THE PROBLEM OF FISHWAY CAPACITY

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ABSTRACT

The paper gives a rationale for studying the question of whether or not crowding obstructs the passage of fish through a fishway.

Average time spent in a fishway increases with numbers present if crowding hinders passage. Average usage time plotted on average number present (no delay from crowding assumed) yields the model. Capacity is reached where values of observations exceed those in the model.

Experimental data show, for a stable entry rate, a significant decrease in the relationship of exit rate to numbers present. This is suggested as one way of detecting delay from crowding in a particular section; it requires only a single test.

It is difficult to measure the capacity of a large fishway.

INTRODUCTION

How big should a fishway be? A fishway too small (or otherwise inefficient) may hinder the spawning migration of anadromous fish, and thus reduce survival to the next generation. On the other hand, a fishway larger than required for efficient passage is too costly.

No criteria for measuring efficiency of passage are accepted universally by fishery and power interests. One might argue that survival to the next generation is the most realistic measure. But this kind of survival data would be both difficult and expensive to obtain.

Fishery scientists, working on runs of anadromous salmonoids in a laboratory at Bonneville Dam on the Columbia River, recently have gathered another type of data in prototype-scale experiments: The numbers of fish passing through a fishway per unit time (Elling and Raymond, 1959). These studies are being financed by the U. S. Army Corps of Engineers, a major dam-building agency concerned both with the need to protect the fish and the cost of doing so.

From the cost standpoint it is realistic to evaluate fishway capacity in terms of numbers of fish per unit time. The net efficiency of passage is the result of the separate efficiencies at two stages: (1) Attraction into a fishway, and (2) passage through a fishway. One may apply an empirical notion of capacity to each stage. For a given set of conditions, entrance capacity may be defined as the maximum number entering a fishway per unit time; internal capacity, as the maximum number passing through a fishway per unit time. If an entrance can pass some maximum number per unit time, unnecessary cost may be involved in building a fishway of internal capacity greater than required to pass this number.

We propose here a rationale, leading to a rough model, for evaluating the internal capacity of a fishway. The need for such a study arose in connection with the work reported by Elling and Raymond (1959).

I am grateful to Dr. D. G. Chapman of the Department of Mathematics, University of Washington, Seattle, Washington for suggesting the concept of average usage time. I wish also to thank Glenn Pedersen and D. D.

Worlund of the Fish and Wildlife Service for their helpful comments.

DEFINITION OF TIME SPENT IN A FISHWAY

It is difficult to record the time spent by an individual fish when even a small group is present in a fishway. However, under appropriate conditions one can record the numbers passing two (or more) points in successive units of time. If one does this at the entrance and exit (or any other locations of interest), he may calculate an average time of entry and an average time of exit. The difference between these averages is then a measure of the average time spent in the fishway by the individuals of the group.

Two such averages, the mean and the median elapsed time, have been used by Elling and Raymond (1959). Of course, both may be derived without regard to the order in which particular fish enter and leave. One may compute the median as soon as half of the number of fish entering is recorded at the exit. However, since individual times of entry and exit are not recorded, the observed and true medians will differ by some unknown amount. The observed mean, on the other hand, will be identical with the true mean unless a test is stopped before all fish have passed through the fishway.

In practice, some fraction of those entering usually fail to leave in a reasonable time. When this fraction is large, unfavorable conditions exist for fish passage and such information is essential for planning new fishway designs. To avoid waiting for a few fish and thus to permit reasonable scheduling, Elling and Raymond (1959) terminated most tests before all entering fish had passed through the fishway. The fact that their observed means and medians differed only slightly in tests not terminated before all fish had left suggests, at least for the limited scope of their operation, that this procedure was reasonable.

In what follows we shall use the term "average" time. It will make no difference to the concept of capacity whether this average is the mean or the median.

DEFINITION OF DELAY

The idea of capacity implies that the average time spent in a fishway by individuals is some function of the number of fish present. For example, Pretious, Kersey and Contractor (1957) state: "It is known from experience with the salmon runs on the Fraser River that the crowding of fish in a limited area reduces freedom of movement and slows down the migration of fish. Thus, if the fishway design capacity (in numbers of fish) were to be exceeded, it could be expected that the numbers of fish passing through the fishway per unit time would diminish rather than increase during the time that the fishway was overcrowded."

The actual relationship between average time and the number present could be of various types. For example, average time might be less at a moderate than at a low number present.

But for the present let us postulate the situation of figure 1. Here, the increase in T related to a particular N is given by the vertical difference between any T, N coordinate and the dashed line. For the moment we shall apply the term "delay" to such differences.

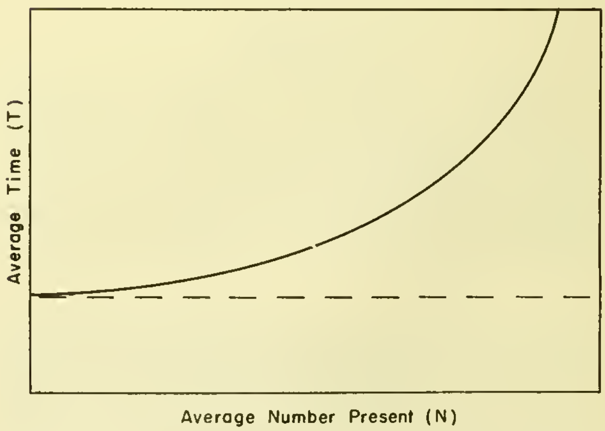

Figure 1.--Hypothetical relationship between average time and average number present.

EXPERIMENTAL COMPLICATIONS

The idea of delay is simple to graps, but delay defined as above is hard to measure. What, exactly, do we mean by "average number present"? The computed average time necessarily applies to all fish passing in the entire test interval. However, the relationship of figure 1, derived from a series of tests, is of most interest during a central portion of the test interval when the "average number present" is at a maximum. The number present, of course, fluctuates widely over the entire interval. But if one were to average the numbers present at successive time units in the center of a test interval, as between time units 2 and 4 in figure 2 when entry and exit rates are sustained, he would both satisfy the requirement of figure 1 and reduce the variation around the average number present.

We may visualize, from figure 2a, a large number of test fish available for entry into an experimental fishway containing no fish. The available fish begin to enter at time-unit 0, then maintain a quite constant entry rate between time-units 1 and 4. By time-unit 5 this entry rate is decreased because the numbers available are reduced. Since a time lag is required for fish to ascend the fishway, the exit rate does not reach a high level until time-unit 2; then it is sustained through time-unit 5. It decreases by time-unit 6, since nearly all available fish now have passed.

This, briefly, is the type of passage encountered in practice (Elling and Raymond, 1959). The difficulty is in collecting sufficient numbers of fish to sustain, together, the entry and exit rates long enough to yield a reasonable estimate of "maximum" average number present.

Under this definition of average number present, the relationship of figure 1 is complicated by the fact that the average time applies to the entire test interval while the average number present applies only to a central portion of this interval. To estimate the relationship of figure 1 as precisely as possible, one should terminate entry as soon as the entry rate begins to decline.

Factors other than the difficulty of collecting large numbers of fish make this

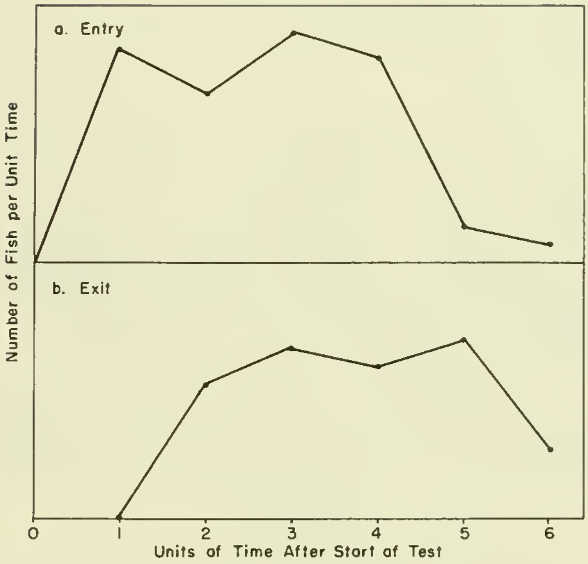

Figure 2.--Distribution in time of fish entering and leaving a test fishway.

type of experimentation difficult. For example, the fish available for entry at any time will represent a complex and usually unknown combination of fatigue and motivation states. Further, the effects of fatigue and motivation on observed performance are complicated by the fact that species composition changes from time to time in most operating fishways. Thus, it will be difficult to estimate the effects of crowding and to consider at the same time the effects of these other factors. Success in this type of work will demand rigorous attention to the principles of experimental design. Perhaps small-scale studies will provide data for a statistical separation of effects where appropriate designs cannot be adapted to practical demands on the prototype scale.

The ultimate test, of course, is whether the experimental approach can be made realistic enough to be useful. In spite of the difficulties we now shall attempt a definition of capacity.

DEFINITION OF CAPACITY

To define capacity as a quantity which can be measured from the performance of fish, we must combine our notions of average time and average number present into a standard against which performance can be evaluated.

The reader will recall (figure 1) that we defined delay in terms of a minimum average time which we assumed would occur at low numbers present. In practice, of course, group behaviour effects might well lead to a lower average time at moderate than at low numbers present. Thus, it would be unrealistic to define capacity in terms of an untested assumption.

A simple way to avoid this and still to provide a standard for evaluation is as follows:

Let T = average time

N = average number present

T/N = average usage time

Now if in fact T is <u>not</u> decreased by increasing N, we have T = k, a constant. Then if we let y = k/n and x = N, we have the simple hyperbola

$$xy = k \quad \ldots\ldots \text{(equation 1)}$$

transposing,

$$y = k/x \quad \ldots\ldots \text{(equation 2)}$$

The model given by equation 2 is shown in figure 3, arbitrarily using T = k = 150 and some arbitrary values of N.

To use this model one would calculate an average T from a series of T's observed over a range of N, use his average T = k in equation 2, and plot the hyperbola with his values of N. Then where particular average times increase with numbers present, his observed values of average usage time will be higher than those postulated by the model. For the average number present at which this begins to occur we propose the term <u>capacity</u>.

The reader will note that observed average usage times might also be less than those given by the model. This would mean that groups behaviour is decreasing the average time for the average numbers present at which this happens.

AN ALTERNATIVE APPROACH

It usually will be very hard to get, under comparable conditions, enough points on graphs like figure 3 to tell where capacity is reached. But one still may judge whether crowding hinders passage in a particular fishway section. Under the hypothesis of delay due to crowding we would expect, during an interval of non-declining entry rate, that the relationship of exit rate to numbers present would at some point fail to increase. If we found this to be true over a widely changing entry rate, we could not interpret it simply on the basis of numbers present. A changing entry rate might itself stimulate movement out of a pool or section.

So let us define this relationship only for a period of relatively constant entry rate. From tables 3 and 4 of Elling and Raymond (1958) we give in table 1 the numbe bers entering and leaving, and the numbers present in the lowest fishway pool during each of the first 30 minutes of a test.

During minutes 6-22 the entry rate was relatively constant; we accordingly plot, in figure 4, exit rate on numbers present for minutes 6 to 22.

From the data of figure 4 we reject the hypothesis that exit rate is independent of numbers present (<u>t</u> is about 15, with 15 degrees of freedom). Since this decreasing exit rate occurred when entry rate was quite stable, we conclude that movement was hindered by crowding.

For one section of a fishway the capacity, as defined in the previous section, could be evaluated from a series of such

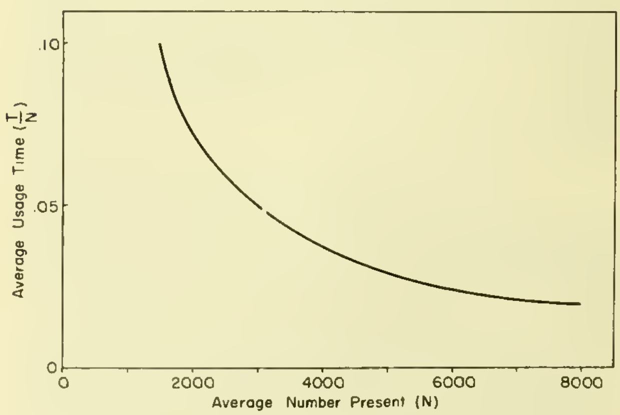

Figure 3.--Relationship between average usage time and average number present, assuming average time is independent of number present.

Table 1.--Numbers of fish entering, leaving, and present in the lowest fishway pool during each of the first 30 minutes of a test interval.

Minute	Number entering	Number leaving	Number present at end of minute
1	16	6	10
2	75	35	50
3	50	40	60
4	54	40	74
5	75	60	89
6	50	35	104
7	60	60	104
8	55	65	94
9	55	45	104
10	53	49	108
11	45	49	104
12	54	49	109
13	42	39	112
14	64	50	126
15	47	43	130
16	54	42	142
17	53	49	146
18	51	39	158
19	47	26	179
20	39	32	186
21	43	43	186
22	49	25	210
23	31	27	214
24	30	32	212
25	33	17	228
26	15	25	218
27	23	18	223
28	26	17	232
29	14	24	222
30	15	9	228

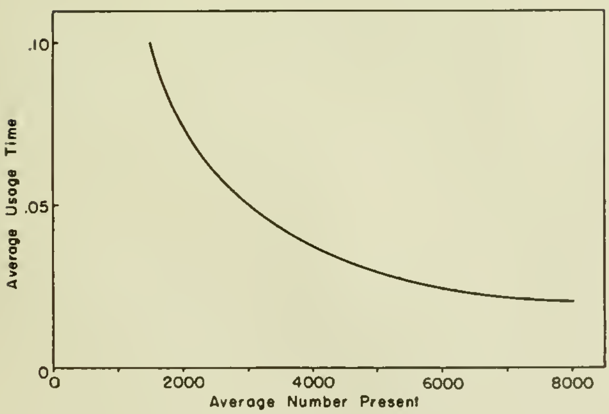

Figure 4.--Relationship between exit rate and number present in a fishway section during a period of constant entry rate.

tests. However, one test can yield useful information.

SUMMARY AND CONCLUSIONS

We have set up a simple model (assuming average usage time is independent of average number present) for determining, under appropriate experimental conditions, whether the internal capacity of a fishway is exceeded. Capacity as defined here occurs when the observed values are higher than the values given by the model. At present we have no data against which to test this model.

For an interval of reasonably stable entry rate one also may judge whether crowding obstructs passage through a fishway section. This occurs when the relationship of exit rate to numbers present decreases significantly. This is demonstrated with actual data.

Any judgment about capacity or delay requires a rather complex experimental situation; the section on Experimental Complications explains a few of the problems.

We expect that the rationale given here will be refined and extended. In the meantime, the reader may find these concepts useful starting points in experimental work in which crowding is a factor under study.

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