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Introduction

Until recently, very little quantitative work has been done on the daily or short term movements of fresh water fish. Investigations by Hasler and Bardach (1949) have verified the existence of a diurnal movement of the yellow perch (*Perca flavescens* Mitchill) in Lake Mendota, Wisconsin.

The present paper reports the results obtained from an investigation of the movements of yellow perch in Lake Okoboji, Dickinson County, Iowa. The investigation was undertaken in the summer of 1950 at the Iowa Lakeside Laboratory, and was primarily an attempt to ascertain: 1) do these fish undergo a diurnal movement, 2) is there a pattern to this movement, and 3) if they move regularly, what is the reason for this movement. The methods employed in this investigation were patterned after those used on Lake Mendota. The authors wish to thank Dr. John E. Bardach of the Iowa Lakeside Laboratory staff, for his guidance and assistance in this undertaking.

Statistical analysis of data thus far obtained definitely establishes the existence of differential diurnal activity among the perch of Lake Okoboji[1]. However, a great many questions concerning the perch movements still remain unsettled, and we wish to emphasize that this paper is merely a progress report on investigations which will require considerable further work before precise conclusions can be drawn.

Description of Lake Okoboji

Lake Okoboji (Figure 1), site of the Iowa Lakeside Laboratory, is situated in Dickinson County, in the Northwestern corner of Iowa. The lake is approximately 8.79 km. (5.5 miles) long and a maximum of approximately 4.57 km. (2.8 miles) wide. It is irregular in outline, with a number of sharply dilineated bays. The surface area of the lake is 1535 hectares. The lake is believed to be glacial in origin, and is a portion of an ancient river valley. It is roughly

[1]The authors wish to thank Mr. F. Lott, of Iowa State Teachers College, for his assistance with the statistical analysis.

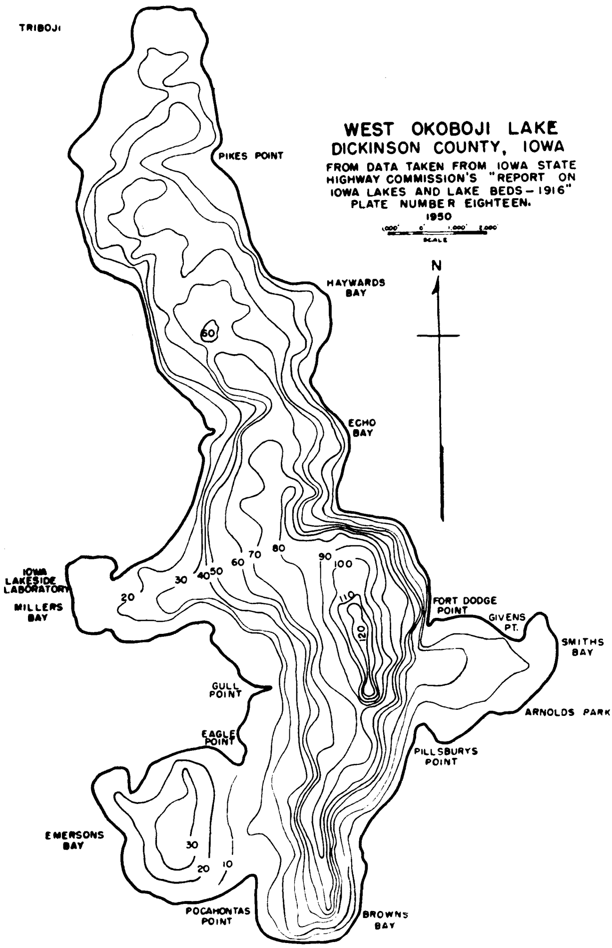

Figure 1.

V-shaped in cross section, and has a maximum depth of 40 meters (132 feet). A more detailed account of the morphometry of the lake may be found in Birge and Juday (1920).

The area surrounding the lake is rather thickly settled, the location being the center of the Iowa summer resort area. Lake Okoboji is highly eutrophic. It supports an abundant flora and a large fish population. The most numerous panfish in the lake are yellow perch.

Methods and Procedure

In this investigation, the number of fish caught in a specific unit of time, in gill nets set at previously selected stations on the lake, has been used as an index of fish activity.

The gill nets were generously loaned to us by the Iowa Conservation Commission's Fish Hatchery at Spirit Lake. The nets were 6 feet high and 25 feet long and had a bar mesh of 1 inch. They were adjusted so that they set upright on the bottom like a fence when they were placed in the water. The mesh size employed enabled us to catch perch of two years or older. This limited our study to the adult members of the perch population.

Settings were made over the daylight, sunset, and darkness hours, an arrangement which enabled us to study fish activity during three portions of the diurnal cycle. Limitations of time, man-power, and equipment prevented us from studying fish activities during the

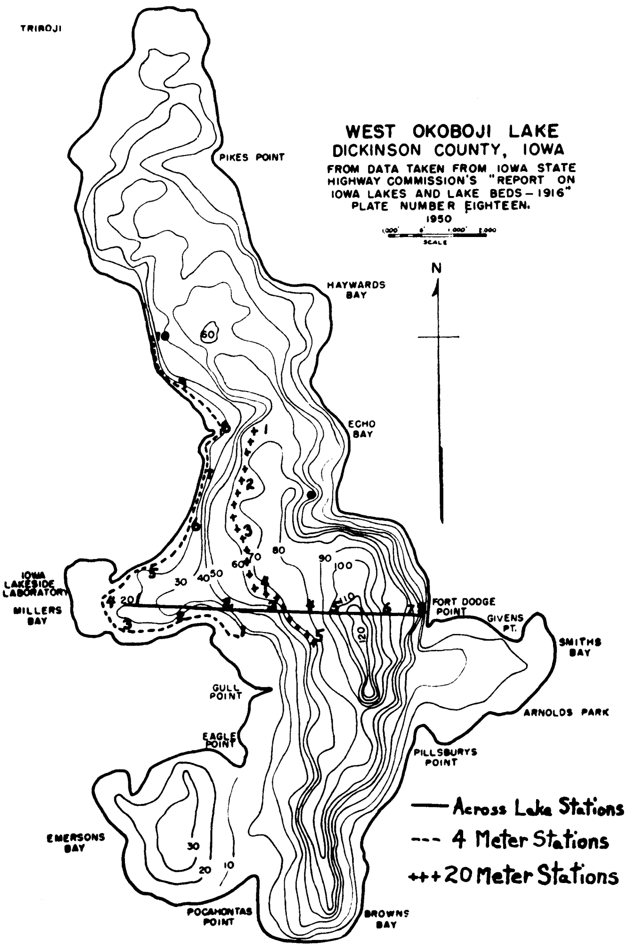

Figure 2.

sunrise hours. The following series of net settings were made (Figure 2):

1. settings at stations along the 4 meter contour line
2. settings at stations along the 20 meter contour line
3. cross lake sets at stations located in a straight line across the widest part of the lake with stations at 20, 40, 60, 80, 100, 80, 60, and 30 feet, see contour-map (Fig. 2).
4. some short period sets along the 4 meter contour line.

The distance between the nets on each of the above lines was kept roughly about 515 meters for the 4 meter contour, 485 meters for the 20 meter contour, and at varying intervals for the cross the lake sets. The locations of these stations were marked by homemade buoys.

Plans were made to set nets daily, weather permitting, in the five week interval from July 16th to August 18th. Weather conditions were recorded but we observed no correlation between them and the size of the catches. It must be noted, however, that there were some days with very high winds when no nets could be set.

All fish caught were sexed and examined for external lesions of infection. Although not a primary objective in this study, an investigation of stomach contents was also made. Stomach contents were collected at random from a few fish in each catch, labelled, and preserved for later examination. A total of 160 settings were made which yielded a total catch of 609 perch.

Every effort was made, though not always successfully, to leave each net in the water for the same amount of time in comparable sets. For all but the short period sets, settings were made for three ical breakdowns were compensated for in the statistical analysis. hours. Such irregularities as arose due to weather and/or mechan-

Results and Discussion

The catches were tabulated according to the statistical treatment they were to receive. Analysis of variance tests were performed on the data of nettings from series 1, 2, and 3 (Snedecor 1947). In addition, a "t" test (Snedecor 1947, pp. 82-84) was applied to data from all catches within the bay as compared to all catches in the lake at large, on the 4 meter contour.

It appears from the cross the lake data (Table I) that more perch were caught during the day than at night. It should be noted that all these stations lay beyond the 6 meter contour. The difference between day and night catches is significant at the 5%, and almost significant at the 1%, level. This means that in only 1 to 2 out of

100 such treatments could the results obtained be due to chance. This, as well as other observations, suggested that the perch move shoreward at night. However, the results at present cannot be taken to reveal more than merely a differential activity among the perch between daylight and darkness hours. Comparing one station with another (between stations F) it appears that chance alone could account for the difference in catches.

The data of the 20 meter sets (Table 2) also show more perch caught during the day, but this analysis only approaches a significant result at the 5% level. The 5% level of probability is generally regarded as the minimum acceptable to discard the hypothesis that the difference in the two treatments under consideration is due to chance alone. Since the analysis of data from this set of stations only approaches this level of significance it can only lend strong support to the hypothesis of migration as described. Again, there is no significant difference between catches at the various stations.

The analysis of variance for the 4 meter net sets (Table 3) does not show a significant differnce between either the stations or the time of sets.

However, the raw data indicated a difference between the catches inside the bay and in the lake at large, along the 4 meter contour, both during the day and at night. Analysis revealed a significant difference between the catches from these two areas (Table 4). The results of this analysis suggest that the bay areas of the lake may contain discreet perch populations.

Netting stations were evenly spaced along the 4 meter contour, with the intention of showing the difference between the 4 meter and the 20 meter level, day and night, anywhere in the lake, and not between the bays and the lake at large. When net catches at the 4 meter level in the lake at large were compared (Table 5), it appeared that there were significantly more perch caught at night. This is in accord with our hypothesis that there are more perch in the shallow water during these hours.

Short period sets on the 4 meter contour were made in an attempt to pinpoint the peak of the postulated shoreward migration. Peak catches were found to occur during the sunset hours (Table 6), at the time of rapidly diminishing light intensity. Two possibilities for this activity suggested themselves, although there may be further causes not here considered. These are: a) that the fish are responding directly to light intensity, or b) that they are following the movement of their food organisms (which in turn may respond to changes in light intensity). Preliminary measurements with a Weston Photographic light meter showed peak activity at .5-1.0 foot-candles. Physiological experiments, in tanks, under controlled conditions, must be conducted to determine precisely the sensitivity of perch to changes in light intensity. Only then can this factor be evaluated. Precise feeding studies should also be made in the natural habitat.

As these results stand at present, they cannot be taken to reveal more than merely a differential activity among the perch between daylight and darkness hours. Whether the fish are always at the same depth and merely become more active (and therefore are caught more frequently by net and hook and line) at a certain time of day, or whether large numbers of them tend to move uniformly from one depth to another at a certain time. cannot be determined from our results so far. Investigations in Lake Mendota showed that migrations took place there, and we have certain indications which lead us to believe that this is also the case in Lake Okoboji. It is interesting to note that data obtained correspond quite precisely to reports from fishermen concerning when and where they catch most fish.

Statistical analysis of the data indicated that insufficient settings were made at most of the stations to furnish statistical proof of the above hypothesis.

As mentioned earlier, some stomach samples were taken from every catch. This was done with the hope of utilizing the results of another group of Lakeside Laboratory workers who were studying the distribution of bottom organisms at various depths in the lake. For example the stomach contents of a fish caught at sunset at 4 meters might indicate whether or not the fish had previously been feeding in deeper water. In the stomachs of the fish were found larvae of *Chironomus*, *Leptodora*, and other insects, *Daphnia*, crayfish, small molluscs, and minnows. In a few instances, evidence of cannibalism was also present.

With the few stomachs examined so far, no definite correlation could be made between stomach contents, the depth at which the fish were caught, and the depths at which various food organisms are found. However, there is an indication that perch in the day catches had fed heavily on *Chironomus* larvae, thus indicating bottom forage in deep water. A number of the perch stomachs from evening catches at 4 meters contained molluscs and plankton, possibly ingested during travel of the fish from deep to shallow water.

As has been suggested throughout this paper, there are a number of other questions which have been brought to light, and it seems appropriate to mention them at this time. It is interesting to note, for example, that at no time were fish ever caught at a depth greater than 27 meters. However, very few deep water sets wre made, and th maximum depth at which nets were set was 30 meters. Why no fish were ever found at a depth greater than 27 meters is not felt to be pertinent to the work discussed here, but it is certainly a question worthy of further attention.

We have already indicated the possibility that the perch within Millers Bay (and therefore possibly also within the various other bays of the lake) move and generally behave as a population distinct from the perch population of the main body of the lake. It will require a great many more net settings to ascertain whether this is actually the case. It is further known that the perch swim close to the bottom and it may be important to ascertain the effect that the bottom configuration may have on the direction of movement of the fish.

These problems are of course among the first to be investigated in future work on fish movement in Lake Okoboji. In addition to these, there are a number of more general and far reaching questions which would follow from a positive demonstration of diurnal migration by the fish. Assuming that present indications will eventually be replaced by proof of a perch migration from deep to shallow water at sundown, the cause or causes of such a migration would suggest itself as a topic to be investigated. The two most likely possibilities (response to changing light intensity or response to movement of food organisms) have already been mentioned.

Although the information had no direct bearing on the movement of the perch, we wish to take this opportunity to report the results of the breakdown of our total catch as regards sex and parasitic infection in the fish which were caught (Table 7). These infections are very similar to those caused by the sporozoan Myxobolus. These data immediately raise the question as to whether or not there is a correlation between the higher infection rate in males and the smaller number of males in the total population. The reader is again reminded that these figures deal with the adult perch population. Whether these ratios apply to the immature fish cannot be determined from the samplings which were made.

Summary

Studies conducted at the Iowa Lakeside Laboratory have led to the demonstration of differential diurnal activity in the population of adult yellow perch in Lake Okoboji, Iowa. These studies have been made using the catches of perch in gill nets, at various depths and at various times of the day, as an index to the activity of the perch. The methods employed in the use of these nets have been described.

Certain results from investigations which are yet to be completed have led to the hypothesis that the differential activity which was demonstrated is intimately associated with, or even represents, a deep to shallow water migration by the perch during the hours of decreasing illumination leading to sunset. Data have been presented which indicate that perch in bay areas of the lake do not take part in this general movement. Suggestions have been outlined for future work designed to test these hypothesis.

Mention has been made of a subsidiary study on the possible correlation of sex ratios and parasitic infection among the population of adult perch which was under study.

Table I

Analysis of Variance of Perch Catches in Gill Nets Set Across Lake West Okoboji

Data

Station / Time	20 ft.	40 ft.	60 ft.	80 ft.	100 ft.	80 ft.	60 ft.	30 ft.	Means
Day[1]	32	42	39	0	0	7	36	17	21.63
Night[1]	7	5	6	0	0	0	10	2	3.75
Means	19.5	23.5	22.5	0	0	3.5	23	9.5	12.69

[1]The variates used here represent total catch at each station.

Source	D.F.	Sum of Squares	Variance	F
Between times of set	1	1278.0625	1278.06	12.12*
Between stations	1564.9375	7	223.56	2.12[2]
Error	7	738.4375	105.49	
Total	15	3581.4375		

*Significant at the 5% level and almost at the 1% level.
[2]Not significant.

Table II

Analysis of Variance of Perch Catches in Gill Nets Set at the 20 meter Contour Line in West Lake Okoboji

Data

Station / Time	1	2	3	4	5	Means
Day[1]	21	33	66	61	30	42.5
Night[1]	5	11	15	11	32	14.8
Means	13	22	40.5	36	31	28.5

[1]The variates used here represent catches during 9 hours of netting at each station.

Source	D.F.	Sum of Squares	Variance	F
Between times of set	1	1876.9	1876.9	7.18[2]
Between stations	4	978.0	244.5	.93[3]
Error	4	1045.6	261.4	
Total	9	3900.5		

[2]Nearly significant.
[3]Not significant.

Table III

Analysis of Variance of Perch Catches in Gill Nets Set at the 4 meter Contour Line in West Lake Okoboji

Data

Station / Time	1	2	3	4	5	6	7	8	9	10	Means
Day[1]	.96	.36	2.36	3.84	.36	1.39	.51	5.84	2.46	7.32	2.540
Night[1]	9.70	1.15	1.47	.44	.82	4.19	6.97	15.9	3.02	7.59	5.131
Means	5.33	.755	1.92	2.24	.59	2.79	3.74	10.9	2.74	7.46	3.836

[1]The variates used here represent the average for 3 hours of netting at each station.

Source	D.F.	Sum of Squares	Variance	F
Between times of set	1	33.566405	33.566	3.46[2]
Between stations	9	188.259145	30.918	2.15[2]
Error	6	87.407545	9.712	
Total	19	309.233095		

[2]Not significant.

Table IV

Catches Inside and Outside Millers Bay at 4 meters.

Data

Location	No. of Stations	Total Catch at Each Station[1]
Bay	4	1.51, 3.83, 4.28, 1.18
Outside Bay	6	10.66, 5.58, 7.48, 21.74, 5.48, 14.91

[1]The variates used here represent the average for 3 hours of netting at each station.

Summary of Statistics for Comparison of Catches
Inside and Outside the Bay at 4 meters.

Location	No. of Stations	Degrees of Freedom	Mean Catch	Sx^2	$s^2 = \frac{Sx^2}{d.f.}$	$sx^2 = s^2n$	$t_{.05}$
Bay	4	3	2.70	7.4998	2.499	.6249	3.182
Outside Bay	6	5	10.97	202.9849	40.5969	6.7661	2.571
	10	8	$x = 8.27$			7.3910	

$sx = \sqrt{7.3910} = 2.718$ $x/sx = 8.27/2.718 = 3.04$

$$5\%\ \text{level} = \frac{(.6249)\ (3.182) + (6.7661)\ (2.571)}{7.3910} = 2.62$$

Table V

Analysis of Variance of the Numbers of Perch Caught on the 4 meter Contour in Nets Set Outside of the Shallow Bay

Data

Station / Time	1	6	7	8	9	10	Means
Day[1]	.96	1.39	.51	5.84	2.46	7.32	3.08
Night[1]	9.70	4.19	6.97	15.9	3.02	7.59	7.895
Means	5.33	2.79	3.74	10.8	2.74	7.46	5.4875

[1]The variates used here represent the average for 3 hours of netting at each station.

Source	D.F.	Sum of Squares	Variance	F
Between times of set	1	69.5526	69.5526	7.86*
Between stations	5	101.4892	20.2978	2.29[2]
Error	5	44.2252	8.845	
Total	11	215.2670		

*Significant at the 5% level.
[2]Not significant.

Table VI.

Short Period Catches at Stations 6, 7, 8, 9, and 10 on the 4 meter Contour Line.

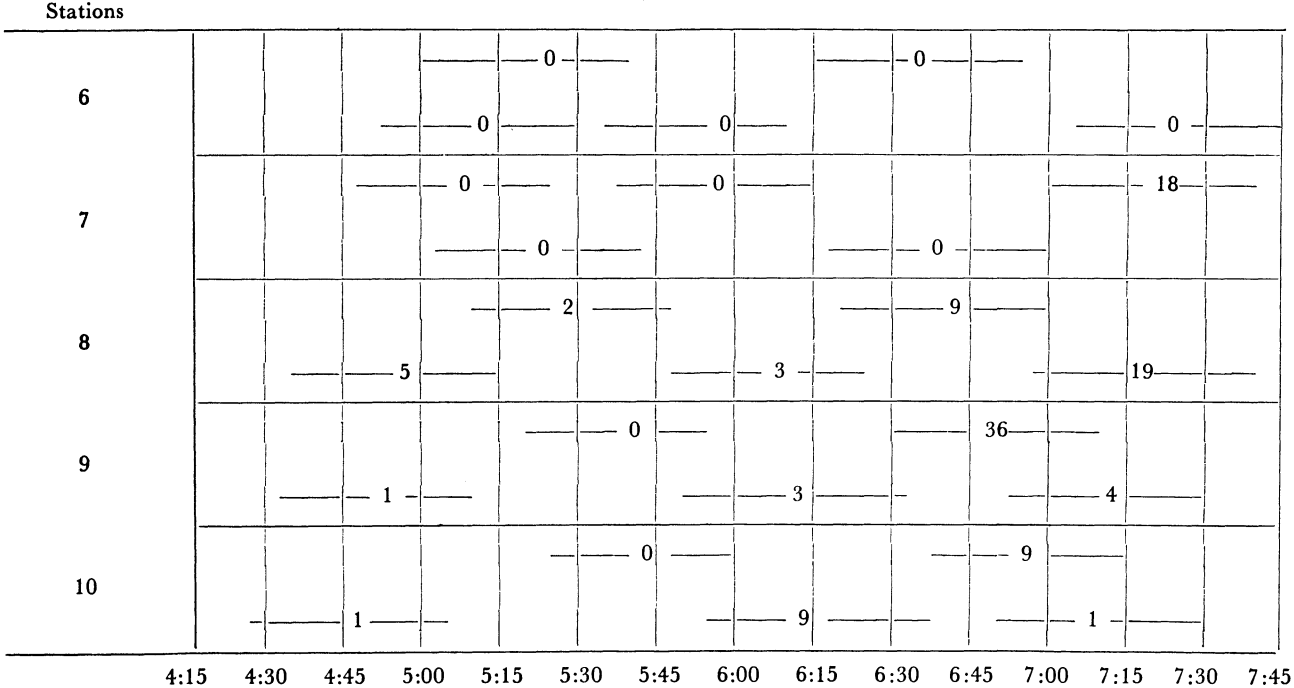

Table VII

Breakdown of Total Catch for Sex and Parasitic Infection.

	Total	Healthy	Infected	% Infected
Males	203	127	76	37.4
Females	406	291	115	28.3
All fish examined	609	418	191	31.3

Ratios: males to females 1:2
healthy males to infected males 5:3
healthy females to infected females 5:2

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