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Limnology and Fish Stocking Feasibility Report of Bass and Wildcat Lakes

(*Point Reyes National Seashore*)

by Thomas Johnston

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Abstract

A limnology survey of Bass and Wildcat Lakes was conducted to understand the feasibility of planting fish in the two lakes. In addition, an explanation was found for the existence of a population of fish in nearby Crystal Lake. The lake survey found that the eutrophic nature and strong thermocline of Bass and Wildcat Lakes instigates a cycle where hydrogen sulfide is produced in the summer hypolimnion. The fall overturn mixes the hydrogen sulfide throughout the lake causing fish in the lake to perish. On the other hand, in the relatively shallow Crystal Lake, continual vertical mixing of the lake's water ensures an adequate supply of oxygen for fish throughout the entire year and prevents the production of hydrogen sulfide.

To illustrate the destructive potential of hydrogen sulfide to fish, a number of examples from the literature were cited [29] [30] [31]. The lake studies cited are similar to Bass and Wildcat Lakes and conclusively show the serious and persistent problem hydrogen sulfide is in a lake. In order to make either of the lakes available for a self-sustaining fish population, alteration would have to be taken on their natural states. Two options are discussed, aeration and copper sulfate treatment. Finally, a less radical management proposal of Bass and Wildcat Lakes is mentioned. Either a yearly stocking of catchable size fish can take place or the lakes can be left in their natural state.

Introduction

In the summer of 1984, Park Rangers Dave Self and Ranlett and myself undertook a freshwater fish survey of the lakes and creeks in Point Reyes National Seashore. [2] The findings of the survey were especially interesting in a cluster of three lakes along the coast-Bass Lake, Wildcat Lake and Crystal Lake. The first and largest lake sampled, Bass Lake, found our nets devoid of fish. At first we wondered whether the nets were effective at catching fish. The next day, however, we placed the nets in Crystal Lake with completely different results. This time the nets were full. The fish caught in Crystal Lake included twelve healthy Largemouth Bass, three Sacramento Suckers, and fifty five Golden Shiners of various sizes. Similar to Bass Lake, the last lake we sampled, Wildcat Lake was devoid of fish

As a group, John, Dave, and myself discussed the reasons for our findings and, most importantly, the question of whether fish could be planted in Bass or Wildcat lakes. It became clear that we lacked the information to come to any answers. The need for a detailed limnology survey of Bass and Wildcat Lakes became apparent. A planned study would access the feasibility of stocking the lakes with fish. Also, it was hoped that a clear reason for the presence of fish only in Crystal Lake could be found.

Field work for the report started in January of 1985 and continued till September of the same year. This report will address the results of the field work and describe a number of management options for the lakes.

For a temperate lake the year long cycle begins with the natural process of lake stratification, that is, two distinct layers of water separated by a thermocline (metalimnion).

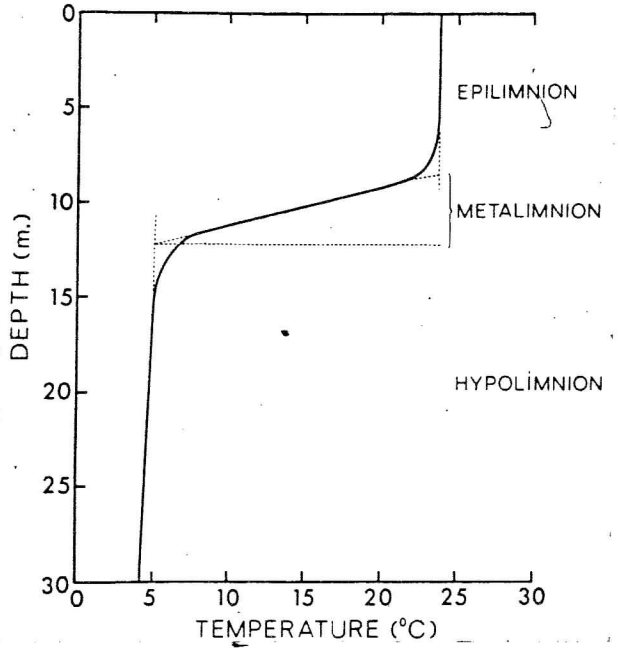


Figure 9, Typical thermal stratification in a lake. [20]

In lakes in the temperate zone, the water above the thermocline in the epilimnion is much warmer and lighter than the colder, more dense bottom water. As the warmer months continue the thermocline becomes more pronounce, deep and stable. The thermocline becomes more pronounced until the cool months of the fall begins. The cooling of the surface waters causes the newly formed cooler and dense surface water to sink. A critical point occurs where the now cooler surface water, helped by a windy storm, displaces the bottom water, forcing it upward in what is known as the fall overturn.

Until the fall overturn there is no mixing of the hypolimnion and epilimnion waters between the thermocline. A lakes will have separate, noninteracting water layers. This is the core of the problem for the lack of fish in many temperate lakes. Dissolved oxygen is needed by fish and other aquatic organisms to survive. Because the bottom water remains stagnant and is not oxygenated, the biological processes soon uses up the oxygen in a temperate lake's hypolimnion, opening the potential for a fish kill.

Typically, the main user of dissolved oxygen of a lake's hypolimnion is bacteria decomposing biological matter that has sunk to the lake bottom [6]. The explosive populations of the algae eventually die and rain down to the hypolimnion of the lake. The increased organic matter raining down causes an increase in the concentration of bacteria which uses up the oxygen in performing their needed task. Another consumption of oxygen, however less important, is plant and animal respiration [8].

If the hypolimnion is too limited in size to store enough oxygen an oxygen deficiency occurs. At this point fish must swim to more oxygenated waters or perish. The bacteria that existed in an oxygen-rich environment can no longer live and are replaced by their anaerobic bacteria counterparts.

The anaerobic bacteria profoundly change the chemical environment of the hypolimnion. The decomposition of the anaerobic bacteria oxidizes hydrogen sulfate (SO_4) into hydrogen sulfide (H_2S), which, unfortunately is effectively sealed off at the bottom. As decomposition of organic matter continues so does the build up of hydrogen sulfide. When fall finally arrives, the surface water cools and the fall overturn occurs. This breaks the thermocline and brings the smelly hydrogen sulfide to the surface which causes the objectionable odor of rotten eggs. If enough hydrogen sulfide is built up over the summer, the fall overturn will cause a massive fish kill by depriving the water of oxygen or by direct contact of hydrogen sulfide by the fish. The build up of hydrogen sulfide in the hypolimnion of a temperate lake can make lakes uninhabitable for a sustained fish population.

Sample Sites

Bass Lake:

Bass Lake is a temperate coastal lake of small surface area and great depth. The lake lies at 38 degrees North latitude, 1400 meters form the coastline and is 117 meters above sea level.

The greatest depth of Bass Lake obtained in the survey was 16 meters. The bottom sediments of the lake had the smell of hydrogen sulfide.

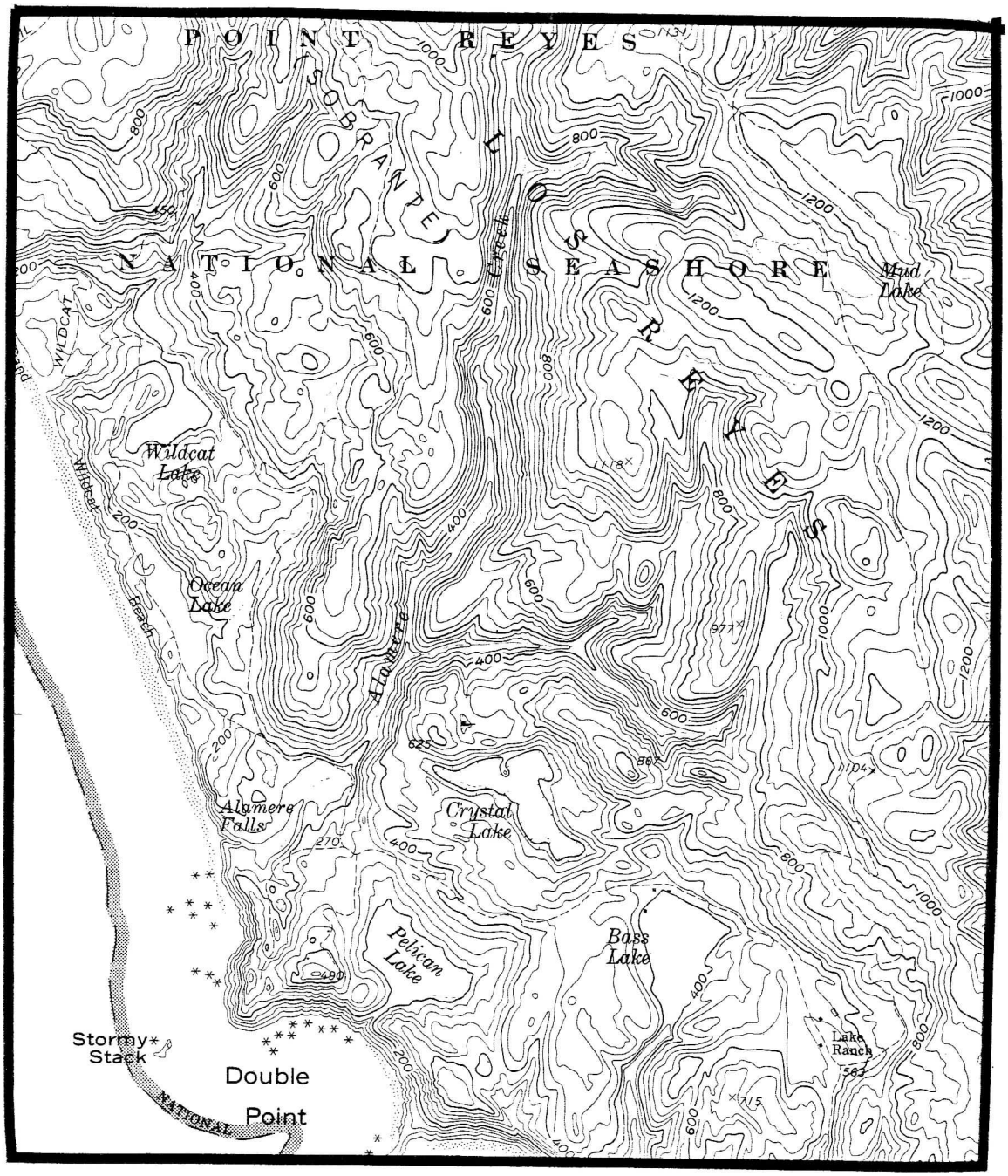
The shore of Bass Lake is very steep. A dense yet limited amount of macrophytes is present along the shore. Over the nine months that the lake was sampled, only a slight decrease of less then half a meter in the water level was observed. The Lake is fed by two small streams which normally flow year around. The surface drainage of Bass Lake is reported to be 163 acres and the surface area of the lake is 7.4 acres. [3]

Wildcat Lake:

Wildcat Lake is a small coastal freshwater lake. Like the other nearby lakes studied, Wildcat Lake lies 38 degrees North latitude and is high enough above sea level such that there is no interaction with the ocean. The bands along Wildcat Lake are full of macrophytes that extend out only a short distance from shore. The lake lacks any substantial shallow water. By observation, the surface area of Wildcat Lake is less than Bass Lake; however, no accurate surface area measurements off Wildcat Lake has been taken.



Location of Lakes in California.



Topographical Map of Bass, Wildcat and Crystal Lakes.

Method

"The Analytical Methods in Oceanography" Manual was used for all the analysis. [1]

Phosphorus:

For phosphate analysis samples were placed in polyethylene bottles and frozen. A method reported by Striclandf and Parsons was used (A practical Handbook of Seawater Analysis, 2nd ed., 1972). In the method samples are treated with a mixed reagent solution containing molybdate ion and ascorbic acid. The phosphate present reacts to form phosphomolybdic acid. Ascorbic acid reduces this to a blue color complex. The light absorbence at 885 nm is proportional to the original phosphate.

Nitrates:

For nitrates a method reported by Strickland and Parson was used (A practical Handbook of Seawater Analysis 2nd ed., 1972) Samples were passed through columns containing copper-clad cadmium. With the copper acting as a catalyst, nitrate is reduced to nitrite by the cadmium. Sulfanilanide in an acidic solution is diazotized in the presence of nitrite. It is subsequently coupled to N-(1-Naphthyl)-Ethylenediamine to give a red color whose absorbence of 543 nm light is proportional to the original nitrate concentration. Nitrite concentrations in the water are assumed to be negligible.

Oxygen:

Dissolved oxygen determinations were all made by a slight modification of Carpenter's procedure for the classical Winkler titration (Limnology. Oceanography 10: 14-143 1965).

Results

Bass Lake:

Date	Depth(m)	Oxygen(um/l)	Nitrate(um/l)	Phosphate(um/l)	Temperate(C)
1-27-85	1	272	11.24	0.45	10.5
	5	247	20.34	0.51	10.0
	10	242	23.15	0.46	10.0
	12	245	22.96	0.55	10.0
2-23-85	0	393	0.54	0.48	13.2
	3	434	1.77	0.69	12.0
	5	278	17.51	1.28	10.5
	12	175	42.83	0.90	9.8
3-29-85	0	323	3.16	0.62	14.5
	3	321	3.18	0.36	13.2
	4	326	2.94	0.27	13.0
	6	230	10.79	0.90	12.5
	11	101	27.30	0.74	10.5
4-27-85	1	370	0.22	0.13	17.0
	3	323	0.42	0.16	16.9
	6	205	18.09	0.43	13.8
	8	123	30.45	0.35	12.1
	12	28	25.05	0.49	10.0
	14	32	-----	----	10.5
6-29-85	1	388	0.52	0.06	21.5
	4	412	0.51	0.08	21.0
	7	147	13.34	0.49	16.2
	9	77	21.60	0.68	13.5
	12	56	16.48	2.66	11.5
	14	0	4.05	2.26	11.0
7-27-85	2	285	0.26	0.09	21.5
	6	266	----	0.09	21.1
	8	18	0.29	0.35	18.8
	10	22	18.79	0.73	14.0
	12	19	12.85	4.75	12.0
	15	0	0.34	----	11.0
8-29-85	0	---	0.52	0.12	21.0
	4	---	0.73	0.12	19.5
	9	---	0.48	0.50	17.5
	14	---	0.16	3.85	11.0

Wildcat Lake:

Date	Depth(m)	Oxygen(um/l)	Nitrate(um/l)	Phosphate(um/l)	Temperature(C)
2-23-85	1	319	34.44	2.62	13.0
	3	16	19.38	2.42	12.0
	6	16	4.47	12.74	11.0
3-29-85	0	326	39.91	2.03	13.5
	3	294	33.72	4.76	13.2
	5	92	23.21	3.77	12.5
	7	0	0.50	2.96	12.0
8-29-85	0	196	0.29	0.35	18.5
	2	171	0.61	0.28	18.0
	4	0	0.16	1.58	15.5
	6	0	0.34	6.88	13.5
	8	0	0.52	7.99	11.0
Crystal Lake:					
8-29-85	0	266	0.63	0.20	19.0
	2	264	0.52	0.10	18.7
	4	258	1.7	0.10	18.8

Figure 1 Bass Lake Temperature-depth Profiles

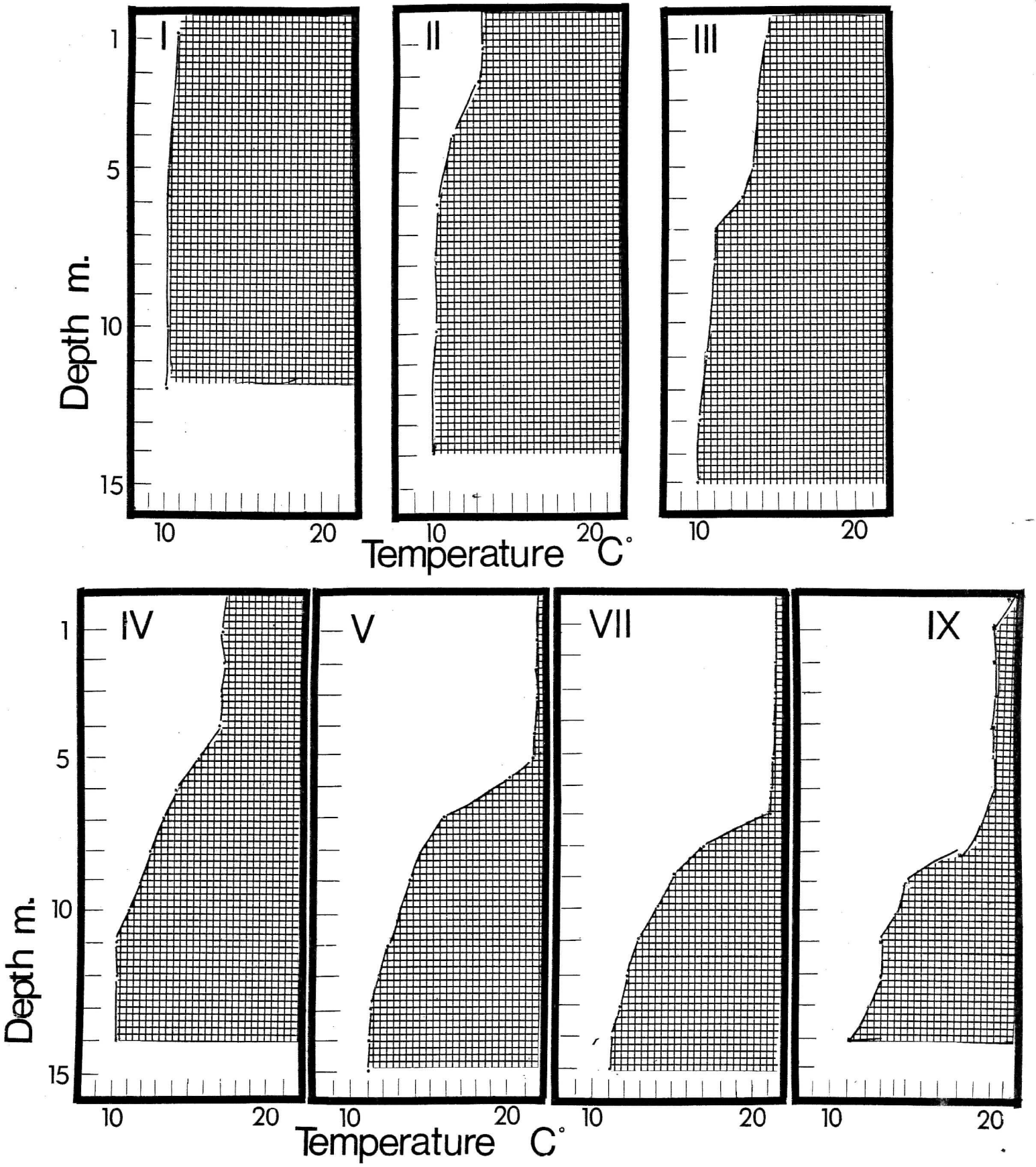


Figure 2 Bass Lake Phosphate-depth Profiles

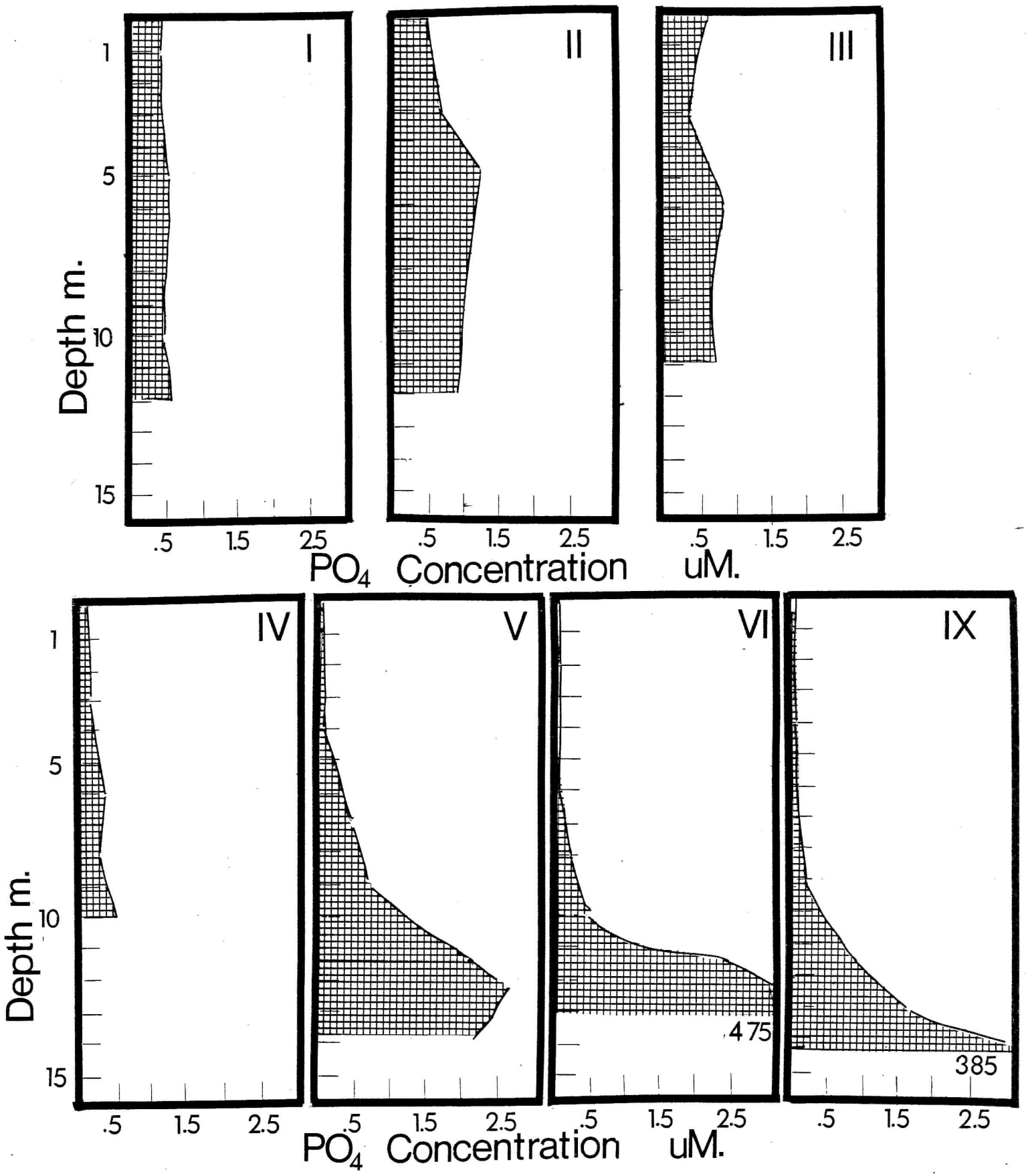


Figure 3 Bass Lake Nitrate-depth Profiles

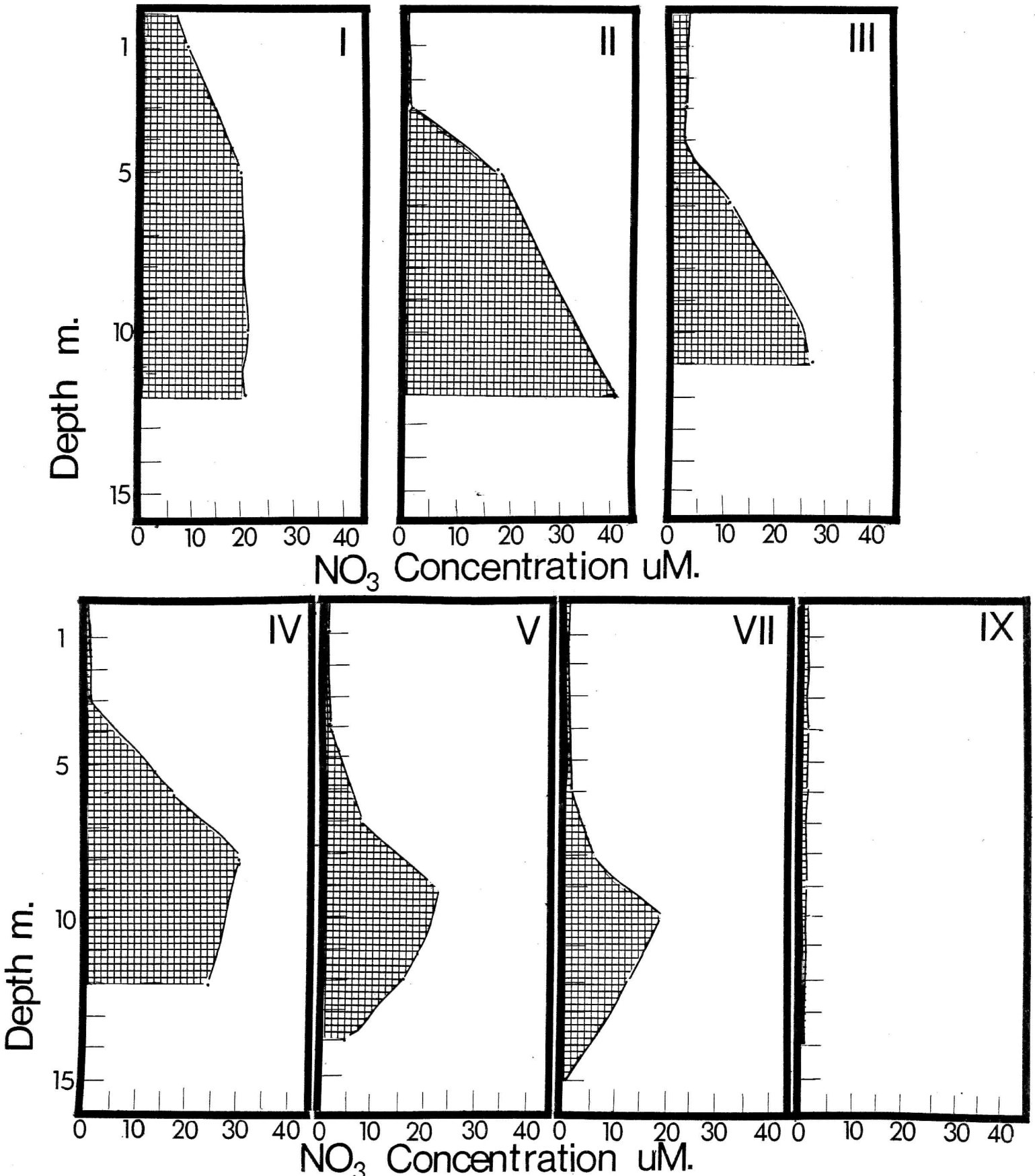


Figure 4 · Bass Lake Oxygen-depth Profiles

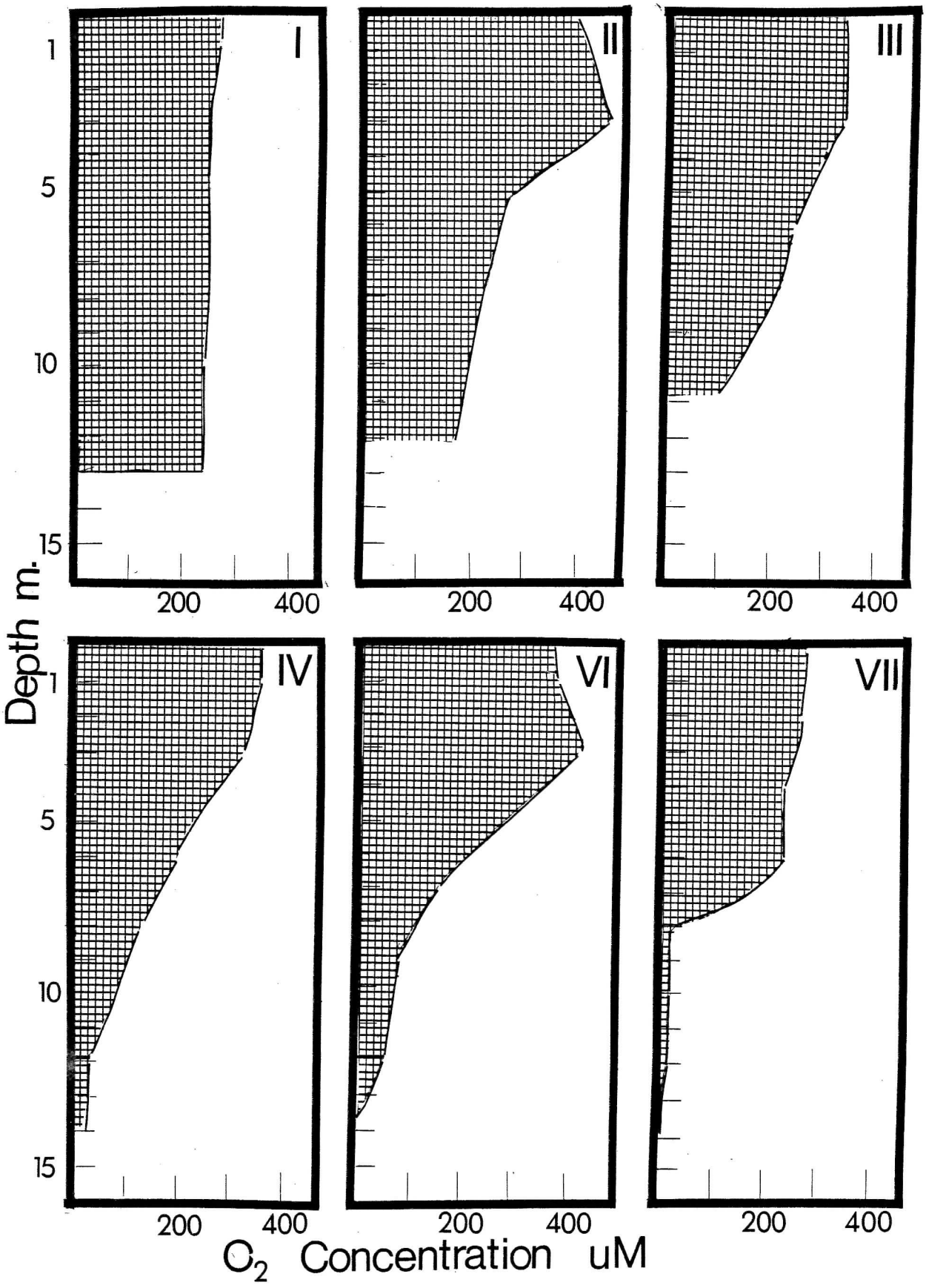
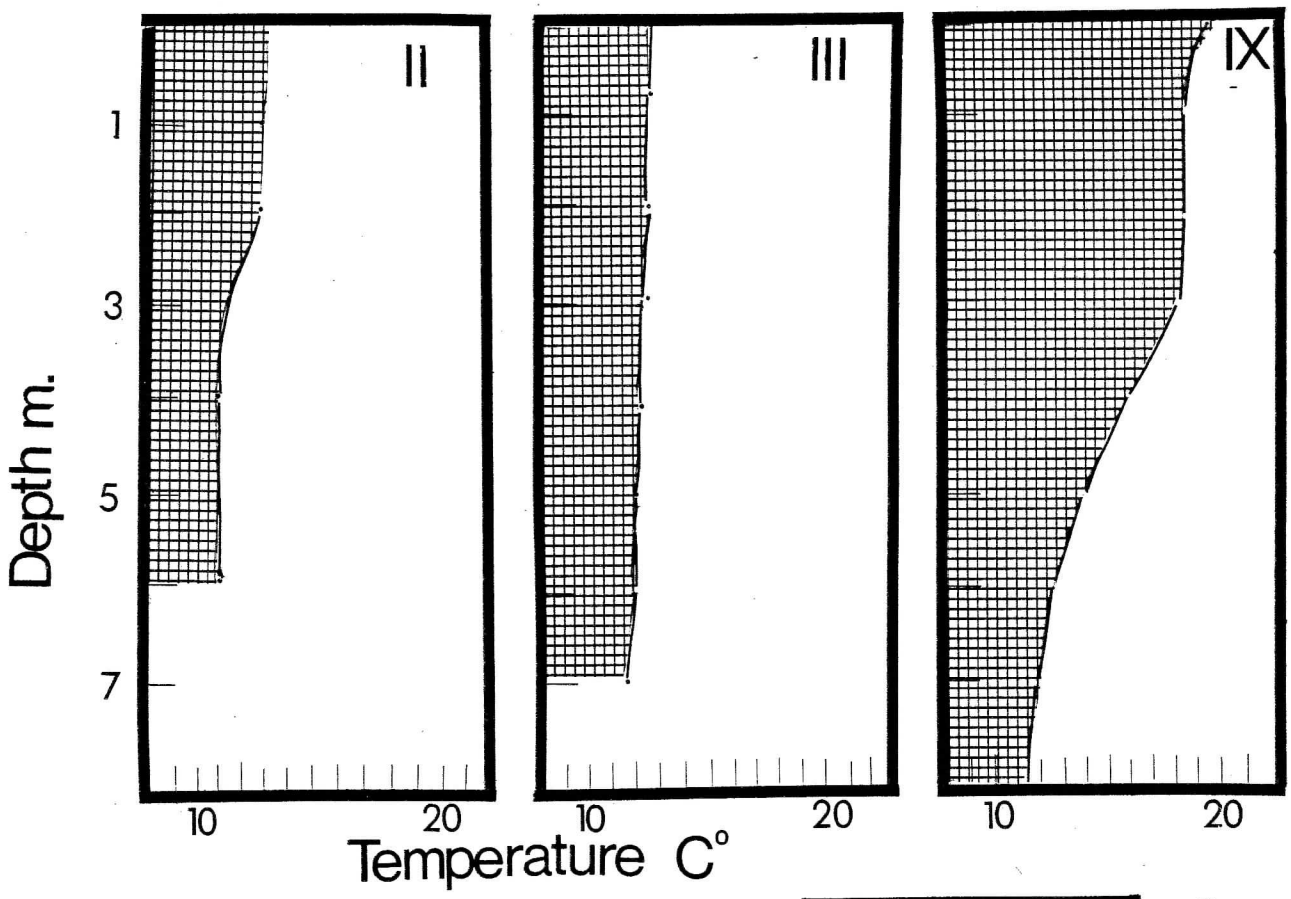


Figure 5 Wildcat & Crystal Lakes Temperature-depth Profiles



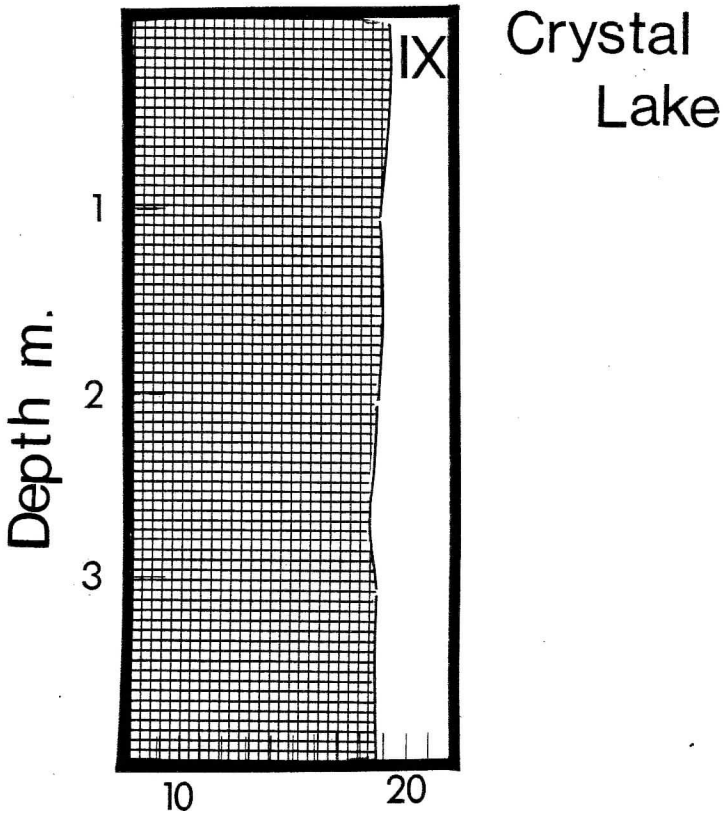
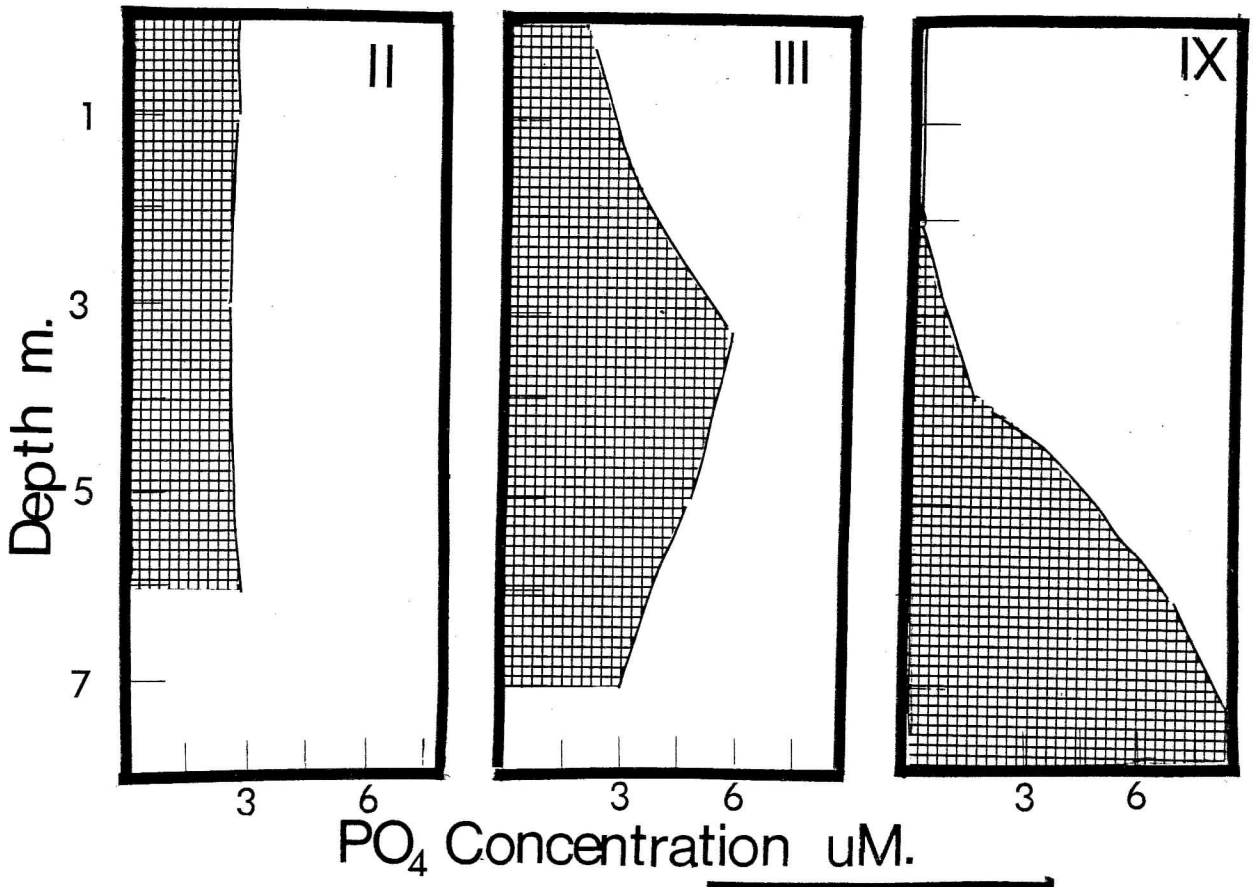
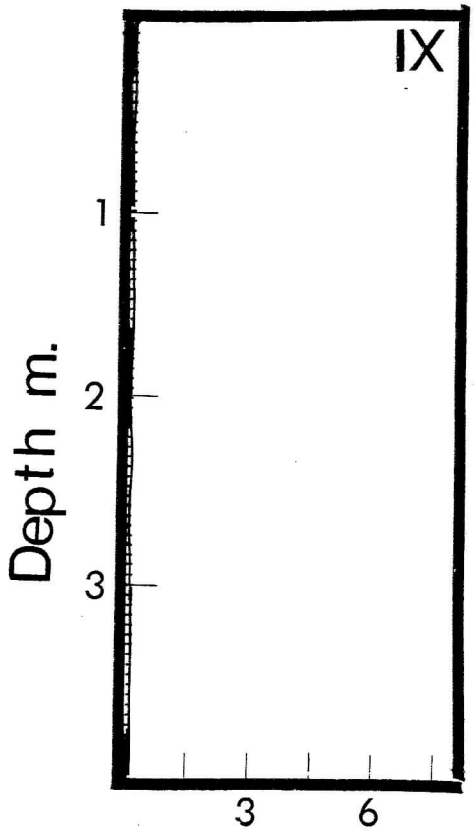


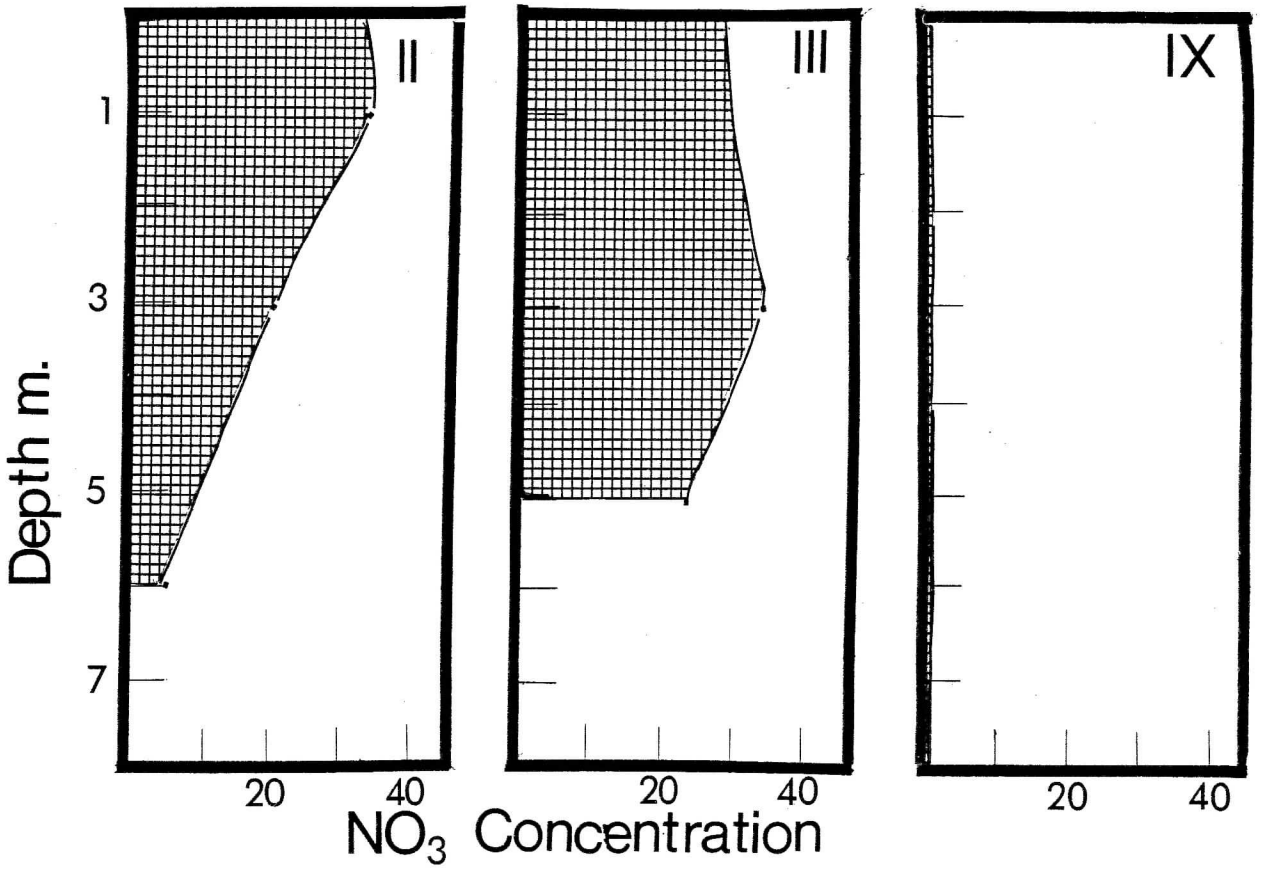
Figure6 Wildcat & Crystal Lake Phosphate-d. Profiles





Crystal Lake

Figure 7 Wildcat & Crystal Lakes Nitrates–depth Profiles



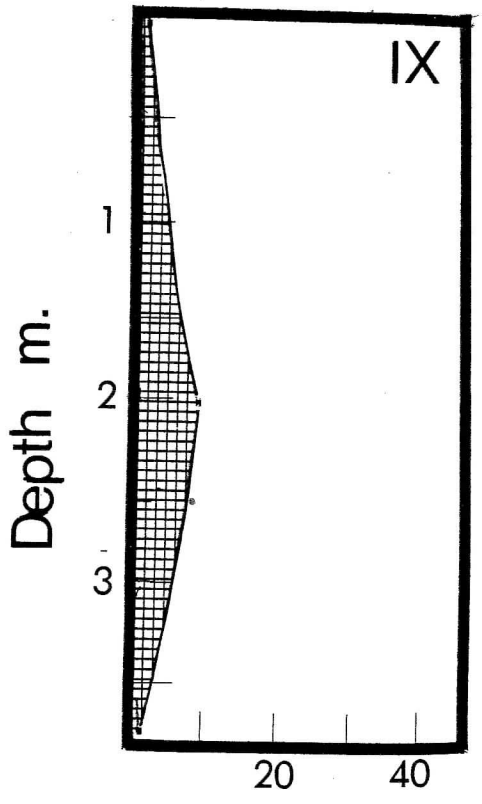
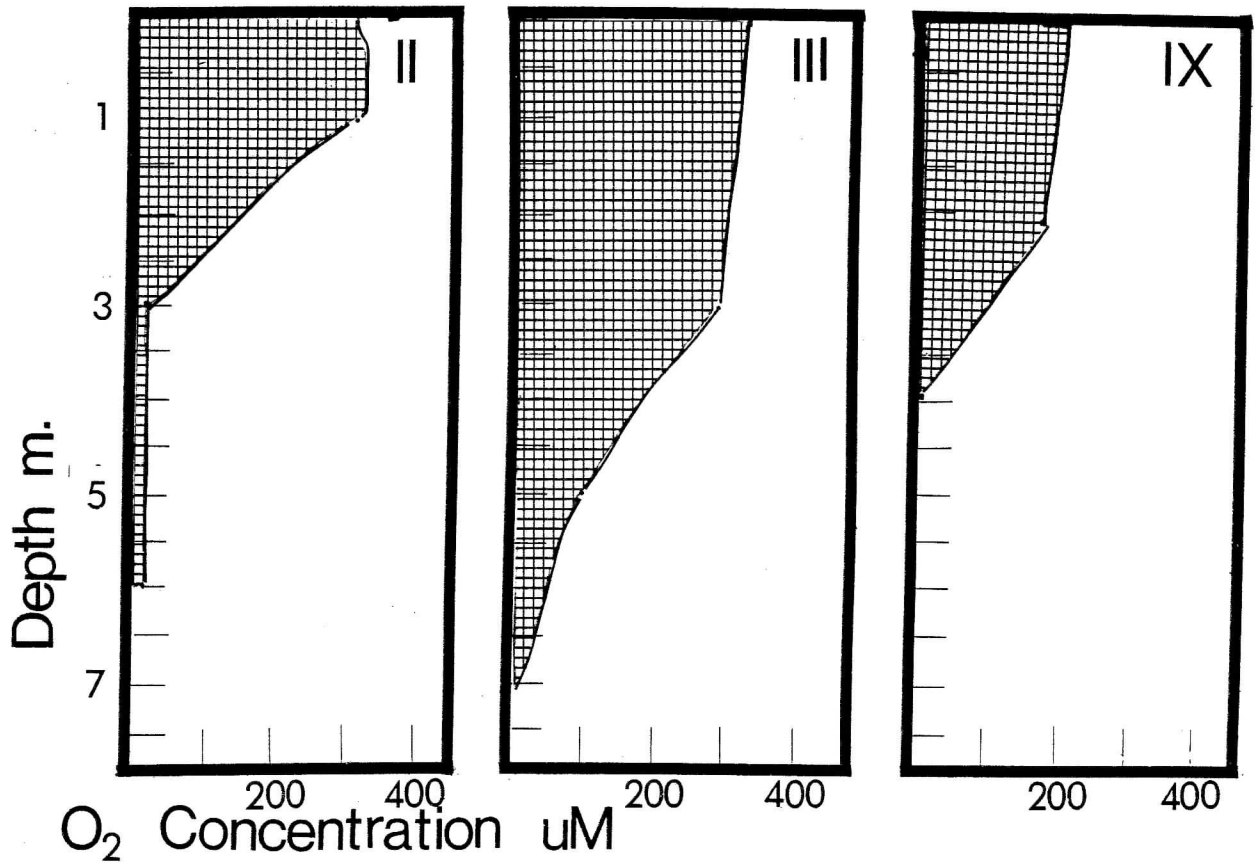
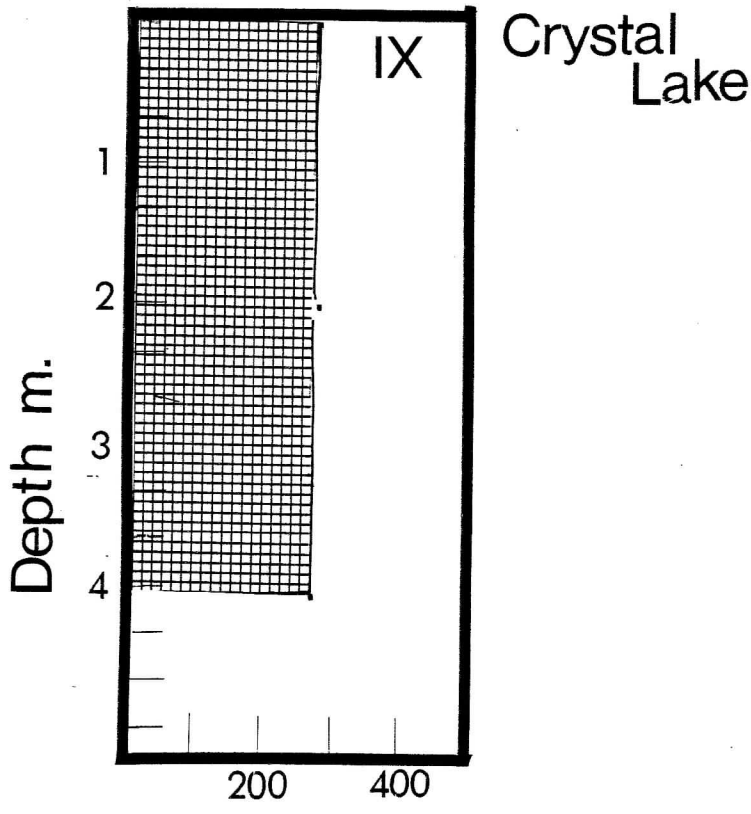


Figure 8 Wildcat & Crystal Lakes Oxygen-depth Profiles





Discussion

Bass Lake Phosphorus Cycle

Along with nitrates phosphorus is necessary in order to sustain life in a lake. In general, total phosphorus in a lake can be divided into two categories. First there is inorganic and soluble orthophosphate, PO_4, which makes up less than 10% of the total phosphate. It is, however, the form of phosphate assimilated by organisms in a lake. The large majority of phosphorus is organic phosphorus, bound in living or dead particulate organic matter.

Bass Lake contains high levels of phosphorus. A typical total phosphorus value for uncontaminated surface waters is 0.10 uM to 0.52 uM P-1. [4] Compared to the phosphate level of Bass Lake roughly averaging 0.70 uM, (highest phosphate level recorded was 2.64 uM P-1) the concentration of phosphorus is high in Bass Lake.

The high level of phosphorus in Bass Lake is a result of natural processes. The amount of phosphate in a lake is in accordance with the geological structure of the region. A lake with a drainage that contains sedimentary rocks (especially if hydroxylapatite $Ca_5(OH)(PO_4)_3$ is present) is typically higher in phosphate than a lake with crystalline geomorphology.

The phosphorus cycle of a lake is more important to consider than the amount of phosphorus in a lake. The first month sampled, January, shows a uniform orthophosphate concentration at varying depths (figure 2). The fall overturn for Bass Lake typically occurs in December[5] and thoroughly distributes phosphate through the entire water column of the lake. In February the partitioning of phosphate begins.

The downward movement of phosphate in February is caused by the interactions between the orthophosphate and phytoplankton (algae) in the epilimnion. In the month of February a higher concentration of phosphate is contained in the metalimnion and

hypolimnion than the epilimnion (figure 2). A plausible explanation for the downward movement of phosphate is related to the algae blooms that occur in Bass Lake. To start the movement of phosphate down the water column the algae quickly assimilates any free orthophosphate (PO_4) in the epilimnion. Bacteria in the epilimnion then recycles the organic phosphorus contained in the dead phytoplankton back to dissolved inorganic orthophosphate (PO_4). There are times, however, especially during phytoplankton blooms, where the bacteria cannot degrade the entire production of phytoplankton. At these times the organic phosphorus contained in the dead phytoplankton rains down the water column. Eventually the organic phosphorus of the dead phytoplankton will be degraded into orthophosphate, but not until the degradation of the organic phosphorus has occurred in the metalimnion or hypolimnion. In this way there is a net transfer of orthophosphate down the water column.

The continued high phosphate levels in the March surface water of Bass Lake occurs because of recycling of orthophosphate by the algae and bacteria. The waste product of algae, extracellular organic phosphorus, is rapidly converted to soluble orthophosphate (PO_4). At the same time as phosphate recycling is occurring a transfer of phosphate down the water column also occurs in all months where thermal stratification is present. By April the phosphate levels of the surface water is low and probably constitutes a limit to the growth of life in the photic zone of the lake (figure 2). The loss of phosphate in the epilimnion continues to get more extreme in the summer and fall months for Bass Lake.

The general downward trend of phosphate in the deeper parts of Bass Lake is shown by the data. A plausible conclusion drawn from the data is that the sediments are a sink for phosphates under aerobic conditions. During the months of March and especially April, the phosphate concentration in the metalimnion noticeably decreases (figure 2). This appears contrary to the earlier statement that the metalimnion is being loaded with more phosphate when a thermocline is present. However, there is an explanation. The phosphate is absorbed into the sediments. This hypothesis is supported by Wetzel and

others:

> Under aerobic conditions, it is clear that the exchange equilibrate (PO_4) are largely unidirectional to the sediments. [6]

The phosphate is scavenged by the sediment layer under aerobic conditions. However, when the hypolimnion of the lake turns anaerobic the reverse occurs; phosphorus is released into the water column. The redox potential of the sediments becomes more positive and eventually reaches the point where the phosphorus is released into the water.

In the month of May, when Bass Lake's hypolimnion first went anoxic, a large increase in phosphate in the hypolimnion was recorded (figure 2). Figure 2 also shows that as the anoxic hypolimnion continues from month to month more phosphate is released into the deep water of Bass Lake. The sediments were releasing the phosphorus that had built up in the previous months back into the water column. Given sufficient time the phosphate will diffuses up the water column and reach the upper levels of the lake. [7] The upward movement of phosphate occurs in the months of August and September in Bass Lake; however, the fall overturn occurs before the diffusing phosphate contained in the hypolimnion has any significant effect on the life in the photic zone. This is shown by the fall phosphate levels in Widmer's report on Bass Lake where complete mixing of the water in Bass Lake occurred.

Wetzel noted that as long as there is no outside influences by man on the phosphorus cycle, a lake will sustain a similar phosphorus pattern year after year. [8] To conclude, Bass Lake is a phosphorus rich lake which nourishes algae blooms for only a small part of the year. The anoxic hypolimnion in the summer and fall has a major effect on the distribution of phosphorus in the lake.

The high levels of phosphorus in Bass Lake may in part be explained by the lack of a littoral region. The morphology of Bass Lake is well known to the countless swimmers

that frequent the lake. The lake steeply dips down form the shore so that at a distance of ten feet from shore, the water is well above a person's head. Although it is nice for swimming, the lack of plants in Bass Lake means the absence of a major phosphorus sink. The deepness of the shoreline prevents aquatic macrophyte plants form growing along the shore. The extreme importance of a littoral zone for the uptake of phosphorus is explained by Wetzel:

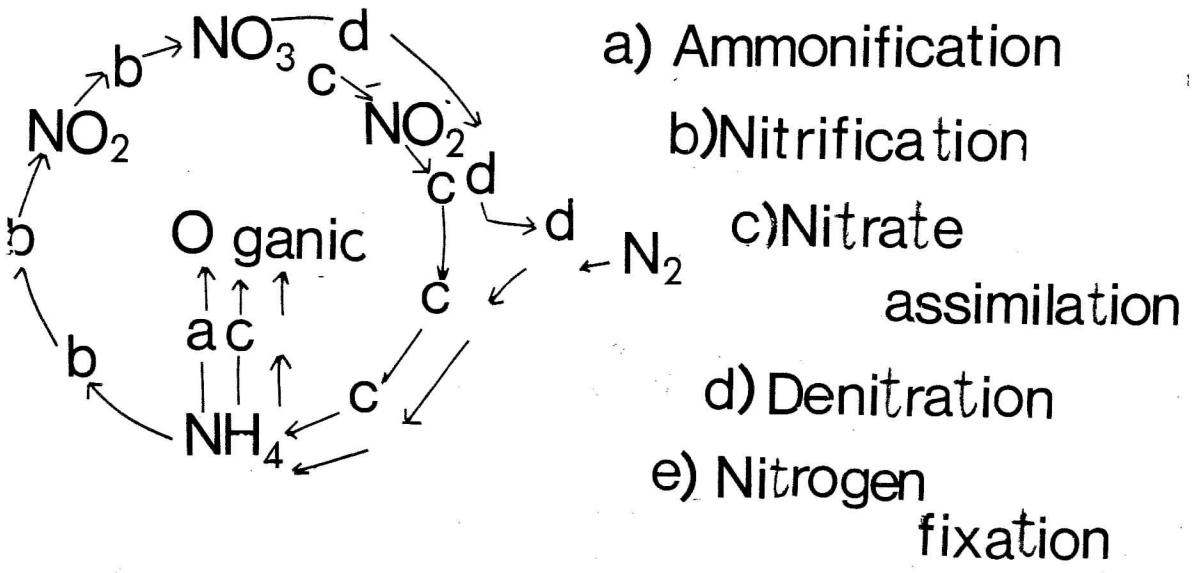
> In Toussaint Lake, a small acidic lake with a well-developed littoral zone of rooted aquatic plants, the littoral region was the most important contributor to the turnover of phosphorus in the epilimnion; phosphorus was lost to this compartment ten times faster than to the hypolimnion and sediments, and 50 times more rapidly than is lost through the outlet. [9]

Without the retention of phosphorus by rooted aquatic plants in Bass Lake, more phosphate is free to circulate in the waters of Bass Lake.

Bass Lake Nitrogen Cycle

Nitrates as well as phosphates have the potential of limiting the growth of life in a lake. A major reason is that nitrogen is also a common constitute of cells. For all practical purposed, the nitrogen cycle of lakes is microbial in nature: bacterial oxidation and reduction of nitrogen coupled with photosynthetic assimilation and utilization by algae and larger plants. [10]

Unlike phosphorus, nitrogen comes in many forms in fresh water systems. Although nitrate, NO_3 , is the most sought after food source of nitrogen, the other forms of nitrogen play an important role in the nitrogen cycle. The different forms of nitrogen are diagramed below to help with the discussion of Bass Lake's nitrogen cycle:



(figure 9) Various forms of nitrogen in natural waters. [10.5]

The current study of Bass Lake began in January when a high concentration of nitrate in the hypolimnion and metalimnion. In addition a slight tapering off of nitrate in the epilimnion was also found (figure 3). The nitrate in the epilimnion is enough to sustain a large and prolific algae population.

The next month, February, showed a rapid and marked decrease of nitrates in Bass Lake's epilimnion. Undoubtedly, intense nitrogen assimilation (figure 9) by algae occurred. This conclusion is supported by a statement reported by Wetzel where he notes that NO_3-N concentrations of 20 uM L-1 can be assimilated by organisms in a month. [12].

The large algae populations using the nitrate in the surface water increases the nitrate concentration of Bass Lake's deep water. In the month of February an extremely large increased nitrate concentration was observed in the deeper waters of Bass Lake (figure 3). The nitrate source for the deep water is particulate organic nitrogen raining down form dead algae. Bacteria decomposes the algae that rains down from the photic zone and ammonia is liberated. In oxygenated waters, nitrification (figure 9) by bacteria quickly occurs and nitrate is produced. To sum up, in the month of January a straight and vertical gradient of nitrate occurred in Bass Lake. By February the thermocline had been established in Bass Lake and the lake has stopped mixing. A net transfer of nitrate into the metalimnion and hypolimnion occurred because of algae production in the photic zone. It should be noted, that although ammonia (NH_4) is a major excretory product of aquatic animal (which gets oxidized immediately to nitrate), this nitrogen source is quantitatively minor in comparison to that formed by bacteria decomposition.

An interesting development in the next month of March in Bass Lake was the reappearance of nitrogen in the epilimnion (figure 3). Either an inflow of nitrogen from the watershed or nitrification of the ammonia waste products in the epilimnion of the algae is occurring. Although both processes are occurring to some degree, most likely the recycling of the ammonia released by the algae is the dominate cause of the reappearance of nitrates in the epilimnion. The conclusion is based on the absence of

man made pollution in Bass Lake and the low concentrations of nitrates in the two small creeks that run into Bass Lake. [13]

The next months showed a progressive loss of nitrogen in the epilimnion (figure 3). Bass Lake is effectively limited in the growth of life in the photic zone by the month of April. This condition prevails until the deep water mixes up causing nitrate to be replenished in the epilimnion during the fall overturn in December. Bass Lake's nitrate concentration in the metalimnion and hypolimnion stays fairly constant in the months of March and April (figure 3). Bacteria still decomposes any nitrogen-containing organic matter that rains down the water column. However, by May the large influx of organic matter to the deeper part of the lake has thought to have stopped. This is because of the lack of phosphates or nitrates in the photic zone.

A curious drop of nitrates in the hypolimnion between May and September can be explained by the lake turning anoxic. Under anaerobic conditions, bacterial nitrification, by which ammonia (NH_4) is progressively oxidized through several intermediate compounds to nitrite (NO_2) and nitrate (NO_3)(figure 9) ceases. Ammonia begins to build up. Besides nitrate (NO_3) production ceasing, nitrate is also lost under anaerobic conditions. Denitrification, where nitrate (NO_3) is converted to nitrogen (N_2), occurs in oxygen-free waters (figure 9).

The final step of the nitrogen cycle for Bass Lake is the fall overturn where the entire lake mixed. This effectively replenished the nitrate in the epilimnion, allowing the resumption of algae growth. The accumulation of ammonia (NH_4) in the anoxic hypolimnion is quickly oxidized into nitrate (figure 9) when it is placed in the oxygenated epilimnion during the fall overturn.

At this point, the nitrogen year long cycle for Bass Lake is complete. There are two important points: First, eight or so months out of the year nitrogen limits the growth of microbial life in Bass Lake's photic zone. Secondly, it should be noted that the nitrogen cycle pictured for Bass Lake is a product of the strong thermocline and anoxic hypolimnion of the Lake.

Oxygen Profile Bass Lake

The oxygen profile of Bass Lake shows a uniform concentration of oxygen in January which steadily decreases each month in the hypolimnion until the hypolimnion is devoid of oxygen by June (figure 4). The well developed thermocline in Bass Lake directly affects the loss of oxygen in the hypolimnion. The scenario begins with the mixing of the deep bottom water during the fall overturn. This replenishes the supply of oxygen to the hypolimnion and the lake has a uniform oxygen concentration at various depths. Bass Lake will continuously circulate, providing an ample supply of oxygen to the hypolimnion as long as there's no density gradient in the lake (caused by the thermocline).

However, like all lakes located in temperate climates, thermostratification of Bass Lake occurs with the warmer temperatures of spring and summer. In Bass Lake, formation of distinct, non-interacting layers of water begins in February and is solidly in place by March (figure 1). By February the bottom water of Bass Lake is stagnant. There is no replenishment of oxygen to the hypolimnion. The oxygen used by organisms will be shown in figure 4 by the decreasing oxygen profile of the hypolimnion each month.

An important point is that the last bit of oxygen is used up in June in the hypolimnion of Bass Lake. The ramifications of this fact are extremely important to the life of Bass Lake and will be discussed in detail further on in this report. Another point to note is the high phosphate and nitrate concentrations in Bass Lake affect the speed and consistency by which the hypolimnion becomes anoxic. This will be explained when describing Wildcats Lake's oxygen profile.

Bass Lake pH

The pH of Bass Lake is slightly basic overall. The epilimnion of the lake is consistently higher in pH than the hypolimnion. The highest pH in the epilimnion recorded was 8.2 in August and the lowest pH recorded was 7.0 in January. The hypolimnion of Bass Lake stayed a consistent 7.0 to 7.2 throughout the entire sampling period.

Wildcat Lake Phosphorus Cycle

The three months of data collected on Wildcat Lake suggests that Wildcat Lake and Bass Lake have a similar phosphorus cycle. It should be emphasized that Wildcat Lake has an extremely high concentration of phosphate.

Because of the fall overturn in either January or December, the month of February shows an even distribution of phosphate through the water column (figure 6). However, by March a redistribution of phosphates to the metalimnion has occurred(figure 6). Again similar to Bass Lake, the high concentration of phosphates in the epilimnion allows for large amounts of algae growth. The dead algae is decomposed by heterotrophic bacteria as it floats down the water column. Phosphate is subsequently released down the water column.

Six months later the concentration of phosphate in the epilimnion has decreased to a small fraction of the amount present in March (figure 6). Over the past six months algae has assimilated the phosphate in the epilimnion reducing the phosphate level and limiting growth in the upper levels of Wildcat Lake. By September, large amount of phosphates have accumulated in the anoxic hypolimnion of Wildcat Lake (figure 6). Finally, the nutrients will be replenished in the epilimnion when the lake overturns in the fall.

The main point to make regarding phosphates levels in Wildcat Lake is that they are extremely high. The result is the large production of phytoplankton which has a major effect on the oxygen cycle of the lake. This point will be explained fully in the Wildcat Lake oxygen cycle section.

Nitrate Cycle Wildcat Lake

Wildcat Lake has an extremely high level of Nitrates. From the three months of data collected one can surmise that Wildcat Lake's nitrate distribution resembles a highly eutrophic lake.

The first month sampled, February, shows the highest concentration of nitrates in the epilimnion and a steady decrease of nitrates at increasing depths (figure 7). Although not documented, an overturn of part or all of Wildcat Lake's deep water probably occurred in December or January. During the fall overturn, ammonia (NH_4) contained in the anoxic hypolimnion and nitrogen loaded in the lake's bottom soil would be oxidized in the epilimnion to nitrate (NO_3) under aerobic conditions. By February the nitrate is present in the epilimnion and algae are free to use the nutrient in their metabolism. The extremely high concentration of nitrate in Wildcat Lake during the month of February suggest that algae blooms must be common.

Similar to Bass Lake, because the algae can grow at an explosive rate, some of the dead algae rains down to the lower parts of the lake. Heterotrophic bacteria liberates the nitrogen during degradation of the dead algae in the form of ammonia (NH_4). The ammonia is then quickly oxidized by bacteria to nitrate under aerobic conditions. This explains the increase of nitrates in the metalimnion and hypolimnion during the month of March in Wildcat Lake (figure 7).

Seven months later the nitrate is depleted by the algae in the epilimnion. The growth of micro-organisms in the photic zone is limited in Wildcat Lake. The net

transfer of nitrate down the water column by algae will occur until the epilimnion is devoid of nitrate. When the lake becomes anoxic however, the nitrate is lost in the hypolimnion and metalimnion as the lake becomes anoxic (figure 7 September). The nitrate is reduced to ammonia. To complete the nitrate cycle the return of high nitrate concentration in the epilimnion of Wildcat Lake will occur again when the lake overturns.

Oxygen Cycle Wildcat Lake

Wildcat Lake's eutrophic nature and long duration of thermal stratification ensures that the lake's hypolimnion will repeatedly become anoxic. The high nitrate and phosphate levels in Wildcat Lake are also related to the hypolimnion becoming anoxic by: The high nitrate and phosphate levels in Wildcat lake allows for a large production of algae. The algae, when it dies, rains down to the hypolimnion. Oxygen consumption by animals, plants and especially bacteria in decomposing the algae causes the hypolimnion to lose oxygen. The decrease in the oxygen concentration is directly related to the amount of algae that rains down to the hypolimnion. Free oxygen consumption by bacteria respiration is intensive at all levels, but the oxygen in the hypolimnion is not generally offset by the renewal mechanisms of circulation and photosynthesis that occur in the epilimnion and metalimnion.

In February, Wildcat Lake already has a metalimnion and hypolimnion that has allow concentration of oxygen (figure 8). The corresponding temperature profile for February shows a small degree of thermal stratification (figure 5). Combining the two facts, one can conclude that oxygen isn't mixing into the depths of Wildcat Lake because of the thermal stratification present in February. Also, the large amount of bacteria is fast depleting the oxygen in the hypolimnion. It should be emphasized that the large numbers of bacteria are related to the excessive amounts of nitrates and phosphates in the lake. The high levels of nutrient contained in Wildcat Lake affects the oxygen concentration in Wildcat Lake's hypolimnion.

Two changes happen to the oxygen levels in Wildcat Lake during the month of March: The hypolimnion becomes anoxic and an increase in oxygen occurs in the upper levels of the lake (figure 8). The low concentration of oxygen found the previous month in the hypolimnion left little doubt that the small amount of oxygen left would be used by the bacteria. What came as more of a surprise was the increased oxygen concentration in the first five meters of the lake (figure 8). A simple explanation of the oxygen

replenishment was found by again relating the temperature profile (figure 5) and oxygen profile (figure 8) for the month of March in Wildcat Lake. In March, the temperature of Wildcat Lake surface water cooled and allowed the lake's water to circulate. The data shows that the circulation wasn't strong enough to replenish the bottom of Wildcat Lake with oxygen; however, the upper levels of Wildcat Lake increased in oxygen content.

The most important point is that Wildcat Lake's hypolimnion has a strong tendency to turn anoxic early and stay that way for a large part of the year. The ramification of an anoxic hypolimnion is the probability of a yearly fish kill. This subject will be discussed in detail later.

Wildcat Lake pH

Various depth pH readings of Wildcat Lake were taken in the month of February, March, and September. The results were spectacular. The pH was fairly uniform at various depths varying by less than one pH unit in February and March. The average pH concentration for February and March was 7.1 with the highest reading being 7.4 and lowest reading 6.8. By September, the pH of Wildcat Lake varied widely with depth. The surface pH of Wildcat Lake rose to 8.6 and the hypolimnion decreased to a pH of 6.6.

Crystal Lake

Crystal Lake, unlike Bass or Wildcat Lakes, is able to support a varied fish population. The one water sampling of Crystal lake done in September shows a vastly different lake than Bass or Wildcat Lakes. The most important difference of Wildcat Lake is its relatively shallow depth compared to Bass and Wildcat Lakes. The four meter depth of Crystal Lake ensures that no thermocline develops (figure 5). Even by the late month of September, when the long months of the summer have had time to warm up the surface of Crystal Lake, no thermocline is seen in Crystal Lake. The winds are strong enough to constantly mix the entire water of Crystal Lake. No deep bottom water exists in Crystal lake. Unlike either Bass or Wildcat Lakes, there is no stagnant layer of water in any part of Crystal Lake. The year round replenishment of oxygen throughout Crystal Lake means no part of the lake will become anoxic. The formation of hydrogen sulfide, which is a common yearly event in Bass and Wildcat Lakes can't occur in the aerobic environment of Crystal Lake. The shallowness of Crystal Lake prevents the fish mortalities in Crystal Lake.

Hydrogen Sulfide

Under anaerobic conditions, conditions present in the bottom of both Bass and Wildcat Lakes, bacteria that can only survive without oxygen start to appear. During metabolism, the heterotrophic bacteria oxidizes sulfur containing compounds and excretes sulfur ions by the following chemical equation:

The sulfur ions produced by the bacteria quickly turn into hydrogen sulfide in natural waters. Two chemical species of hydrogen sulfide can occur, unionized hydrogen sulfide (H_2S) or ionized hydrogen sulfide (HS). The following is the mass balance equations for the two chemical species of hydrogen sulfide:

When understanding toxicity of total hydrogen sulfide to fish, it should be emphasized that only the unionized form of hydrogen sulfide (H_2S) is toxic.

One must consider the pH, and to a lesser extent the temperature of the water to calculate the unionized hydrogen sulfide concentration from the total. If the pH of the hydrogen sulfide laden water is measured, then one can multiply the total hydrogen sulfide by the percentage given by the table below to obtain the unionized hydrogen sulfide concentration:

pH	%	pH	%
5.0	99.0	7.5	24.4
5.5	97.0	8.0	9.3
6.0	91.1	8.5	3.1
6.5	76.4	9.0	1.0
7.0	50.6		

Table 1 Percent unionized hydrogen sulfide at 25 degrees C. with various pH's. [14]

The above table shows the extreme effect the pH has on producing unionized hydrogen sulfide which is toxic to fish. The lower the pH of the anoxic waters, the more toxic hydrogen sulfide is produced.

Hydrogen Sulfide as a Fish Toxin

Hydrogen sulfide is a potent toxin to fish. In on study by Fung and Bewick, Whitefish, Rainbow Trout, Yellow Perch, and Largemouth Bass were exposed to a wide range of hydrogen sulfide concentrations. Water temperature, fish size, dissolved oxygen and pH were varied and the LD-50 of the hydrogen sulfide levels was found. The results of the test are as follows:

Species and Lifestage	DO, mg/litre	Temperature, deg C	pH	LC_{50} (mg/litre unionized H_2S) 1 h	24 h	48 h	72 h	96 h
Whitefish								
Sac fry	11.5	7.0	8.0	0.105	0.003	0.002	0.002	0.002
Sac fry	10.5	10.0	8.0	...	>0.011	0.006	0.005	0.004
Sac fry	11.2	7.0	7.5	0.239	>0.005	0.005	0.003	0.003
Sac fry	10.5	10.0	8.0	0.081	0.017	0.008	0.008	0.005
Juveniles	10.1	10.0	8.0	0.206	>0.014	>0.014	>0.014	0.012
Rainbow trout								
Sac fry	10.9	7.0	8.0	0.336	>0.090	0.052	0.047	0.047
Sac fry	11.6	7.0	7.5	0.304	>0.025	0.024	0.021	0.019
Sac fry	10.7	10.0	8.0	0.344	0.033	0.025	0.025	0.025
Juveniles	10.9	7.0	7.5	0.224	0.035	0.026	0.023	0.023
Juveniles	8.9	20.0	8.0	0.037	>0.019	>0.019	0.007	0.007
Adults	10.5	7.0	7.5	0.471	0.079	0.043	0.043	0.043
Adults	8.3	20.0	8.0	0.153	0.027	0.012	0.012	0.012
Yellow perch								
Sac fry	10.0	10.0	7.5	1.55	>0.182	0.031	0.015	0.010
Sac fry	8.4	20.0	8.0	0.046	0.002	<0.002	<0.002	<0.002
Juveniles	10.1	10.0	7.5	1.719	0.075	0.064	0.039	0.036
Juveniles	8.9	20.0	8.0	0.082	0.024	0.010	0.010	0.008
Largemouth bass								
Sac fry	9.0	15.0	7.5	0.313	0.032	0.030	0.030	0.030
Sac fry	8.1	20.0	8.0	0.041	0.011	0.011	0.011	0.011
Juveniles	9.4	15.0	7.5	0.576	0.129	0.081	0.065	0.063
Juveniles	8.5	25.0	8.0	0.260	0.172	0.076	0.059	0.059

Table 2. LD-50 test of various fish to H S [15]

The data not only shows the powerful effect hydrogen sulfide has on killing fish but also points out that fish fry are the most vulnerable to hydrogen sulfide. In Bass and Wildcat Lakes hydrogen sulfide is present throughout the entire lake for only a short period of time. The few days or possibly hours in which hydrogen sulfide is present in the lake is disastrous for any fish in the lake.

The Tendency for Bass and Wildcat Lake's Hypolimnion to become Anoxic.

A number of different reports on Bass and Wildcat Lake conclusively show that the lakes' hypolimnion are prone to become anoxic. This report documents that oxygen was absent from the hypolimnion is Bass Lake by the month of June and in Wildcat lake by the month of March. Another limnology survey of Bass lake [16] repeats the findings of

an anoxic hypolimnion in July. In addition to the above reports, a 1947 lake survey done by the California Department of Fish and Game on Bass Lake again discovered an anoxic hypolimnion [17].

Confirmation of Wildcat Lake's hypolimnion becoming anoxic is shown by the "Preliminary Survey and Management Plans for Point Reyes National Seashore area waters". [18] In the report, a brief summary of Wildcat Lake states that a strong odor of hydrogen sulfide was noted in water taken at a depth of 20 meters. Water quality reports of Bass and Wildcat Lakes shows a history of the lake's hypolimnion becoming anoxic. There is no reason not to expect this phenomenon to continue in the future.

Mixing of Hydrogen Sulfide

A mixing of the anoxic and hydrogen sulfide laden water of the hypolimnion occurs during the fall overturn. Although water samples of Wildcat and Bass Lakes were discontinued in the fall, it can be assumed that a rapid loss of thermostratification occurs in the fall. In late summer and fall, declining air temperatures result in a negative heat income to the lake. Loss of heat exceeds inputs from solar radiation. The now cooler and denser surface water sinks and mixes in the epilimnetic waters by a combination of convection currents and wind-induced epilimnetic circulation. By late fall the thermocline of Bass and Wildcat Lakes are most likely weakly defined. At this point in time, a strong and persistent wind would have enough mechanical energy to mix the lakes. The weaker the thermal stratification of the two lakes, the less strong the wind has to be to overturn the lakes. Finally, the entire volume of Bass and Wildcat Lakes (including the hydrogen sulfide) will be circulated. Wetzel explains in his introductory limnology text the striking speed by which a lake overturns:

> The transition from the finial stages of weak summer stratification to autumnal circulation usually is dramatic, and can occur in a few hours especially if associated with the high wind velocities of a storm. [19]

It is clear that at in Bass and Wildcat Lakes the fall overturn mixes hydrogen sulfide throughout the lake (hydrogen sulfide was documented in Bass and Wildcat Lakes on September 1, 1985 by colormetric determination). The maximum concentration of hydrogen sulfide that is distributed through the entire lake after the fall overturn is uncertain. The fate of the hydrogen sulfide is to quickly convert back to hydrogen sulfate (SO) in oxygenated waters. Even if a reliable and accurate analytical technique was developed for measuring hydrogen sulfide in an oxygenated water environment, it would still be difficult to predict the date of the fall overturn. A daily monitoring of the lakes'

waters would be necessary to time the fall overturn and collect the hydrogen sulfide containing water samples.

Lake studies similar to Bass and Wildcat Lakes

Studies of lakes similar to Bass and Wildcat Lakes describe events that have lead to persistent and large scale fish kills. All the examples have two events in common with Bass and Wildcat Lakes, an anoxic hypolimnion containing hydrogen sulfide and a sudden overturning of the lake's water. A statement by Boyd surprisingly sums up the literature on the subject of fish mortality in anoxic lakes:

> Fish kills following overturns (thermal destratification) are commonly encountered, but this problem has apparently received little study. [21]

However, a number of studies do substantiate the potency of hydrogen sulfide mixed throughout a lake in causing a fish kill. The first indication of the occurrence was when data showing Bass Lake becoming anoxic was presented to Professor Ken Bruland. Immediately he hypothesized a scenario of the hypolimnion turning anoxic, hydrogen sulfide being produced, and hydrogen sulfide mixing throughout the lake. He continued by stating that he had encountered the same problem in Loch Lomond Reservoir in Santa Cruz County.

In a paper which collaborates Professor Bruland's hypothesis, Clark and Greenbank conclude that the cause of a sudden fish kill in Park Lake New Mexico, was the result of high hydrogen sulfide concentration in the hypolimnion (9.5 ppm.) combined with a sudden overturn of the lake. [22] Park Lake is similar in size and temperature to Bass Lake. The scenario behind the limnology report of Park Lake is as follows: In the 1950's a persistent problem of fish kills in lakes and reservoirs of New Mexico was occurring.

The problem was presented to the Chemistry Department of the University of New Mexico with a number of interesting hypothesis:

> In one case a fish disease seemed to explain the deaths, but in most cases no evidence of disease or parasite infestation appeared. In some of the cases lack of oxygen seemed to be a cause, but by the time the investigators reached and analyzed the water, the oxygen supply was found to be adequate, although not abundant. Poisons in the waters were suspected at times, but chemical analysis always failed to reveal them. The spectacular explanation-dynamite-was always advanced, but in none of the causes where the dead fish were examined was it substantiate.[23]

Park Lake was chosen to study because of a documented fish kill which occurred on July 7, 1936:

> On or about the morning of July 7, 1936, at Park, or Stink Lake, near Santa Rosa New Mexico, dead fish were everywhere. Apparently no one attempted to count them; but the junior author was told there were "scads" of them. [24]

Water analysis of Park Lake showed the same anoxic hypolimnion and the resultant production of hydrogen sulfide as in Bass and Wildcat Lakes. The same conclusion for the absence of fish in Bass and Wildcat Lakes that was present in this paper was forwarded as the cause of the fish kill in Park Lake. Clark and Greenbank concluded that hydrogen sulfide brought up and mixed throughout the entire lake can have disastrous effects on fish:

> However, any circumstance, such as a sudden wind, etc., which would cause abrupt mixing of the water in a lake could be very disastrous, for where the accumulated hydrogen sulfide in the bottom to be suddenly disseminated throughout the lake, the fish, which are always sensitive to abrupt chemical changes, would perish. [25]

Also, chemical analysis of the water taken after the fish kill revealed free hydrogen sulfide in the water.

In man-made reservoirs, the same scenario, of hydrogen sulfide in the anoxic hypolimnion combined with the overturn of a lake can cause striking instances of fish mortality. An example of such an event was written in a U.S. Government technical bulletin by William A. Hanson and Frans Bigelow. [26]

A man made reservoir called Westlake Lake was built around a housing development on the Los Angles Ventera county line. Westlake Lake is some what larger and shallower than Base Lake. However, the 18 foot depth of Westlake Lake is deep enough to produce a strong thermocline similar to the thermocline found in both Bass and Wildcat Lakes. Associated with the thermoclines of all the lakes is the now familiar anoxic hypolimnion and related hydrogen sulfide. A sudden turning over of the anoxic bottom water in Westlake Lake in which the fish managed to survive is described by Hanson and Bigelows:

> Laboratory figures had kept us aware that the lake was in a dangerous condition (less than 1 ppm of dissolved oxygen at a depth of 5 to 7 feet with 18 feet totally oxygen-deprived water). If this suddenly mixed, as it had, the oxygen depletion will kill all the fish in the area.
>
> Prayers, however, were answered. We were sent a dire warning, but the scales were not tipped enough to kill the fish. The dissolved oxygen at the surface had dropped from 8 ppm to a lethal 1 ppm in 24 hours! I stopped into the lab the next moring and found my fears of a sudden turnover were well founded. But we did not lose a single fish; they had apparently felt the forces underway and left for other parts of the lake that still had adequate oxygen. [27]

Only the deepest parts of Westlake Lake had the sudden turnover of the bottom water. The area of the overturn was only a small fraction of the total surface area of Westlake Lake. In Bass and Wildcat Lakes the fish wouldn't have the luxury of moving to a safe part of the lake during the fall overturn. The semi-round shape of Wildcat and Bass Lakes ensures no part of the two lakes will escape the mixing of hydrogen sulfide.

Although Hanson and Bigelow attributed an expected fish kill to low dissolved oxygen levels, in the following passage they recognize the significance of hydrogen sulfide in the lake:

> Below this stratification, the water usually runs out of oxygen and starts building up noxious hydrogen sulfide gas, which can cause massive fish kills when the lake naturally destratifies in the fall. [28]

The great effectiveness and completeness of hydrogen sulfide in causing a massive fish kill is stated by Greenbank in the paper,"A Cause of Death of Fish in the Southwest":

> In the course of his investigation (John Greenbank) estimated that practically 100% of all of the fish in the lake, with the exception of a few small ones, had been killed. [29]

The articles described thus far show the effectiveness of hydrogen sulfide mixing throughout an entire lake during the fall overturn causing sudden and massive fish mortality. The typical and natural nature of such an event occurring in lakes is indirectly shown by Clark and Greenbank. In their report on the cause of death of fish in the Southwest they correlated the possibility of many fish kills in New Mexico lakes, to hydrogen sulfide mixing throughout the entire lake. Most of the lakes studied in New Mexico by Clark and Greenbank are natural and without any influences by man. Man made effects are not the cause for the conditions in Bass and Wildcat Lakes. Simply put, the climate of the area combined with the geomorphology of the small deep lakes cause a stable thermocline to set in over the spring and summer months. Because of the stability brought about by the thermocline, the hypolimnion naturally turns anoxic and the production of hydrogen sulfide ensues.

The history of a lake continuously becoming anoxic far into the geological past is shown in the accounting of fish fossils. W.H. Bradey, in describing fossil fish of Eocene lakes, points out two hypothesis for the death of the fish. Both explanations can be applied to Bass and Wildcat Lakes:

> The only part of the story lacking now is how the fish died and got into the hypolimnion. Limnology offers two possible explanations. Sometimes when the surface of a lake gets excessively warm, fish will plunge into deep water and might thus penetrate the hypolimnion, be overcome by hydrogen sulfide, and also have the gas in their swim bladders chilled so that they sank at once to the bottom. Once there, only anaerobic bacteria would attack them. The other hypothesis is that the thermally stratified lake was suddenly chilled so that it overturned more rapidly than the hydrogen sulfide could be oxidized and so killed off large numbers of fish. This seems a little more probable as the fossil fish are of all ages and kind. [30]

The loss of fish in the Eocene lakes is obviously a natural event.

Three examples of the disastrous effects of hydrogen sulfide mixing throughout a lake were given. In each case, the water chemistry of the lakes where fish kills occurred were similar to Bass and Wildcat Lakes. The common chemical features of the lakes were a well defined thermocline in the summer and spring, an anoxic hypolimnion and the production of hydrogen sulfide in the hypolimnion. In addition, the fish that were kill in the examples all were killed suddenly. In each case the fall overturn, which occurs in both Bass and Wildcat Lakes, caused the deadly redistribution of hydrogen sulfide.

Its clear that the potential for a yearly fish kill of any planted fish in Bass or Wildcat Lakes exists. The fact that no fish exist in either Lakes,[31] even though both Wildcat and Bass Lakes have been planted periodicly with fish substantiates the problem of annual fish kills due to hydrogen sulfide.[32]

Obviously, any blind planting of fish will fail. In British Columbia during the 1950's random planting of fish was a common practice to see if a lake was suitable for fish. [33] Many fish were sacrificed and much money spent because of the poor

understanding of lakes. As stated by Larkin:

> However, for the remainder, there has not been devised as yet any simple method of detecting that they will not support a trout population the year round. In consequence, each year of hatchery operations sees several thousand Kamloops trout fry sacrificed in attempts to bring such lakes in production. [34]

Management Options

Several options are available to make Bass and Wildcat Lakes plantable for fish and available for fishing. The purpose of this section is not to weigh the costs of a management option, outline the far reaching consequences of a particular action to the environment, determine the needs of the public pertaining to the lakes, or compare the options to the directives set forth to the National Park Service. These important questions are best answered by Point Reyes National Seashore.

A possibility to initiate fishing in Bass and Wildcat Lakes is simply to plant a predetermined amount of catchable size fish in the lakes. Of course, no fish would be expected to last through the fall overturn because of the hydrogen sulfide. A strong desire from the public and an effective advertisement of the fish planting would be needed to make a fish planting project a success. A question the Park Service must consider is whether a fish truck would be permissible in a designated wilderness.

In order to make either Wildcat Lake or Bass Lake available for a sustained fish population, hydrogen sulfide production must be prevented in the hypolimnion. To prevent hydrogen sulfide production both lakes must be altered so that an ample supply of oxygen is present in the hypolimnion at all times. Bacteria respiration consumes the majority of oxygen in the bottom of lakes. This suggests that a reduction of bacteria by limiting algae raining down from the photic zone would be effective in preventing the hypolimnion becoming anoxic. Copper sulfate is commonly used to control algae for such purposes. Another alternative would be to provide a supply of oxygen to the lake's hypolimnion and causing the lake to circulate. This is known as aeration.

The practice of adding copper sulfate in the control of phytoplankton populations is commonly used in lake management. Many workers have determined the toxicity of copper sulfate to algae. For example Maloney and Palmer evaluated the toxicity of copper sulfate to thirty species of algae. As a general guideline to the effectiveness of

copper sulfate in controlling algae Maloney and Palmer found 0.25, 0.50, 1.0, and 2.0 mg/l copper sulfate controlled 0,13,37,and 53 percent respectively of all species tested. [35]

Care must be given to the application of copper sulfate because of its possible highly toxic nature to fish. The effect of copper sulfate on fish have been widely investigated with different conclusions. The results of the studies are reviewed by Mckee and Wolf [37] and Jackson. Undoubtly, the variation in the toxicity of copper sulfate to fish is due to varying environment criteria of the experiment such as water temperature, pH and oxygen concentration. An example of a safe application of copper sulfate to fish in control of algae is given in a management bulletin of Westlake Lake. [38]

The early mistakes in the management of Westlake Lake were clearly presented in the report. When the lake first became clogged with algae, direct action was demanded by the home owners and the only viable solution at the time was the application of strong chemicals. The results were disastrous. Out of control growth of competing plants and numerous fish kills continued. Finally, copper sulfate, which is a less potent but effective chemical was used:

> To take the place of the Hydrothol that controlled the filamentous shoreline algae, we devised a much safer and less expensive treatment using copper sulfate crystals. [39]

Hanson and Bigelow also noted in their report that copper sulfate has been proven safe to fish in Westlake Lake:

> No fish kills have occurred since this treatment of copper sulfate has been used. [40]

The reason behind the safety of copper sulfate to fish is its slow dissolving rate:

> The crystals takes from 2 to 5 days to completely dissolve, allowing enough contact time with the copper ions to control the algae without saturating the area with copper and risking harm to other life. [41]

Care must be given to the application copper sulfate in the control of algae; however, if done properly copper sulfate will not harm fish.

Algae blooms can be disastrous for a lake. The intent of adding copper sulfate is to prevent explosive algae growth in a lake. In order to prevent the raining down of dead algae into the hypolimnion, algae blooms must be prevented. The trick is to develop competition among the various algae species so that one doesn't become overly dominate. In this way when a species of algae cycles out the numbers of algae are small and bacteria can decompose the algae in the epilimnion. The nutrients from the dead algae are subsequently released in the epilimnion. Other plant species are able to quickly use the free nutrients. Competition between the plant species begins again in the lake. Copper sulfate is added to prevent any one species of algae to overly dominate. Once a species of algae shows signs of growing out of control, the numbers of that particular species are reduced by the addition of copper sulfate. After the goal of copper sulfate treatment is achieved, A well-balanced lake will have enough competition for the limited nutrient supply which prevents the complete domination of any one species.

Again, care must be taken when adding copper sulfate. If a large algae bloom have already begun, the addition of copper sulfate will simple kill large quantities of phytoplankton and thus cause reduction of oxygen in the hypolimnion. Boyd points out this problem and gives two examples form Sohack [42] and McIntosh and Kevern [43]:

> The decomposition of algae killed following copper sulfate application may result in depletion of dissolved oxygen. Sohacki et al. (1969) reported a marked decline in

> dissolved oxygen following treatment of a pond with a mg/l of copper sulfate, and McIntosh and Kevern (1974) reported that treatment of a pond with 3 mg/l copper sulfate caused oxygen depletion. [44]

The above example shows the need for proper timing in the application of copper sulfate. A detailed study of the lake's phytoplankton populations dynamics would be needed to wisely use copper sulfate in the reduction of phytoplankton.

In the example of Westlake Lake, copper sulfate has been extremely effective in controlling algae blooms:

> Chemical expenses have decreased over the past four years because their use has decreased. Less chemicals have been needed because the lake is developing its own system of checks and balances. [45]

The lasting effects of copper sulfate treatment on Westlake Lake has allowed the lake to obtain a non-destructive state.

Finally, Hanson and Bigelow attest to the fact that controlling phytoplankton growth prevents the hypolimnion from becoming anoxic. This is the exact aim of managing Bass and Wildcat Lakes:

> The amount of decomposing matter determines the amount of oxygen needed in the hypolimnion. As we had been applying our biological control program to the management of weeds and algae in the water, we had less productivity, less decomposition, and less demand for the dissolved oxygen in the hypolimnion. [46]

Any uses of chemicals to control phytoplankton blooms must be done with a degree of confidence and insight. Copper sulfate has been proven effective in the control of algae in eutrophic lakes.

Aeration

Artificial aeration of the hypolimnion is another alternative in preventing an anoxic hypolimnion. For deep water lakes (such as Bass and Wildcat Lakes) the principal behind aeration is to cause an artificial circulation of the lake's water. The deep water of the hypolimnion will come in contact with the air and be replenished with oxygen. Also, if hydrogen sulfide is present in the hypolimnion, the circulation of the lake will allow hydrogen sulfide to diffuse into the atmosphere. Ideally, if hydrogen sulfide is present in the bottom of a lake, a slow circulation of the lake would be desirable. This would prevent the quick and disastrous release of the hydrogen sulfide containing deep water.

The compression of oxygen into the bottom layer of water is one method of causing circulation of the deep water in a lake. The following diagrams a diffused-air system for pond or lake aeration:

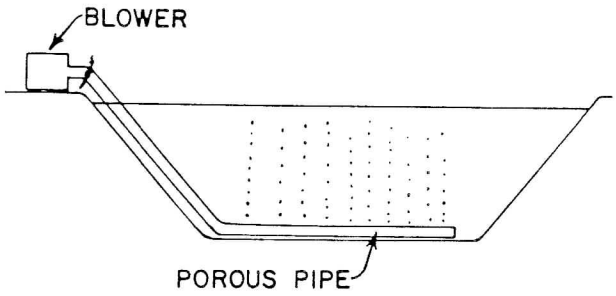


Figure 11 Diffused-air system for pond aeration. [47]

The aeration system was used successful in circulating the lake for the 15 acres of Westlake Lake that continuously turned anoxic. The effort and planning into the Air Aqua system proved to be a good investment of time. The advantages of the Air Aqua system are described by Hanson and Bigelow:

> It is an aesthetically pleasing system avoiding the boils present with most other systems.

It employs a series of small motors making sound control simpler and reducing the possibility of total system failure at critical periods. It is readily available, has a demonstrated effectiveness, and is backed by a substantial company which specializes in the field.

Prior to making this recommendation the author had reservations concerning the maintenance requirements of this system. The author discussed this and other aspects of the water system with representatives of California American Water Company (San Clemente Reservoir, Monterey, California) and San Marcos County Water district, each of whom have been operating a similar system for about 10 years. Both districts indicated a very high level of satisfaction with the system. [48]

An aeration system chosen must meet the needs of the lake. The system must be aestheticly pleasing and inconspicuous. A aeration system similar to the "Air Aqua" system in Westlake Lake meets the above criteria. The initial start up costs in 1976 dollars is given by Hanson and Bigelow for the aeration system used in Westlake Lake:

Aeration Equipment Costs*

1,875 feet leader hose ($.55 per foot)	$1,031.25
1,000 feet air hose ($.65 per foot)	650.00
40 feet radiator hose ($.70 per foot)	28.00
Four ¾-horsepower piston air pumps	920.00
Electrical costs	600.00
Materials for pump house	150.00
Miscellaneous hardware	50.00
Total Cost	$3,429.25

*These are approximate as costs may vary from one manufacturer to another.

Table 4. Aeration Equipment Costs for Westlake Lake. [49]

Most of the time, according to the report, was spent on the construction of a small pump house. The installation of the aeration tubes was a relatively simple task. If an aeration system is ever seriously considered for Bass or Wildcat Lakes, a consulting engineer familiar with aeration systems should be consulted. The purpose of discussing in detail the aeration system used in Westlake Lake was to show that such a system can work for either Bass or Wildcat Lakes. Careful, detailed, and individual planning is needed for an aeration system for the lakes.

An aeration system chosen must meet the needs of the lake. Bass and Wildcat Lakes pose special problems for any aeration system. The two lakes are in a designated wilderness which prevents the use of a motor for the compression of air in an aeration system. An idea was forwarded by Clark and Greenbank on there study of Park Lake which suggested the use of a windmill to power an aeration system. Unusual methods of providing power to aeration system would be explored.

It should be noted that there's a number of different aeration systems available. For example, Boyd describes a floating pumping devise that is designed to rake up the thermostratification of a lake:

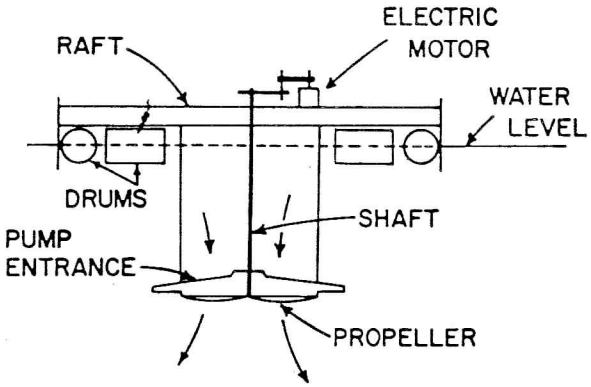


Figure 12, A Quintero-Garton pump for destratifying lakes and ponds. [50]

The Third Option

Sometimes the most radical solution to a management problem is to do nothing. In the cases of Bass and Wildcat Lakes, to do nothing means no sustainable fish population can ever be expected to survive. But on the other hand, doing nothing will leave Bass and Wildcat Lake in their natural state. In my opinion changing the natural environment by man is a serious undertaking. Instead of a linear relationship of causes and effects in the environment of a lake occurring, a circular effect of any management action occurs. So, in the opinion of the author, a minimum amount of effects on the environment should be considered in management of the wilderness lakes. For that reason, and others, the final recommendation of the report is that Bass and Wildcat lakes should be left in their natural state.

Conclusion

Bass and Wildcat Lakes can not sustain a population of fish in their natural state. Hydrogen sulfide forming in an anoxic hypolimnion and then mixing throughout the lake was found to be the cause for the lack of fish in Bass and Wildcat Lakes.

The water in Crystal Lake was found to be constantly mixing. Crystal Lake failed to produce a thermocline because of it's relativity shallow depth of 4 meters. The influx of oxygen during all times of the year means that a population of fish can be sustained in Crystal Lake.

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