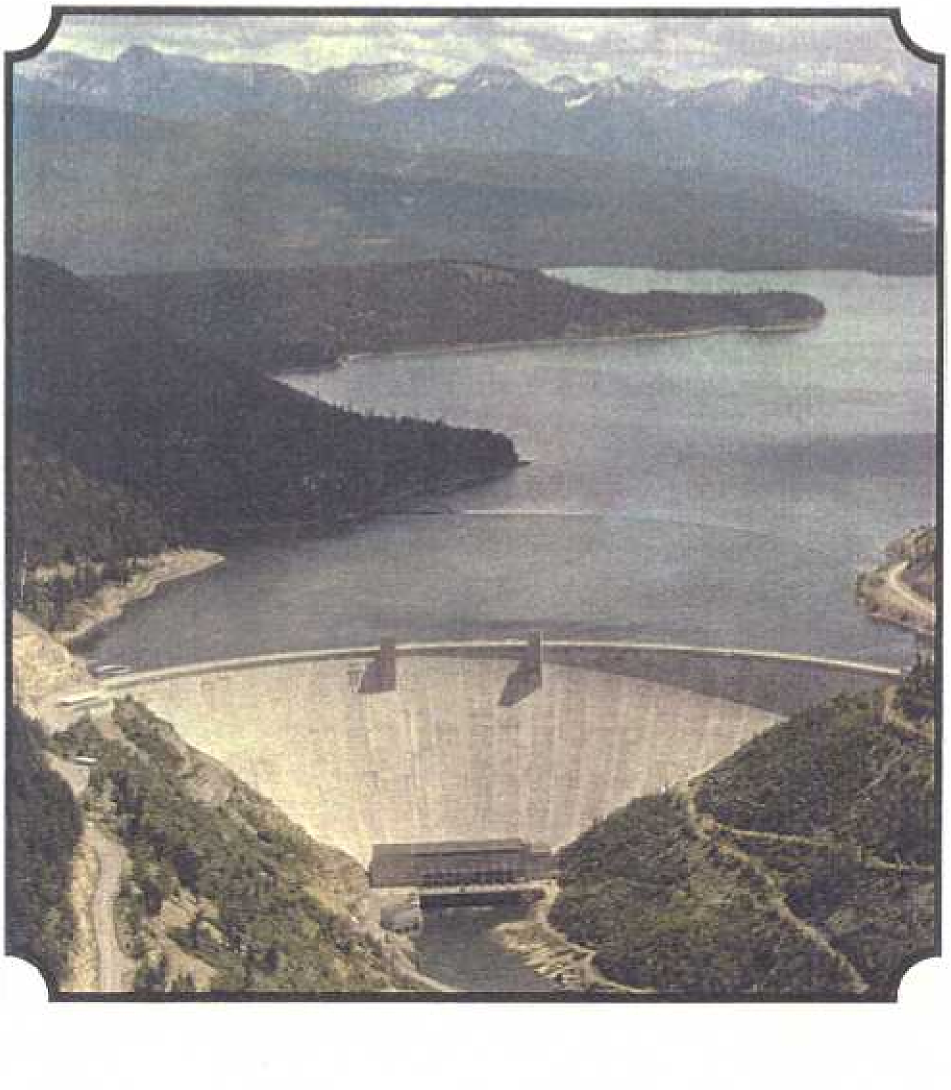
HUNGRY HORSE DAM FISHERIES MITIGATION

MINIMIZING ZOOPLANKTON ENTRAINMENT AT HUNGRY HORSE DAM: IMPLICATIONS FOR OPERATION OF SELECTIVE WITHDRAWAL



JUNE 1998

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Minimizing Zooplankton Entrainment at Hungry Horse Dam: Implications for Operation of Selective Withdrawal

FINAL REPORT

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EXECUTIVE SUMMARY

The South Fork Flathead River in northwest Montana was impounded in 1952 by Hungry Horse Dam. The dam created Hungry Horse Reservoir approximately 8 km upstream from the confluence of the South Fork and main stem Flathead River. Hungry Horse Dam was originally designed to release water (4-6 °C) from the bottom of the reservoir year round. Long-term cooling effects during summer and fall and short-term temperature fluctuations associated with peaking impaired biological productivity in the Flathead River downstream. Installation of a selective withdrawal structure on each of the dam's discharge penstocks was determined to be the most cost-effective means to provide constant, permanent temperature control without impacting power production and flexibility in dam operation.

The selective withdrawal system was completed and began operation in August 1995. Thermal modeling results indicated an increased incidence of zooplankton entrainment (washout) from the reservoir when selective withdrawal was simulated. Modeling results and logistic limitations also pointed to the need for empirical data on zooplankton distribution, abundance, and washout rates under different operational scenarios. In this study, we collected field measurements of the vertical distribution of zooplankton in the dam forebay and washout rates in the discharge under different operational scenarios.

Based on this information and certain logistic limitations, we developed the following operational recommendations for the selective withdrawal system:

1. Outflow temperatures should be maximized each summer (beginning June 1) until reservoir stratification allows optimum temperature targets to be met consistently. In 1996 and 1997, this required that control gates be used exclusively and at the highest (elevational) setting possible until the end of July.

2. During periods of peak thermal stratification in the reservoir forebay (early August to early September in 1996), operators should incorporate mixing from different layers. We recommend that control gates be returned to the highest elevation possible and that slide gate

apertures be opened as much as possible without compromising temperature targets.

3. As the reservoir destratifies (early September - October in 1996), we recommend that operators return to exclusive use of the control gates. There was little evidence that method of operation affects zooplankton outwash rates during this period and options available to meet temperature targets decrease as upper reservoir layers cool. However, zooplankton densities are generally highest in surface layers, so control gates should be positioned as low as possible without compromising temperature targets.

4. If possible, selective withdrawal should be operated continuously from June 1 - October 31 each year.

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ACKNOWLEDGMENTS

We thank the Bureau of Reclamation (BOR) for having the foresight to retrofit Hungry Horse Dam (HHD) with a selective withdrawal system and, despite the cost involved, recognizing the long term benefits to natural resources downstream. We also thank the BOR and Bonneville Power Administration for funding provided for this field study. Thanks to the maintenance personnel at HHD for their practical assistance with time, labor, and materials. The people involved were: Louie Saldamando, Sam Dezell, Clyde Houge, and Tom Church. We also thank Dennis Christenson, Rich Clark, Ralph Carter, and all the control room operators for their insights and cooperation. They provided contract administration, engineering knowledge, schematics of HHD, and their time for running the different withdrawal scenarios. Todd DeVries, John Borkowski, and Steve Cherry from Montana State University assisted with sampling design.

Finally, we acknowledge the work of MFWP field personnel Lori Thompson, Terry Werner, Gary Michael, and John Wachsmuth. Lori was responsible for processing entrained and vertical profile zooplankton samples and data entry. Gary provided his practical knowledge and experience in developing sampling gear that kept entrained plankton intact. Terry provided full-time assistance on sample days and input which streamlined our sampling procedure. John came in and provided his able field hands in relief when needed. Special thanks to Greg Hanzel for his creative genius in fabricating a truck-mounted davit and winch system that allowed us to work off the dam face safely and efficiently.

Introduction

Program measure 903(h)(6) of the Columbia Basin Fish and Wildlife Program directed Bonneville Power Administration and the U.S. Bureau of Reclamation to "...immediately begin actions to result in installation of a selective withdrawal structure at Hungry Horse Dam to allow for temperature control to benefit resident fish" (Northwest Power Planning Council 1987). The selective withdrawal system was completed and began operation in August 1995.

A computer model to simulate operation and effects of selective withdrawal was appended to the quantitative biological model of Hungry Horse Reservoir (HRMOD) developed by Montana Fish, Wildlife, and Parks (MFWP) and Montana State University. Thermal modeling results indicated an increased incidence of zooplankton entrainment (washout) from the reservoir when selective withdrawal was simulated (Marotz et al. 1995). This finding resulted in design modifications on the withdrawal structure to mitigate zooplankton loss from the reservoir. Modeling results and limitations also pointed to the need for empirical data on zooplankton distribution, abundance, and washout rates under different operational scenarios.

Aquatic invertebrates comprise the base of the food web in Hungry Horse Reservoir. Zooplankton (particularly *Daphnia* spp.) are important food items for bull trout, westslope cutthroat trout, and other species of fish in the reservoir, especially during early life stages and winter months when insects are unavailable (May et al. 1988). Minimizing zooplankton washout through Hungry Horse Dam is one step toward maximizing biological productivity in the reservoir.

In this study, we collected field measurements of the vertical distribution of zooplankton in the dam forebay and washout rates in the discharge under different operational scenarios. Based on this information and certain logistic limitations, we developed operational recommendations for the selective withdrawal system.

Study Area

The South Fork Flathead River drains an area of approximately 4,403 km^2 (1,087,981 Acres) on the west side of the Continental Divide in northwestern Montana (Figure 1). Hungry Horse Dam impounds the South Fork approximately 8 km upstream from the confluence with the main stem Flathead River. At full pool (1085.8 m or 3560 ft msl), the reservoir is 56 km in length with an area of 9,632 ha and an operational volume of 4.24 km^3 (3,468,000 acre-ft).

Operation of Selective Withdrawal

Prior to 1995, Hungry Horse Dam released water (4-6 °C) from the bottom of the reservoir year round. Rapid temperature changes of up to 8.3° C were measured in the Flathead River downstream of the South Fork confluence, controlled by dam discharges. These short-term temperature fluctuations and long-term cooling effects during summer and fall impaired biological productivity in the Flathead River. Installation of a selective withdrawal structure on each of the dam's discharge penstocks was determined to be the most cost-effective means to provide constant, permanent temperature control without impacting power production and flexibility in dam operation.

Selective withdrawal operates on each penstock using a gate system that resembles a three-section telescope cut in half lengthwise. The selective withdrawal structures are 72.3 m long when fully extended and average 6.25 m in diameter (Figure 2). The top section, called the control gate, can move up and down over a 37 m distance. Lowering the gate allows warm surface water to flow over the gate and through the dam. Because of hydraulic constraints, the control gate cannot be stationed closer than 6.1 m from the surface. Five side-by-side slide gates located 15.2 m below the top of each control gate allow operators to mix in cold water. The control gates slide against the middle stationary gates. The bottom section, the relief gate, rests on the concrete apron at the bottom of the trashrack. In winter, the relief gates are raised and water passes through the original penstock openings to release hypolimnetic water.

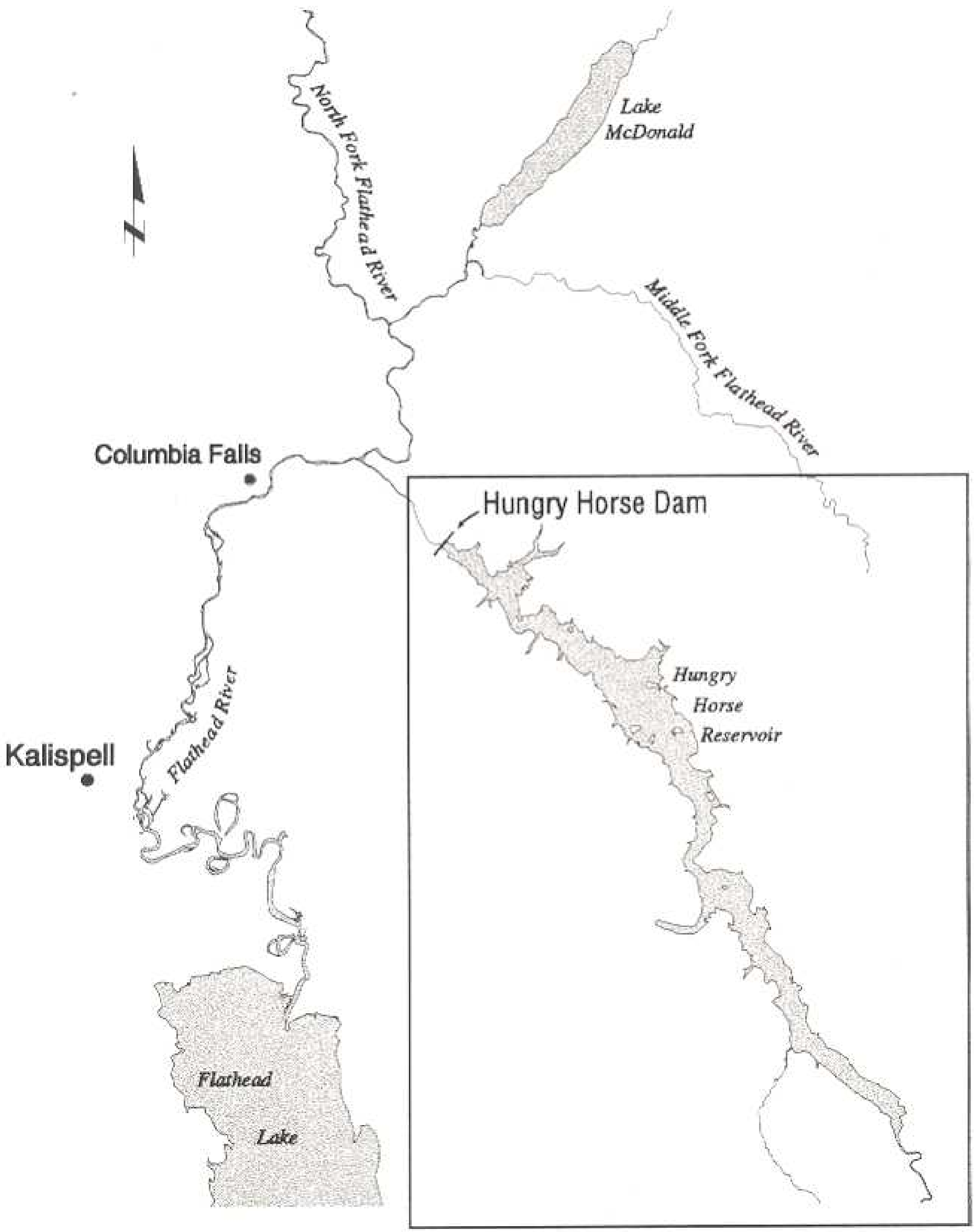

Figure 1. Location of Hungry Horse Dam project in northwest Montana.

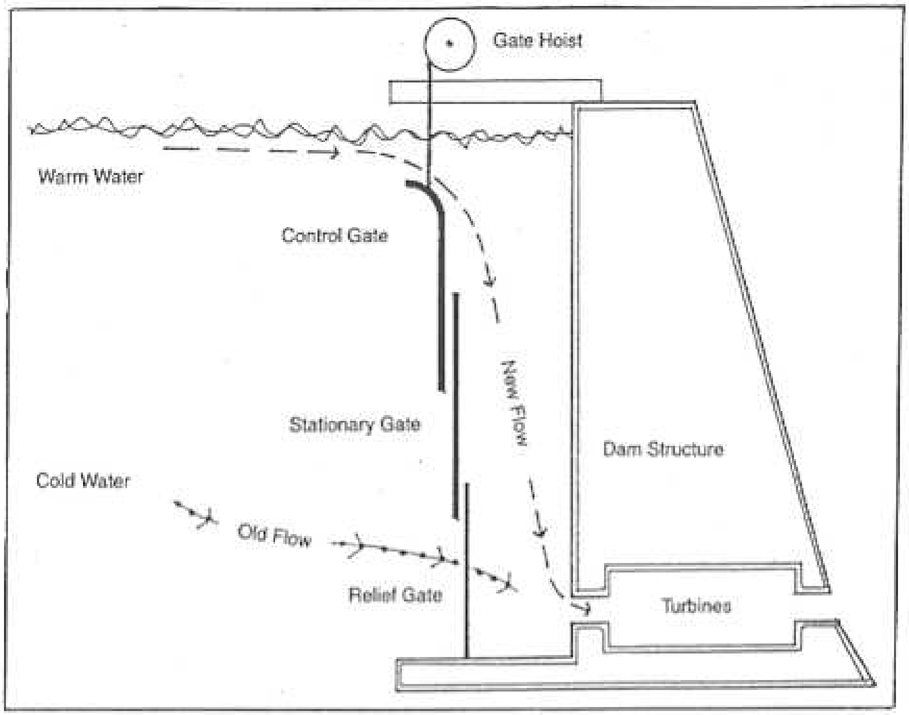

Figure 2. Selective withdrawal structure at Hungry Horse Dam.

Reservoir discharge at Hungry Horse Dam flows downward into the selective withdrawal structure and enters the penstock apertures 73.5 m below full pool (1011.9 m msl). Discharge then enters the scroll case, passes through the wicket gates, and into the turbine at approximately 14.1 kg/cm^2 of pressure (at full pool). A 20.3 cm diameter pipe in the scroll case wall receives water at a constant 5447 L/min and proceeds through the dam to cool turbine electrical generation equipment. This provided a convenient source of scroll case water for sampling zooplankton passing through the dam.

Operation of selective withdrawal began in August, 1995. Use of the structure in 1995 terminated after only one and a half months (mid-August through September). Henceforth, the structure has operated from June or early July through October each year. In 1996, selective withdrawal was operated exclusively using the control gates, except during slide gate tests.

Methods

Research began in September 1995 to quantify zooplankton distribution, density, and washout rates from the reservoir. We used the brief period of operation in 1995 to refine sampling methods and logistics. All zooplankton and water temperature data were collected (on the same day) weekly during September. The vertical distribution of zooplankton in the dam forebay was assessed using a 30 L plexiglass Schindler plankton trap (Schindler 1969) with a 63 mu mesh plankton bucket. The trap was deployed using a winch system on the dam to collect triplicate samples at each depth from the surface to 15 m (3 m intervals), then from 15 m to 35 m (5 m intervals). Zooplankton were preserved in 95% ethyl alcohol.

Samples of zooplankton entrained in the turbine penstock were taken from a small pipe off of the scroll case. Since this cooling water is under extreme hydraulic pressure, we designed an extraction apparatus that preserved zooplankton body integrity. A 1.27 cm diameter ball valve was mounted on a bend in the cooling water pipe so that the opening faced the direction of flow. With the valve completely open, water is decanted through copper tubing (1.27 cm diameter) coiled to the bottom of a 227 L plastic barrel to reduce turbulence. Collection of water for each sample required approximately 100 seconds. Zooplankton were expelled out the bottom of the barrel, filtered through a 63 mu plankton bucket, and preserved in 95% ethyl alcohol. During each sampling period, three 210 L samples were collected. We also recorded the reservoir elevation, control gate elevation, and turbine unit discharge during each sampling period.

Schindler trap zooplankton samples were enumerated and identified to genus (*Daphnia*, *Bosmina*, *Diaptomus*, *Epischura*, *Cyclops*, cyclopoid and diaptomid nauplii). Entrained zooplankton samples were subsampled (five 1.0 ml portions after dilution to 50-100 zooplanktors/ml), enumerated and identified to genus. The mean of the five subsamples constitutes the final zooplankton density in each sample. We counted samples using a dissecting scope under 15X power.

Reservoir water temperatures were obtained from the Bureau of Reclamation (BOR) temperature array attached to the dam face. Vertical temperature profile data were collected from immediately below the water surface to 35 m (1.5 m intervals).

Methods and results during September 1995 were the basis for the sampling design used in 1996. Sampling was much more rigorous in 1996 and covered the entire period when selective withdrawal was in operation (July - October). Weekly sampling was completed using the protocol described previously, except for the changes noted below. We sampled zooplankton in the dam forebay using an 8.2 L acrylic Alpha water sampler from two locations off the dam face. Point one was the 1995 sampling location adjacent to the temperature array, approximately 15 m east of turbine unit I. Point two was 15 m west of turbine unit IV. Sample depths were also modified: 5 samples at 3 m to 15 m (3 m intervals), then at 20 m and 30 m from the surface. Sampling from each point on the dam was completed 3 times daily, including morning, afternoon, and evening samples.

We sampled at two locations on the dam to verify that zooplankton distribution was similar along the dam face (adjacent to different turbines). Trends in zooplankton distribution were compared for these two locations on 19 July, 29 Aug, and 16 Oct. Trends in density were very similar on all three dates (Appendix I). We felt that the observed differences did not warrant further processing of samples from both sites. Therefore, only data collected from site 1 are presented in the following section.

Entrained zooplankton were collected using the same methods as in 1995, except that samples were collected from each functioning turbine. In 1996, we completed total counts of all zooplankton samples and used the mean of the three daily samples as an estimate of density.

We examined the effects of slide gate operation on zooplankton entrainment rates on 30 Aug and 26 Sept, 1996. Slide gates are located 15.2 meters below the top of each selective withdrawal control gate. Slide gates work hydraulically using a common header. Depending on various parameters any one of the five gates can open first. The gate that opens first will continue to open to full position before another gate begins. The gates continue in this manner till they all reach the fully opened position. The dam operator can attain percent gate area opened by viewing a monitor in the control room inside the dam. Apertures on the slide gates (1.5 m x 2.1 m) were adjusted (25, 50, 75, and 100 percent open) to achieve varying mixtures of water from shallow and deep layers of the reservoir. Water from the two levels can be mixed to achieve the appropriate temperature, while avoiding the intermediate layer (generally believed to contain the highest density of zooplankton). We collected entrained zooplankton samples from the turbine scroll case after each incremental change in the slide gate opening. Samples were preserved and processed in the same manner as described previously.

The effect of different slide settings on total zooplankton and *Daphnia* entrainment was tested using one-way analysis of variance procedures (ANOVA). If significant ($p<0.05$) differences among slide gate settings were detected, we used linear regression to test for trends in entrainment rates as slide gate aperture changed.

Results and Discussion

Figures 3-6 display the vertical distribution of zooplankton (and *Daphnia* only) relative to temperature profiles on selected dates in 1996. Our goal in measuring the vertical distribution of zooplankton was simply to identify trends in density relative to depth and relate these to selective withdrawal operation and entrainment rates. The vertical distribution of zooplankton was variable among both sampling periods and taxa (total zooplankton vs. *Daphnia* only). However, peak zooplankton densities tended to occur at depths less than 15 m during all sampling periods. These data represent mean abundances during the 1 day sampling intervals. The three daily sampling periods likely did not capture temporal differences in zooplankton density associated with diel migration or patchiness, especially since samples were only collected during the day. However, logistic realities of selective withdrawal operation negate the need for detecting minute changes in zooplankton distribution.

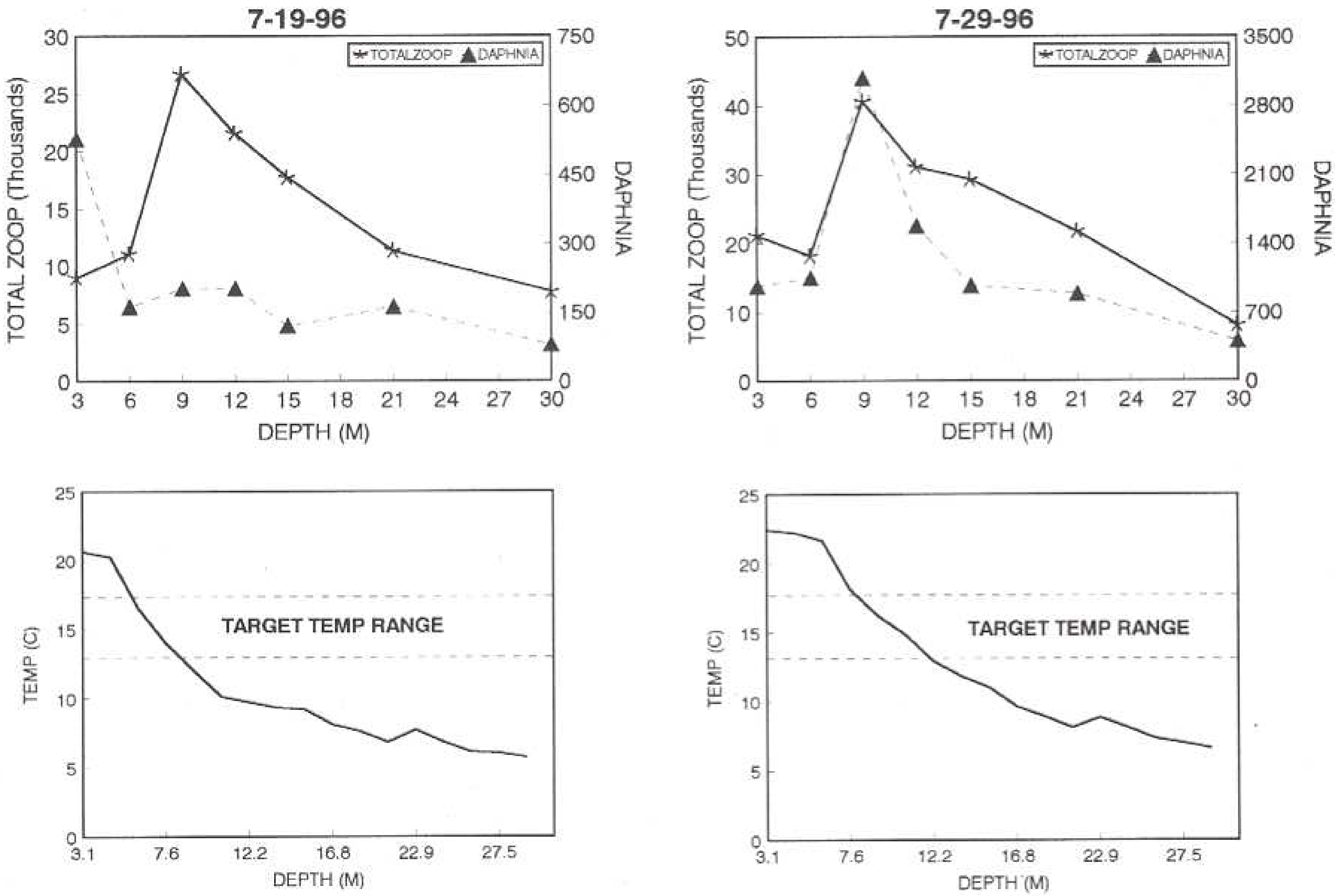

Figure 3. Zooplankton and temperature profiles in the Hungry Horse Dam forebay in July, 1996. Target temperatures for selective withdrawal are shown for each date on lower figures.

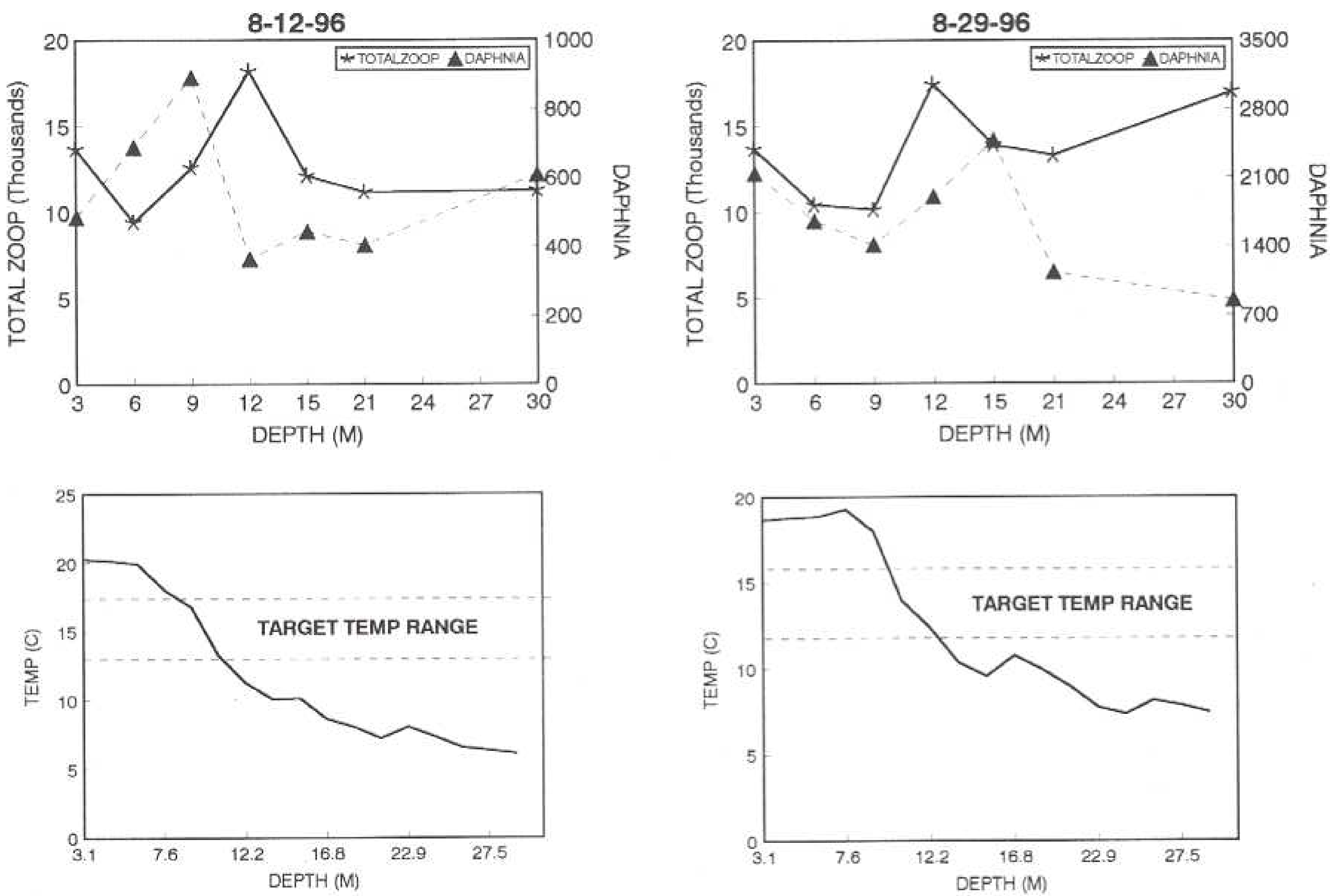

Figure 4. Zooplankton and temperature profiles in the Hungry Horse Dam forebay in August, 1996. Target temperatures for selective withdrawal are shown for each date on lower figures.

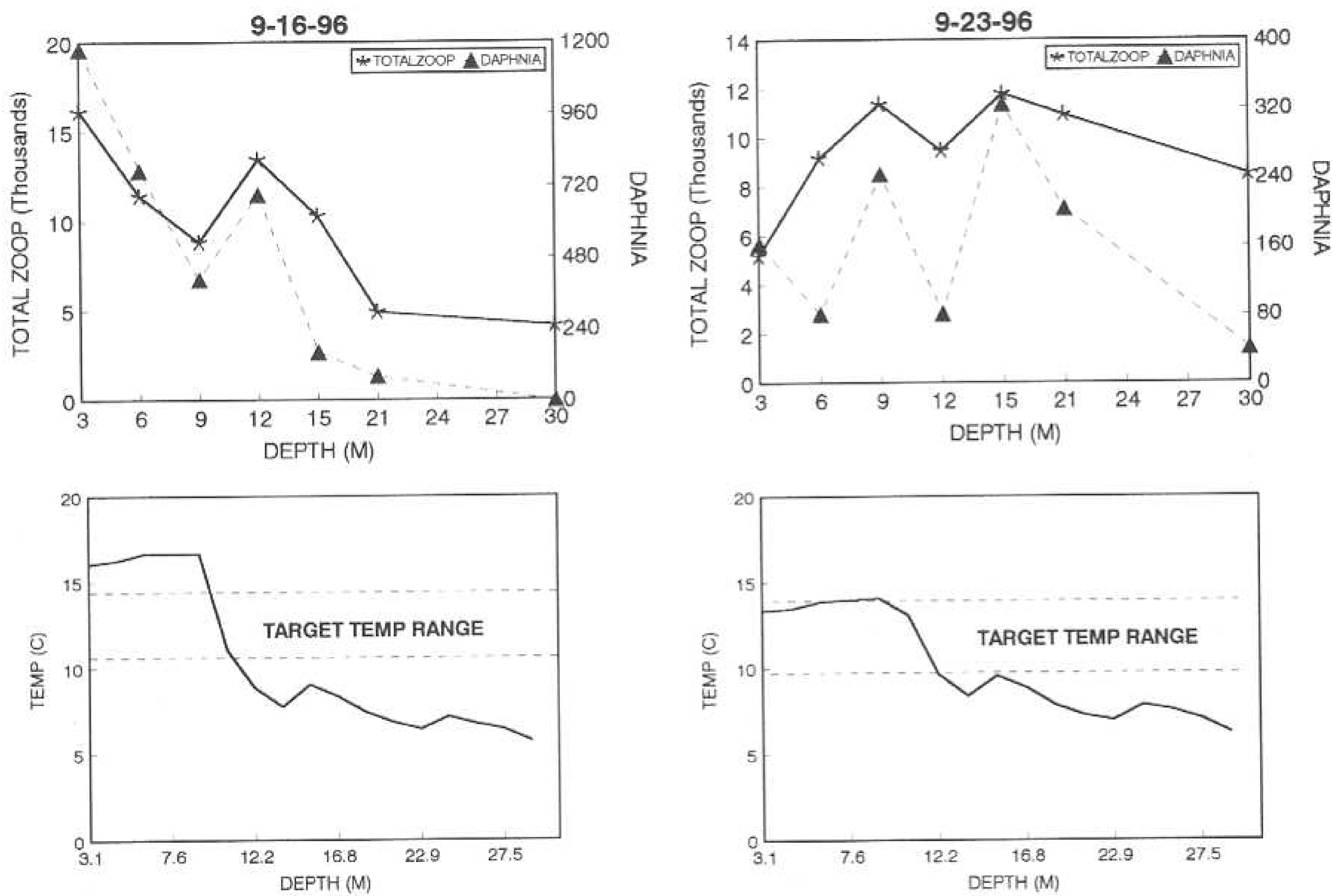

Figure 5. Zooplankton and temperature profiles in the Hungry Horse Dam forebay in September, 1996. Target temperatures for selective withdrawal are shown for each date on lower figures.

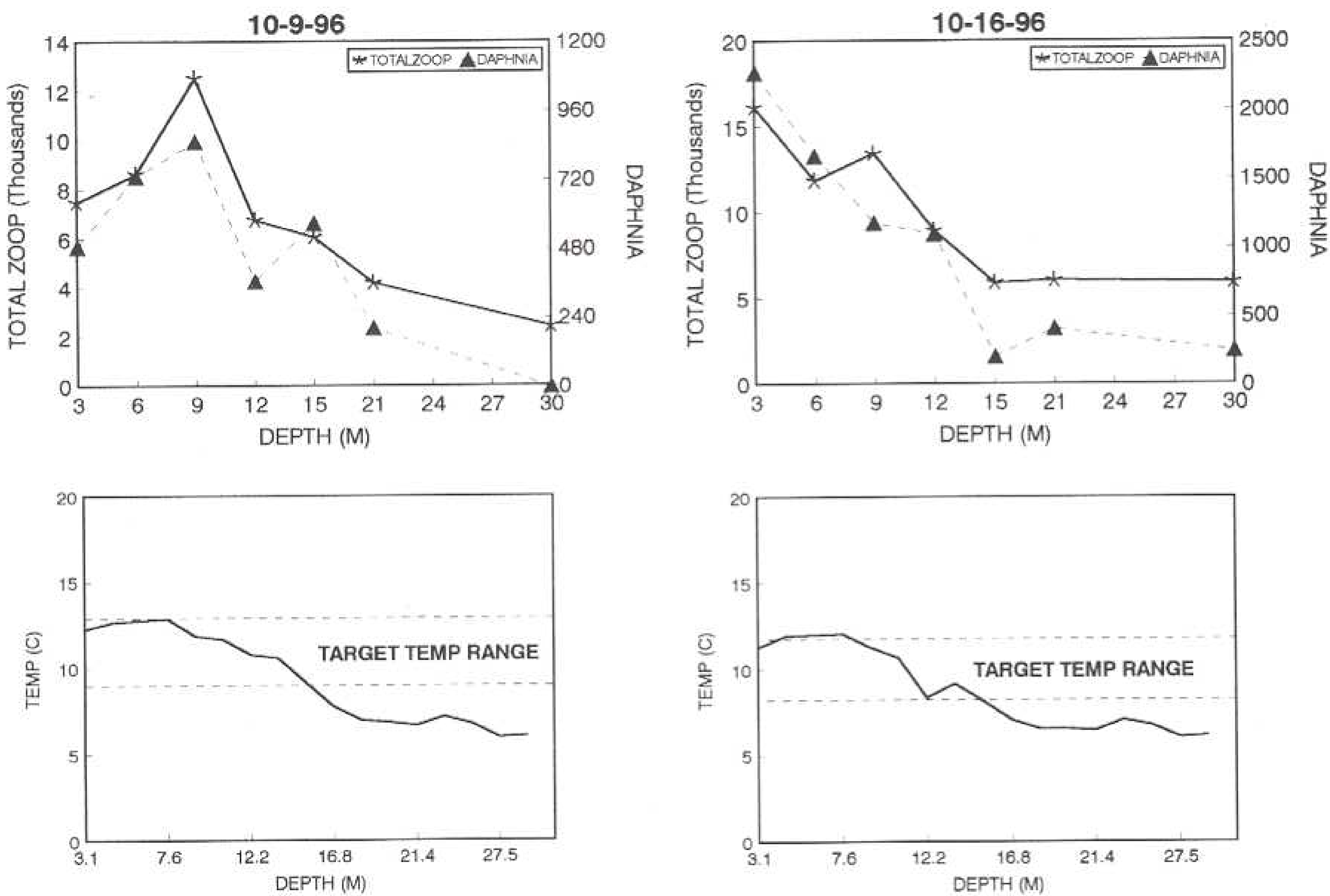

Figure 6. Zooplankton and temperature profiles in the Hungry Horse Dam forebay in October, 1996. Target temperatures for selective withdrawal are shown for each date on lower figures.

Because of high inflow from snowpack runoff and rapid reservoir filling during May - early July, stratification was limited during early summer. In most years, operators must position the control gates at our near their maximum elevation (6-7 m below the surface) and use them exclusively to meet temperature targets prior to mid-July. Although zooplankton densities were not measured during this period (selective withdrawal was not initiated until June 27 in 1996), there is little operational flexibility for minimizing zooplankton entrainment if temperature targets are to be met or strived for. We consider meeting temperature targets to be the highest priority in operating selective withdrawal.

During the last half of July in 1996, maximum zooplankton densities occurred at 9-12 m below the surface. It appears that operators could continue to use the control gates exclusively until the end of July and still minimize zooplankton washout. Despite the highest peak total zooplankton and *Daphnia* densities of the year on 19 July and 29 July (Figure 3), washout rates were low relative to later samples (Figures 7 and 8). This likely occurred because water flows downward into the control gate intake apertures. In other words, water entering the control gates (set at 7-9 m below the surface) was actually from shallower layers where zooplankton densities were less.

The most definitive period of thermal stratification usually takes place during August. As a result, it is also the period when dam operators have the greatest flexibility in operating the selective withdrawal units. In 1996, early August had the highest total zooplankton entrainment rates of any sampling period. *Daphnia* washout were highest during the period from 22 Aug- 9 Sept. In slide gate tests on 30 Aug (Figure 9), there was no indication that total zooplankton entrainment was affected by slide gate settings (ANOVA, $p>0.99$) . However, there was strong evidence ($p= 0.01$, $R^2 = 0.92$) of decreased *Daphnia* entrainment as slide gates were opened (Figure 10). Therefore, incorporation of (cool) water from greater depths via the slide gates is most appropriate during August or when thermal stratification is strongest.

Results of sampling during mid-September to October provided little evidence that methods of operation tested affected zooplankton washout rates. Despite inconsistent patterns in

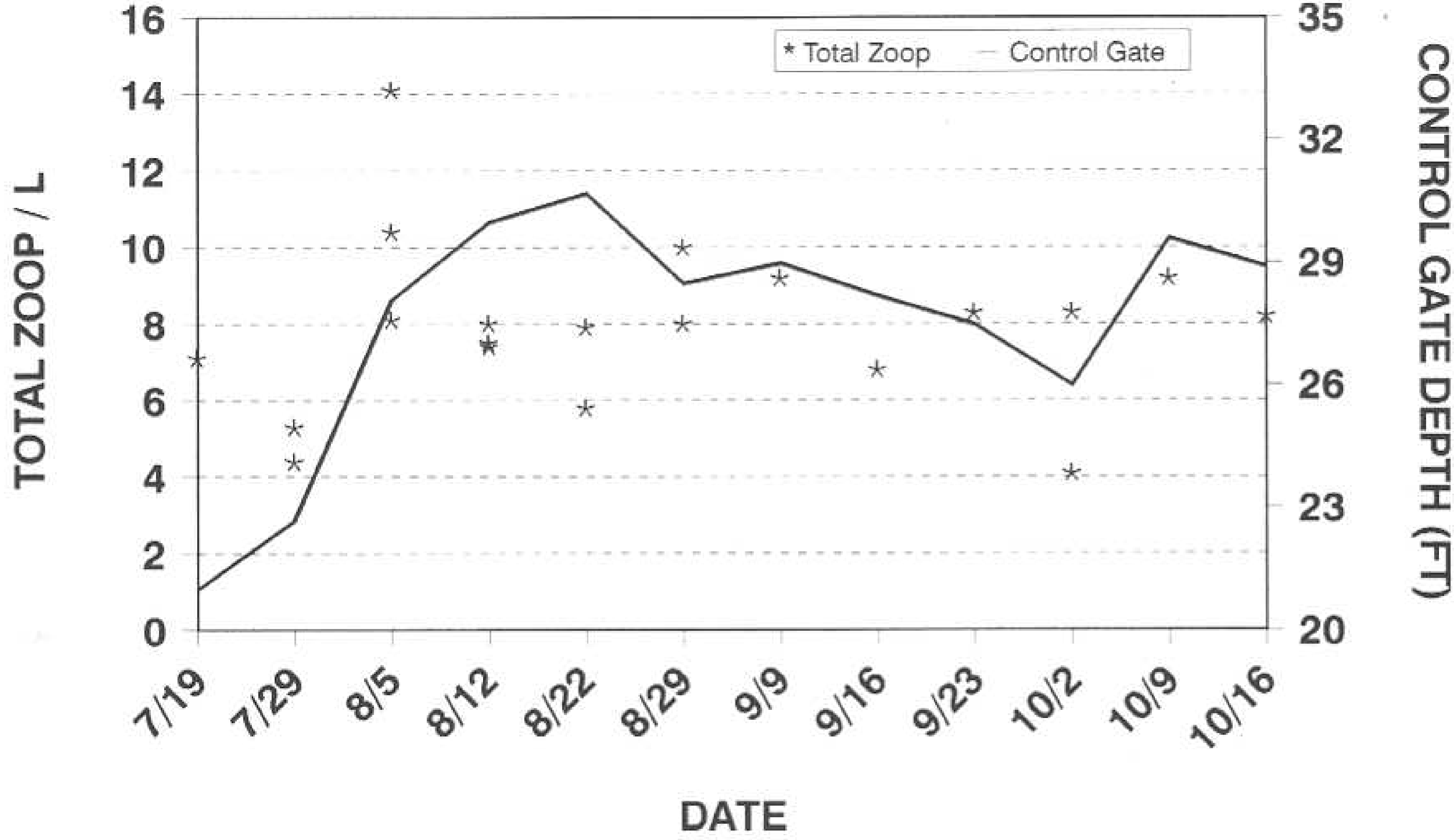

Figure 7. Total zooplankton densities in entrainment samples taken inside Hungry Horse Dam (asterisks). Control gate elevation (solid line) represents the distance from the reservoir surface (ft) at the time of zooplankton sampling. In 1996, selective withdrawal was operated exclusively by adjusting the control gates. The number of data points on each date represent the number of turbines in operation at the time of sampling.

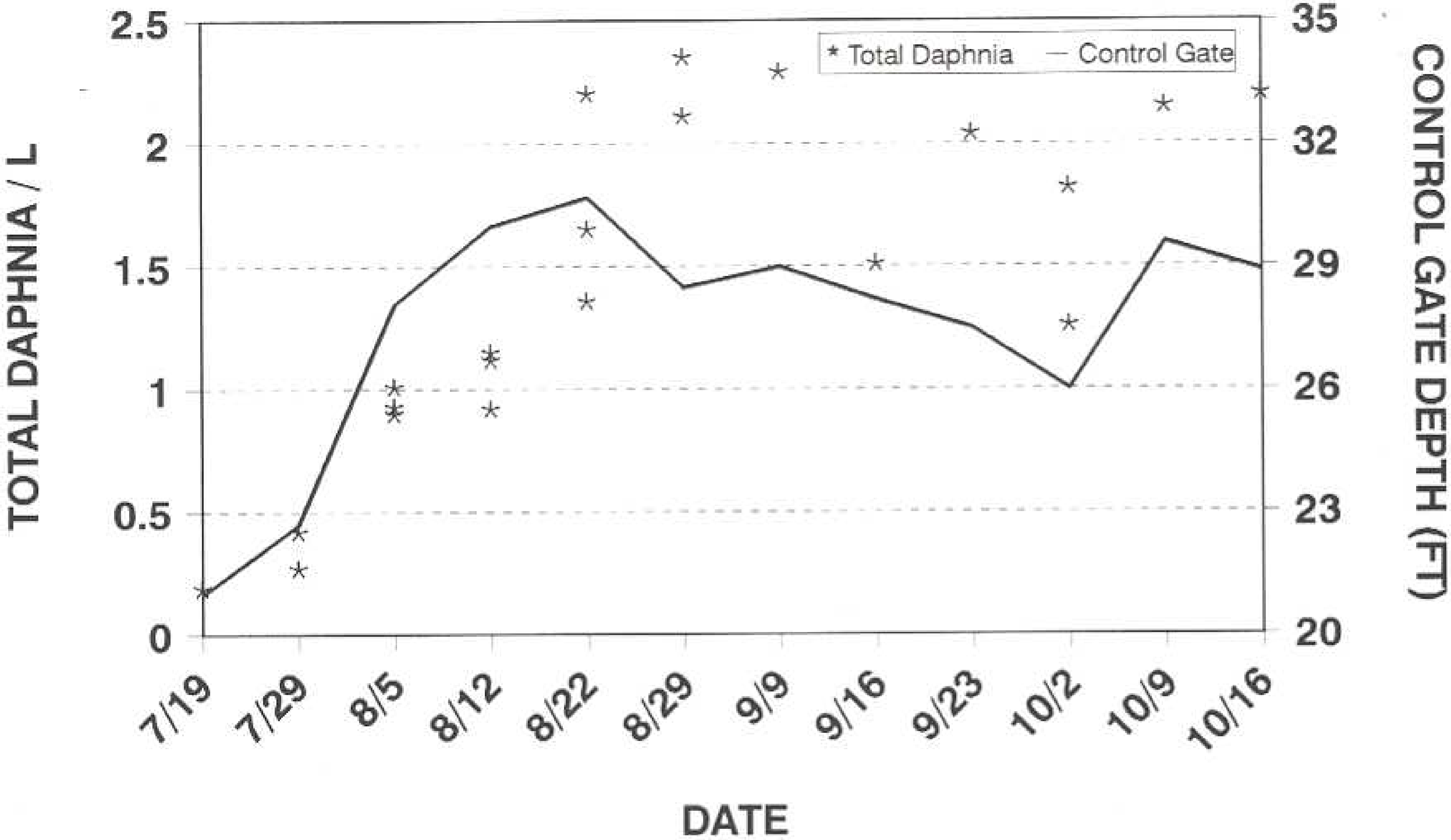

Figure 8. Total daphnia densities in entrainment samples taken inside Hungry Horse Dam (asterisks). Control gate elevation (solid line) represents the distance from the reservoir surface (ft) at the time of zooplankton sampling. In 1996, selective withdrawal was operated exclusively by adjusting the control gates. The number of data points on each date represent the number of turbines in operation at the time of sampling.

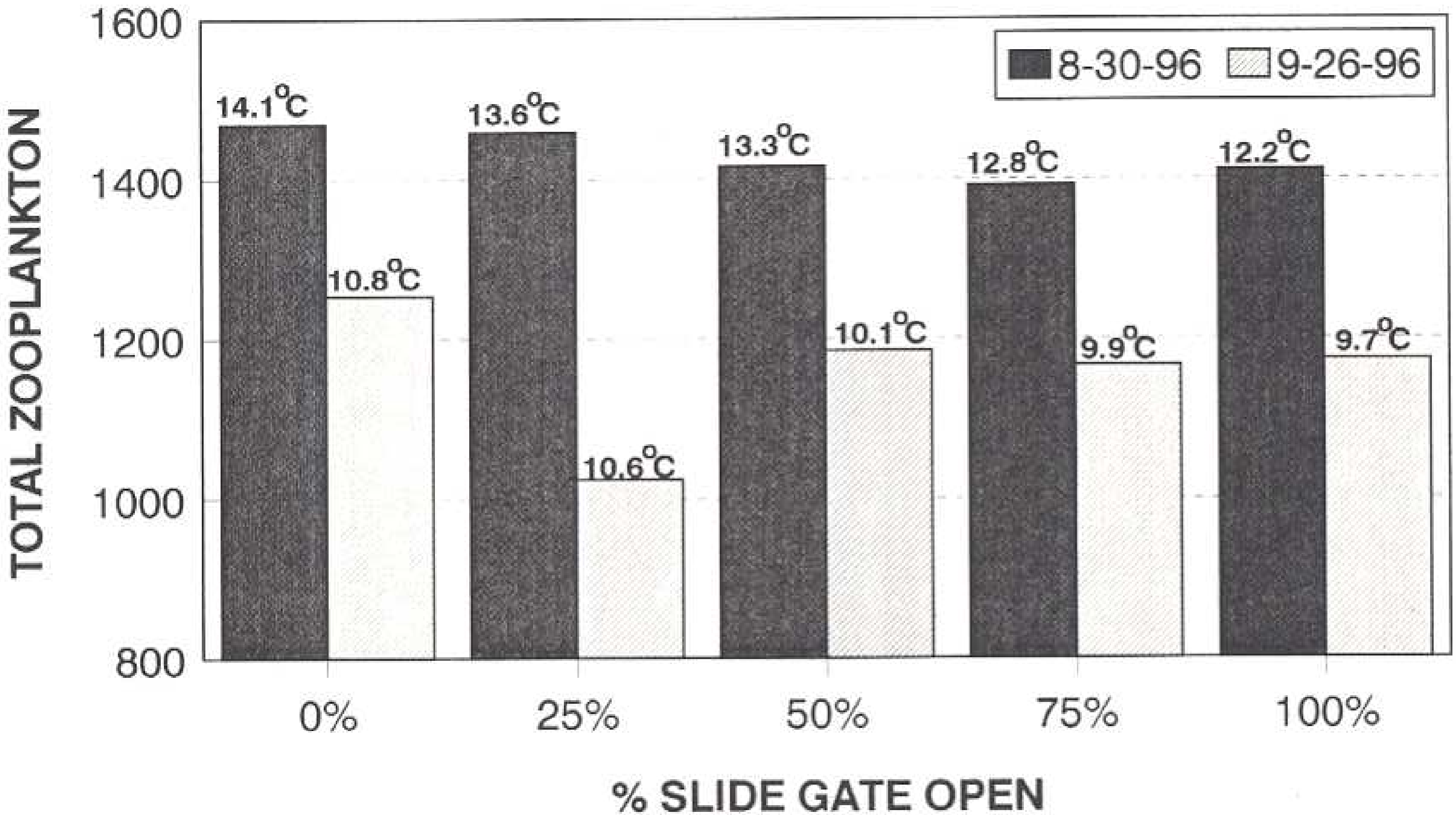

Figure 9. Zooplankton entrainment during slide gate tests on two dates in 1996. Slide gates were opened at 25% increments. Zooplankton counts represent means of three samples taken at the same turbine. Changes in outflow temperature with changes in slide gate aperture are shown above each bar.

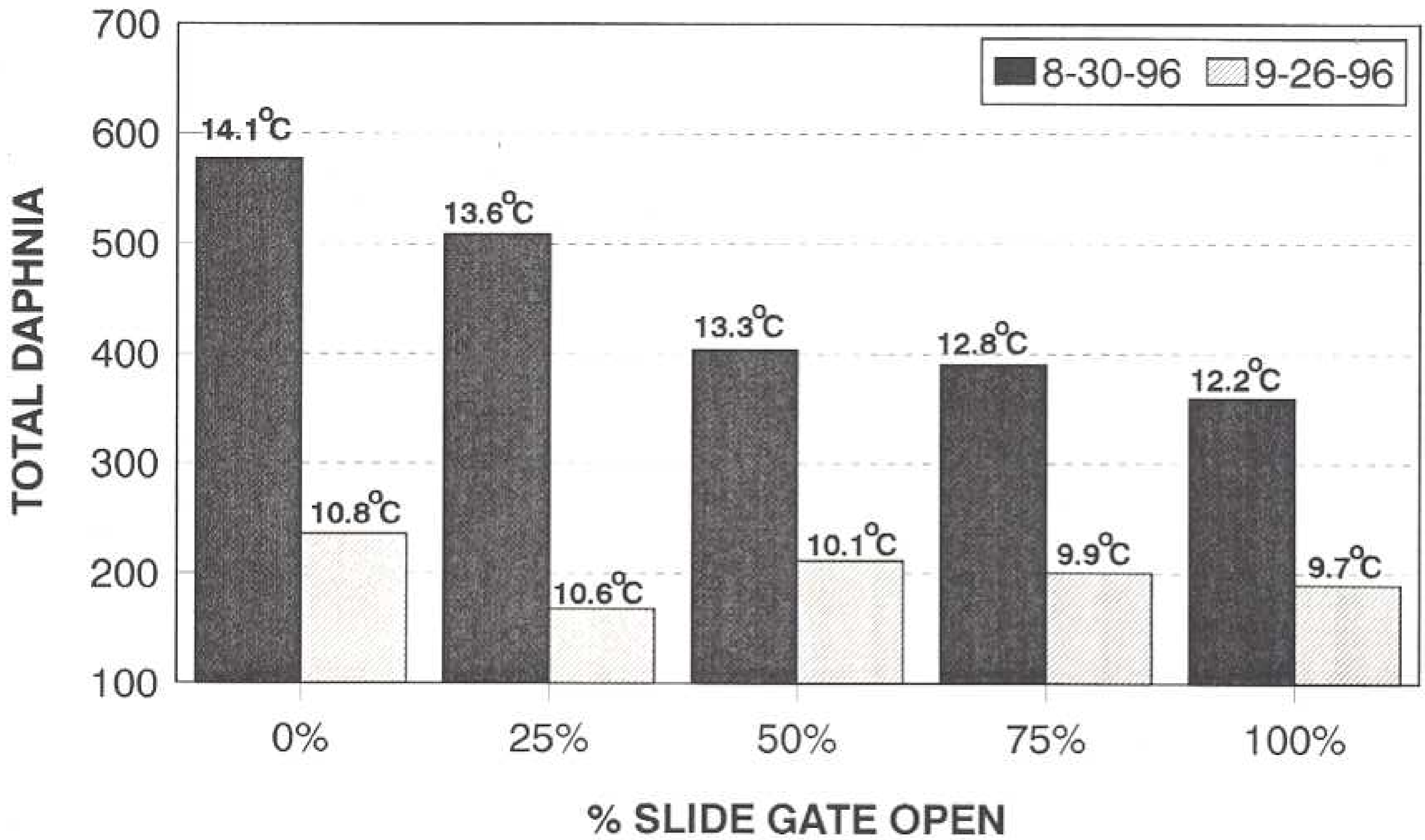

Figure 10. Daphnia entrainment during slide gate tests on two dates in 1996. Slide gates were opened at 25% increments. Daphnia counts represent means of three samples taken at the same turbine. Changes in outflow temperature with changes in slide gate aperture are shown above each bar.

zooplankton vertical distribution (Figures 5 and 6) during relatively stable control gate settings (~26-29 m below the surface), there were no perceivable changes or patterns in entrainment among sampling dates (Figures 7 and 8). When slide gate tests were conducted on 26 Sept, control gates were moved up to within 7 m of the surface. No changes in total zooplankton or *Daphnia* entrainment were detected (Figures 7 and 8), even as slide gates were incrementally opened (ANOVA $p > 0.50$). As thermal stratification diminishes during the fall period, operational options also decrease. Exclusive use of control gates will probably be required to meet temperature targets by the end of October. Despite inconsistent patterns in zooplankton distribution in fall, the highest concentrations were generally near the surface in both 1995 and 1996. If control gates are used exclusively, they should be positioned as low as possible, while meeting temperature targets.

Recommendations for Operation

1. Outflow temperatures should be maximized until reservoir stratification allows optimum temperature targets to be met consistently. In 1996 and 1997, this required that control gates be used exclusively and at the highest (elevational) setting possible until the end of July.

2. During periods of peak thermal stratification in the reservoir forebay (early August to early September in 1996), operators should incorporate mixing from different layers. We recommend that control gates be returned to the highest elevation possible and that slide gate apertures be opened as much as possible without compromising temperature targets.

3. As the reservoir destratifies (early September - October in 1996), we recommend that operators return to exclusive use of the control gates. There was little evidence that method of operation affects zooplankton outwash rates during this period and options available to meet temperature targets decrease as upper reservoir layers cool. However, zooplankton densities are generally highest in surface layers, so control gates should be positioned as low as possible without compromising temperature targets.

4. If possible, selective withdrawal should be operated continuously from June 1 - October 31 each year.

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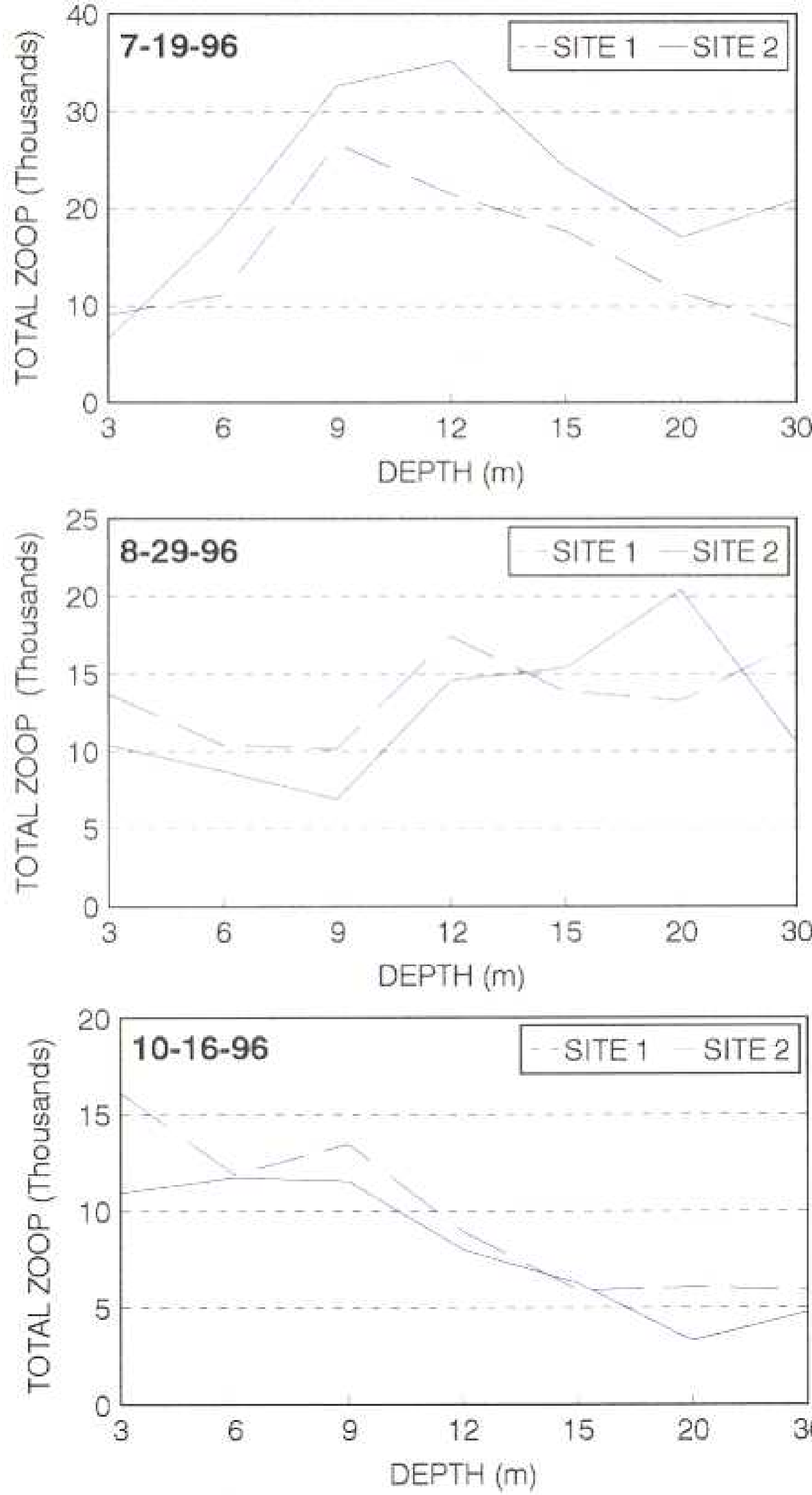
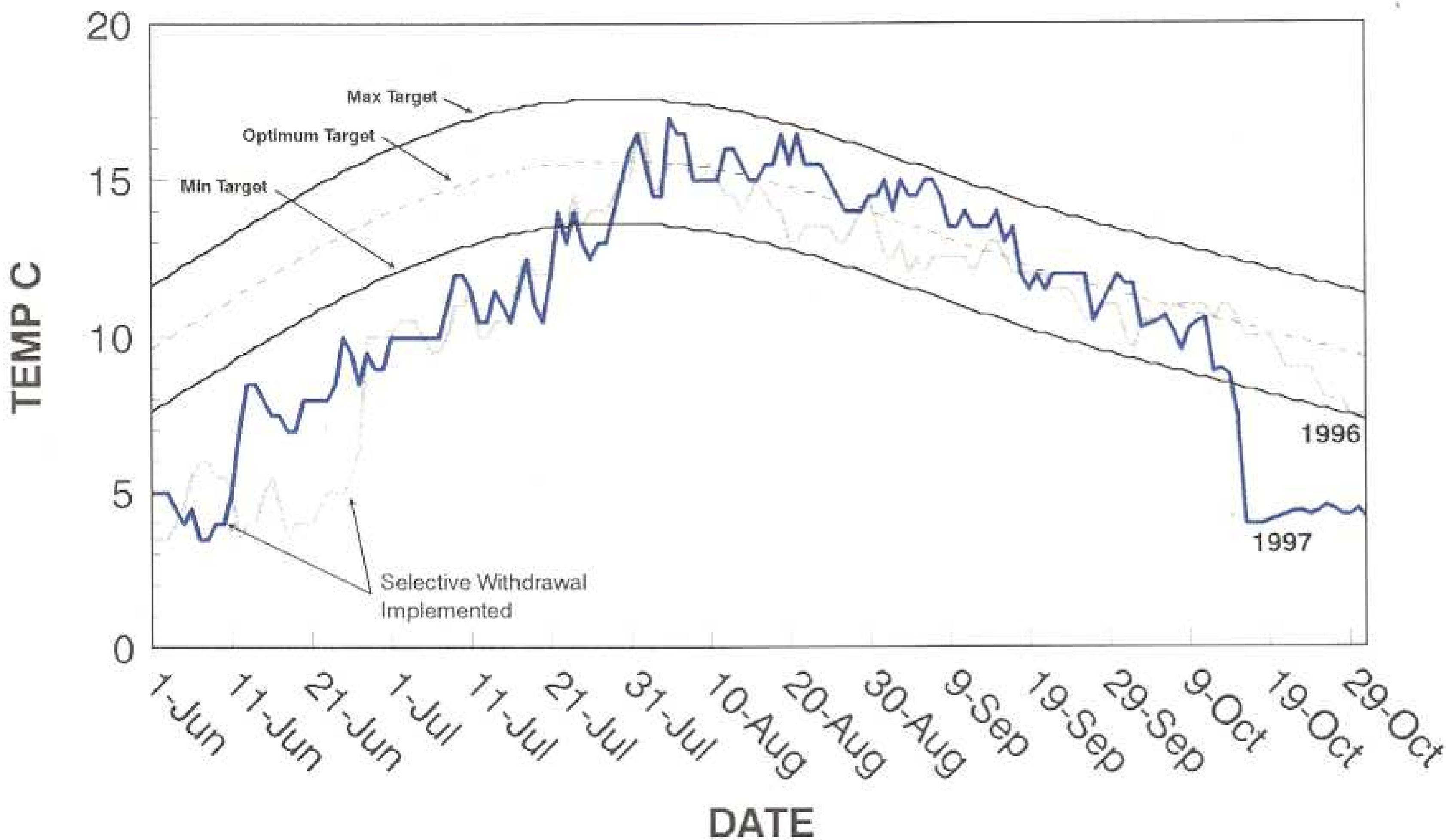


Appendix 1. Comparison of zooplankton vertical profiles at two sites on Hungry Horse Dam in 1996.



Appendix II. Temperature targets for the South Fork Flathead River under operation of selective withdrawal at Hungry Horse Dam. Minimum and maximum temperatures represent the limits of the target range at each date. Actual temperatures achieved in the South Fork below the dam are shown for 1996 (grey) and 1997 (dark). Targets could not be met until the end of July in these years because of high reservoir inflow and delayed thermal stratification.