A LIMNOLOGICAL RECONNAISSANCE OF GRAND MESA, COLORADO*

By Robert W. Pennak†

Since 1938 the writer has been concerned with several aspects of the comparative limnology of northern Colorado (Pennak, 1941, 1945, 1945a, 1946), and especially with the wide variety of lakes occurring within a radius of 40 miles of the University of Colorado and lying at altitudes of 1500 to 3800 meters (roughly 5000 to 12,500 feet). Numerous friends and colleagues, being acquainted with this program, often spoke of an interesting group of lakes in another part of the state—namely, the lakes of Grand Mesa in western Colorado. It was not until August, 1947, however, that the writer had an opportunity to visit this region and make observations and limnological determinations. The present paper is based on that visit and constitutes a brief preliminary account of the limnology of the Mesa, particularly as compared with lakes at similar altitudes in north-central Colorado.

GENERAL CHARACTERISTICS OF GRAND MESA

Grand Mesa is large, relatively flat-topped, but hilly and rolling. It lies in west-central Colorado about 60 to 80 miles from the Utah line and is an offshoot of the main north-south mass of the Rocky Mountains. In outline the Mesa is roughly elongated and extends in a west-southwesterly direction, but the western extremity is bilobed (Fig. 1). The altitude of the Mesa top varies between 2740 and 3230 meters (9000 and 10,600 feet), the 9000-foot contour being an approximation of its edge. From the periphery of the Mesa there is a sharp drop to the Colorado and Gunnison river valleys on the north and south, respectively. Though only 10 to 20 miles from the Mesa, these rivers are at altitudes of 1520 to 1830 meters (5000 to 6000 feet). In some places the edge of the Mesa forms a sharp escarpment, but the top is accessible by three fair gravel roads, each with numerous switchbacks. A gravel road also traverses most of the length of the Mesa top from west to east and passes close to most of the larger lakes.

The surface deposits of about two thirds of the area within the 9000-foot contour in Figure 1 are lavas, especially andesite and basalt. Rocks of the other one third, particularly at the periphery of the Mesa, are sedimentary.

Annual precipitation on the Mesa totals about 30 inches, but it is only 10 to 15 inches in the valleys to the north and south.

* Contribution No. 15, Limnology Laboratory, Department of Biology, University of Colorado. This investigation was made possible through grants from the Penrose Fund of the American Philosophical Society and the University of Colorado Graduate School Research Fund. The author is most grateful for such aid.

† Professor of Biology.

Above the 9000-foot contour the terrain is generally covered with almost pure stands of Engelmann spruce (*Picea engelmanni*) and alpine fir (*Abies lasiocarpa*). The forest has an abundance of open meadows characterized by heavy growths of grasses and forbs.

THE LAKES IN GENERAL

For its area, Grand Mesa has an incredible number of lakes, about 220 being shown in Figure 1. In addition, there are probably more than a thousand permanent ponds of various sizes which could not be drawn to scale for Figure 1. Most of the lakes are small, the largest one (Eggleston Lake) being only about one quarter of a mile wide and one and one quarter miles long, with an area of about 200 acres. Island Lake (Plate 2, B) is only slightly smaller. Few of the lakes have areas exceeding 50 acres (20 hectares). The five largest lakes were sounded by the writer, but the greatest depth recorded was only 20 meters, in Ward Lake (Plate 2, A). Local fishermen nevertheless insist that this lake is more than 2000 feet deep! Unquestionably the great majority of the lakes have maximum depths of less than 8 meters.

Many of the ponds are seepage ponds with no surface inlet or outlet, but only a very few of the lakes shown in Figure 1 are seepage or semidrainage, nearly all being on small streams that drain continuously into the Colorado or Gunnison systems. Although all of the Mesa lies within the boundaries of Grand Mesa National Forest, the drainage systems are utilized considerably for irrigating cultivated fields and orchards in the valleys below the Mesa. In order to conserve as much water as possible for utilization during critical periods in crop development, the outlets of many lakes have been supplied with head gates; some lakes have been deepened by the construction of earthen dikes along one or two sides; and some irrigation supply ditches have been constructed, which draw off water directly from lakes and streams on the Mesa top and bring it to cultivated areas below. In fact, a great many of the bodies of water are called "reservoirs" rather than lakes. Depending on the need for water and the specific location and morphometry of a lake, its water level may be lowered by as much as two to four meters by late August as compared with the spring level. Such lakes with wide fluctuations have a poor littoral flora and fauna. Plate 1, A (Military Park Reservoir) shows a lake which provides an example of excessive water utilization; the maximum depth in the spring is about 5 meters and the area about 40 acres, but when the photograph was taken on August 20 it had a maximum depth of only 1 meter and an area of about 3 acres. Fortunately the levels of the larger lakes, where most of the fishing is done, do not appear to fluctuate more than a meter during the year.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE LAKES

Between August 20 and 25, 1947, various limnological determinations were made on 13 Grand Mesa lakes. These bodies of water are indicated by number in

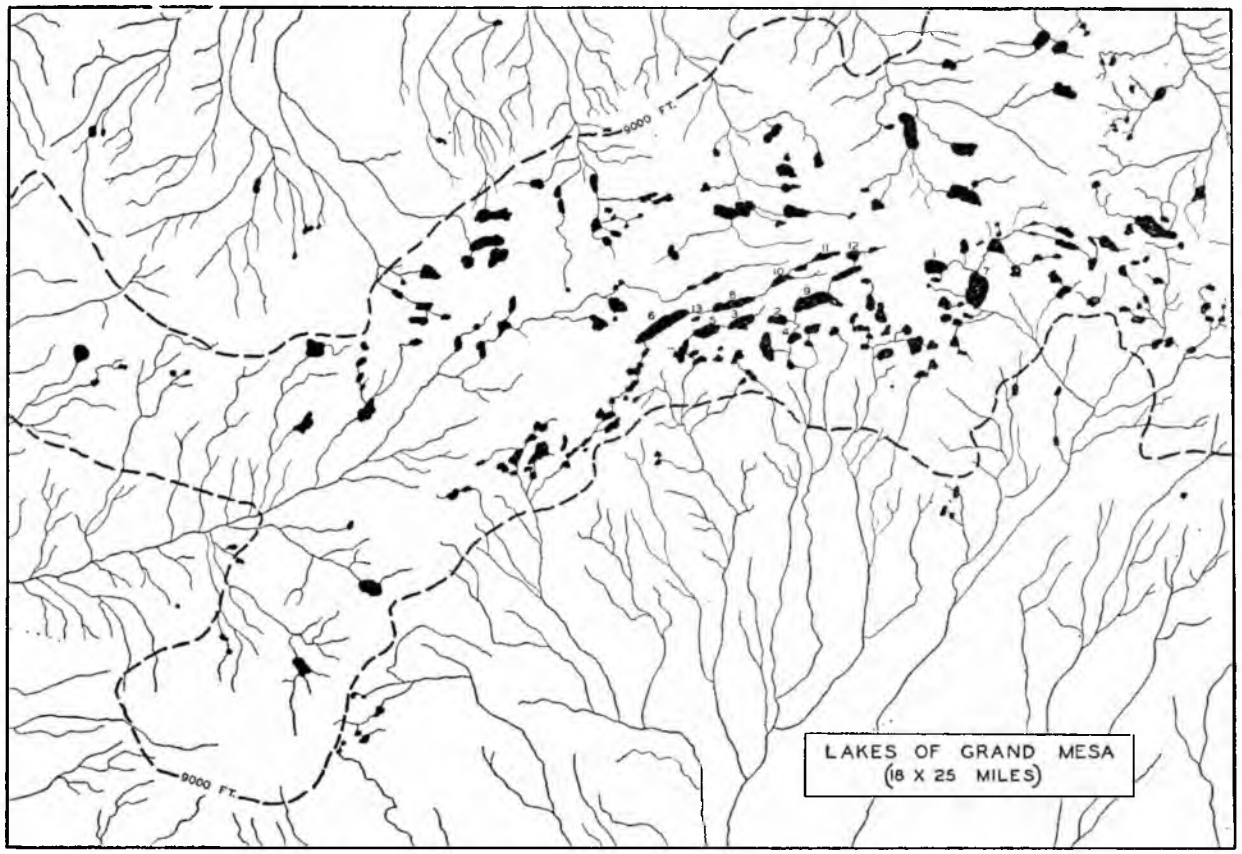

FIGURE 1. Grand Mesa, Colorado lake district. Nine-thousand-foot contour roughly represents the edge of the Mesa. Colorado River drainages to the north; Gunnison River drainages to the south.

Table I and Figure 1. Though they are all within a relatively small area, preliminary observations on more distant parts of the Mesa showed that they are undoubtedly typical and representative of the range of limnological conditions obtaining on the Mesa. Some of these lakes are shown in Plates 1 to 4.

In size, they ranged from about 3 acres (Military Park Reservoir) to 200 acres (Eggleston Lake). Depths ranged from 1 meter (Military Park Reservoir) to 20 meters (Ward Lake). Shore lines and littoral zones were variously composed of rocks, gravel, sand, organic mud, clay, and mixed materials. Barron Lake had extensive areas of rooted floating and emergent vegetation; Bullfinch Lake had a

TABLE I

Limnological characteristics of some lakes of Grand Mesa, Colorado, August 20 to 25, 1947

Lake		Maximum depth, meters	pH		p.p.m. free CO_2		p.p.m. bound CO_2		Total residue, mg. per liter	
Name	Number		Surface	Bottom	Surface	Bottom	Surface	Bottom	Organic	Ash
Military Park Res.	1		8.7		−1.8		22.0			
Barron Lake	2	10.4	8.2	6.4	−2.4	44.8	22.0	32.3		
Alexander Lake	3		8.7		−2.0		18.8			
Reed Lake	4		8.7		−1.4		18.8			
Ward Lake	5	20.0	8.4	6.6	−3.7	7.8	18.0	25.1	10.39	28.26
Island Lake	6		8.3		−1.7		17.7			
Trickle Park Res.	7		8.7		−2.5		17.5			
Hotel Twin Lake	8	9.4	8.4	6.4	−2.0	51.4	17.5	31.7	14.21	16.02
Eggleston Lake	9	13.6	8.5	6.6	−0.3	33.4	15.8	41.4	10.50	26.98
Forest Lake	10		8.9		−2.0		12.0			
Butts Lake	11		7.4		3.8		9.4			
Bullfinch Lake	12		7.1		4.0		8.6			
Carp Lake	13	9.4	7.1	7.0	3.3	2.4	7.3	7.1		

few water lilies; all of the lakes had varying quantities of rooted submerged aquatics, but in Island and Butts lakes these growths were very scanty.

As shown by Table I, these 13 lakes appear to fall into two distinct categories. The first ten in this list are drainage lakes with regular inlets and outlets. Three typical drainage lakes are shown in Plates 1, B; 2, A; and 2, B (Barron, Ward, and Island lakes). Their surface waters were all decidedly alkaline, with readings ranging from pH 8.2 to 8.9. Free carbon dioxide determinations on the surface waters all gave negative values, ranging from −0.3 to −3.7 p.p.m. and indicating photosynthetic activity. According to the water-hardness criteria suggested by Pennak (1945a), their surface waters were all medium with respect to bound carbon dioxide, the range being 12.0 to 22.0 p.p.m.

Vertical series of hydrogen ion determinations, free carbon dioxide, bound carbon dioxide, dissolved oxygen, and temperature readings were made on four of the deeper drainage lakes (Barron, Ward, Hotel Twin, and Eggleston). All four showed pronounced stratification. Bottom hydrogen ion concentrations were 6.4 and 6.6. Three had large accumulations of free carbon dioxide in the bottom waters, ranging from 33.4 p.p.m. in Eggleston Lake to 51.4 in Hotel Twin Lake; Ward Lake was exceptional in having only 7.8 p.p.m. at a depth of 15 meters. All four had the characteristic late summer accumulations of bound carbonates in the bottom waters. Secchi disc readings ranged from a minimum of only 1.6 meters in Ward Lake to a maximum of 4.8 meters in Barron.

Temperature and oxygen stratification curves (Fig. 2) were similar for these four drainage lakes, with surface temperatures ranging from 14.1° to 16.3° C. and thermoclines somewhere between 4 and 8 meters. Oxygen was above the saturation point in the top four to seven meters and reached 120 per cent saturation in the surface sample at Ward Lake, while the lowermost two to five meters were below 10 per cent saturation with hydrogen sulphide being present in the deepest water samples.

The last three lakes listed in Table I are clearly in a different category (Plates 3, A and B, and 4, A). Butts and Bullfinch are semidrainage lakes (see discussion in Pennak, 1945a) and have small inlets and outlets only in occasional years and for only part of the year. Carp Lake is a seepage lake and is fed by springs and seepage; it has no surface inlet or outlet. The surface waters of these three lakes were all near neutrality, with a hydrogen ion concentration ranging from pH 7.1 to 7.4. Free carbon dioxide ranged from 3.3 to 4.0 p.p.m. and bound carbon dioxide from 7.3 to 9.4 p.p.m. All three therefore are soft-water lakes. Vertical series of temperatures and dissolved oxygen determinations in Carp Lake revealed no stratification and complete circulation (Fig. 2)—a situation undoubtedly maintained by the springs in this lake. The disc reading was 8.1 meters, which is exceeded in Colorado only by Grand Lake (in the northern part of the state), where 9.2 meters has been recorded by the writer.

PLANKTON

Vertical series of quantitative zooplankton samples were taken with a ten-liter trap in Barron, Ward, Eggleston, Hotel Twin, and Carp lakes. The dominant copepod in all of these lakes was *Cyclops bicuspidatus*; in addition, both Ward and Eggleston contained *Diaptomus tyrelli*, the former in abundance. The cladoceran *Daphnia longispina* was also present in all five of these lakes; a few *Chydorus sphaericus* were taken in Barron Lake and a few *Bosmina longirostris* in Hotel Twin. The rotifer populations consisted chiefly of such common species as *Keratella quadrata, Filinia longiseta, Polyarthra vulgaris, P. major, Conochilus unicornis,* and

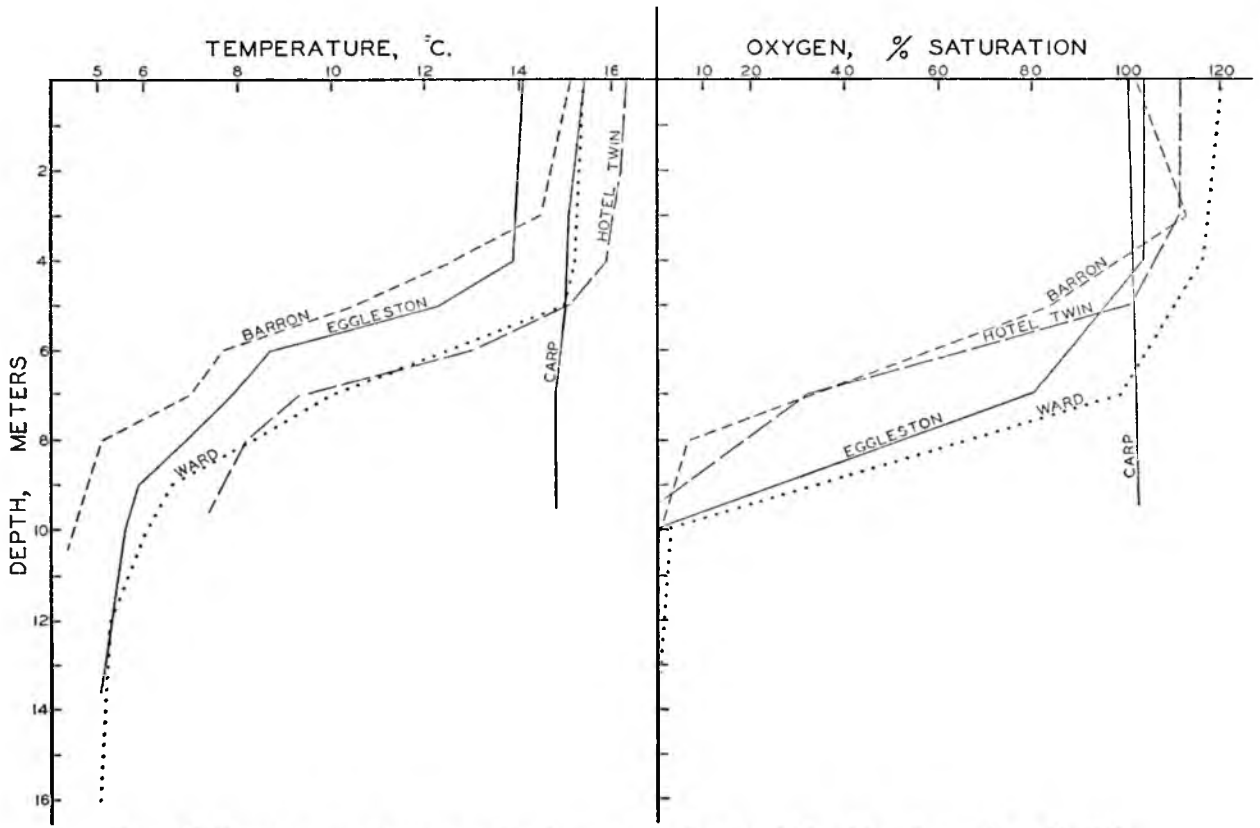

FIGURE 2. Temperature and oxygen stratification curves for five Grand Mesa lakes, August 20 to 25, 1947.

Euchlanis dilatata. *Ceratium hirundinella* was the only abundant unicellular zooplankter, but it was absent from Hotel Twin Lake. Because the zooplankton samples were taken between 10 AM and 2 PM, the organisms were always most abundant in the lower half of the lakes; this condition was to be expected in view of the daily cycle of vertical movements in response to subsurface illumination.

Table II is a summary of the zooplankton populations in these five lakes. So far as Colorado mountain lakes are concerned, Barron, Ward, Eggleston, and Hotel Twin lakes all had exceptionally large populations of entomostraca, totaling 244, 238, 91, and 58 per liter, respectively; the first two figures are particularly striking. Carp, the seepage lake, had a negligible population of entomostraca, totaling only 19 per liter; comparable populations in northern Colorado have been found only in alpine lakes.

TABLE II

Zooplankton of some lakes of Grand Mesa, Colorado, August 21 to 24, 1947, expressed as average numbers of organisms per liter, surface to bottom

Lake	Organisms per liter			
	Copepoda	Cladocera	Rotatoria	Protozoa
Barron	227	17	159	243
Ward	215	23	79	701
Eggleston	56	35	413	7
Hotel Twin	36	22	153	—
Carp	14	5	33	12

The rotifer and protozoan populations were highly variable and not particularly different from the variety of conditions obtaining in groups of lakes elsewhere. Rotifer populations ranged from 33 per liter in Carp Lake to 413 per liter in Eggleston Lake. *Ceratium* was most abundant in Ward Lake where it averaged 701 per liter.

Only superficial observations were made on the phytoplankton populations. However, so far as high-altitude lakes are concerned, Ward Lake had an unusually large crop of *Anabaena*. In fact it was a well-defined "bloom", the algae being so dense that the Secchi disc reading was only 1.6 meters. Though not dense enough to be called a bloom, there was a heavy crop of *Fragilaria*, *Asterionella*, and *Anabaena* in Eggleston Lake. Hotel Twin Lake likewise contained an abundance of *Asterionella* and *Anabaena*. The total particulate organic matter (seston) for the surface waters of these three lakes was also high for mountain lakes, a further indication of unusual production. In Ward, Eggleston, and Hotel Twin lakes it amounted to 2.13, 1.94, and 1.20 mg. per liter, dry weight, respectively. Carp

Lake, at the other extreme, had a negligible algal population; it consisted of a few diatoms.

No bottom samples were taken, but, judging from the numerous flights of midges, there must have been a rich fauna in some lakes.

COMPARISON WITH NORTHERN COLORADO LAKES

Disregarding the few atypical semidrainage and seepage lakes, the lakes of Grand Mesa differ from lakes of comparable altitudes in northern Colorado in several ways. First, all of the ten Mesa drainage lakes studied were rather homogeneous and decidedly alkaline, whereas of 40 montane lakes in northern Colorado the writer has recorded only two whose surface waters gave readings above pH 8.0.

Further, bound carbon dioxide varied but little in the Mesa lakes, the range being 12.0 to 22.0 p.p.m. This condition is in contrast to the range of 4.1 to 47.0 p.p.m. in northern Colorado montane lakes. The average for the former, however, was 18.0 p.p.m. as compared with 14.0 for the latter, but this difference is not significant.

A third difference is the fact that the Mesa lakes had much more pronounced late-summer oxygen stratification and greater depletion in the bottom waters than do montane lakes in the northern part of the state. This condition is probably a reflection of the unusually large plankton populations and high seston determinations in typical Mesa lakes. Zooplankton populations of Barron, Ward, Eggleston, and Hotel Twin lakes were more nearly like populations in the productive lakes of the plains zone of northern Colorado (Pennak, 1946). Similarly, the Mesa lakes' phytoplankton populations were greatly in excess of those occurring in the northern montane area; such blooms and near-blooms are unknown in the latter.

It is probable that the generally greater production by the Mesa lakes is due to the fact that weathering of the lavas contributes significantly greater amounts of essential plant nutrients to these waters. In northern Colorado the exposed rocks are mostly schists, gneisses, and granites, as compared with andesites and basalts of the Mesa.

PONDS OF THE MESA

Only incidental notes were made on the Mesa ponds, though scores of them were seen. In size, these ponds range from mere puddles 3 or 4 meters in diameter to others as large as an acre or two. Most of them appear to be permanent bodies of water; some are on drainage channels; others are dependent on seepage or surface drainage into small, isolated depressions. Depth varies from a few centimeters to about a meter.

The periphery and substrate are variously composed of sand, gravel, pebbles, rocks, organic mud, and organic debris which has blown or fallen in. Some ponds

PLATE 1

A. Military Park Reservoir at low water.

B. Barron Lake, Grand Mesa.

PLATE 2

A. Ward Lake, Grand Mesa. The deepest spot, 20 meters, is about in the center of the photograph.

B. Island Lake, Grand Mesa.

A. Butts Lake, Grand Mesa. A semidrainage lake.

B. Bullfinch Lake, Grand Mesa. A semidrainage lake.

A. Carp Lake, Grand Mesa. A semidrainage lake.

B. A typical forest pond of Grand Mesa. Note the figure on the far shore.

contain no rooted aquatic vegetation; others have rank growths. There is also a wide variation in the composition of the aquatic insect and entomostraca populations. Plate 4, B, shows a typical forest seepage pond with a rocky bottom and poor fauna.

FISHES OF THE MESA LAKES

Though there are reputed to be more than 100 miles of trout streams on Grand Mesa, they are quite small and support only a negligible fish population. In spite of the abundance of lakes, their total area is relatively small, and fishing pressure is heavy, especially in the lakes along the main east-west road of the Mesa.

About 60 lakes are said to stocked regularly by the Forest Service, but the great majority of fish are planted in the ten or twelve lakes that receive more than 90 per cent of the fishing effort. Most of the plantings are legal-sized rainbow trout (*Salmo gairdnerii*), the most successful species, but some cutthroats (*S. clarkii*) and brooks (*Salvelinus fontinalis*) are also planted.

Some fly and bait fishing is done from the shores, but most of the fish are taken by trolling from rowboats with long tandem spinners and spoons. Although the writer examined catches totaling about 100 trout, none of the fish were more than 12 inches long.

Only recently has the sucker (*Catostomus commersonnii*) become sufficiently abundant to be a nuisance and serious competitor of the trouts. The level of one lake was being lowered in preparation for an efficient rotenone treatment early in September, 1947, in order to eliminate the large sucker population. Incidentally, Carp Lake is a decided misnomer; this species is certainly not present on the Mesa.

LITERATURE CITED

PENNAK, R. W.

1941 "An Introduction to the Limnology of Northern Colorado," *University of Colorado Studies, Series D*, 1: 203–220.

1945 "Hydrography and Morphometry of Some Northern Colorado Lakes," *Ibid.*, 2: 245–262.

1945a "Some Aspects of the Regional Limnology of Northern Colorado," *Ibid.*, 263–293.

1946 "The Dynamics of Fresh-water Plankton Populations," *Ecological Monographs*, 16: 339–356