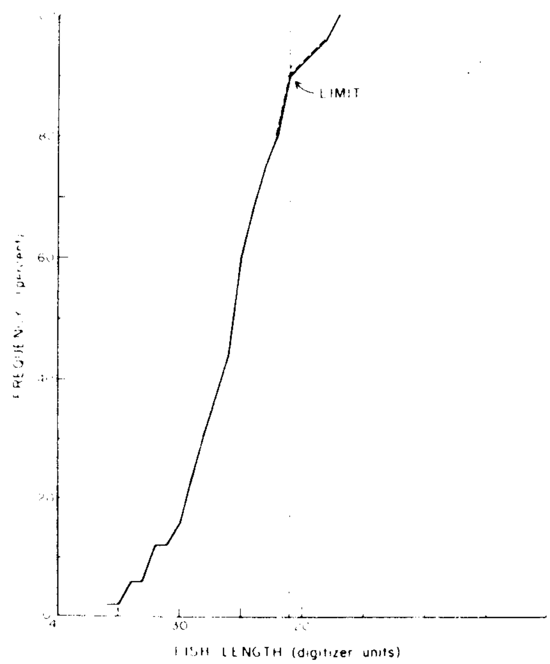

FIGURE 3.—The cumulative percent of length frequencies (in arbitrary units) for the fish measured in photograph 10 (Figure 4). Graphs of this form were made for each photograph analyzed in order to determine the distance beyond which all fish images were not resolved. The limit was made arbitrarily at the first apparent decrease in slope of the distribution.

ber of fish by the volume of the truncated cone between the planes of the largest and smallest fish image.

In September 1974, 14 camera drops were made in the Santa Barbara Channel on anchovy schools located by sonar. Observation of camera drops revealed that the slow sinking rate and $^{1}/_{1,000}$-s strobe flash did not disturb the fish. A space of about 4 m in diameter opened up in the school below the system as the camera descended. The increase in the school density caused by formation of the open space in the school was not detected in my analysis.

Anchovy schools appeared on 16 of the 230 photographs taken. For the 10 photographs in which the fish seemed to be perpendicular to the camera, the mean density of the school was 114.8 fish/m^3 where s = 99.1 fish/m^3 and the mean of the mean distance to the nearest neighbor was 1.2 body lengths with s = 0.3 body length (Figure 4, Table 1).

Photographs 6-10 were of the same school taken over a 10-min period. Excluding photograph 7, in which the fish appeared to be reacting to the camera or a predator and are more compact, the densities calculated for this school were 60, 56, 51, and 55 fish/m^3 with a mean distance to the nearest neighbor of 1.27, 1.28, 1.63, and 1.42 body lengths, respectively.

The interfish distances estimated for the schools photographed in this field study are, in general, larger than those reported in laboratory studies. This suggests that the small tanks used in these studies have caused fish to form more compact schools than they typically do under natural conditions.

The camera and these techniques could be of considerable value in determining the density and species composition of pelagic fish schools for sonar surveys. They should also be of value in the study of the behavior of schooling fish. School densities are known to change during feeding, predatory attack, and under diminished light intensity (Shaw 1970; Radakov 1973). Using the drop camera, it may now be possible to study the behavior of schools in the sea since interfish distance is as yet the best characteristic to measure changes in schooling tendencies.

TABLE 1.—Parameters of schooling compaction generated by the computer program for the 10 photographs in Figure 4.

Photo number	Fish/m^3	Mean distance (body lengths) to the nearest neighbor
1	100	1.24
2	174	0.84
3	78	1.38
4	50	1.35
5	366	0.79
6	60	1.27
7	158	0.86
8	56	1.28
9	51	1.63
10	55	1.42
Mean	115	1.20
Standard deviation	99	0.28

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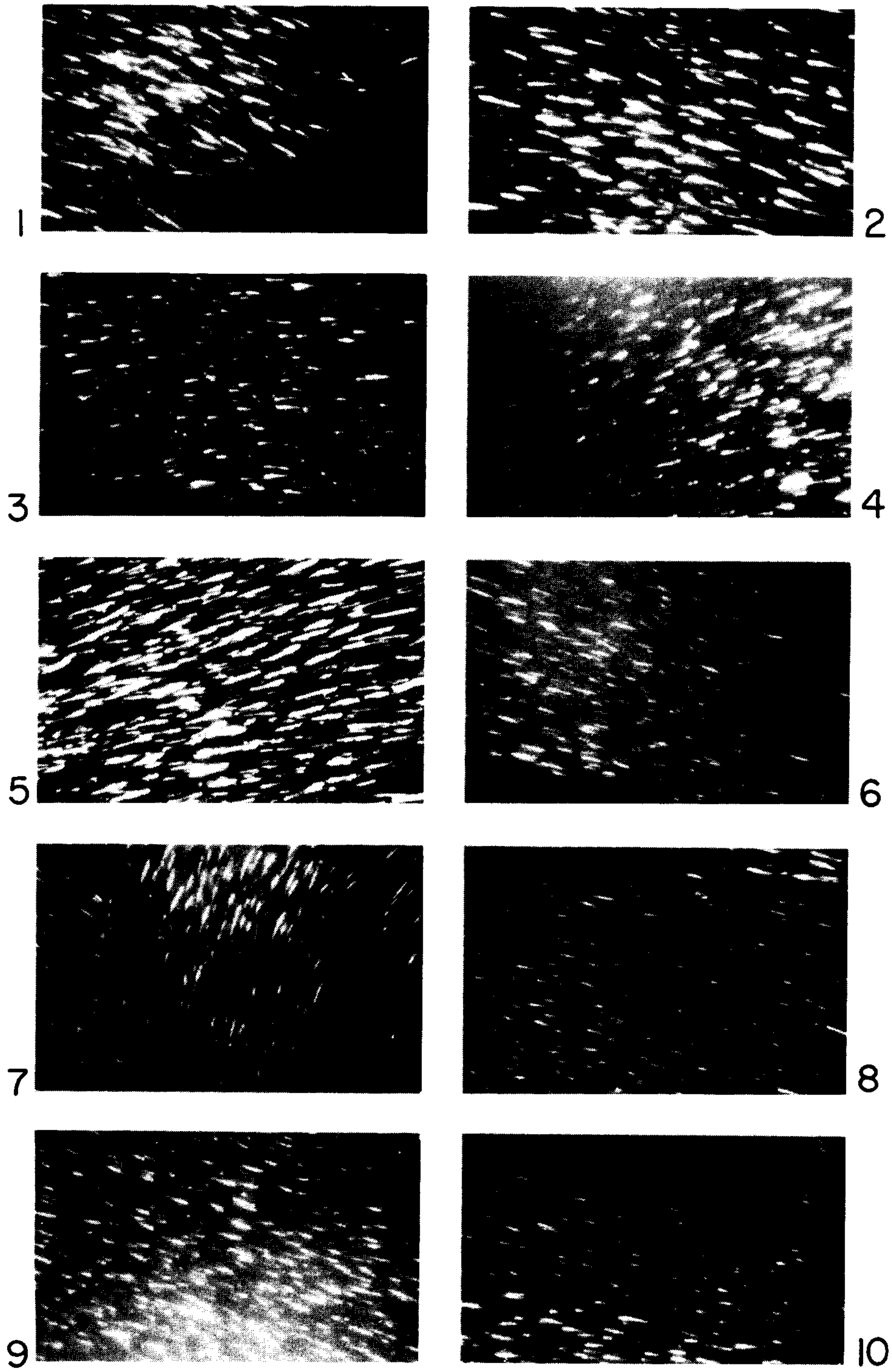

FIGURE 4.—Anchovy schools photographed in the Santa Barbara Channel with the Isaacs-Brown free vehicle drop camera during September 1974. Estimated fish density (fish/m^3) in each photograph, left to right, top row 100, 174, second row 78, 50, third row 366, 60, fourth row 158, 56, fifth row 51, 55.

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