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GEOLOGICAL SURVEY

LIMNOLOGY OF NINE SMALL LAKES, MATANUSKA-SUSITNA BOROUGH, ALASKA, AND THE SURVIVAL AND GROWTH RATES OF RAINBOW TROUT

By Paul F. Woods

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Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
4230 University Drive, Suite 201
Anchorage, Alaska 99508-4664

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CONVERSION FACTORS

To convert International System (SI) of units in this report to inch-pound units, multiply by the following factors:

Multiply SI unit	by	To obtain inch - pound unit
cubic hectometer (hm^3)	810.7	acre-foot (acre-ft)
gram (g)	0.002205	pound (lb)
gram per square hectometer (g/hm^2)	0.0008924	pound per acre (lb/acre)
meter (m)	3.281	foot (ft)
millimeter (mm)	0.03937	inch (in.)
square hectometer (hm^2)	2.471	acre
degree Celsius (°C)	°F=[9/5°C]+32	degree Fahrenheit (°F)

Other abbreviations in this report are:

mg/L, milligram per liter

µg/L, microgram per liter

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ABSTRACT

The survival and growth rates of rainbow trout (*Salmo gairdneri*) were concurrently measured with selected limnological characteristics in nine small (surface area less than 25 square hectometers) lakes in the Matanuska-Susitna Borough. The project goal was to develop empirical models for predicting rainbow trout growth rates from the following variables: total phosphorus concentration, chlorophyll *a* concentration, Secchi disc transparency, or the morphoedaphic index--a means of characterizing potential biological productivity. No suitable model could be developed from the data collected during 1982 and 1983.

The lack of significant correlation was attributed in part to the wide variation in survival of rainbow trout. Winterkills, caused by severe depletion of dissolved oxygen, were suspected in four of the lakes. Varied levels of fishing pressure and competition with threespine stickleback (*Gasterosteus aculeatus*) also influenced survival of rainbow trout but their effects were overshadowed by winterkill. Predictive capability was also reduced because of inconsistencies in rankings generated by each of the four limnological variables chosen as indicators of potential biological productivity. A lake ranked low in productivity by one variable was commonly ranked high in productivity by another variable.

The survivability of rainbow trout stocked in lakes such as these nine may be a more important indicator of potential biomass production than are indicators of lake fertility. Assessments of a lake's susceptibility to winterkill and the degree of competition with threespine stickleback are suggested as important topics for additional research.

INTRODUCTION

The acquisition of fish production data by capture methods in lakes is often time-consuming and expensive; hence, various models have been developed to empirically estimate fish production. Ryder (1965) developed a model of this type, the MEI (morphoedaphic index), which uses the ratio of total dissolved solids and mean depth to empirically predict the fish yield of a lake. Its theoretical basis is that fish production is negatively correlated with mean depth and is positively correlated with total dissolved solids, a surrogate variable for lake nutrient concentration. Variables other than the MEI have been used to empirically predict fish production from lake characteristics. Hanson and Leggett (1982) found that total phosphorus concentration correlated more strongly with fish biomass and yield than did the MEI. Oglesby (1977) reported that annual primary production and phytoplankton standing crop were correlated with fish yields in ponds, lakes, and reservoirs located from the equator to northern temperate latitudes.

The ADF&G (Alaska Department of Fish and Game) initiated a study in 1973 to determine the effects of limnological characteristics on the survival and growth of rainbow trout (Salmo gairdneri) stocked in southcentral Alaskan lakes. The ADF&G had used the MEI in that study to rank the potential productivity of lakes being considered for stocking. The application of the MEI by ADF&G as an index of biological productivity differed from that of the original model because Ryder (1965) used fish yield, expressed as kilograms per hectare per year, as the dependent variable.

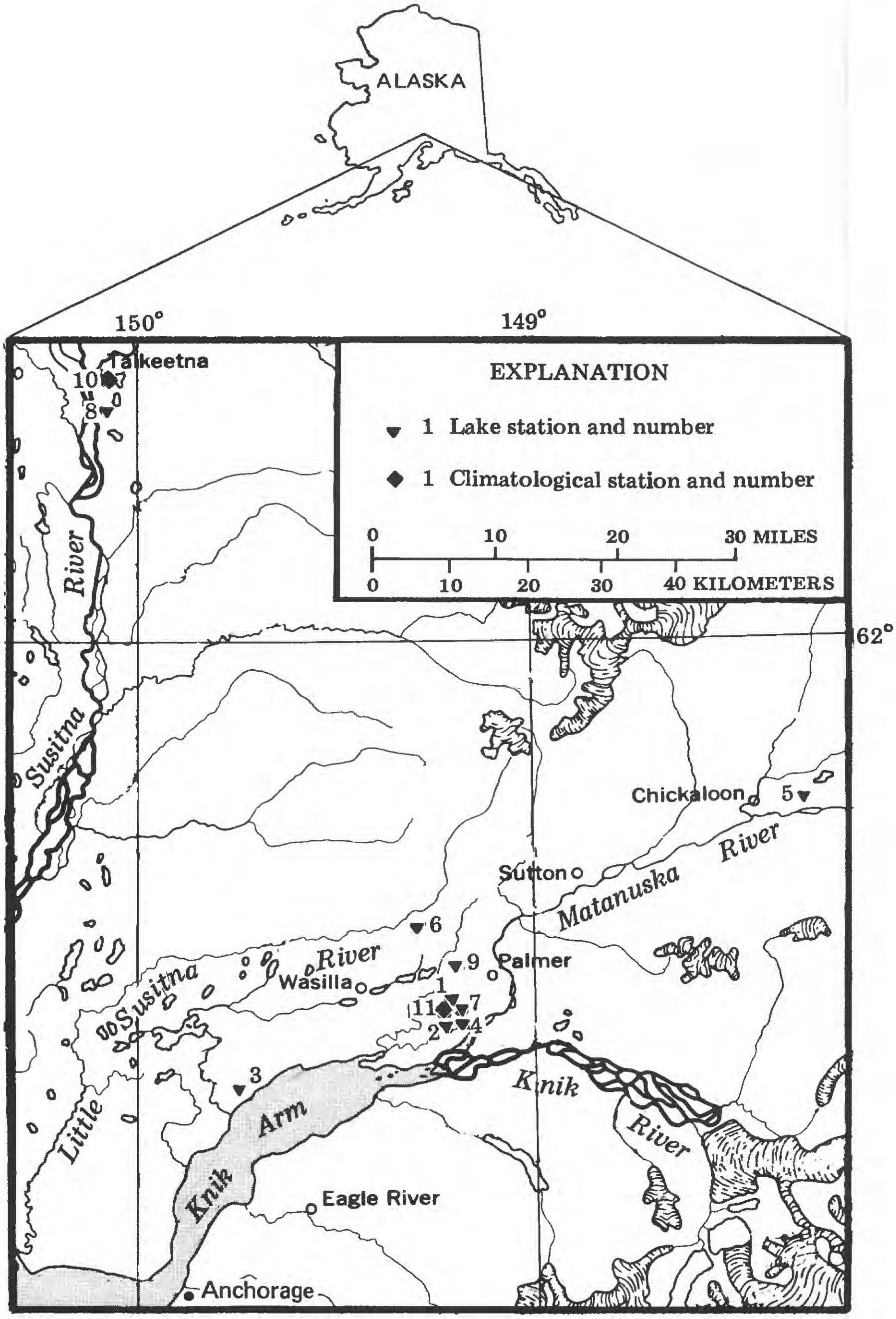
In 1982, the ADF&G proposed an expansion of the 1973 study; they wanted further testing of the hypothesis that a significant correlation exists between the MEI and rainbow trout growth rates in southcentral Alaskan lakes. The ADF&G requested that the U.S. Geological Survey collect limnological data from nine lakes that had been chosen for concurrent assessment of survival and growth rates of rainbow trout. The objective of this cooperative project between the Geological Survey and the Alaska Departments of Fish and Game and Natural Resources was to determine if any correlations could be shown between rainbow trout growth rates and the MEI and other selected limnological variables. The project was conducted during 1982 and 1983 in nine lakes within the Matanuska-Susitna Borough of southcentral Alaska.

ACKNOWLEDGEMENTS

The author expresses his appreciation to A. C. Havens and L. J. Engel, Alaska Department of Fish and Game, Sport Fish Division, Palmer, Alaska, for their assistance and cooperation in providing fisheries data and consultation on analysis of survival and growth rate data.

STUDY AREA

The names and locations of the lakes are depicted in figure 1 and their morphometric characteristics are listed in table 1. All the lakes are less than 25 hm^2, landlocked, and have little or no residential development around their shoreline. Ravine Lake contains sodium bicarbonate water, whereas the other lakes are of the calcium bicarbonate type (Engel, 1974; Watsjold, 1975). Historic winter samples revealed the nine lakes were commonly undersaturated with dissolved oxygen (Alan Havens, Alaska Department of Fish and Game, written commun., 1983). The hypolimnia of Johnson, Junction, Knik, Matanuska, and Sliver Lakes were anoxic during winter; however, winterkill has been confirmed in only Johnson and Sliver Lakes. The lakes are stocked with rainbow trout, but Johnson Lake is closed to fishing.



STATION NUMBER AND NAME	LATITUDE	LONGITUDE
1 Johnson Lake	61 33 59	149 13 51
2 Junction Lake	61 33 35	149 15 25
3 Knik Lake	61 27 39	149 43 36
4 Matanuska Lake	61 33 18	149 13 44
5 Ravine Lake	61 48 12	148 17 25
6 Reed Lake	61 39 49	149 18 55
7 Sliver Lake	61 33 26	149 13 07
8 Tigger Lake	62 16 58	150 03 41
9 Walby Lake	61 37 06	149 12 38
10 Talkeetna	62 18 –	150 06 –
11 Matanuska Agricultural Experiment Station	61 34 –	149 16 –

Figure 1.--Location of the nine study lakes within the Matanuska-Susitna Borough.

Table 1.--Selected morphometric features of the nine lakes

Lake	Altitude (m)	Surface area (hm^2)	Volume (hm^3)	Maximum depth (m)	Mean depth[a] (m)
Johnson	35	16.3	99.4	14.0	6.1
Junction	25	4.4	23.9	14.6	5.4
Knik	10	20.4	118.9	11.3	5.8
Matanuska	15	24.9	261.2	25.3	10.5
Ravine	580	5.0	18.3	7.6	3.7
Reed	180	7.9	24.9	6.1	3.2
Sliver	20	4.0	8.5	6.7	2.1
Tigger	120	9.3	32.6	10.1	3.5
Walby	110	16.2	36.1	6.1	2.2

[a] Volume divided by surface area

Climatological data (U.S. Department of Commerce, issued annually) from Talkeetna (years of record: precipitation, 57; temperature, 61) and the Matanuska Agricultural Experiment Station near Palmer (years of record: precipitation and temperature, 61) characterize temperature and precipitation within the study area. Mean annual precipitation at Talkeetna is about 700 mm; at the Experiment Station it is about 400 mm.

March and April receive the least precipitation, whereas August is the wettest month. Air temperatures during July average 14.5 °C at Talkeetna and 14.4 °C at the Experiment Station. January temperatures fall to an average of -13.1 °C at Talkeetna and -11.4 °C at the Experiment Station. Ice as thick as 1 m covers the lakes generally from October into May. Length of day at summer solstice is nearly 20 hours but is only 5 hours at winter solstice.

During the study, the annual precipitation at Talkeetna was 808.2 mm in 1982 and 579.4 mm in 1983. The Experiment Station received 376.4 mm of precipitation in 1982 and 325.9 mm in 1983. Annual mean air temperatures were within 2 °C of normal at both climatological stations in 1982 and 1983.

METHODS

Limnological data were collected in June and September 1982 and in March, May, and September 1983. Full-depth profiles of water temperature, pH, specific conductance, and dissolved-oxygen concentration were obtained at the deepest part of each lake. Water column transparency was measured with a Secchi disc. Based on these profiles, water samples were then collected at three depths with an opaque Van Dorn bottle. The three samples were composited on the June 1982 sampling trip but were analyzed individually on later sampling trips.

The water samples were analyzed for dissolved solids, specific conductance, pH, total phosphorus, dissolved nitrite plus nitrate, and total ammonia plus organic nitrogen. The two samples from the upper part of the water column were analyzed for chlorophyll a using the high-pressure liquid chromatography method. The analytical procedures are detailed in Greeson (1979) and Skougstad and others (1979). A complete listing of the limnological data collected at the nine lakes is available in annual reports of the U.S. Geological Survey (1983, 1984).

The ADF&G conducted the fisheries portion of this study. Rainbow trout were stocked in the lakes in August and September 1981 and again in August 1982. Population estimates were made in June and September of 1982 and 1983 using either Chapman's modification of the Peterson estimator or Chapman's modification of the Schnabel multiple census estimator, both of which are reported in Ricker (1975). Lengths and weights of fish were measured concurrent with the population estimates. Havens (1983, 1984) presents detailed information on methods used to stock, estimate fish populations, and analyze the fishery data for the nine lakes.

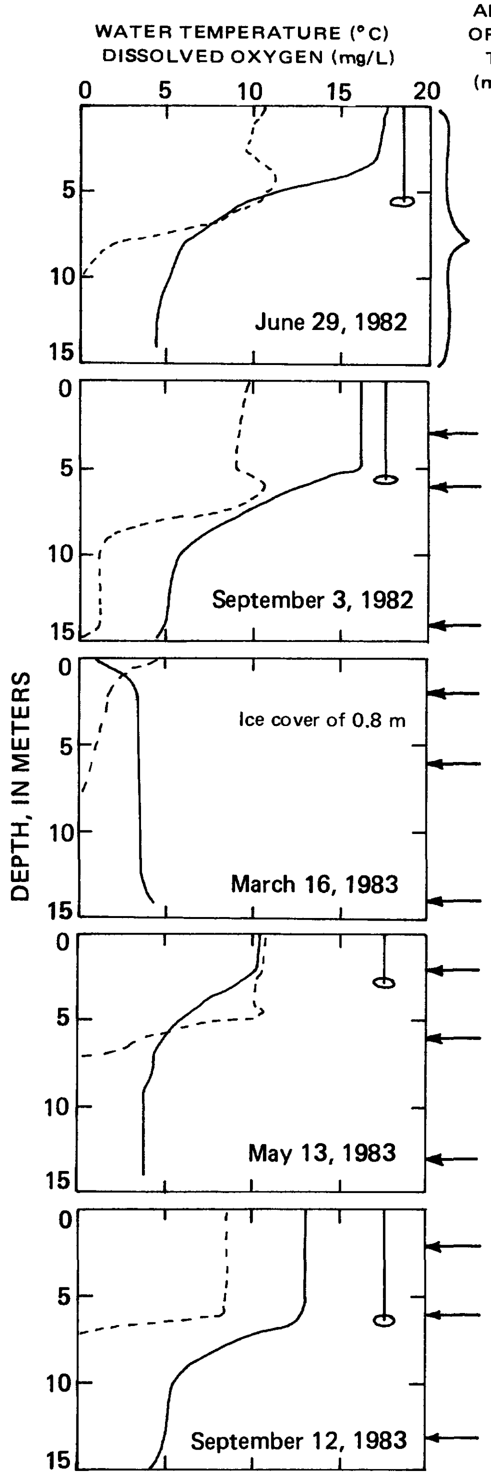
LIMNOLOGICAL CHARACTERISTICS

Johnson Lake

Johnson Lake is the third largest in surface area of the nine lakes. The lake is closed to public fishing because it is used for fish-management experiments by ADF&G. Limnological sampling revealed the lake had well-developed thermal stratification during the summers of 1982 and 1983 (fig. 2). Reaeration of the water column in the spring was incomplete in that the lake was anoxic below 6.75 m within 10 days of "iceout" (melting of winter ice cover) in May 1983. Although the lake was homothermous at iceout there was insufficient circulation to facilitate full-depth reaeration prior to the onset of thermal stratification. The hypolimnion was anoxic or near-anoxic on all sampling trips. ADF&G hypothesized that a complete winterkill occurred in 1983 because of the anoxic conditions under ice cover (Alan Havens, Alaska Department of Fish and Game, written commun., 1983). Metalimnetic dissolved-oxygen maxima were recorded in June and September 1982 and in May 1983. Secchi disc transparencies ranged from 2.8 to 6.2 m. The 2.8 m value coincided with the largest concentration of chlorophyll a in May 1983. Dissolved-solids concentrations ranged from 73 to 158 mg/L with the larger values from the anoxic hypolimnion. Concentrations of total phosphorus and total ammonia plus organic nitrogen in the hypolimnion were also larger than epilimnetic concentrations. This pattern was not repeated by dissolved nitrite plus nitrate concentrations which generally were below the detection limit of 10 µg/L, except in March 1983. Chlorophyll a concentrations were low in all samples except one; a value of 16 µg/L was measured in the metalimnion in May 1983.

Junction Lake

Junction Lake has the second smallest surface area of the nine lakes and was densely populated by aquatic macrophytes in its littoral zone. This lake had well-developed thermal stratification on all but the winter sampling trip (fig. 3).

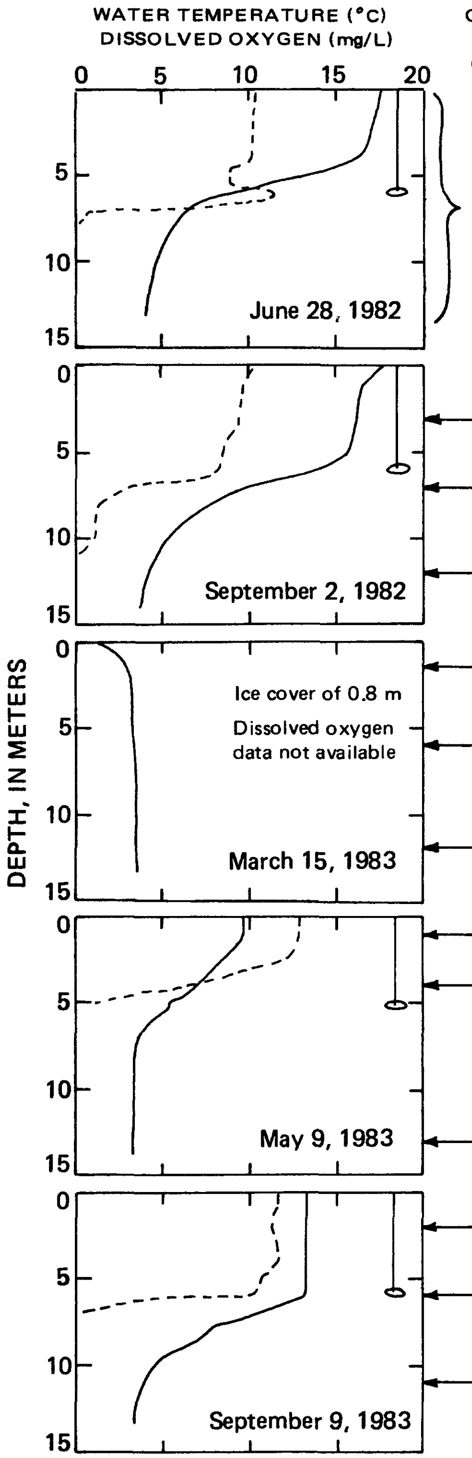


Date	NITROGEN, AMMONIA + ORGANIC TOTAL (mg/L as N)	NITROGEN $NO_2 + NO_3$ DISSOLVED (µg/L as N)	PHOSPHORUS TOTAL (µg/L as P)	SOLIDS, RESIDUE AT 180°C DISSOLVED (mg/L)	CHLOROPHYLL *-a* PHYTO-PLANKTON (µg/L)
June 29, 1982	2.1	< 10	31	92	2.2
September 3, 1982	1.6	<10	38	114	0.9
	1.0	<10	24	100	0.8
	3.3	<10	54	125	—
March 16, 1983	1.0	202	10	86	1.2
	0.9	205	18	88	1.9
	1.8	34	61	102	—
May 13, 1983	1.0	<10	17	73	1.9
	1.0	13	34	98	16
	2.7	<10	57	158	—
September 12, 1983	0.7	<10	< 5	80	1.6
	0.8	<10	< 5	79	1.6
	3.3	<10	—	129	—

EXPLANATION

- ——— Water temperature
- - - - - Dissolved oxygen concentration
- Secchi disc transparency
- } Composite water sample
- ←— Point water sample

Figure 2.--Limnological characteristics of Johnson Lake on selected dates in 1982-83.



Date	NITROGEN, AMMONIA + ORGANIC TOTAL (mg/L as N)	NITROGEN NO_2+NO_3 DISSOLVED (µg/L as N)	PHOSPHORUS TOTAL (µg/L as P)	SOLIDS, RESIDUE AT 180°C DISSOLVED (mg/L)	CHLOROPHYLL -a PHYTO-PLANKTON (µg/L)
June 28, 1982 (composite)	4.2	<10	27	182	1.6
September 2, 1982	1.5	<10	20	204	0.6
	1.2	10	0	242	5.1
	2.7	<10	58	281	—
March 15, 1983	1.0	38	14	196	0.9
	1.3	17	22	203	1.2
	1.8	22	94	235	—
May 9, 1983	2.4	12	12	115	1.0
	0.8	11	19	205	6.7
	2.6	<10	20	255	—
September 9, 1983	0.7	<10	< 5	131	1.7
	0.6	<10	< 5	132	0.3
	2.5	<10	33	236	—

EXPLANATION

- ——— Water temperature
- - - - - Dissolved oxygen concentration
- ⊥ Secchi disc transparency
- } Composite water sample
- ←— Point water sample

Figure 3.--Limnological characteristics of Junction Lake on selected dates in 1982-83.

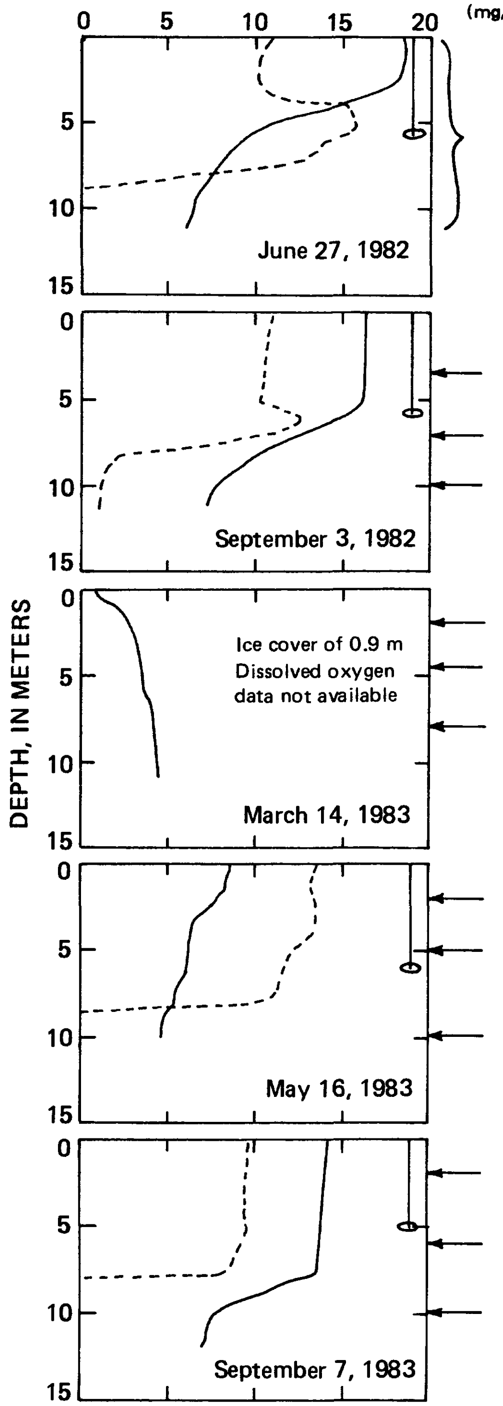
As in Johnson Lake, vernal reaeration was incomplete, which allowed anoxic conditions to persist in the hypolimnion through the September 1983 sampling trip. Dissolved-oxygen samples were not collected in March 1983 because of equipment malfunction. However, the anoxic conditions below the 5 m depth in May 1983 indicated the lake was anoxic over part of its water column during the late winter. A metalimnetic dissolved-oxygen maxima was measured in June 1982. Secchi disc transparencies, which ranged from 5.2 to 6.0 m, were not correlated (visual examination of scatterplot) with chlorophyll _a_ concentrations. Dissolved-solids concentrations in the hypolimnion ranged from 235 to 281 mg/L, whereas near-surface values ranged from 115 to 204 mg/L. The anoxic water contained higher concentrations of total phosphorus and total ammonia plus organic nitrogen than did the epilimnion. Dissolved nitrite plus nitrate concentrations ranged from less than 10 to 38 µg/L with the larger values occurring under ice cover. Chlorophyll _a_ concentrations ranged from 0.3 to 6.7 µg/L with the two largest values measured within the metalimnion.

Knik Lake

Knik Lake has the second largest surface area of the nine lakes and was strongly stratified on three of the five sampling trips (fig. 4). Vernal reaeration was incomplete as in Johnson and Junction Lakes. Although dissolved-oxygen data were not obtained in March 1983, the anoxic conditions in May 1983 indicated part of the lake had been anoxic under ice cover. The lake had an anoxic or near-anoxic hypolimnion on each sampling trip. Metalimnetic dissolved-oxygen maxima were recorded in June and September 1982. Secchi disc transparencies ranged from 5.0 to 6.0 m and were uncorrelated (visual examination of scatterplot) with chlorophyll _a_ concentrations. Hypolimnetic dissolved-solids concentrations ranged from 125 to 148 mg/L and exceeded near-surface values, which ranged from 89 to 120 mg/L. Concentrations of total phosphorus and total ammonia plus organic nitrogen in the hypolimnion were substantially larger than epilimnetic concentrations. In March and May 1983 dissolved nitrite plus nitrate concentrations ranged from 14 to 223 µg/L, but on other sampling trips they were below the detection limit of 10 µg/L. The largest concentration of chlorophyll _a_, 6.2 µg/L, was measured within the June 1982 metalimnetic dissolved-oxygen maximum. At other times, chlorophyll _a_ did not exceed 1.6 µg/L.

Matanuska Lake

Matanuska Lake, the largest and deepest of the nine lakes, was thermally stratified throughout the summer (fig. 5). Vernal reaeration was incomplete as evidenced by anoxic conditions below the 10 m depth within one week of iceout in May 1983. The lake was anoxic beneath 12 m on each sampling trip. A metalimnetic dissolved-oxygen maximum of 18.0 mg/L (162 percent saturation) occurred at 9.5 m in September 1982. Just 2.5 m beneath this maximum concentration dissolved oxygen was absent. The Secchi disc transparencies of 6.7 and 7.5 m measured in 1982 were associated with chlorophyll _a_ concentrations that averaged 1.0 and 6.0 µg/L. In 1983, lower concentrations of chlorophyll _a_ occurred with Secchi disc transparencies of 10.2 and 10.8 m. Differences between epilimnetic and hypolimnetic concentrations of dissolved solids were less in this lake than the three lakes previously discussed.

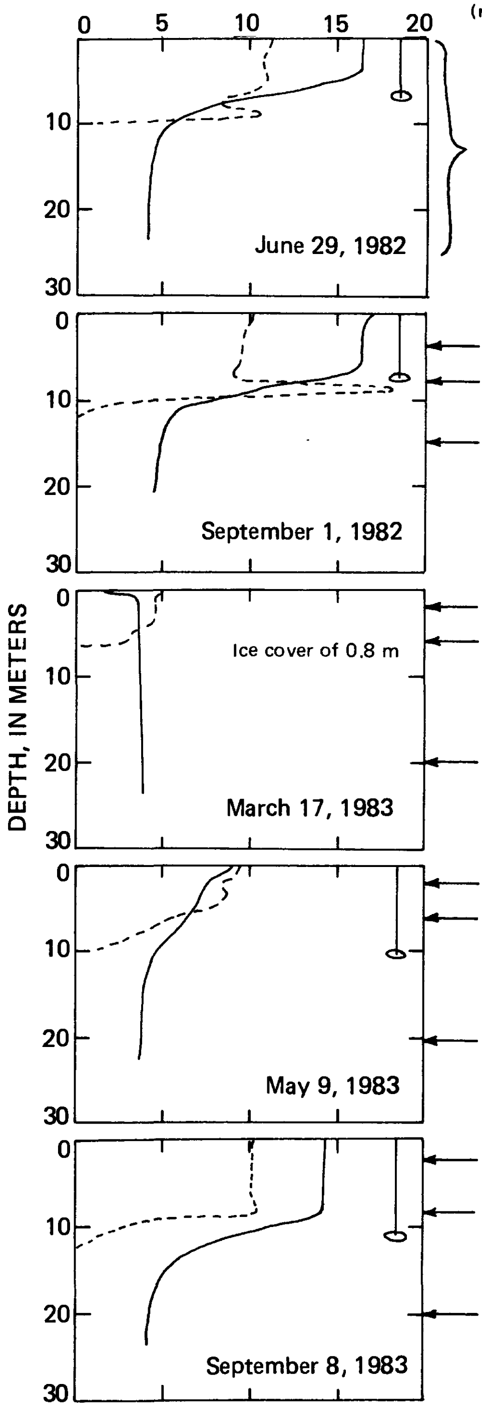


Date	NITROGEN, AMMONIA + ORGANIC TOTAL (mg/L as N)	NITROGEN NO2+ NO3 DISSOLVED (µg/L as N)	PHOSPHORUS TOTAL (µg/L as P)	SOLIDS, RESIDUE AT 180°C DISSOLVED (mg/L)	CHLOROPHYLL -a PHYTO-PLANKTON (µg/L)
June 27, 1982	1.4	<10	43	110	6.2
September 3, 1982	0.9	<10	22	120	0.9
	1.0	<10	22	125	1.6
	3.4	<10	134	148	—
March 14, 1983	0.8	170	9	113	1.0
	0.7	223	7	114	0.9
	2.8	25	17	131	—
May 16, 1983	0.6	63	6	89	0.8
	0.6	74	8	89	1.5
	3.6	14	22	125	—
September 7, 1983	0.5	<10	<5	93	1.6
	0.4	<10	<5	92	0.7
	5.1	<10	436	146	—

EXPLANATION

- ——— Water temperature
- - - - - Dissolved oxygen concentration
- Secchi disc transparency
- } Composite water sample
- ←—— Point water sample

Figure 4.--Limnological characteristics of Knik Lake on selected dates in 1982-83.



Date	NITROGEN, AMMONIA + ORGANIC TOTAL (mg/L as N)	NITROGEN NO_2 + NO_3 DISSOLVED (µg/L as N)	PHOSPHORUS TOTAL (µg/L as P)	SOLIDS, RESIDUE AT 180°C DISSOLVED (mg/L)	CHLOROPHYLL *-a* PHYTO-PLANKTON (µg/L)
June 29, 1982 (composite)	1.6	<10	44	150	6.0
September 1, 1982	1.2	<10	31	171	0.6
	0.9	<10	34	207	1.4
	1.6	<10	49	169	—
March 17, 1983	0.6	19	6	147	0.3
	0.4	28	5	152	0.3
	2.7	19	21	163	—
May 9, 1983	0.7	< 10	11	131	0.3
	0.8	<10	7	146	0.3
	2.1	10	19	173	—
September 8, 1983	0.3	<10	< 5	107	0.7
	0.3	<10	<5	130	0.4
	2.0	<10	110	163	—

EXPLANATION

- ——— Water temperature
- - - - - Dissolved oxygen concentration
- Secchi disc transparency
- } Composite water sample
- ← Point water sample

Figure 5.--Limnological characteristics of Matanuska Lake on selected dates in 1982-83.

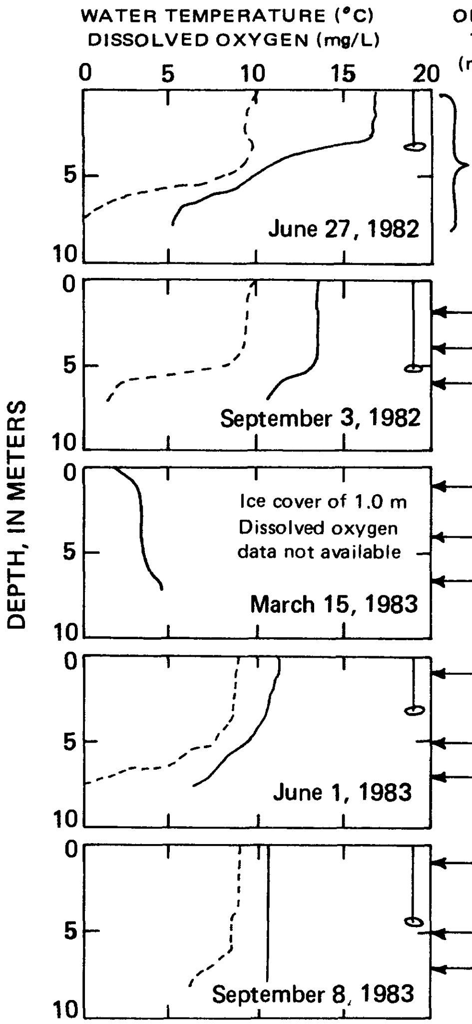
The highest value, 207 mg/L, was measured within 1.5 m of the metalimnetic dissolved-oxygen maximum of September 1982. Hypolimnetic concentrations of total phosphorus and total ammonia plus organic nitrogen were larger than those of the epilimnion. Except for March 1983 samples, all dissolved nitrite plus nitrate concentrations were at or below the detection limit.

Ravine Lake

Unlike the four lakes already discussed, Ravine Lake was not thermally stratified during each summer sampling trip (fig. 6). The other four lakes have mean depths from 5.4 to 10.5 m, whereas Ravine Lake has a mean depth of 3.7 m. Because it is shallow and exposed to wind, Ravine Lake is less likely to maintain thermal stratification. Dissolved-oxygen concentrations were low near the lake bottom in June of 1982 and 1983 and in September 1982. Dissolved-oxygen data are not available for March 1983, but the profiles for June 1983 indicate that low concentrations were present in late winter. No metalimnetic dissolved-oxygen maxima were measured in Ravine Lake. Secchi disc transparencies ranged from 3.2 to 5.1 m and were not correlated (visual examination of scatterplots) with chlorophyll a concentrations. This lake had, on the average, the highest concentrations of dissolved solids among the nine lakes and is the only one that contains sodium bicarbonate water. Dissolved-solids concentrations ranged from 185 to 254 mg/L and on a given sampling date varied only slightly with depth. Concentrations of total phosphorus and total ammonia plus organic nitrogen did not have the larger hypolimnetic values such as those measured in the four lakes previously discussed. March 1983 samples had the highest concentrations of dissolved nitrite plus nitrate, but at other times they were at, or near, the detection limit. Chlorophyll a concentrations did not exceed 2.0 µg/L; interestingly, the two highest values measured were under a 1.0 m thick ice cover that had been wind swept of its snow cover.

Reed Lake

Reed Lake lacked strong thermal stratification throughout the summer months (fig. 7), probably due largely to its shallowness (mean depth of 3.2 m) and exposure to wind. Consequently, the lake was well oxygenated in the summer. The May 1983 profiles indicate that dissolved-oxygen concentrations were probably low under ice cover. This observation was substantiated with data from personnel who had sampled Reed Lake on February 28, 1983 and found 1.7 mg/L of dissolved oxygen at the surface and anoxic conditions at 6 m (Alan Havens, Alaska Department of Fish and Game, written commun., 1984). A small metalimnetic dissolved-oxygen maxima was recorded near the lake bottom in June 1982. Secchi disc transparencies ranged from 2.3 to 4.6 m and were inversely correlated (r^2=0.77) with chlorophyll a concentrations which ranged from less than 0.1 to 4.3 µg/L. Reed Lake had relatively low dissolved-solids concentrations; they ranged from 35 to 71 mg/L and lacked distinct stratification with depth, except in March 1983. During this visit, the concentrations of dissolved solids, total phosphorus, and total ammonia plus organic nitrogen near the bottom were substantially higher than those near the surface. The March 1983 samples contained concentrations of dissolved nitrite plus nitrate from 23 to 26 µg/L, but at other times this variable was less than 15 µg/L.

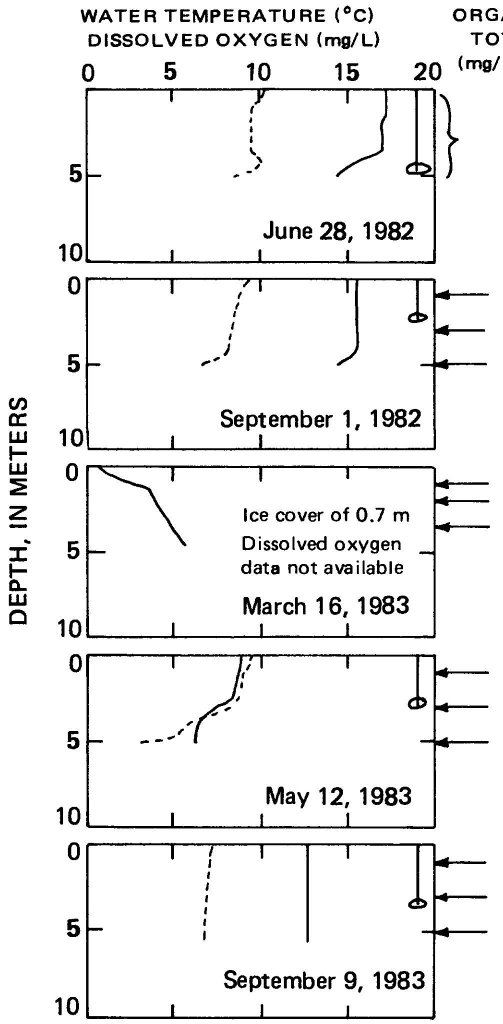


Date	NITROGEN, AMMONIA + ORGANIC TOTAL (mg/L as N)	NITROGEN $NO_2 + NO_3$ DISSOLVED (µg/L as N)	PHOSPHORUS TOTAL (µg/L as P)	SOLIDS, RESIDUE AT 180°C DISSOLVED (mg/L)	CHLOROPHYLL -a PHYTO-PLANKTON (µg/L)
June 27, 1982	1.1	10	19	213	0.8
September 3, 1982	1.1	<10	30	248	0.7
	1.1	<10	34	—	0.8
	1.3	<10	—	247	—
March 15, 1983	1.0	133	13	223	1.7
	1.1	135	9	220	2.0
	2.4	22	21	254	—
June 1, 1983	0.5	<10	17	198	0.6
	0.7	<10	37	201	1.6
	0.6	<10	16	207	—
September 8, 1983	0.5	<10	<5	186	1.3
	0.6	<10	<5	185	1.1
	0.7	<10	<5	187	—

EXPLANATION

- ——— Water temperature
- – – – – Dissolved oxygen concentration
- Secchi disc transparency
- } Composite water sample
- ←—— Point water sample

Figure 6.--Limnological characteristics of Ravine Lake on selected dates in 1982-83.



Date	NITROGEN, AMMONIA + ORGANIC TOTAL (mg/L as N)	NITROGEN NO_2+ NO_3 DISSOLVED (µg/L as N)	PHOSPHORUS TOTAL (µg/L as P)	SOLIDS, RESIDUE AT 180°C DISSOLVED (mg/L)	CHLOROPHYLL -a PHYTO-PLANKTON (µg/L)
June 28, 1982	3.2	10	9	36	< 0.1
September 1, 1982	1.0	< 10	64	69	2.6
	1.0	< 10	31	35	3.0
	1.1	< 10	60	47	—
March 16, 1983	1.7	26	7	51	0.4
	1.5	23	8	52	0.7
	3.5	24	62	71	—
May 12, 1983	1.2	14	30	42	3.1
	1.1	15	22	43	4.3
	1.9	12	27	46	—
September 9, 1983	0.7	< 10	< 5	40	1.8
	0.8	< 10	< 5	42	1.6
	0.8	< 10	< 5	40	—

EXPLANATION

- ——— Water temperature
- - - - - Dissolved oxygen concentration
- Secchi disc transparency
- } Composite water sample
- ←— Point water sample

Figure 7 --Limnological characteristics of Reed Lake on selected dates in 1982-83.

Sliver Lake

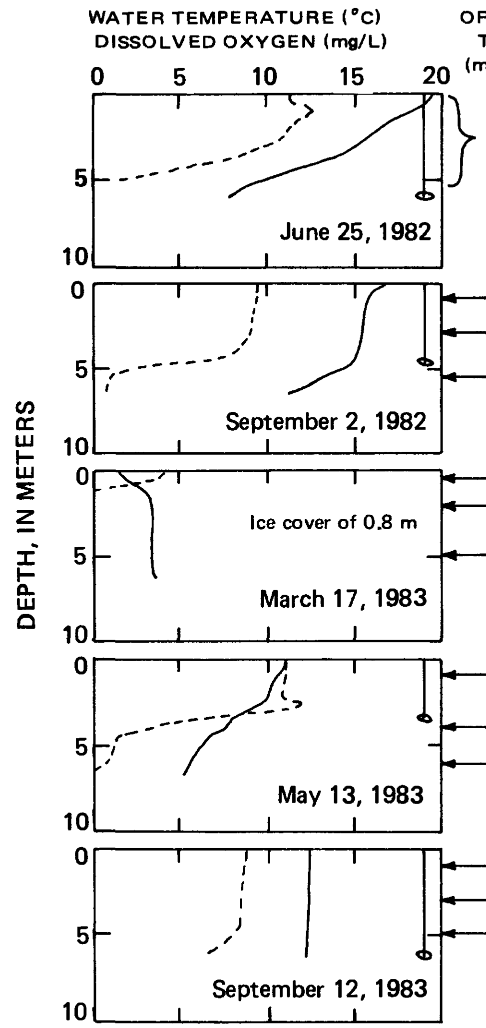
In contrast to Reed Lake, Sliver Lake is very shallow (2.1 m mean depth) yet was thermally stratified in the summer (fig. 8), probably as a consequence of being wind sheltered. When stratified or under ice cover the dissolved-oxygen concentration declined rapidly with depth. In March 1983 only the uppermost 1.0 m contained any dissolved oxygen. A partial winterkill was suspected to have occurred in early 1983 as a consequence of the nearly anoxic conditions (Alan Havens, Alaska Department of Fish and Game, written commun., 1983). A small increase in metalimnetic dissolved oxygen was measured in May 1983 and occurred near the highest chlorophyll a concentration (3.3 µg/L) measured in the lake. Secchi disc transparencies ranged from 3.5 to 6.2 m and were inversely correlated (r^2=0.66) with chlorophyll a. Dissolved-solids concentrations ranged from 132 to 218 mg/L. Under ice cover or during periods of stratification the hypolimnion had higher concentrations of dissolved solids than did the epilimnion. Except for the March 1983 samples, the dissolved nitrite plus nitrate concentrations were at or below the detection limit.

Tigger Lake

Tigger Lake was strongly stratified during May and June sampling trips but had undergone partial circulation during both September visits (fig. 9). Most of the water column was well oxygenated in summer, but concentrations of dissolved oxygen as low as 3.2 mg/L were measured near the lake bottom. Equipment malfunction prevented dissolved-oxygen profiling in March 1983, but ADF&G measurements on March 3 show dissolved-oxygen concentrations of 7.8 mg/L at the surface and 1.7 mg/L at the 6-m depth (Alan Havens, Alaska Department of Fish and Game, written commun., 1984). Secchi disc transparencies ranged from 6.5 to 8.0 m but were not correlated (visual examination of scatterplot) with chlorophyll a concentrations which did not exceed 1.0 µg/L. Tigger Lake had the lowest dissolved-solids concentrations, 23 to 45 mg/L, among the nine lakes. Concentrations of dissolved solids, total phosphorus, total ammonia plus organic nitrogen, and dissolved nitrite plus nitrate showed little stratification with depth. Dissolved nitrite plus nitrate values were highest under the March ice cover but were below the detection limit of 10 µg/L in September.

Walby Lake

Walby Lake is the second shallowest (mean depth of 2.2 m) of the nine lakes studied and was densely populated with aquatic macrophytes. The lake was thermally stratified during only two of the five sampling trips (fig. 10), as a result of its being shallow and exposed to wind. In May 1983 the lake was severely depleted of dissolved oxygen below 5.0 m, which indicated incomplete vernal reaeration and low wintertime dissolved-oxygen concentrations. The suspected low concentrations of dissolved oxygen under ice were verified by results of late February sampling by ADF&G: 1.8 mg/L at the surface and 0.07 mg/L at 6 m (Alan Havens, Alaska Department of Fish and Game, written commun., 1984). Secchi disc transparencies were consistently less than those measured in the other eight lakes. Chlorophyll a concentrations ranged from 1.3 to 8.3 µg/L but were uncorrelated (visual examination of scatterplots) with Secchi disc data. The highest values of chlorophyll a

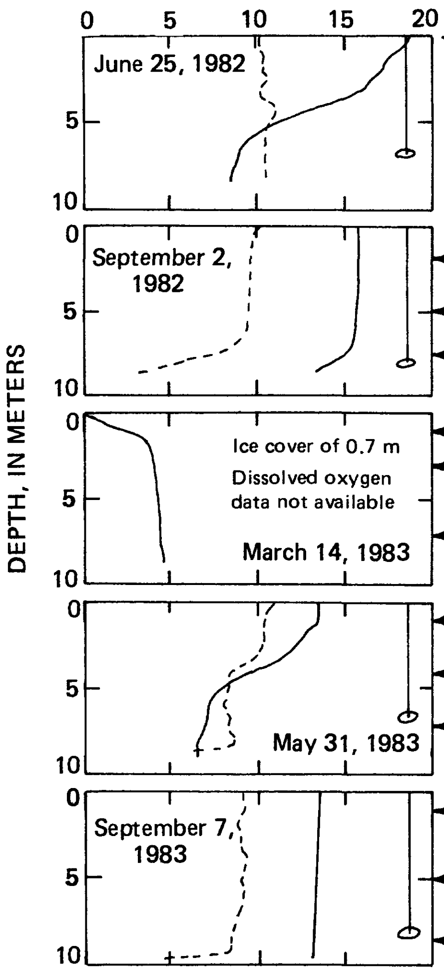


Date	NITROGEN, AMMONIA + ORGANIC TOTAL (mg/L as N)	NITROGEN $NO_2 + NO_3$ DISSOLVED (µg/L as N)	PHOSPHORUS TOTAL (µg/L as P)	SOLIDS, RESIDUE AT 180°C DISSOLVED (mg/L)	CHLOROPHYLL *-a* PHYTO-PLANKTON (µg/L)
June 25, 1982	1.6	10	9	150	0.8
September 2, 1982	2.0	<10	28	170	0.6
	1.0	<10	36	133	1.2
	1.0	<10	36	218	—
March 17, 1983	0.7	124	14	183	0.4
	0.8	42	11	188	2.8
	1.2	17	24	199	—
May 13, 1983	0.7	10	14	146	1.3
	0.6	<10	19	188	3.3
	0.6	<10	26	209	—
September 12, 1983	0.6	<10	<5	132	1.2
	0.5	<10	<5	134	1.1
	0.6	<10	<5	134	—

EXPLANATION

- ——— Water temperature
- - - - Dissolved oxygen concentration
- Secchi disc transparency
- } Composite water sample
- ←— Point water sample

Figure 8.--Limnological characteristics of Sliver Lake on selected dates in 1982-83.

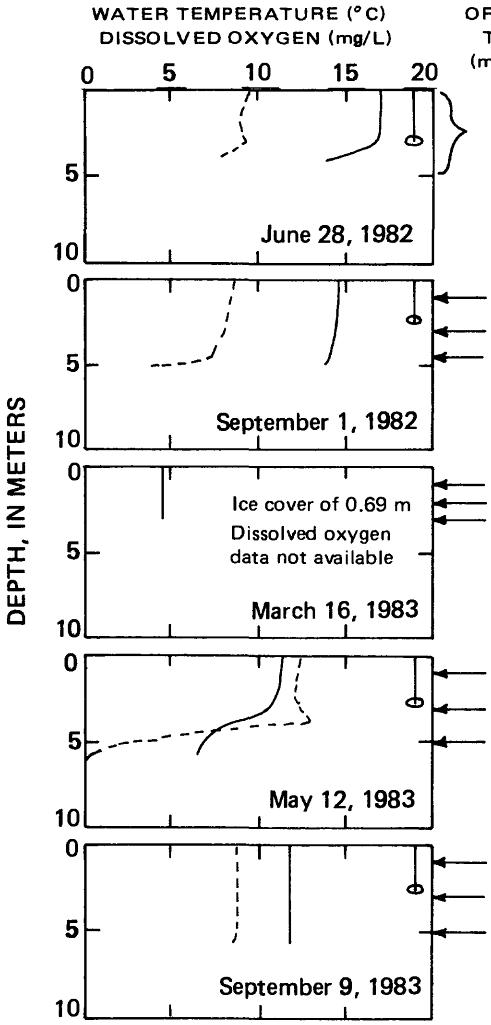


Date	Nitrogen, ammonia + organic total (mg/L as N)	Nitrogen $NO_2 + NO_3$ dissolved (µg/L as N)	Phosphorus total (µg/L as P)	Solids, residue at 180 °C dissolved (mg/L)	Chlorophyll -a- phytoplankton (µg/L)
June 25, 1982 (composite)	0.9	30	7	25	0.4
September 2, 1982	0.8	<10	30	32	0.6
	0.7	<10	21	35	0.8
	1.3	<10	23	36	—
March 14, 1983	0.6	146	6	26	0.6
	0.6	163	5	29	0.2
	0.9	53	9	28	—
May 31, 1983	0.5	22	9	35	0.5
	0.7	24	5	29	0.2
	0.6	22	15	30	—
September 7, 1983	0.5	<10	<5	23	1.0
	0.4	<10	<5	30	0.8
	0.3	<10	<5	45	—

EXPLANATION

- ——— Water temperature
- - - - Dissolved oxygen concentration
- Secchi disc transparency
- } Composite water sample
- ← Point water sample

Figure 9.--Limnological characteristics of Tigger Lake on selected dates in 1982-83.



Date	NITROGEN, AMMONIA + ORGANIC TOTAL (mg/L as N)	NITROGEN $NO_2 + NO_3$ DISSOLVED (μg/L as N)	PHOSPHORUS TOTAL (μg/L as P)	SOLIDS, RESIDUE AT 180°C DISSOLVED (mg/L)	CHLOROPHYLL -a- PHYTO-PLANKTON (μg/L)
June 28, 1982	3.3	10	15	101	1.3
September 1, 1982	1.0	< 10	24	126	2.6
	1.2	< 10	24	153	2.1
	1.0	< 10	24	156	—
March 16, 1983	1.4	27	16	138	6.7
	1.5	18	15	137	8.3
	1.7	16	19	139	—
May 12, 1983	1.0	10	16	97	2.5
	1.2	< 10	19	97	2.0
	3.1	< 10	25	130	—
September 9, 1983	0.8	< 10	< 5	95	1.7
	0.6	< 10	< 5	95	1.9
	0.7	< 10	7	98	—

EXPLANATION

- ——— Water temperature
- – – – – Dissolved oxygen concentration
- Secchi disc transparency
- } Composite water sample
- ←— Point water sample

Figure 10.--Limnological characteristics of Walby Lake on selected dates in 1982-83.

and dissolved nitrite plus nitrate were measured in March 1983 under 0.69 m of moderately clear ice that was devoid of snow. Concentrations of dissolved solids, total phosphorus, and total ammonia plus organic nitrogen were not stratified with depth except in May 1983.

Seasonal Limnological Trends

The lakes generally thaw in early May and are exposed daily to between 16.5 and 17.5 hours of daylight (Watson and others, 1971). The resulting rapid warming, in conjunction with weak winds, hinders lake circulation and allows rapid development of thermal stratification. In years with cloudy and windy conditions during spring iceout these lakes probably would undergo full-depth circulation. The lakes do circulate completely, albeit on an irregular basis, because none of them are chemically meromictic.

The four lakes with mean depths greater than 5.0 m -- Johnson, Junction, Knik, and Matanuska -- were strongly stratified throughout the summer whereas the five shallower lakes were less prone to persistent stratification. All the shallow lakes had undergone partial or complete autumnal circulation by early September, but none of the deeper lakes had.

The strong and persistent stratification in the four deep lakes and their incomplete vernal and autumnal circulation effectively blocked atmospheric reaeration of their hypolimnia. The dissolved oxygen that was available beneath the metalimnion was consumed by biochemical processes. As a consequence, the deep lakes had anoxic or near anoxic hypolimnia on each sampling trip. The shallower lakes were less prone to anoxic hypolimnia because they were more easily reaerated. Shallowness of these lakes also allowed solar radiation to penetrate to the bottom in quantities sufficient to stimulate photosynthetic oxygen production by macrophytes, periphyton, and phytoplankton.

In the lakes with strong thermal stratification, concentrations of total phosphorus, total ammonia plus organic nitrogen, and dissolved solids were commonly higher in the hypolimnion than in the epilimnion. Thermal stratification restricts water column circulation which permits the settling of seston through the metalimnion into the hypolimnion. Seston consists of refractory and labile components that are differentially susceptible to bacterial decomposition. Therefore, both the suspended and dissolved components that make up the total concentration of a chemical constituent are affected by the input of seston to the hypolimnion. Dissolved concentrations of constituents such as ammonia, phosphorus, iron, and manganese are increased when the hypolimnion becomes anoxic at the sediment-water interface; such constituents can then migrate from the sediment into the lake. The net effect of strong thermal stratification and an anoxic hypolimnion was to increase the total (suspended plus dissolved) concentrations of constituents within the hypolimnia of the study lakes.

Potential Biological Productivity

The ADF&G has used the morphoedaphic index (MEI) to rank the potential productivity of many southcentral Alaskan lakes (Watsjold, 1976; Havens, 1983). An MEI value for each of the nine lakes studied here (table 2) was calculated as follows:

$$MEI = \frac{DS}{Z} \qquad (1)$$

where MEI is the morphoedaphic index, unitless;
DS is the mean of four near-surface concentrations of dissolved solids, in milligrams per liter, sampled between September 1982 and September 1983; and
Z is mean depth, in meters.

Table 2.--Morphoedaphic indexes of the nine lakes

Lake	Mean and range of dissolved solids concentration[a] (mg/L)	Mean depth (m)	Morphoedaphic index
Tigger	29.0 (23 - 35)	3.5	8.3
Matanuska	139.0 (107- 171)	10.5	13.2
Johnson	88.2 (73- 114)	6.1	14.5
Reed	50.5 (40 - 69)	3.2	15.8
Knik	103.8 (89- 120)	5.8	17.9
Junction	161.5 (115- 204)	5.4	29.9
Walby	114.0 (95- 138)	2.2	51.8
Ravine	213.8 (186- 248)	3.7	57.8
Sliver	157.8 (132- 183)	2.1	75.1

[a]Based on four near-surface samples taken between September 1982 and September 1983

The MEI values in table 2 are not directly comparable to the values computed by ADF&G investigators because they use specific conductance rather than dissolved-solids concentration and feet, instead of meters, for mean depth. However, the relative ranking for a group of lakes would be the same using either method.

The MEI values in table 2 indicate that Sliver Lake has the best growth potential for fish and Tigger Lake has the lowest potential. Tigger Lake had the lowest MEI because of its low dissolved-solids concentration. Sliver Lake had the third highest average dissolved-solids concentration and had the lowest mean depth and, thereby, earned it the highest MEI among the nine lakes. The second highest MEI computed in this study, 57.8, was for Ravine Lake. Havens (1983) adjusted the ADF&G-computed MEI value for Ravine Lake downward by about 30 percent because he considered the sodium ion concentration of the lake abnormally high. This author elected not to make such an adjustment to the MEI because the lake's sodium ion concentration does not appear to be anomalous. Ravine Lake's MEI would have fallen from 57.8 to 40.5 if it had been downgraded, which would have changed the lake's position in table 2 only slightly.

The use of the MEI by the ADF&G is based on the concept that the chemistry and morphology of a lake interact to affect its biological productivity and its ability to grow fish. Among lakes of similar mean depth, the MEI will predict larger fish production from those lakes with the larger dissolved-solids concentrations.

The concept of relating a lake's biological productivity to index variables is used by limnologists to categorize the nutritional level, or trophic state, of lakes. Trophic state covers a continuum from nutrient-poor to nutrient-rich; however, for ease of categorization, three levels are commonly defined: oligotrophic, or nutrient-poor, eutrophic, or nutrient-rich, and mesotrophic, a "middle-ground" between oligotrophic and eutrophic. Many variables have been used as trophic state indices; some are variables that control biological production, whereas others indicate responses of a lake to environmental conditions. Examples of control variables include influent loadings and in-lake concentrations of nutrients such as nitrogen and phosphorus. Chlorophyll _a_ concentrations, Secchi disc transparency, and hypolimnetic dissolved-oxygen deficits are examples of response variables. A categorization of trophic state based on total phosphorus concentration, chlorophyll _a_ concentrations, and Secchi disc transparency is discussed by Taylor and others (1980) and is summarized in table 3.

Table 3.--Trophic state designation based on concentrations of total phosphorus and chlorophyll _a_, and Secchi disc transparency
[Source: Taylor and others (1980)]

Trophic state	Total phosphorus concentration (µg/L)	Chlorophyll _a_ concentration (µg/L)	Secchi disc transparency (m)
Oligotrophic	less than 10	less than 7	greater than 3.7
Mesotrophic	10 - 20	7 - 12	2.0 - 3.7
Eutrophic	greater than 20	greater than 12	less than 2.0

The objective of this study was to ascertain if the MEI or other limnological variables could be used to empirically predict rainbow trout growth in small, landlocked lakes of southcentral Alaska. ADF&G stipulated that the variables must be relatively easy to quantify. The three variables listed in table 3 were selected as potential predictors because they have been used to classify lake trophic state and they are easily measured. The data in figures 2 through 10 were used to categorize each lake's trophic state based on the criteria in table 3. Near-surface concentrations of total phosphorus yielded trophic states from oligotrophic to eutrophic (table 4), because each lake had a wide range of total phosphorus concentrations. Chlorophyll _a_ concentrations of near-surface samples indicated each lake to be oligotrophic. Secchi disc transparencies generally indicated oligotrophy; however, Ravine, Reed, and Walby lakes had some values in the mesotrophic range.

Table 4.--Trophic states of the nine lakes
[O = Oligotrophic, M = Mesotrophic, E = Eutrophic]

Lake	Basis for trophic state designation[a]		
	Secchi disc transparency	Total phosphorus concentration[b]	Chlorophyll _a_ concentration[b]
Johnson	O	O,M,E	O
Junction	O	O,M	O
Knik	O	O,M,E	O
Matanuska	O	O,M,E	O
Ravine	O,M	O,M,E	O
Reed	O,M	O,M,E	O
Sliver	O	O,M,E	O
Tigger	O	O,M,E	O
Walby	M	O,M,E	O

[a]Refer to table 3
[b]Based on near-surface samples

In table 2 the nine lakes are ranked from low to high potential productivity based on their MEI values. A similar ranking is presented in table 5 in which the lakes are ranked as to their potential productivity based on the MEI, Secchi disc transparency, total phosphorus concentration, and chlorophyll _a_ concentration. Note that the four measures of potential biological productivity generally yield dissimilar rankings. Tigger Lake is the only lake with consistently low rankings. None of the lakes ranks consistently high on all four measures.

Table 5.--Ranking of the relative potential biological productivity of the nine lakes based on four limnological variables
[Values of variables in parentheses and lake names abbreviated]

Rank[a]	MEI[b]	Secchi disc transparency[c]	Total phosphorus concentration[d]	Chlorophyll *a* concentration[d]
1	TIGG (8.3)	MATA (8.8)	KNIK (10.5)	MATA (0.5)
2	MATA (13.2)	TIGG (7.3)	TIGG (12.5)	TIGG (0.7)
3	REED (14.5)	JUNC (5.8)	JUNC (12.8)	SLIV (0.9)
4	JOHN (15.8)	KNIK (5.6)	MATA (13.2)	JUNC (1.0)
5	KNIK (17.9)	SLIV (5.2)	WALB (15.2)	KNIK (1.1)
6	JUNC (29.9)	JOHN (5.0)	SLIV (15.2)	RAVI (1.1)
7	WALB (51.8)	RAVI (4.0)	RAVI (16.2)	JOHN (1.4)
8	RAVI (57.8)	REED (3.3)	JOHN (17.5)	REED (2.0)
9	SLIV (75.1)	WALB (2.7)	REED (26.5)	WALB (3.4)

[a]Ordered from lowest to highest potential biological productivity

[b]MEI values from table 2

[c]Mean of four values measured in meters between September 1982 and September 1983

[d]Mean of four near-surface samples measured in micrograms per liter between September 1982 and September 1983

SURVIVAL AND GROWTH RATES OF STOCKED RAINBOW TROUT

Survival Rates

The survivability of rainbow trout stocked in these nine lakes is dependent upon factors such as their physiological health at time of stocking, availability of suitable habitat and adequate food, predation by and competition with other fish, level of fishing effort, and incidence of lethal dissolved-oxygen concentrations under ice (winterkill). Survival rate estimates were also influenced by uncertainties associated with the June and September population censuses. Survival rates of rainbow trout (table 6) varied widely within the six time periods analyzed. Survival rates over each 1-year period ranged from 0.02 (Sliver Lake, 1983) to 0.72 (Ravine Lake, 1982). Survival rates for each summer period ranged from 0.26 (Reed Lake, 1982, 1983) to 0.99 (Ravine Lake, 1982).

Table 6.--Survival rates of rainbow trout stocked in the nine lakes

Lake	1982 Survival period and rate[a]			1983 Survival period and rate[b]		
	8-9/81 to 6/82	8-9/81 to 9/82	6/82 to 9/82	8/82 to 6/83	8/82 to 9/83	6/83 to 9/83
Johnson	0.05	0.03	0.63	c	c	c
Junction	.39	.30	.77	d	d	d
Knik	.32	.18	.58	d	d	d
Matanuska	.23	.13	.59	d	d	d
Ravine	.73	.72	.99	0.62	0.36	0.58
Reed	.16	.04	.26	.24	.06	.26
Sliver	.22	.09	.42	.02	.02	.71
Tigger	.39	.19	.48	.35	.21	.60
Walby	.11	.08	.79	.34	.25	.74

[a]Stocked in August and September 1981, sampled in June and September 1982

[b]Stocked in August 1982, sampled in June and September 1983

[c]Complete winterkill during early 1983

[d]Rehabilitation with rotenone in October 1982

Overwinter survival rates through June were less than 0.20 in four lakes (Johnson, Reed, Sliver, and Walby) during 1982 and/or 1983. Complete or partial winterkills in these lakes were suspected because dissolved-oxygen concentrations were at or near zero in late winter (Alan Havens, Alaska Department of Fish and Game, written commun., 1983). Some of the other lakes had very low concentrations of dissolved oxygen under ice, yet had overwinter survival rates greater than 0.20. Some fish may have found refuge in spring areas that prevented ice formation and thus allowed atmospheric reaeration.

The levels of fishing effort in the nine lakes were ranked as light, moderate, and heavy (Alan Havens, Alaska Department of Fish and Game, written commun., 1983). Lakes Knik, Matanuska, Ravine (1983), and Reed were heavily fished whereas moderate fishing occurred at Junction, Ravine (1982), and Sliver Lakes. Tigger and Walby lakes were fished lightly and Johnson Lake was closed to fishing. The survival rate data for both summers revealed no definitive trend that could be related to levels of fishing effort. Of the heavily fished lakes, only Reed Lake had a very poor survival rate over the two summers. Walby Lake, which was lightly fished, had summer survival rates greater than 0.75; however, this lake is heavily vegetated with aquatic macrophytes and may have been difficult to fish successfully.

These nine lakes were chosen for study by ADF&G partly because some contained populations of threespine stickleback (*Gasterosteus aculeatus*), a fish reported to compete with rainbow trout (Kalb, 1975; Wenderoff, 1982). The survival rates in the six lakes that contained threespine stickleback in 1982 (Junction, Knik, Matanuska, Sliver, Tigger, and Walby) ranged from 0.08 to 0.30 from time of stocking to September 1982 (table 6). The lowest survival rates during this period occurred in Johnson and Reed Lakes, both free of threespine stickleback. Ravine Lake was also free of threespine stickleback and had a survival rate of 0.73. In 1983, Ravine Lake again had the highest survival rate from stocking through September 1983. Reed Lake had one of the lowest survival rates in 1983. Only three lakes containing threespine stickleback were available for analysis in 1983 because Junction, Knik, and Matanuska Lakes were chemically treated with rotenone, a fish suffocant, to remove all fish prior to restocking with rainbow trout in August 1983. In 1983, Tigger and Walby Lakes had lower survival rates than Ravine Lake (free of threespine stickleback). Sliver Lake had the lowest survival rate of the five lakes. Recall that low survival rates in Johnson, Reed, Sliver, and Walby Lakes were likely due to winterkill; thus it is not feasible to relate differences in survival rates only to the presence or absence of threespine stickleback because winterkill was a dominant covariate.

Havens (1984) examined a much larger data set in which survival rate estimates for age 1 rainbow trout were available for numerous lakes with or without threespine stickleback. He found an average survival rate of 0.41 in lakes without threespine stickleback and 0.29 in lakes with threespine stickleback. Havens concluded from the available data and literature that threespine stickleback can compete with stocked rainbow trout and may often reduce both the survival and growth rates of the trout.

Growth Rates

Growth rates of stocked rainbow trout were computed in two ways. The first focused on changes in biomass of the rainbow trout population per unit area of lake surface per day (equation 2).

$$B = \frac{\dfrac{(N_1 \times \overline{W}_1) - (N_0 \times \overline{W}_0)}{A}}{T_1 - T_0} \qquad (2)$$

where B is change in biomass, in grams, of rainbow trout per square hectometer of lake surface per day;

N_0 is number of rainbow trout at T_0;

N_1 is number of rainbow trout at T_1;

$\overline{W}_0$ is mean weight, in grams, of rainbow trout at T_0;

$\overline{W}_1$ is mean weight, in grams, of rainbow trout at T_1;

A is area, in square hectometers, of lake surface (table 1);

T_0 is julian date at start of growth measurement interval; and

T_1 is julian date at end of growth measurement interval.

The second method considered the mean change in weight per individual rainbow trout per day (equation 3).

$$W = \frac{\overline{W}_1 - \overline{W}_0}{T_1 - T_0} \qquad (3)$$

where W is mean weight change, in grams, per rainbow trout per day;

$\overline{W}_1$ is mean weight, in grams, for rainbow trout weighed at T_1;

$\overline{W}_0$ is mean weight, in grams, for rainbow trout weighed at T_0; and the remaining variables are as defined in equation 2.

The method represented by equation 2 assesses a lake's ability to convert its primary and secondary productivity into rainbow trout biomass, irrespective of fish size. The biomass computed by equation 2 depends heavily upon survival rate estimates because the number of fish per unit area is an integral part of the equation. One could theoretically obtain the same value of B for two populations: one composed of numerous small fish with slow growth, the other composed of few large fish with rapid growth.

The method represented by equation 3 assesses the ability of an individual rainbow trout to gain weight and may be a useful index to a lake's ability to yield catchable-size fish following initial stocking. This growth capacity is indirectly affected by survival rate estimates because fish growth is regulated, in part, by population density.

Because survival rates of rainbow trout over the winter months of 1982 and 1983 were highly variable (table 6), growth rates were computed only for the summers of 1982 and 1983. Daily increases in rainbow trout biomass and mean weight during the summers of 1982 and 1983 are listed in table 7. Daily biomass gains ranged from 2.9 to 37.6 $(g/hm^2)/d$ with Ravine Lake achieving the largest values in both summers. Lakes that showed small daily gains in biomass (less than 5 g/hm^2) included Matanuska (1982), Reed (1982), Sliver (1983), and Walby (1982). Mean daily weight increases ranged from 0.4 to 3.0 g/d (table 7). Johnson Lake rainbow trout grew most rapidly in 1982; Sliver Lake rainbow trout did so in 1983. These two lakes had very low overwinter survival rates and hence low population densities in the spring months immediately preceeding their summer months of rapid weight gain. Fish gained weight slowly (less than 0.5 g/d) in Knik (1982), Matanuska (1982), Tigger (1983), and Walby Lakes (1982 and 1983).

Table 7.--Daily increase in trout biomass per unit area and mean weight per trout for rainbow trout stocked in the nine lakes during June through September of 1982 and 1983

Lake	Increase in trout biomass per unit area of lake surface (grams per square hectometer per day)		Mean weight increase per trout (grams per day)	
	Summer 1982[a]	Summer 1983[b]	Summer 1982[a]	Summer 1983[b]
Johnson	6.4	c	3.0	c
Junction	17.6	d	.7	d
Knik	6.1	d	.5	d
Matanuska	4.2	d	.5	d
Ravine	37.6	34.7	.6	0.8
Reed	4.0	5.7	1.7	1.9
Sliver	5.5	4.4	.8	2.5
Tigger	8.4	7.9	.6	.4
Walby	2.9	9.0	.4	.5

[a]Stocked in August and September 1981, sampled in June and September 1982

[b]Stocked in August 1982, sampled in June and September 1983

[c]Complete winterkill in early 1983

[d]Chemical rehabilitation in October 1982

RELATION BETWEEN LIMNOLOGICAL CHARACTERISTICS AND RAINBOW TROUT GROWTH RATES

Previous sections of this report have ranked the potential biological productivity of these nine lakes based upon their morphoedaphic indexes, Secchi disc transparencies, and concentrations of total phosphorus and chlorophyll a (table 5). Growth rates of stocked rainbow trout are ranked similarily in table 8 in which each value is the mean biomass production or mean weight increases over the summers of 1982 and 1983. Three levels of biomass production are apparent in table 8. Ranks 1 through 7 encompass lakes of low biomass production whereas Junction Lake ranks substantially higher and Ravine Lake ranks highest. Mean daily weight increases of rainbow trout can also be separated into three groups (table 8). Lakes ranked 1 through 6 are those lakes in which weight gains were relatively low (less than 1.0 g/d); Sliver and Tigger Lakes had similar and higher values, and Johnson Lake ranked highest in weight gain.

Table 8.--Ranking of means of biomass production and mean weight increases by rainbow trout stocked in the nine lakes during the summers of 1982 and 1983
[Values of variables in parentheses and lake names abbreviated][a]

Rank[b]	Increase in trout biomass per unit of lake surface (grams per square hectometer per day)	Mean weight increase per trout (grams per day)
1	MATA (4.2)	WALB (0.4)
2	REED (4.9)	MATA (0.5)
3	SLIV (5.0)	KNIK (0.5)
4	WALB (6.0)	TIGG (0.5)
5	KNIK (6.1)	RAVI (0.7)
6	JOHN (6.4)	JUNC (0.7)
7	TIGG (8.2)	SLIV (1.7)
8	JUNC(17.6)	REED (1.8)
9	RAVI(36.2)	JOHN (3.0)

[a]Values are mean of both summers' growth rates

[b]Ordered from lowest to highest growth rate

The rankings of lakes by limnological variables (table 5) and by growth rate variables (table 8) were pooled in a single illustration (fig. 11) to facilitate discussion of potential correlations between the two sets of variables. Examination of figure 11 revealed that rankings of the lakes based on limnological characteristics were generally inconsistent with those based on rainbow trout growth rates. Only Matanuska Lake ranked low for the six variables; none of the lakes ranked high in all six variables. A large amount of scatter was present in the ranking for each lake as well as among the lakes.

The data in figure 11 indicated that no significant correlation existed between limnological characteristics and growth rates. This hypothesis of no significant correlation was tested by plotting each limnological variable against the two growth rate variables. The resulting scatterplots were then examined for evidence of a relationship between the two plotted variables. In most of the scatterplots there was no clearly defined relationship. Most scatterplots also contained one or two outliers that would have strongly influenced the derivation of a regression model. The strongest relationship found was between total phosphorus concentration and mean daily weight gain (fig. 12). However, several factors make this regression model inappropriate for prediction of rainbow trout growth rate. The slope of the regression was not significantly different from 0 and the standard error of the estimate was large. In addition, this model is unrealistic because a total phosphorus concentration of 8 µg/L predicts no daily weight gain. In summary, none of the scatterplots were deemed suitable for development of a regression model capable of predicting rainbow trout growth rates without unacceptable levels of error.

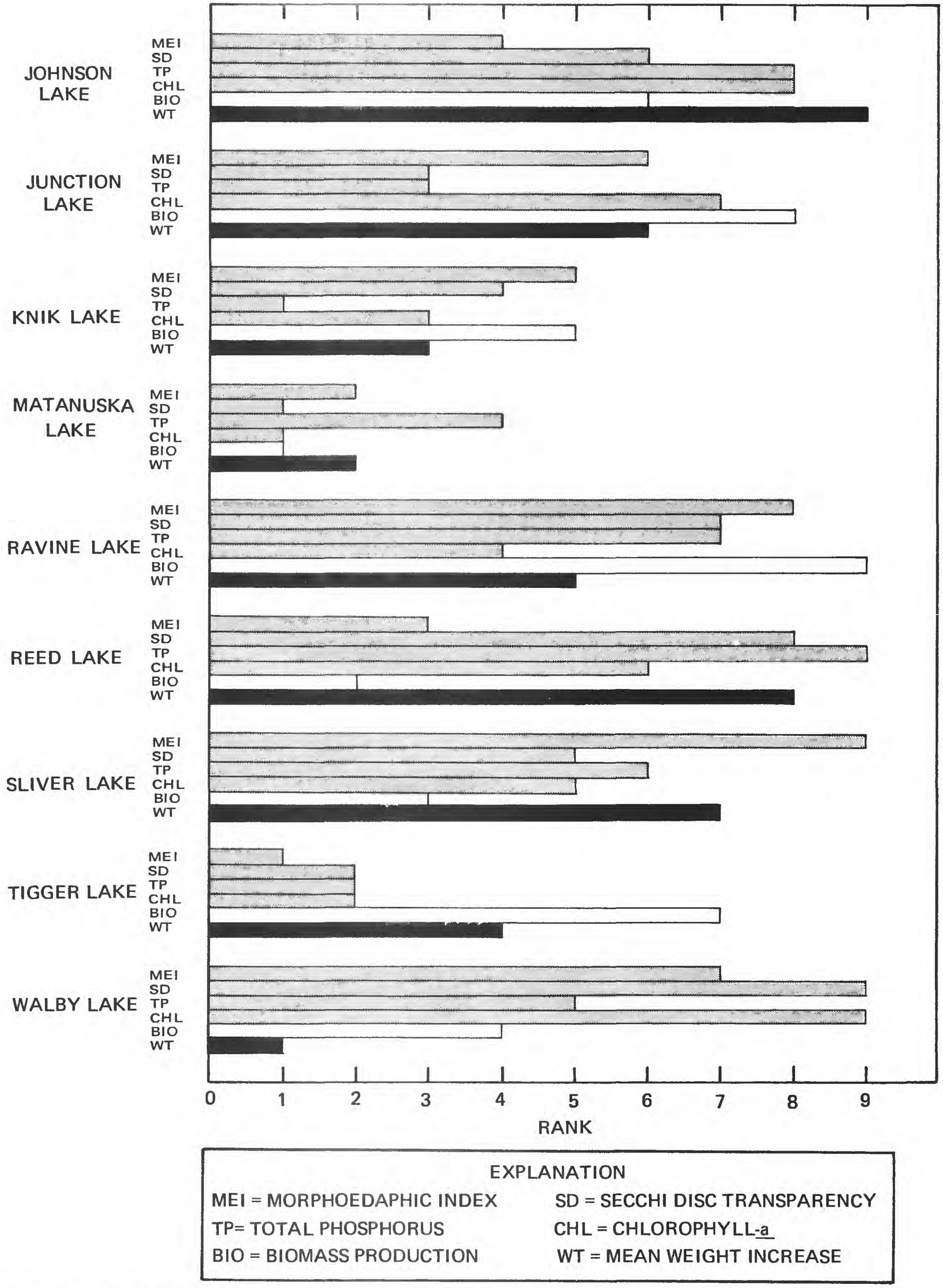


Figure 11.--Ranks of four limnological variables and two growth rate variables for the nine lakes.

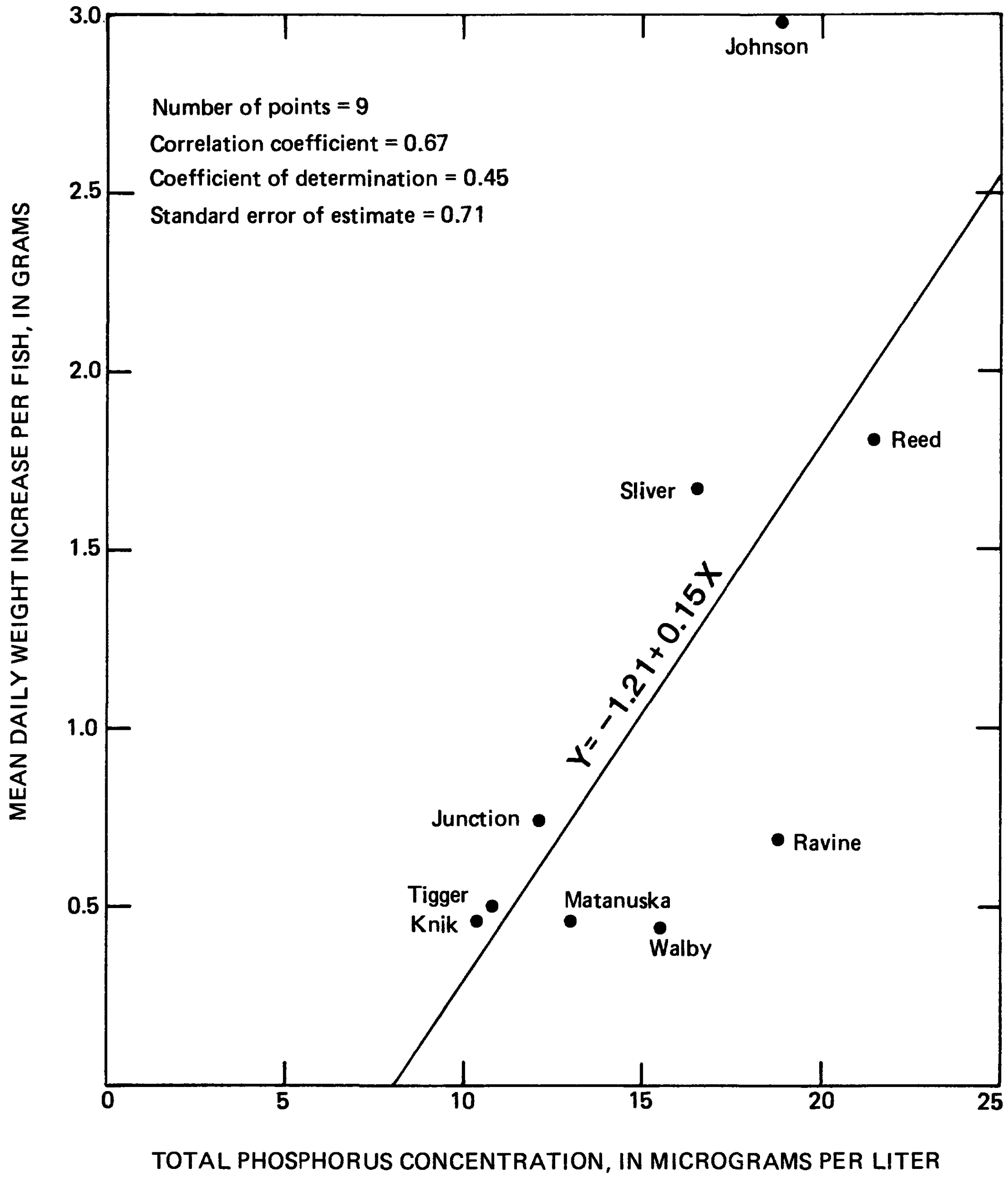


Figure 12.--Scatterplot and regression equation of total phosphorus concentratio and mean daily weight increase per trout from the nine lakes.

Several studies (Matuszek, 1978; Jones and Hoyer, 1982; Schlesinger and Regier, 1982; Prepas, 1983; and Schlesinger and McCombie, 1983) have reported significant correlations between limnological variables and fish production variables. In the present project, however, the growth rates of rainbow trout stocked in nine south-central Alaskan lakes could not be correlated with the four selected limnological variables. Watsjold (1976) was also unable to correlate rainbow trout growth curves to the MEI in southcentral Alaskan lakes, but he did find a good correlation between the MEI and growth rates of coho salmon (Oncorhynchus kisutch). Watsjold attributed this to differences in survival; rainbow trout exhibited poor survival in low productivity lakes whereas coho salmon exhibited good survival.

An important reason for the lack of correlation between growth rates and limnological characteristics is the instability of rainbow trout populations in these nine lakes. At the time of lake stocking, the ADF&G attempted to achieve equal fish biomass per unit area of lake surface. Then, given equal survival rates, the "richer" lakes would be expected to produce more fish biomass per unit area over the measurement period. If, however, a large percentage of the initial biomass did not survive in a "rich" lake, then the growth rate, expressed as fish biomass per unit area (equation 2), may be less than that of a lake with low potential productivity but with a high survival rate. Rainbow trout survivability is thus a critical variable to be considered when selecting lakes to stock for enhancement of rainbow trout production.

Survivability of rainbow trout stocked in these nine lakes was affected by the occurrence and intensity of winterkill. Ryder and others (1974) noted that the MEI would probably not be suitable for application to lakes with extensive winterkill because it was an overriding factor affecting fish production. Rainbow trout survival is also adversely affected by competition with threespine stickleback (Wenderoff, 1982; Havens, 1984). Although six of these lakes contained threespine stickleback, the data did not clearly reveal any effects of competition. Data were also insufficient to attribute survival differences to varied levels of fishing pressure. Although survivability of rainbow trout may have been affected by competition from threespine stickleback and by fishing pressure, the effects of winterkill masked their influence.

Limnological data revealed important differences among the lakes with respect to the occurrence and persistence of thermal stratification, the completeness of spring and autumn water-column circulation, the severity of dissolved-oxygen depletion, and the vertical distribution of constituents such as phosphorus, nitrogen, dissolved solids, and chlorophyll a. These differences contributed to the lack of correlation between rainbow trout growth rates and limnological characteristics in the nine lakes. The results of ranking potential biological productivity (table 5) illustrate some of the consequences of these differences in limnology. For example, Reed Lake's MEI ranks fourth lowest in potential biological productivity, but based on total phosphorus concentration this lake ranks as the most productive. The other lakes tend to behave similarily. A lake's potential biological productivity is, therefore, biased by the choice of limnological variable used for ranking. The measured value for a limnological characteristic such as chlorophyll a concentration or total phosphorus concentration also varied with time and depth, thus adding additional uncertainty to the relationship between rainbow trout growth rates and limnological characteristics.

CONCLUSIONS

The ADF&G's desire to empirically predict rainbow trout growth rates from easily measured limnological characteristics remains a viable objective. However, additional research is needed to either include rainbow trout survival into the predictive model or to subdivide lakes into groups having similar fish population and habitat characteristics. More intensive limnological sampling might also be implemented to better define seasonal variations in those factors which can be used as independent variables to predict fish growth rates. A fruitful area of study would be the prediction of occurrence and intensity of winterkill in southcentral Alaskan lakes.

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