STRATIFICATION IN WESTERN LAKE ERIE IN SUMMER OF 1953: EFFECTS ON THE HEXAGENIA (EPHEMEROPTERA) POPULATION

N. WILSON BRITT[1]

Franz Theodore Stone Institute of Hydrobiology, Ohio State University, Put-in-Bay, Ohio

Although the water temperature and chemical composition of western Lake Erie are usually uniform from top to bottom, occasionally there are short periods of temperature stratification during unusually calm warm weather. These have usually been of such short duration that no appreciable chemical or biological changes have been observed. Chandler (1940: 297; 1944: 204) reported such temporary thermal stratification in western Lake Erie in 1939 and 1940. Chandler and Weeks (1945: 437) found similar conditions in 1942. Wright and Tidd (1933: 273) reported temporary thermal stratification in the eastern part of the Island Section of Lake Erie. However, in this instance the temperature stratification was associated with a reduction of oxygen near the bottom where a low of 8.6 per cent saturation was reached.

Unusually low wind velocities prevailed in the Bass Islands region throughout the month of August and the first few days of September, 1953. The near calm conditions were especially pronounced during the period August 20 to Sept. 3, when the average velocity at Sandusky, Ohio, the nearest weather station, was below 4.3 miles per hour, with 13 miles per hour being the highest velocity observed during the period. Associated with this unusually calm weather were clear skies and high temperatures, in some cases exceeding the all-time records.

In this paper it will be shown that these conditions resulted in high water temperature and oxygen depletion near the bottom. This condition, in turn, resulted in changes in the bottom fauna.

METHODS AND EQUIPMENT

The temperature records were made with a bathythermograph that had been calibrated against an accurate stem thermometer. The water samples were collected in the Kemmerer water sampler. For samples near the bottom, the sampler was lowered until it touched the bottom, then it was raised a few centimeters and moved to one side before closing. In this position a vertical column of water about 42 cm. in length was collected a few centimeters above the bottom. The top of this vertical column may have been as much as 75 cm. above the bottom in some samples. Mortimer (1941-1942) showed that in some thermally stratified lakes oxygen depletion in the hypolimnion was greatest at the mud-water interface. Therefore, the quantity of oxygen at the true bottom, or mud-water interface, of Lake Erie was probably much lower than the results obtained in the samples. The Rideal-Stewart modification of the Winkler method was used for the oxygen determinations.

The 22.8 x 22.8 cm. Ekman dredge was used to obtain bottom samples. Four dredge hauls (1/5 sq. meter) were made at each station. Samples were taken only in mud bottom where this form of dredge performs most efficiently. The samples were washed in a screen of about twenty meshes per centimeter. The organisms removed were counted and preserved.

PHYSICAL AND CHEMICAL CONDITIONS

Temperature recordings and oxygen determinations were made at stations A to H (Fig. 1). The temperature records and oxygen concentrations at the top and bottom are shown in Figure 2. These records indicate that temperature and oxygen stratification existed between September 1 and September 4. It is not known when these conditions began to appear, but it is probable that temperature stratification began during the last week of August, followed by a gradual depletion of oxygen near the bottom in the deeper water. Observed differences between the surface and bottom temperatures never exceeded 4° C.

In the several years that Chandler studied this part of the lake, he reported only one instance in which oxygen was below five parts per million. On September 7, 1938, he (Chandler 1940: 304) found that oxygen at the bottom was 4.94 p.p.m. Wright and Tidd (1933: 273) found low oxygen in only one instance in the two years of their study (1929 and 1930), but this occurred near the eastern boundary of the western end of Lake Erie. In contrast to this, all samples taken at the bottom in the deep water between September 1 and September 5, 1953, had less than 5 p.p.m. of oxygen. Stations G and H indicate that

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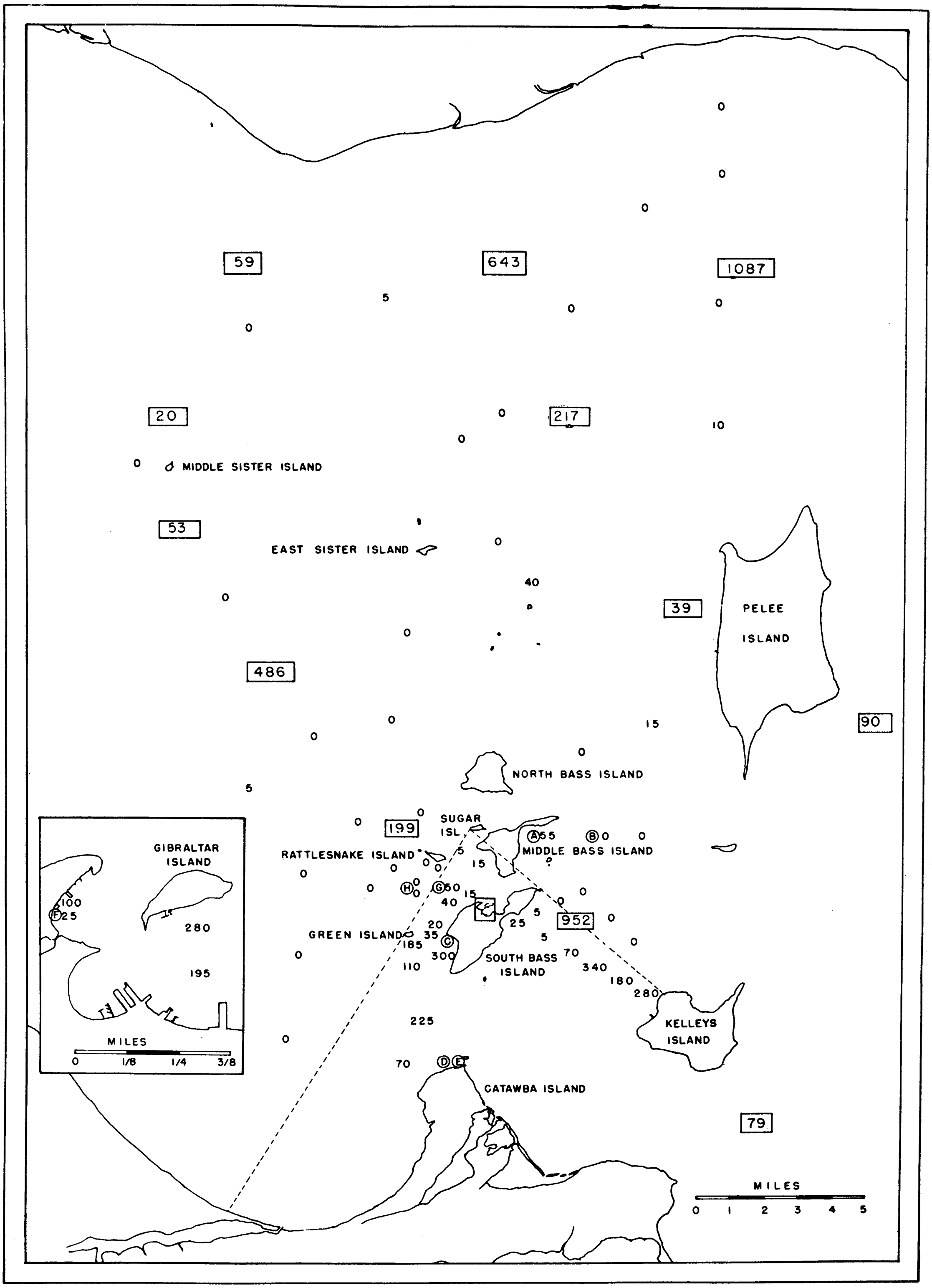

FIG. 1. Map of the Island Section of western Lake Erie. A to H, stations where temperature and oxygen were checked. Small numerals represent the number of living *Hexagenia* nymphs collected per square meter in this study. The larger numerals enclosed in rectangles represent the average number of living nymphs per square meter (from at least 10 samples in each area) collected by Wood in 1951-1952. Dashed lines enclose area where survival of nymphs was greatest.

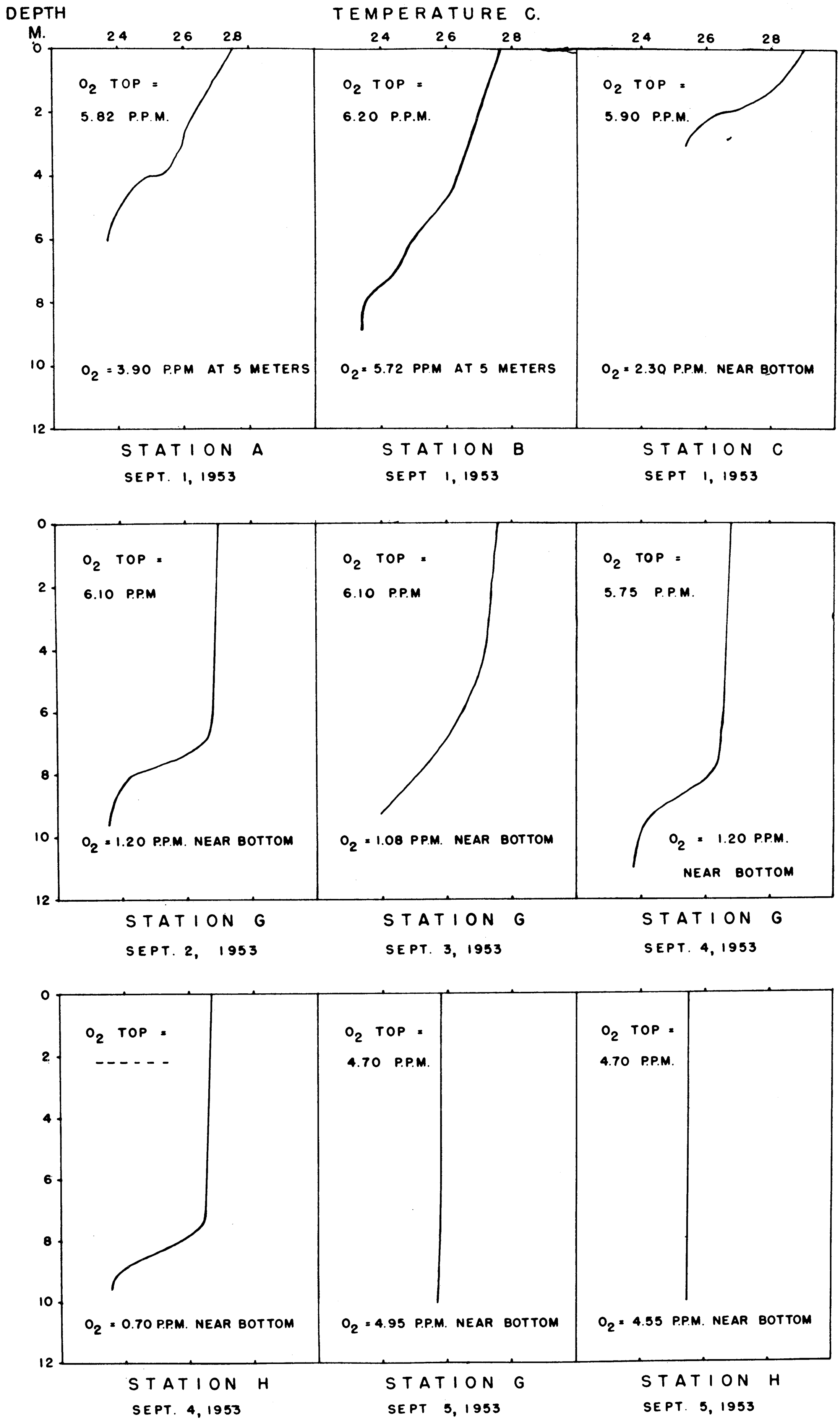

FIG. 2. Temperature and oxygen conditions in western Lake Erie on September 1-5, 1933.

oxygen depletion became gradually worse on succeeding days until circulation was restored on September 5.

The duration of the low oxygen conditions at the bottom is unknown. At station G the maximum value recorded for three days was 1.20 p.p.m. Station H had the lowest value, 0.70 p.p.m., but unfortunately, this station was sampled only once before the stratification was destroyed. It should be noted that even after circulation was again restored, the oxygen levels were low from top to bottom. This appears to be due to the dilution of the better aerated surface water by the low oxygen-content water from the bottom.

Effect on Hexagenia Population

Preliminary studies of the bottom fauna of the area showed that in some places the entire mayfly population, *Hexagenia rigida* McDunnough and *Hexagenia limbata occulta* (Walker), had been killed. Four dredge hauls (1/5 sq. meter) were taken at station H on September 5, at the time when the temperature and oxygen data were taken. The yield per square meter from this sample was 10 living Sphaeriidae, 5 living Hirudinea, 30 Tendipedidae (33% dead), and 465 *Hexagenia* nymphs (all dead). The dead *Hexagenia* nymphs were removed before the sample was processed in the screens. In the screening process, a high-pressure stream of water was used to break up the mud and force it through the screens. It is possible that this rough treatment may have been responsible for the dead Tendipedidae larvae. Some of the *Hexagenia* nymphs were bady decomposed, but were still intact. These nymphs decompose rapidly at high temperatures such as prevailed at that time; therefore, it was estimated that they had been dead only a few hours, or at most only a few days.

Since the population of *Hexagenia* nymphs had been completely destroyed at this particular station, it was desirable to determine the extent of destruction over a larger area. Obviously, the most satisfactory method of obtaining this information would have been to make extensive dredgings before the nymphs had decomposed. Dredging could not be resumed, however, until September 14. Thus at the prevailing temperature there was ample time for the decomposition of any nymphs that had been killed by the low oxygen conditions prior to September 5.

From September 14 to September 26 and on November 13, a total of 61 collections were made in the area between the Canadian Shore and Catawba Island on the south shore of western Lake Erie. Only the *Hexagenia* component of the samples has thus far been analyzed. The results are shown in Figure 1.

Out of a total of 61 collections, 32 (about 52%) contained no living *Hexagenia* nymphs. It should be noted that two subsequent collections from the area where the dead nymphs were found revealed no nymphs. The average number of living nymphs per square meter per collection for the 61 collections was only 44.3. If a line is extended from the west end of Sugar Island to the northwest end of Kelley's Island and another from Sugar Island along the west shore of Green Island to the south shore of the lake as in Figure 1, a total of 38 collections will be outside the acute angle and 23 inside it. The average number of living nymphs per square meter outside the angle was only 3.4 per collection. Inside the angle the average number per square meter was 112 per collection. These averages indicate that at that time a larger population per unit area was present in the relatively small area near the islands and the South Channel than was present in the larger more open areas of the lake. There are at least two possible explanations for this. Since the thermocline was usually below the 6-7 meter depth, the nymphs in the more shallow areas were not subjected to the extremely low oxygen conditions. The other explanation appears to be more complex. The studies on the currents of Lake Erie by Verber (1953) appear to show a movement of water from Sandusky Bay and vicinity into the island area. The survival of a larger population of nymphs in the channels may be due to these currents carrying water of higher oxygen concentration into these areas. Regardless of the cause of this survival, the area is rather small in comparison with the large open areas of western Lake Erie.

In order to show the extent of reduction in the mayfly population, it appears necessary to show that the area studied was previously inhabited by large populations of nymphs. Some data on this subject are found in previous studies made in this locality. Wright and Tidd (1933: 279) reported that in 1929 and 1930 the average number of *Hexagenia* nymphs in the Island Section of Lake Erie was 283 and 510 per square meter respectively. Wood (1953) made a survey of the bottom fauna of western Lake Erie. He used a front iron dredge similar to that described by Richardson (1922: 367-368). He made collections from May 9 to 31, 1951, and from September 24, 1951, to May 26, 1952. Using his conversion factor (0.09 sq. meter), the average volume of sediment per haul (16.3 liters), and the number of nymphs collected per haul, a rough estimate of

320 nymphs per square meter was obtained for the 150 collections made in the present study area. The averages for different parts of this area are shown on the map (Fig. 1). In one area 12 samples gave an average of over 1000 nymphs per square meter. In the present study no nymphs were found in this particular area. In the autumn of 1942 and 1943 Chandler (personal communication) made collections in the island area just south of Rattlesnake Island. The average number of *Hexagenia* nymphs per square meter from the three collections in 1942 was 493. The average for the three collections in 1943 was 351 per square meter.

The writer with the aid of his Limnology classes of 1952 and 1953 made collections in the same area. A total of 388 nymphs per square meter was collected on June 17, 1952. On June 23, 1953, a total of 300 nymphs per square meter was collected. Of the 300 nymphs, 284 were small first-year nymphs. Normally in Lake Erie these do not emerge until the following spring. Therefore, this population should have remained in the area until June or July of 1954. However, collections made on September 16, 1953, showed the nymphs to be absent from the area. Since this was near the area where the 465 dead nymphs were collected, it appears that these nymphs may have suffered a like fate.

Other evidences that the area sampled had recently been inhabited by the nymphs were the presence of deserted burrows in the mud dredged from most of the stations and the abundance of sclerotized parts of the nymphs.

A comparison of the average number of nymphs found in previous years with the numbers collected in this study shows population reductions ranging from a few per cent in limited areas to 100 per cent in much of the open lake.

The cause of the reduction is believed to have been the low oxygen concentration at the bottom, associated with relatively high temperature. Temperature at the bottom did not exceed 24° C. until September 5, when mixing brought the bottom temperature up to about 25.5° C. Even then, the bottom temperature in the deeper water was no higher than that near the shores where survival was greatest. *Hexagenia* nymphs have been kept alive for days in shallow pans of water in the laboratory where the air temperature was as high as 29° C. Therefore temperature alone does not appear to have been the cause of the destruction of the population.

Morgan and Wilder (1936: 168) studied oxygen consumption of the closely related mayfly, *Hexagenia recurvata* Morgan, in winter. They state that this species may survive when the oxygen concentration is as low as 0.50 cc. per liter of water. They showed the metabolic rate of this species to be low in winter and to vary with temperature. Since the highest average temperature used in their experiments was only 12.3° C., it is questionable whether or not their specimens could have survived the above oxygen concentration at temperatures of 24° to 25° C.

At station H on September 4, the oxygen concentration a few centimeters above the bottom was 0.70 p.p.m. or about 0.50 cc. per liter. The oxygen concentration in the mud and in the burrows is unknown, but it probably was much lower than that indicated by the water sample. Therefore, it appears likely that the low oxygen concentration at the bottom was the major cause of the reduction of the *Hexagenia* population in western Lake Erie.

The ultimate effects of the reduction of this population are unknown at the present time, but since these mayflies are known to form a large proportion of the food of several kinds of fishes in Lake Erie, this reduction could have a rather far-reaching effect on the fishes of the area.

Kinney (1950) studied the food of the trout perch, *Percopsis omiscomaycus* (Walbaum), which is an important forage fish in this area. He found that more than half of the adult stomachs from 22 collections contained only *Hexagenia* nymphs. In another case, *Hexagenia* nymphs constituted 96 per cent of the volume of the stomach contents of 162 specimens. Removal of *Hexagenia* from the food of this fish may result in a reduction in the population remaining in this area.

In a study now in progress, Kinney (personal communication) has compiled some comparative figures on the foods found in the stomachs of the silver chub, *Hybopsis storerianus* (Kirtland), another important forage fish in this area. The percentage of specimens containing any food was lower for the September and November collections in 1953 than for the comparable period of 1952. The percentage of specimens containing *Hexagenia* was much lower for 1953 than for the same period in 1952. The volume of *Hexagenia* as per cent of total stomach contents was 67.3 per cent in September 1952 as compared with 4.5 per cent in September 1953, a drop of almost 15-fold. For the month of November the drop was approximately 5-fold between the 1952 and the 1953 collections; however, the 1953 figures are based on a small number of large specimens which may not give a truly representative figure. As mentioned above, there was not only a drop in the *Hexagenia* component of the food of the silver chub, but also a decrease in the percentage of fish that contained any food. This may indicate that the fish have not been able to find enough other food to replace the loss of *Hexagenia* in their diet. If this is true, then a reduced population of silver chub in this area may result.

At certain times, many of the commercial and sport species of fishes in Lake Erie eat large quantities of *Hexagenia* nymphs and adults. Although no specific data are available on this subject at this time, there is the possibility that such a reduction in the *Hexagenia* population may directly influence the feeding habits of these fishes. However, the indirect influence through the small forage fishes is probably more important.

It now appears that the whole economy of western Lake Erie may be affected to some extent by the short period of stratification. While some of the effects are known, the ultimate effects may be very complex, requiring a much longer period of study.

Summary

1. Unusual thermal stratification was observed in western Lake Erie during the period September 1-4, 1953.

2. Oxygen concentrations as low as 0.70 p.p.m. were found near the bottom.

3. Bottom samples collected on September 5, 1953, revealed a total of 465 *Hexagenia* nymphs (all dead) per square meter.

4. In 61 bottom collections made over a large area between the Canadian Shore and Catawba Island on September 14-26, and November 13, 1953, the average number of living nymphs per square meter was 44.3. This was much lower than averages found in other years.

5. The stomach contents of the silver chub, *Hybopsis storerianus* (Kirtland), showed a great reduction in the use of *Hexagenia* nymphs in September and November, 1953, as contrasted with the same period in 1952.

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DEVELOPMENT OF VEGETATION AFTER FIRE IN THE CHAMISE CHAPARRAL OF SOUTHERN CALIFORNIA

J. S. Horton and C. J. Kraebel

California Forest and Range Experiment Station, Berkeley, California[1]

Regrowth of the chaparral cover[2] in southern California after its removal by fire is a phenomenon of more than academic interest. Ecologists are interested because of the remarkable ability of the chaparral species to persist where fires are of common occurrence. Foresters and others who manage wild lands are interested because the return of vegetation on fire-denuded watersheds means reduction of the severe erosion hazard

[1] Maintained by the Forest Service, U. S. Department of Agriculture, in cooperation with the University of California, Berkeley, California.

[2] "Cover" as used in this paper refers to all the vegetation growing on a given area, and does not refer to "density" or to "coverage" as generally used by ecologists.