Great Basin Naturalist 51(3), 1991, pp. 282–285

FACTORS INFLUENCING DISSOLVED OXYGEN CONCENTRATIONS DURING WINTER IN SMALL WYOMING RESERVOIRS

Paula M. Guenther[1] and Wayne A. Hubert[2]

Key words: dissolved oxygen, reservoir, winter, Wyoming.

Fish kills in ice-covered lakes have been described in the upper Midwest and the Great Plains (Nickum 1970, Patriarche and Merna 1970). Fish losses were related to low dissolved oxygen and several associated factors: small, shallow lakes; periods of prolonged or extensive snow and ice cover; lack of surface water inflow into lakes; and high primary productivity (Greenbank 1945, Halsey 1968, Nickum 1970, and Mathias and Barica 1980).

Miller (1989) investigated the geomorphic features that influence winterkill in natural lakes at elevations >2925 m in the Medicine Bow Mountains, Wyoming. He separated lakes prone to winterkill from those without a history of winterkill on the basis of six discriminating variables: basin area, basin relief ratio, lake area, drainage density, lake volume, and maximum water depth. Winterkill lakes tended to be small, shallow lakes and were at lower elevations than nonwinterkill lakes.

We assessed the winter dissolved oxygen concentrations in small reservoirs (<100 hectares at full pool) at elevations >2100 m above mean sea level. Physical, chemical, and climatic characteristics that are related to low dissolved oxygen under the ice were identified.

Methods

Eleven reservoirs were studied during winter, 7 in 1987 and 10 in 1988 (Table 1). Six of the 1988 sites were also sampled the previous year. Study sites were selected to represent a range in elevation, size, and productivity. The reservoirs were located near or within the Laramie and Medicine Bow mountains in southeastern Wyoming. Several reservoirs had known histories of winterkill.

Bathymetric maps were obtained from the Wyoming State Engineer's Office or constructed from soundings that were plotted on reservoir outlines from U.S. Geological Service topographic maps. The maps were used to calculate morphometric variables: maximum water depth, mean water depth, water volume, and volume of unfrozen water during winter. Water levels were monitored to estimate the minimum values of the morphometric variables during winter.

Macrophyte abundance was estimated in fall 1987 for the 10 reservoirs to be studied. A 10-m line attached to a float was thrown from the shore at 10-m intervals around the reservoir. The density of plants along the line was visually estimated on a scale of 0 to 10. The presence or absence of plants beyond the line was noted and rated (0 = absent, 5 = present). Also, a reservoir-wide rating of filamentous algae was made (0 = absent, 3 = present, 5 = pervasive). The averages for the line and beyond-line ratings were summed with the rating for algae to yield Macrophyte Abundance Index (MAI) values ranging from 0 to 20.

Reservoirs were sampled at three-week intervals beginning in January and continuing until ice conditions were unsafe in March or April. Physical and chemical features were measured at one to four sites, depending on the reservoir size. Vertical profiles of dissolved oxygen concentrations were measured. The oxygen meter was standardized in

[1]U.S. Department of Agriculture Forest Service, Medicine Bow National Forest, Laramie, Wyoming 82070.
[2]U.S. Fish and Wildlife Service, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Laramie, Wyoming 82071.

TABLE 1. Physical features of the reservoirs studied in southeastern Wyoming during the winters of 1986–87 and 1987–88. A range indicates variation between years.

Reservoir	Elevation (m)	Surface area (ha)	Mean depth (m)	Maximum depth (m)	Inflow (1 = present, 0 = absent)
Crystal	2126	37	12.2	17.9	1
East Lake	2133	18	1.8	3.2	0
Shirley Basin	2135	6	3.0	4.2	0
Granite Springs	2199	21	11.7	15.3	1
Goforth	2207	2	1.4–1.6	2.2–2.5	1
Leazenby	2234	4–8	0.2–0.4	0.5–1.0	1
King Number 1	2247	50–58	1.4–1.6	3.0–3.5	1
North Crow	2311	14–17	8.9–11.8	12.6–17.1	1
Miller Lake	2763	1	1.6–2.0	2.5–3.0	1
Sucker Lake	3166	2	0.2	0.5	1
Dipper Lake	3261	9–11	1.8–2.8	9.0–10.5	0

the laboratory and calibrated in the field before each use. To verify the reading with the oxygen meter, we collected water samples at points along the profile with a Kemmerer sampler, fixed them immediately, and determined dissolved oxygen concentration using the Azide modification of the Winkler method (American Public Health Association et al. 1975).

Average dissolved oxygen was calculated for each sampling date. Each reservoir was divided into depth strata, and the water volume in each stratum was calculated. Average oxygen concentration in each stratum was computed, and an overall weighted total oxygen concentration was determined. Winterkill conditions were assumed to be likely when daytime average dissolved oxygen was <4 mg/L (Mathias and Barica 1980).

Water inflow and outflow were recorded as present or absent on each visit. Snow and ice thickness were measured, and the mean for all sampling dates was calculated.

Measurements of variables (Table 2) for the two winters were compared using paired *t* tests (Zar 1984). Correlation analysis was used to assess relations between measured variables and average dissolved oxygen concentrations. Stepwise multiple regression and discriminant function analysis were used to identify multivariate relations. We used the Number Cruncher Statistical System (Hintze 1987) to perform the statistical analyses. The critical level chosen for all statistical procedures was $P \leq .05$.

RESULTS

Substantial variation in elevation, surface area, and water depth during winter, and the presence of inflowing water were observed among the reservoirs (Table 1). Low dissolved oxygen (<4 mg/L) was common among the reservoirs (Table 2). Oxygen profiles showed typical stratification, highest concentrations being near the ice-water interface and lowest near the bottom of the reservoir. We observed average dissolved oxygen concentrations <4 mg/L in two reservoirs in 1987 (Dipper Lake and Miller Lake) and in five reservoirs in 1988 (Dipper Lake, Shirley Basin, East Lake, Goforth, and Miller Lake). Water in all reservoirs was saturated with oxygen at the beginning of the winter. We did not observe gradual depletion in dissolved oxygen over the winters.

Weather data from 1955 to 1988 showed that both the 1986–87 and 1987–88 winters were about average in temperature and precipitation. Our data suggest that the winter of 1987–88 was more severe than that of 1986–87. Average snow and ice were both significantly thicker in 1988 than in 1987. Although water levels were higher in 1988 than in 1987, more of the total water volume was in the form of ice. Because of the differing conditions between the two years, we treated each year as an independent sample.

Average dissolved oxygen concentration during winter was significantly ($P \leq .05$) correlated with the absence of inflow ($r = .56$), elevation ($r = -.49$), ice thickness ($r = -.56$), snow and ice thickness ($r = -.49$), and surface area of the reservoir during winter ($r = .49$). When Dipper Lake was excluded from the analysis, the MAI was highly correlated ($r = -.96$) with low dissolved oxygen levels.

TABLE 2. Conditions measured in the reservoirs studied in southeastern Wyoming during the winters of 1986–87 and 1987–88.

Reservoir	Mean dissolved oxygen (mg/L)	Minimum dissolved oxygen (mg/L)	Mean ice thickness (cm)	Mean snow thickness (cm)	Macrophyte abundance index
			1987		
Crystal	7.4	7.4	33	5	
Goforth	11.6	11.3	36	1	
Leazenby	12.4	12.2	32	1	
King Number 1	11.5	11.3	37	3	
North Crow	6.9	5.9	33	5	
Miller Lake	2.3	1.4	53	12	
Dipper Lake	1.5	1.1	111	82	
			1988		
East Lake	3.0	2.6	39	6	13
Shirley Basin	1.8	0.8	42	3	17
Granite Springs	8.7	7.1	38	3	3
Goforth	3.4	1.1	46	1	16
Leazenby	7.6	4.6	45	3	2
King Number 1	10.3	8.6	44	4	0
North Crow	6.9	5.9	33	5	5
Miller Lake	1.1	0.5	95	29	16
Sucker Lake	5.8	4.4	41	121	4
Dipper Lake	2.9	2.5	134	33	0

Stepwise multiple regression was used to determine variables that accounted for variation in average dissolved oxygen. The MAI was measured only in fall 1987, but we assumed that it remained constant over the years in our analysis. The most variability (adjusted $R^2 = .59$) in average dissolved oxygen (DO) among the reservoirs was accounted for by:

$$DO = 16.1 + 3.297\,I - 0.295\,M - 0.004\,E$$

where DO = average dissolved oxygen concentration (mg/L), I = 0 if no inflow and 1 if inflow was present, M = Macrophyte Abundance Index, and E = elevation (meters). All three independent variables were significant at $P \leq .05$.

Discriminant function analysis was used to classify reservoirs having average dissolved oxygen <4.0 mg/L from those that had ≥4.0 mg/L. It was possible to classify 16 of 17 samples based on three variables—presence or absence of inflow, mean winter ice thickness, and MAI. Reduction in classification error attributed to models in which these variables were used was 88%. Wilk's Lambda for the discriminant function was 0.14.

DISCUSSION

Our results indicate that the absence of inflowing water, high elevation, extensive ice and snow, small surface area, and abundant aquatic macrophytes contribute to low dissolved oxygen concentration during winter. Small (<20 ha during winter) reservoirs with no surface water inflow that are at high elevations or have abundant macrophytes (MAI > 12) have a high risk of developing low dissolved oxygen, and subsequently fish mortality, during winter. High risk of winterkill has been associated previously with small, shallow lakes, prolonged or extensive snow and ice cover, limited water inflow, and high primary productivity (Greenbank 1945, Halsey 1968, Nickum 1970, Barica and Mathias 1979, Mathias and Barica 1980).

No previous work has provided information for small reservoirs at >2100 m above sea level. Our findings may assist managers who are trying to prevent winterkill. Several of the variables identified as having an influence on dissolved oxygen during winter—absence of inflowing water, surface area, and the abundance of aquatic plants—may be manageable under various circumstances.