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# FINAL REPORT: Ecosystem Monitoring during Horsetooth Reservoir Refilling

**Prepared by Dr. Brett M. Johnson, Principal Investigator**
**Justin Butteris, Michael Dodrill, Undergraduate Research Assistants**

**Fisheries Ecology Laboratory**
Department of Fishery and Wildlife Biology
Colorado State University
Fort Collins, CO  80523-1474

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## INTRODUCTION

Extended drawdown of reservoirs can have direct and indirect effects on their limnology, fisheries and food webs. Monitoring these ecosystem impacts is important to understanding mechanisms driving water quality and is essential for rational and informed fishery and water management actions. From fall 2000 until fall 2003, the dams that form Horsetooth Reservoir underwent safety improvements. To accomplish the work, US DOI Bureau of Reclamation (BOR) drew the reservoir down to a minimum water surface elevation in November 2000 of 5,302 ft ASL. Volume of the reservoir at this time (6,590 ac-ft; BOR 1984) was about 4% of its normal volume (156,735 ac-ft).

Several potential changes were anticipated from the drawdown of Horsetooth Reservoir and the subsequent refilling. Extended drawdown allows terrestrial vegetation to colonize the former littoral zone of reservoirs. We expected that when terrestrial vegetation was inundated as the normal pool was restored, organic carbon and nutrients released into the water column could increase phytoplankton and zooplankton production. Organic matter was also expected to increase as terrestrial vegetation decomposed, increasing the production of invertebrate detritivores, which are food organisms for some fishes. Flooded terrestrial vegetation can serve as an excellent spawning substrate for yellow perch and a resurgence of that species was expected. We anticipated that the input of organic material could result in a “trophic upsurge” common in new reservoirs (O’Brien 1990; Kimmel and Groeger 1986) as bottom up effects enhanced production at all levels of the food web.

This report documents work by Colorado State University (CSU) to monitor ecosystem conditions during refilling. Our work included an assessment of terrestrial vegetation inputs, changes in limnological parameters, zooplankton and *Mysis* dynamics, and changes to the fishery and food web dynamics. Monitoring by CSU was conducted with the assistance of Colorado Division of Wildlife (CDOW) fishery biologists, and in cooperation with BOR limnologists.

# METHODS

## Site Description

Horsetooth Reservoir is located in the foothills of the Rocky Mountains west of Fort Collins, CO. The reservoir is about 6.5 miles long and 0.5 miles in width. Its maximum surface area and capacity are 2,040 ac and 156,735 ac-ft, respectively (Table 1). Four earthen dams enclose the reservoir, which were completed in 1949. Horsetooth Reservoir is part of the Colorado-Big Thompson Project (CBT) operated by the Bureau of Reclamation (BOR) and the Northern Colorado Water Conservancy District (NCWCD). The CBT diverts water from the west slope to the east slope primarily for drinking water and irrigation (NCWCD 2000). Horsetooth Reservoir also provides water for recreation, and fishing, boating, and water-skiing are very popular. Prior to dam repairs, annual water level fluctuations (maximum – minimum surface elevation) were on the order of 20-30 m.

Table 1. Characteristics of Horsetooth Reservoir, Larimer County, Colorado. Data sources shown in footnotes.

| Parameter | Units | Value |
|---|---|---|
| Year dams completed | -- | 1949[1] |
| Capacity at full pool | ac-ft ($m^3$) | 156,735 ($1.93 \times 10^8$)[1] |
| Normal surface elevation | ft (m) | 5,430 (1,655)[1] |
| Surface area at full pool | ac (ha) | 2,040 (826)[1] |
| Maximum depth | ft (m) | 212 (65)[1] |
| Length | mi (km) | 6.8 (11) |
| Width | mi (km) | 0.62 (1) |
| Primary sport fishes present[2] | -- | walleye, hybrid striped bass, rainbow trout, smallmouth bass, yellow perch |
| Primary planktivorous fishes present[2] | -- | emerald shiner, spottail shiner, yellow perch |

[1] BOR
[2] Ken Kehmeier, Colorado Division of Wildlife

The reservoir has been managed as a "two story" fishery, consisting of cold- and coolwater fishes, since the early 1950s (Johnson and Goettl 1999). The coldwater assemblage has consisted primarily of stocked rainbow trout *Oncorhynchus mykiss*, but brown trout *Salmo trutta*, lake trout *Salvelinus namaycush*, and kokanee *Oncorhynchus nerka* have also been present. The coolwater assemblage is made up of smallmouth bass *Micropterus dolomieu*, walleye *Stizostedion vitreum*, hybrid striped bass *Morone saxatilis x M. chrysops*, white bass *M. chrysops*, and yellow perch *Perca flavescens*.

Dramatic annual fluctuations in the reservoir's surface elevation have precluded growth of aquatic macrophytes and the reservoir lacks a true littoral zone (Edmonds and Ward 1979). Thus, fish production is driven largely by pelagic production.

The configuration of the Horsetooth Reservoir food web has been dynamic for decades. The walleye population was self-sustaining for many years and no walleye were stocked during 1980-1992. Prey availability for piscivores was low after a marked decline in yellow perch abundance beginning in the late 1960s. Low walleye growth rates prompted CDOW to introduce rainbow smelt *Osmerus mordax* in 1983 (Jones 1985). The rainbow smelt population blossomed and adult walleye growth rates increased by about 50% (Jones et al. 1994).

**Figure 1. The walleye (*Stizostedion vitreum)* has been a mainstay of the Horsetooth Reservoir sport fishery for many years (photo: Konrad Schmidt).**

Further, it appeared that the rainbow smelt eliminated *Mysis relicta*, an extremely potent planktivore, from the reservoir. Mysids were not found in the reservoir after 1987 nor were they found in rainbow smelt stomachs after 1988 (Johnson and Goettl 1999) and standardized sampling failed to capture any mysids in 1999 (Martinez 2000). However, the abundance of large zooplankton such as *Daphnia pulicaria* and *D. galeata* dropped to trace levels in the late 1980s and early 1990s as the smelt population expanded. Walleye reproduction ceased, likely a result of predation from or competition with rainbow smelt (Johnson and Goettl 1999). Smelt abundance declined after 1989 until 1996 when sampling for smelt ended. It is believed that the smelt population disappeared in the late 1990s and walleye body condition and growth dropped dramatically. Macrozooplankton populations partially recovered, reaching densities of about half of pre-smelt levels, beginning in 1995.

## Plant Biomass and Nutrient Loading

We conducted a survey to determine the biomass of vegetation located along the shoreline of Horsetooth Reservoir that was submerged when the reservoir was refilled. The mass of phosphorus in that vegetation was also estimated. The reservoir was divided into six strata (Figure A1), and five or six shoreline sites were randomly selected within each stratum; a total of 31 sites were sampled. At each site, a vertical elevation above the water level was randomly selected for sampling. On 18 August 2003 we used a boat to locate five of the 10 sites within strata 4, 5, and 6. Two points from stratum 2 were also sampled on that date. On August 19, 2003 strata 1 and 3, and the remaining three points within stratum 2 were sampled on foot.

At each site a wire hoop (0.581 $m^2$) was placed on the ground and grass shears were used to clip the vegetation at ground level. The vegetation was then gathered and weighed using a spring scale. The relative taxonomic composition (proportion of grasses, forbs and woody vegetation) by area was visually estimated at each site.

**Figure 1. Two views of the South Bay of Horsetooth Reservoir in June 2003 showing extensive colonization of the lakebed by terrestrial vegetation (photos: Marci Koski).**

The area of land submerged when the reservoir refilled was estimated from BOR tables. The surface elevation on 18 August 2003 (5,358 ft ASL) was used to determine the surface area of the reservoir (4,386,796 $m^2$) on that date. The difference between the surface area of the full reservoir (at 5,430 ft ASL; 8,255,594 $m^2$) and the surface area on the sampling date was used to estimate the area of the reservoir shoreline exposed (3,868,798 $m^2$).

To determine the total biomass of vegetation present along the shoreline, the mean biomass density (g/$m^2$) of vegetation sampled across the strata was multiplied by the total area of exposed shoreline. Mass of each vegetation type was computed from the mean taxonomic composition of the vegetation and total vegetation biomass. We determined the mass of phosphorus in the flooded terrestrial vegetation by multiplying the taxon-specific phosphorus concentration by the mass of each vegetation type. Average phosphorus concentrations on a dry weight basis (grass: 0.21%, forbs: 0.27%, and woody vegetation: 0.33%) were obtained from Cook et al. (1977).

## Physical Limnology

Reservoir water operations data were obtained from USGS Water Resources Bulletins, and BOR databases and reports. Vertical profiles of temperature and dissolved oxygen were recorded at mid-basin reference stations established by CDOW in 1983 (HST1: 13T 0485908 4493023; HST2: 13T 0487283 4489111; HST3: 13T 0487784 4486347). Temperature and dissolved oxygen profiles were obtained using an YSI Model 52 digital meter with 60 m cable. Measurements were taken at one meter intervals from 0 to 20 m and at 5 m intervals from 20 m to the bottom; if depth at the station was <30 m then measurements were made at 1-m intervals from the surface to the bottom. Secchi depth measurements were made with a standard 200 mm white and black limnological secchi disc (Wetzel and Likens 1991) by averaging two replicate readings taken on the shaded side of the boat. Turbidity and conductivity measurements were made at the surface at most stations and dates using a LaMotte model 2020 turbidimeter and an Oakton conductivity meter with automatic temperature correction. Additional physicochemical data were obtained from the Big Thompson Watershed Forum's website (http://www.btwatershed.org/btwf/), and from Ben Alexander (City of Fort Collins Water Utility).

### Crustacean Zooplankton

We sampled the reservoir for crustacean zooplankton in September 2003 and monthly during May through September 2004, as part of the present study. We combined these data with those collected by CSU during May-September 2002-2003. Methods and sampling stations in this study were consistent with those used in previous years (Johnson and Graeb 1998; Johnson and Goettl 1999). Zooplankton were collected in two vertical tows from 10 m to the surface at each site of three standardized sites (locations above) with a 153 µm Wisconsin net (Lind 1979) that was 760 mm long and had a 120 mm diameter opening. Efficiency of the net was assumed to be 100% so each 10-m haul sampled 113.1 L. Samples were preserved in 70% ethanol. CSU sampling complemented that conducted by BOR sampling using a 64 µm net (Lieberman 2005).

**Figure 2. Left: Marci Koski, CSU graduate student, collects a zooplankton sample with the Wisconsin net (photo: Brett Johnson). Right: *Daphnia,* a common zooplankton grazer that is also an important prey for many fishes in Horsetooth Reservoir (photo used by permission of Vim Van Egmond).**

In the laboratory we identified, counted and measured zooplankters in each sample using standard methods (Lind 1979). In addition to samples collected by CSU, we also processed the following samples collected by BOR with a 64 µm net: 20 August 2003, 23

September 2003, 23 October 2003, 20 November 2003, 31 March 2004, 28 April 2004, 24 May 2004, and 28 June 2004 (Butteris and Johnson 2004).
Each zooplankton sample was diluted to a known volume to yield a number of organisms in each aliquot that could be efficiently enumerated and measured. While stirring to assure homogeneity, three 1-ml aliquots were removed with a Hensen-Stempel pipette and placed in a Sedgwick-Rafter cell for enumeration under a compound microscope. We identified daphnids to species, other cladocerans to genus, and copepods to order with a Zeiss 32x – 200x compound microscope. Body length measurements were made on *Daphnia* species only; daphnids were measured to the nearest 0.01 mm with an ocular micrometer, from the top of the helmet to the base of the tail spine. Egg counts and carapace condition of daphnids were also documented.

The number of organisms in each sample was determined from the number of aliquots examined, the number of organisms in each aliquot, and the dilution volume. In-lake density (D; plankters•$L^{-1}$) of zooplankton from each sample was estimated by dividing the number of organisms in the sample by the volume sampled.

$$D = \left[ \left( \sum_{i=1}^{n} (C_i \cdot d) \right) \cdot n^{-1} \right] \cdot V^{-1}$$

Where: n = number of aliquots (i) examined from the sample
C = the number of organisms counted in an aliquot
d = the volume of the diluted sample (mL)
V = the volume sampled by the plankton net

In-lake densities per sample at each site were averaged and lakewide density was computed by averaging mean in-lake densities at up to three sites on each date.

### ***Mysis relicta* Monitoring**

*Mysis* sampling was conducted in cooperation with CDOW using a 2-stage stratified design with four geographic strata, plus two depth strata (shallow, 10-25 m; and deep, 25-35 m). Eight stations were sampled in 2003 and 10 stations in 2004 (Table A1). The reservoir has four fairly distinct basins separated by narrow trenches: 1) Inlet Bay, where the Hansen Canal empties into the reservoir, 2) Spring Canyon basin, 3) Dixon Canyon basin, and 4) Soldier Canyon basin. Sampling sites were allocated into these four strata. In strata 2-4 stations were located close to standardized limnological sampling locations.

Sampling occurred on September 30, 2003, and on September 9 and 20, 2004, around the new moon. Sampling began each night at least one hour after sunset. We used a 1-m diameter circular net (0.785 $m^2$ opening) with 500 µm mesh. The net was lowered to the bottom and hauled vertically to the surface at approximately 0.37 m/sec (Martinez 1992) with an electric capstan winch. Samples were preserved in 70% ethanol, and were enumerated under a stereomicroscope. Length was measured from the tip of the rostrum to the tip of the telson (“total length”, TL).

### Fishery Assessment

A combination of seines, electrofishing, midwater trawling and experimental gill nets was used to monitor the fish assemblage. This sampling was conducted by biologists from the CDOW during May-September 2004 according to standard CDOW procedures. Whole-reservoir hydroacoustics surveys were conducted by CDOW in September 2003 and October 2004 in accordance with standardized CDOW protocols.

Gill nets were set at 20 standardized locations (Table A2) used by John Goettl (CDOW research biologist) in the past (Johnson and Goettl 1999). Nets were of CDOW’s standard warmwater configuration. Sampling occurred during 26-28 May 2004. Beach seining was conducted at seven sites on 4 August 2004. Seine hauls were made with a 40 ft bag seine with 3/16 in mesh; hauls were approximately 50 ft long, pulled along the shoreline. The midwater trawl was 6 m long and had a 2 m diameter circular opening. The mesh was graduated from 13 mm at the cod end to 44 mm at the opening. CDOW deployed the midwater trawl during the day on 16 July 2004 (4 hauls) and 19 August 2004 (2 hauls) and at night on 20 September 2004 (3 hauls). The net was towed at 1.5-2.0 mph approximately 195 ft behind the tow vessel.

Hydroacoustics surveys occurred on 29 September 2003, and 6 October 2004. The reservoir was surveyed along its longitudinal axis with two transects in 2003, and with five transects in 2004. The echosounder was an HTI model 243 digital split beam system with 200 kHz transducer. The ping rate was set to 5 pings✍sec$^{-1}$ with a 1.25 pulse width. Detailed specifications are provided in Table A9. In 2004 a side-looking transducer was added and data were collected by multiplexing between the two transducers. The system was calibrated annually by the manufacturer and periodically in the field with a standard 38.1-mm tungsten-carbide calibration sphere.

Fish collected by gill nets in May and September 2004 were measured and weighed, and scales were removed. Fish condition was estimated from relative weight ($W_r$; Murphy and Willis 1996). Scales were pressed on acetate slides and aged at 32x magnification on a microfiche reader. The edge of the scale was counted as an annulus in May and in September. Stomach samples were collected from fish sampled by both gill nets and seines were preserved in 10% formalin. Stomach contents were removed and analyzed under a stereomicroscope to the lowest taxonomic level possible. Structures resistant to digestion were used as diagnostics for identification and backbones of fish were measured to compute the live TL of each prey item. Diet was computed on the basis of percent composition by wet mass.

## RESULTS AND DISCUSSION

### Plant Biomass and Nutrient Loading

The species composition of vegetation in the dewatered zone of the reservoir's basin was primarily forbs, with smaller fractions of grasses and woody plants (Table 2). We estimated that the mass of terrestrial vegetation along the shore of Horsetooth Reservoir that was submerged when the reservoir was re-filled was 2,213,000 kg. After decomposition the mass of phosphorus that could be released was estimated to be approximately 5,800 kg.

Table 2. Vegetation type, mean percent cover per quadrat, biomass of vegetation type and approximate phosphorus concentration (Cook et al. 1977) used to compute the mass of phosphorus in vegetation submerged when Horsetooth Reservoir was refilled. The mean above ground biomass density of all vegetation was 0.572 kg/m$^2$ (wet) and the estimated area of exposed shoreline was 3,868,798 m$^2$.

| Vegetation Type | Areal cover (%) | Biomass (kg) | Phosphorus concentration (%) | Phosphorus submerged (kg) |
|---|---|---|---|---|
| Grass | 18.3 | 405,467 | 0.21 | 400 |
| Forb | 76.3 | 1,688,215 | 0.27 | 2,300 |
| Woody | 5.3 | 117,954 | 0.33 | 200 |
| Sum | | 2,211,636 | | 2,900 |

The estimated mass of vegetation and phosphorus submerged are likely biased low for two reasons. We underestimated the dewatered surface area because slope of the shoreline was not taken into account, and, because the reservoir was already refilling when our survey occurred, some vegetation was already submerged prior to sampling. It is important to note that phosphorus release will depend on decomposition rate of the vegetation and on chemical conditions at the substrate. Some of the plant material may be refractory, decomposing very slowly. It appears that submerged vegetation already enhanced invertebrate production- large numbers of 50 mm long crayfish were captured in beach seine hauls at sites with large amounts of decaying vegetation (Ken Kehmeier, CDOW, unpublished data).

## Physical Limnology

The morphometry of Horsetooth Reservoir's basin is such that the system became divided into three main pools connected by trenches (Figure 4) when the reservoir was drawn down. Throughout the period of the drawdown it appeared that the water in Spring Canyon and Dixon pools that was above the elevation of the connecting trenches flowed north into Soldier Canyon and then out the outlet works. As a result, epilimnial water from Spring Canyon and Dixon pools was transported to the Soldier Canyon pool. The hypolimnetic outlets then depleted the hypolimnion of the Soldier Canyon pool (Ben Alexander, City of Fort Collins, personal communication) leaving the water column weakly stratified. These hydrological effects of the drawdown contributed to differences in the limnological characteristics observed in Horsetooth Reservoir's three main pools.

**Figure 3. Horsetooth Reservoir during the drawdown (photo: Ben Alexander). The view is to the north, with Spring Canyon pool in the foreground connected to Dixon pool by a trench. A trench also connected Dixon and Soldier Canyon pools, with Soldier Canyon at the top of the image.**

Drawdown altered the usual pattern of seasonal stratification and these stratification patterns differed among basins in 2003 but not in 2004 (Figure 5; Tables A3, A4). Soldier Canyon was nearly isothermal during 2003 and a cold hypolimnion was absent. Stratification was present at the Dixon and Spring Canyon, with late summer epimnion depths of approximately 15 m and 12 m, respectively. Warm water persisted to a greater depth in 2003 than in 2004, perhaps owing to the reduced volume in 2003 resulting in increased warming. The hypolimnion temperature was about 10° C in both locations during 2003, about 3° C warmer than in 2004. In 2004, the three basins showed very similar seasonal patterns, each with strong stratification, a shallower epilimnion (5-10 m), and colder hypolimnetic temperatures (around 7° C) than in 2003.

Dissolved oxygen concentrations were lower in 2003 than in 2004, and were not different among basins (Figure 6; Tables A5, A6). In general, dissolved oxygen concentrations were < 5 mg/L below about 12 m in each basin in 2003. These low oxygen levels become limiting to most fishes and many invertebrates, forcing coldwater organisms into shallower, warmer water. Dissolved oxygen concentration was greater than 5 mg/L at all depths in all basins until July 2004. After July, there was a significant dissolved oxygen minimum in the metalimnion that likely had a significant impact on the depth distribution of the fauna. It remains to be seen how the input of organic matter from flooded vegetation will affect total organic carbon (TOC) and dissolved oxygen in the hypolimnion as that material decomposes.

In general, turbidity declined during 2000-2004 (Figure 7), but was quite variable within years. Variation in summertime turbidity was greatest during the first three years of the drawdown, and turbidity increased throughout the summer.

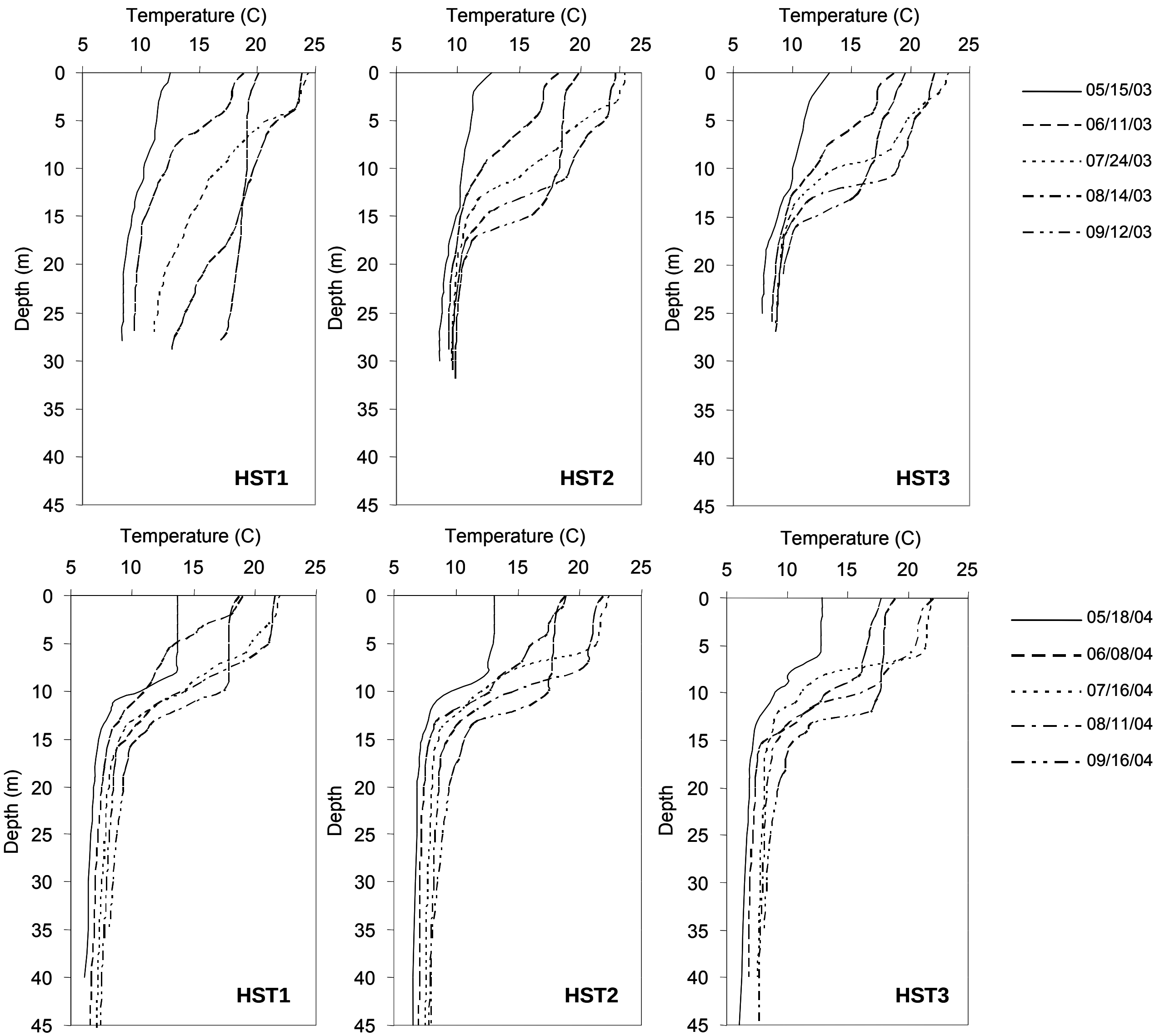

**Figure 5. Temperature (°C) profiles measured at Soldier Canyon (HST1), Dixon (HST2), Spring Canyon (HST3) sampling stations during summer 2003 (top) and 2004 (bottom).**

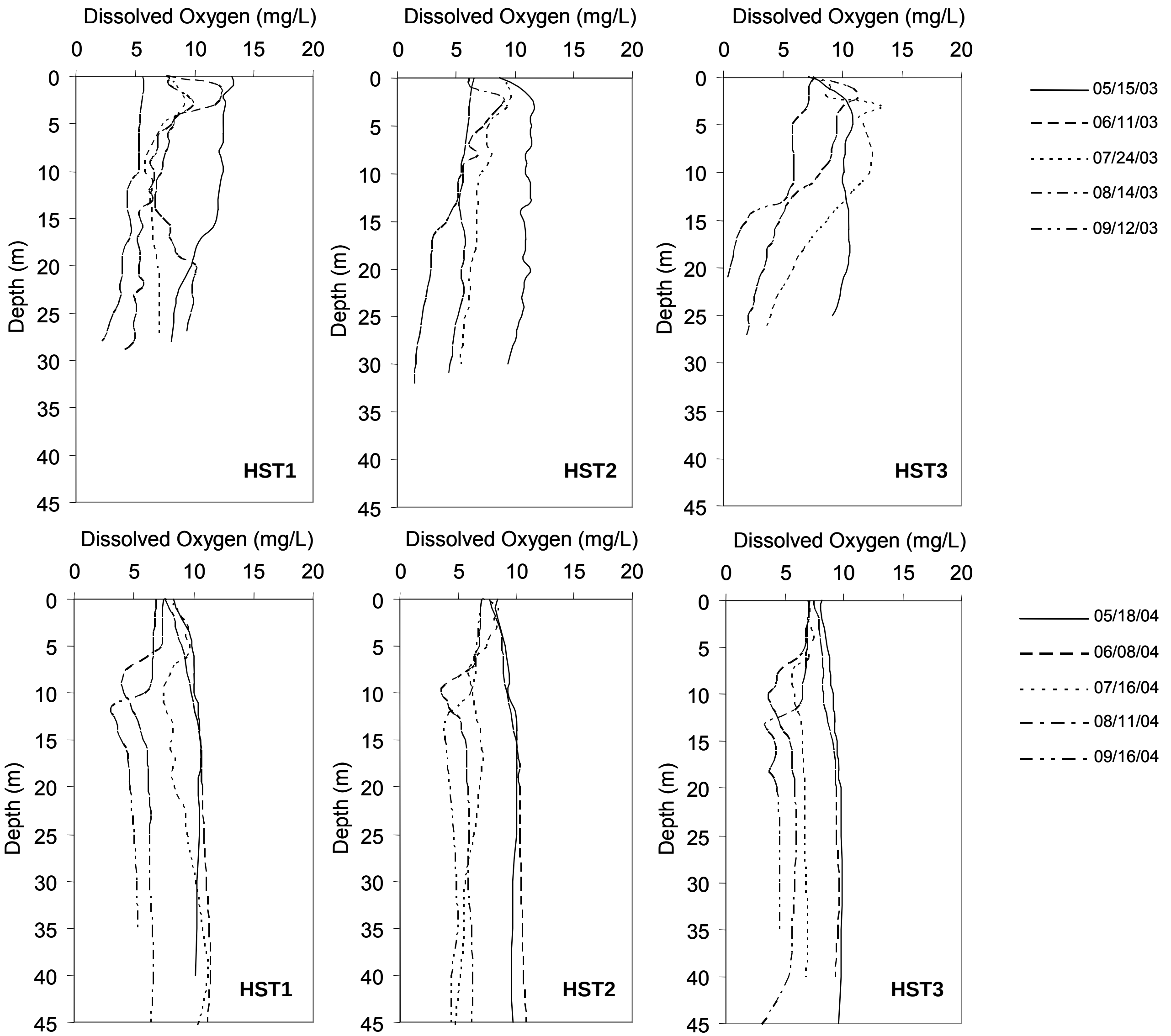

**Figure 6. Dissolved oxygen (mg·L$^{-1}$) profiles measured at Soldier Canyon (HST1), Dixon (HST2), Spring Canyon (HST3) sampling stations during summer 2003 (top) and 2004 (bottom).**

A turbidity spike was recorded on 16 July 2002, during a period of rapid drawdown. This phenomenon, in which the reservoir's turbidity increases sharply when there is a rapid decrease in surface elevation, has been observed in the past. For example, turbidity spikes were recorded in 1977 (Ben Alexander, City of Fort Collins, personal communication) and in 1999 (Johnson and Graeb 1999). The exposure of fine sediments deposited during normal operations coupled with wave action and precipitation events during the drawdown probably also contributed to higher turbidity, as was predicted by BOR (NCWCD 2000).

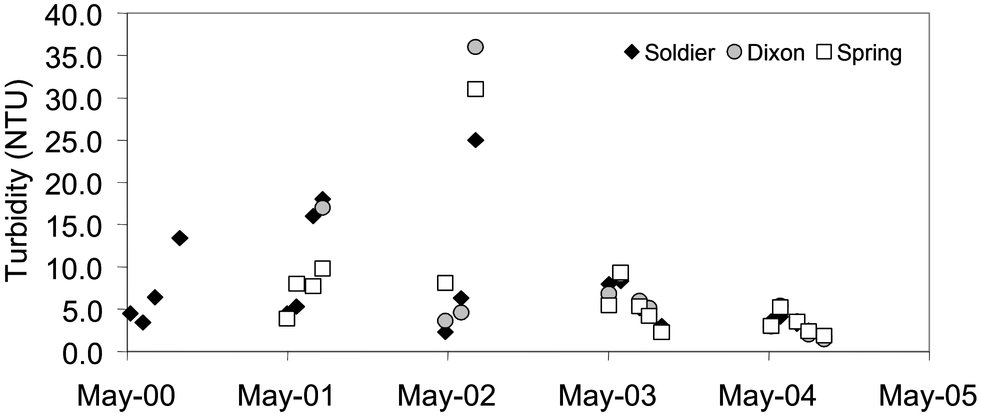

**Figure 7. Turbidty (Nepholometric turbidity units, NTU) measured at three sites in Horsetooth Reservoir during 2000 (BTWF 2004) and 2001-2004 (CSU Fisheries Ecology Lab).**

By 2003 when the reservoir started refilling, and during the more normal operating pattern in 2004, turbidity levels remained consistently low (< 10 NTU, often < 5 NTU). The lowest values were observed in late summer. Secchi depth was also more variable during 2000-2002 than during 2003-2004 (Figure 8). During 2000-2002, secchi depth was greatest in May and declined thereafter. The opposite pattern was observed in 2003-2004 when water clarity increased during the growing season.

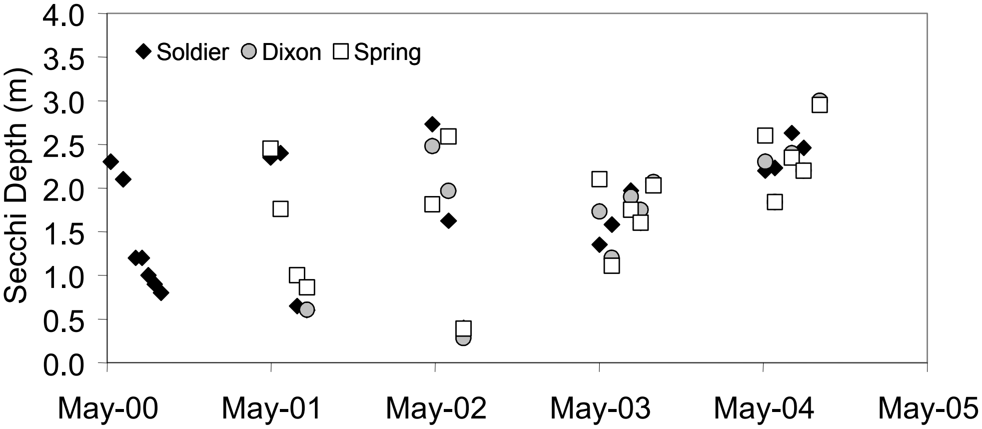

**Figure 8. Secchi depth (m) measured at three sites in Horsetooth Reservoir during 2000 (BTWF 2004) and 2001-2004 (CSU Fisheries Ecology Lab).**

Conductivity data were not available in 2000; during 2001-2004 there was a weak increasing trend in surface conductivity from a mean in 2001 of 46 μS/cm to 65 μS/cm in 2004.

Chlorophyll-a concentration (BTWF 2004) was similar in 2000-2004, but no data were available to compare with pre-drawdown conditions. Secchi depth was highly correlated with turbidity (r = -0.84) and more weakly correlated with chlorophyll-a concentration (r = -54). This suggests that inorganic turbidity (i.e., suspended sediments) may have been driving water clarity more than phytoplankton. Similar conclusions were reached by Jassby and Goldman (1996) in their review of Horsetooth Reservoir's limnology. Given known instances where turbidity increased and water clarity declined very rapidly, it appears that inorganic material plays an important role in determining water clarity, and it would be inadvisable to draw inferences about algal productivity in Horsetooth Reservoir based on surrogate measures such as secchi depth.

Trophic State Index (TSI; Carlson 1977) indicated that on a relatively coarse temporal scale, the productivity of the reservoir may have been relatively stable. While TSI was developed for lakes and reservoirs with little inorganic turbidity, it can serve as a rough indicator. During 1998-2004 the mean TSI based on chlorophyll ($TSI_{Chl}$) was 44 and mean $TSI_{SD}$ (based on secchi depth) was 51. The TSI was within the range reported for 1995 (TSI = 40-50, Jassby and Goldman 1996) and is indicative of mesotrophic conditions.

## Crustacean Zooplankton

The macrozooplankton assemblage was dominated by copepods (Figure 9), as has been observed in several other Colorado reservoirs (Johnson et al. in prep; Martinez 2000). Cyclopoid copepods were the most abundant taxon in 2003 and calanoid copepods were in 2004. *Bosmina*, a small cladoceran, was rare throughout 2003-2004. The species was found in similarly low abundance by Johnson and Goettl (1999).

*Daphnia* is the keystone species in the Horsetooth Reservoir food web; energy flow in most years is largely dependent on pelagic production and *Daphnia* are a key conduit channeling energy into fishes. In most lakes and reservoirs, *Daphnia* populations typically bloom during May and June, and then decline during the remainder of the growing season. This pattern was exhibited by Horsetooth Reservoir *Daphnia* populations. Interannual variation in the density of *Daphnia* was relatively low during 2002-2004. The mean May-June density did increase each year from 2002 to 2004 (mean = 7.3 daphnids•L$^{-1}$, 9.1 daphnids•L$^{-1}$, and 11.1 daphnids•L$^{-1}$, in 2002, 2003 and 2004, respectively). However, with only three sampling stations power was too low to test for statistical differences. By 2004, it appears that *Daphnia* populations had recovered from any possible effects of the drawdown, reaching historic levels. For example, the mean May-June density of daphnids in 1994-1996 was 11.9 daphnids•L$^{-1}$ (Johnson and Goettl 1999) and 11.3 daphnids•L$^{-1}$ in 1999 (Johnson and Hobgood 2000).

The average size of daphnids sampled each month (Figure 10) in 2003 was slightly lower (1.18 mm) than that in 2004 (1.28), but again, differences were not tested statistically due to sample size constraints. This change in size was probably due to a switch from a predominance of *Daphnia galeata* to *D. pulex*, a large cladoceran, in 2004.

To fully evaluate the magnitude of effects of the drawdown on *Daphnia* populations a comparison with other factors is informative. Selective predation has been shown to greatly affect size structure of plankton assemblages (Brooks and Dodson 1965). Lower mean size generally indicates high planktivory conditions. In some years during the period of high smelt abundance (1989-1993) the mean length of *Daphnia* was <1.0 mm (Johnson and Goettl 1999), quite a bit lower than observed in the present study. During 1989-1993 the mean daphnid density was only about 0.53 daphnids•L$^{-1}$ or about 7% of the density in 2002, during the middle of the drawdown period. Thus, the effects of the drawdown and refilling on *Daphnia* were much less pronounced than the effects of predation by an abundant planktivore population (rainbow smelt).

Both the density and size structure of the zooplankton are useful metrics for tracking the intensity of predation exerted by planktivorous fish. Continued monitoring of the zooplankton assemblage would provide managers with a sensitive indicator of the food availability for fish at a key link in the food web.

### ***Mysis relicta* Monitoring**

A single mysid was captured in 2003 (Martinez 2004). A total of 27 mysids were captured in September 2004 (Table A7) and the mean volumetric density was 0.068 mysids • m$^{-3}$. Their mean length was 18 mm TL. A length-frequency distribution showed that most of the individuals appeared to be of the 2003 year class (P.J. Martinez, CDOW, personal communication, 2004). Mean areal density of mysids sampled in September 2004 was

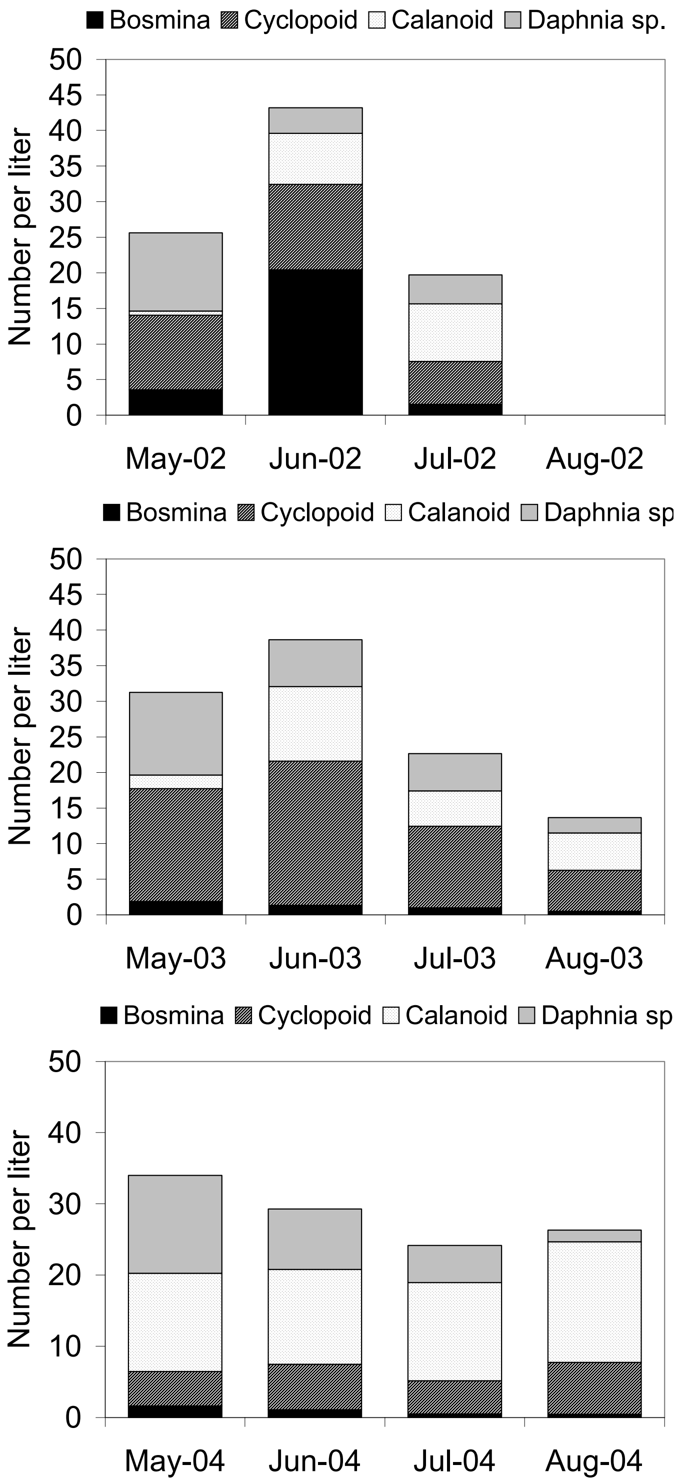

**Figure 9. Abundance (organisms$\cdot$L$^{-1}$) of four taxonomic groups of zooplankton sampled from three stations in Horsetooth Reservoir during 2002-2004.**

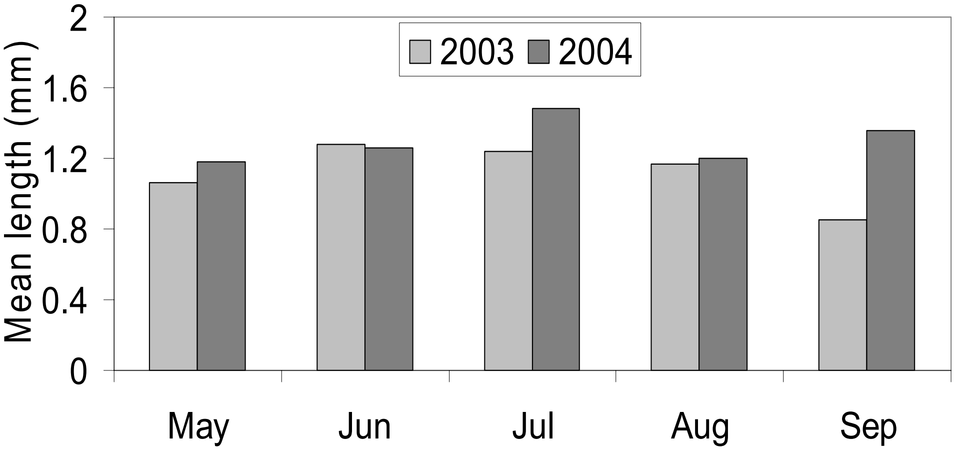

**Figure 10. Mean length (mm) all Daphnia species measured from monthly samples at three stations in Horsetooth Reservoir during 2003 and 2004.**

1.72 mysids•m$^{-2}$ (SD = 3.2, n = 10). This compares with a mean of 342 mysids•m$^{-2}$ (SD = 213, n = 10) measured at Carter Reservoir in 1999 (Johnson and Hobgood 2000) and 488 mysids•m$^{-2}$ (SD = 376, n = 9) in Lake Granby during 1991-1999 (P. J. Martinez, CDOW, unpublished data), suggesting that the Horsetooth Reservoir *Mysis* population is at a relatively low density. During the drawdown dissolved oxygen concentrations in late summer were low below the 14°C isotherm (the upper limit of the animal's thermal tolerance) in many regions of the reservoir (Figure 5, 6). With refilling of the reservoir *Mysis* may find a greater volume of suitable habitat, allowing the population to increase.

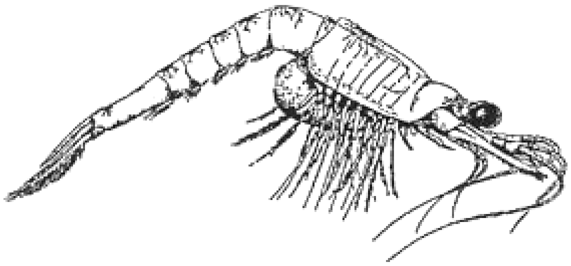

**Figure 11. Opossum shrimp, *Mysis* relicta (image: Royal British Columbia Museum).**

Mysids have been shown to have significant effects on the mortality of *Daphnia* (Goldman et al. 1979; Murtaugh 1981). During laboratory experiments *Mysis relicta* preferred large prey such as *Daphnia* (Cooper and Goldman 1980). While *Mysis* density is currently low in Horsetooth Reservoir, it appears that the population has recently reinvaded: no mysids were captured in sampling or in fish guts during 1988-1996 (Johnson and Goettl 1999) and intensive sampling conducted by CDOW in October 1999 (Johnson and Hobgood 2000) also failed to capture any mysids. If the population expands, the return of *Mysis* *relicta* to Horsetooth Reservoir may alter the food web by reducing *Daphnia* abundance and thereby reducing grazing pressure on phytoplankton and food availability for planktivorous fishes. Standardized monitoring of zooplankton and *Mysis* density will give fishery managers and "early warning" sign that the carrying capacity of planktivorous fishes and ultimately, piscivores, is declining and that stocking rates and harvest regulations may need to be adjusted to maintain acceptable growth rates of sport fishes.

### The Fishery

Changes in the Horsetooth Reservoir food web were already occurring prior to or coincident with the drawdown and refilling. CDOW began manipulating the fish assemblage in anticipation of the drawdown and refilling. Approximately 45,000 emerald shiners were stocked in 2001 and 2002 and approximately 7,000 spottail shiners were stocked in 2001. Forage fish introductions in 2001-2002 appeared to be quite successful, establishing reproducing populations of both emerald shiners *Notropis atherinoides* and spottail shiners *Notropis hudsonius.* Emerald and spottail shiners were the most abundant fish in beach seining conducted by CDOW in August 2002 (K. Kehmeier, CDOW, personal communication, 2004). In 2004 the prey fish assemblage at Horsetooth Reservoir was still dominated by shiners but age-0 yellow perch were also abundant (Table A8).

**Figure12. Spottail shiners (*Notropis hudsonius;* left) and emerald shiners (*Notropis atherinoides*; right) were recently stocked into Horsetooth Reservoir to provide a forage base for piscivorous gamefish (photos: Konrad Schmidt).**

Emerald shiner was the predominant prey fish sampled. The species made up 53% of the total catch of all species in beach seining; age-0 emerald shiners were only 0.5 in long and may not have been fully vulnerable to the seine. Age-0 spottail shiners ranged in size from 0.5 to 1.25 in suggesting the possibility of multiple spawns. Of the prey-sized fish (<150 mm TL), emerald shiners were 55% of the catch, age-0 yellow perch made up 33% of the catch, spottail shiners 10%, and other species making up about 1.5% in aggregate. Large schools of what appeared to be emerald shiners were observed in water too deep to seine at numerous sites in August. Emerald shiners were also sampled by boat electrofishing in September. We observed shiners near the surface in September during night sampling for *Mysis,* but we could not determine the species.

In other systems, emerald shiners are important prey for many piscivorous fishes, including walleye and yellow perch (Scott and Crossman 1973). The recent buildup of shiner biomass probably enhanced growth of walleyes large enough to prey on shiners. However, walleye recruitment was not documented in 2003 or 2004 (K. Kehmeier, CDOW, personal communication). It is not known if the new forage fish assemblage will be detrimental to age-0 walleye growth and survival, as was the case with the rainbow smelt during the 1980s.

Rainbow smelt dominated the fish assemblage during the period of 1983-1993 and they appeared to control zooplankton species composition and size structure (Johnson and Goettl 1999). Although adult walleye growth increased by 50% over pre-smelt levels, walleye recruitment dropped precipitously, coincident with the expansion of the smelt population. Johnson and Goettl (1999) offered two hypotheses to explain the pattern: predation by rainbow smelt on larval walleyes, and competition among smelt and larval walleyes. Midwater trawling for smelt was discontinued in 1996; however, none have been observed since that time (Ken Kehmeier, CDOW, personal commuciation). Continued monitoring of zooplankton biomass and walleye recruitment should be conducted to evaluate the potential effect of forage introductions on walleye recruitment.

One rudd *Scardinius erythrophthalmus,* approximately 4 in long, was sampled by the seine. This species is an exotic introduced into the United States from Europe; it has been expanding its range rapidly throughout the U.S. (Easton et al. 1993). The species has not been observed before in Horsetooth Reservoir and this individual must have been stocked illegally or inadvertently by "bait bucket introduction". Rudd have been found in other reservoirs in the Arkansas and the South Platte River drainages (USGS 2004). It remains to be seen if the species will become established in Horsetooth Reservoir, but if it does it could result in competition for invertebrate prey with a number of the reservoir's sport fishes.

**Figure 13. European rudd S*cardinius erythrophthalmus*, an exotic species recently discovered in Horsetooth Reservoir (photo: USGS Nonindigenous Aquatic Species program).**

No fish were captured during midwater trawling, possibly due to gear avoidance or lack of spatiotemporal overlap with the fish. Emerald shiners are pelagic, inhabiting deep water during the day, but rarely below the thermocline (Becker 1983). At night they are known to come to the surface, but can be difficult to capture by trawling (Trautman 1981). Spottail shiners are known to migrate onshore at night, making them less vulnerable to midwater trawling after dark (Trautman 1981). While trawling was unsuccessful in 2004, the methodology provides one of the only sampling tools for estimating abundance of pelagic species. Results of hydroacoustics surveys were being analyzed at the time of this report, but the technique clearly has potential to become an assessment tool for estimating biomass of pelagic shiners. In practice, its utility remains uncertain until side-scanning methods are refined by CDOW. Physical sampling would still be required to estimate species composition and size structure of pelagic targets. Development of an improved trawl design and deployment methods would be a valuable means of monitoring the biomass of pelagic forage fish in the future.

Petersen length-frequency analysis (Figure 14) showed that two age classes of emerald shiners were present in August (means: 66 mm, 103 mm) and one in September (mean: 72); very few age-0 emerald shiners were sampled (Table A8). Growth information presented in Becker (1983) suggested that it is likely that age-2 (2002) and age-3 (2001) fish were present in the August sample and only age-2 fish in September. Two year classes of spottail shiners were present in August 2004 seine samples. Age-0 and older fish were about equally abundant in samples. Age-0 fish were not measured, but the length-frequency distribution of older spottail shiners appeared to be normal with a relatively small standard deviation (mean = 78, SD = 4, N = 22), suggesting that a single year class of older fish was captured. In Ohio, spottail shiners reach 51-76 mm by their first October and 64-84 at age-1 (Trautman 1981). While aging was not performed, it appears that spottail shiners sampled in August 2004 were age-1+ (2003 year class).

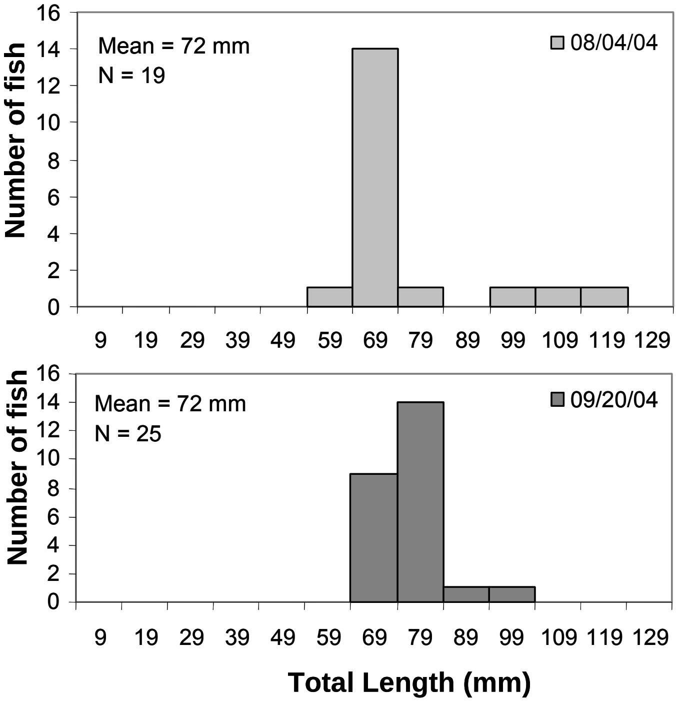

**Figure 14. Length-frequency histograms of emerald shiners sampled by shoreline seining at Horsetooth Reservoir during August and September 2004.**

Based on length-at-age, the growth of walleyes in Horsetooth Reservoir during 2001-2004 was slightly slower than the mean size at age of walleyes from a variety of North and South Dakota reservoirs (Carlander 1997; Figure 15). However, the growth benefit of the shiner introduction has not yet been fully manifested because walleyes from year classes before 2002 may have experienced slow growth in the first years of life when forage fish abundance was low. Body condition in 2004 was much better than in 2000, before the shiners were introduced (see below) suggesting that walleye growth rates may continue to show improvement. The length-frequency distribution from the 2004 gill net catch (Figure 16) suggests that there was a strong year class of walleye produced in 1999 or 2000. The particular year of strong recruitment of walleyes could not be determined because age-5 or older walleyes were not present in our age and growth data. The mean length of walleyes sampled in May 2004 was 353 mm (SD = 61, N = 350), compared to 307 mm in July 2000 (Ken Kehmeier, CDOW, unpublished data).

Yellow perch grew faster in Horsetooth Reservoir than observed in Dakota reservoirs (Figure 15). The length-frequency distribution of yellow perch in the 2004 gill net catch (Figure 16) suggests that yellow perch have produced measurable year classes every year since 1999.

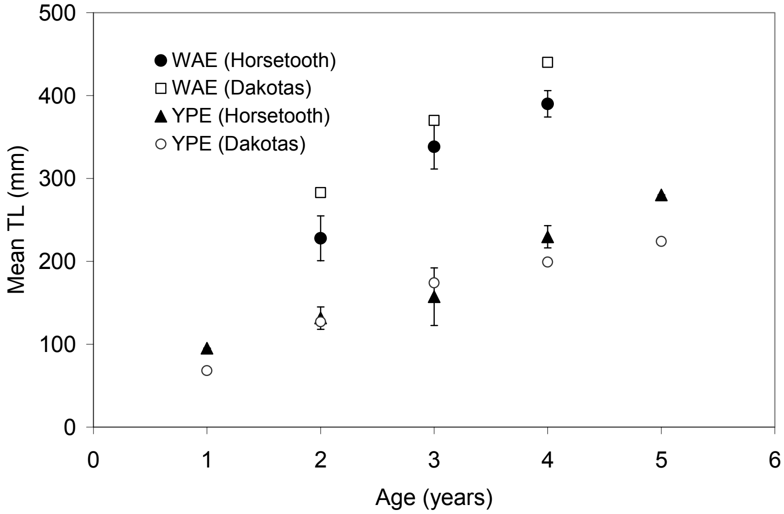

**Figure 15. Growth (total length (TL) at age) of walleye (WAE) and yellow perch (YPE) in Horsetooth Reservoir measured in 2004, and in North and South Dakota reservoirs (Carlander 1997). Error bars show ± 1 standard deviation.**

Modes of the length-frequency distribution corresponded very well with mean lengths at age estimated from scales, corroborating our scale aging technique for that species. Five smallmouth bass collected in September 2004 were all age-2 with a mean length of 119 mm (SD = 7). Length-frequency histograms of fish sampled in experimental gill nets in May 2004 revealed that larger fish were present (Figure 16) but we were not able to determine their ages.

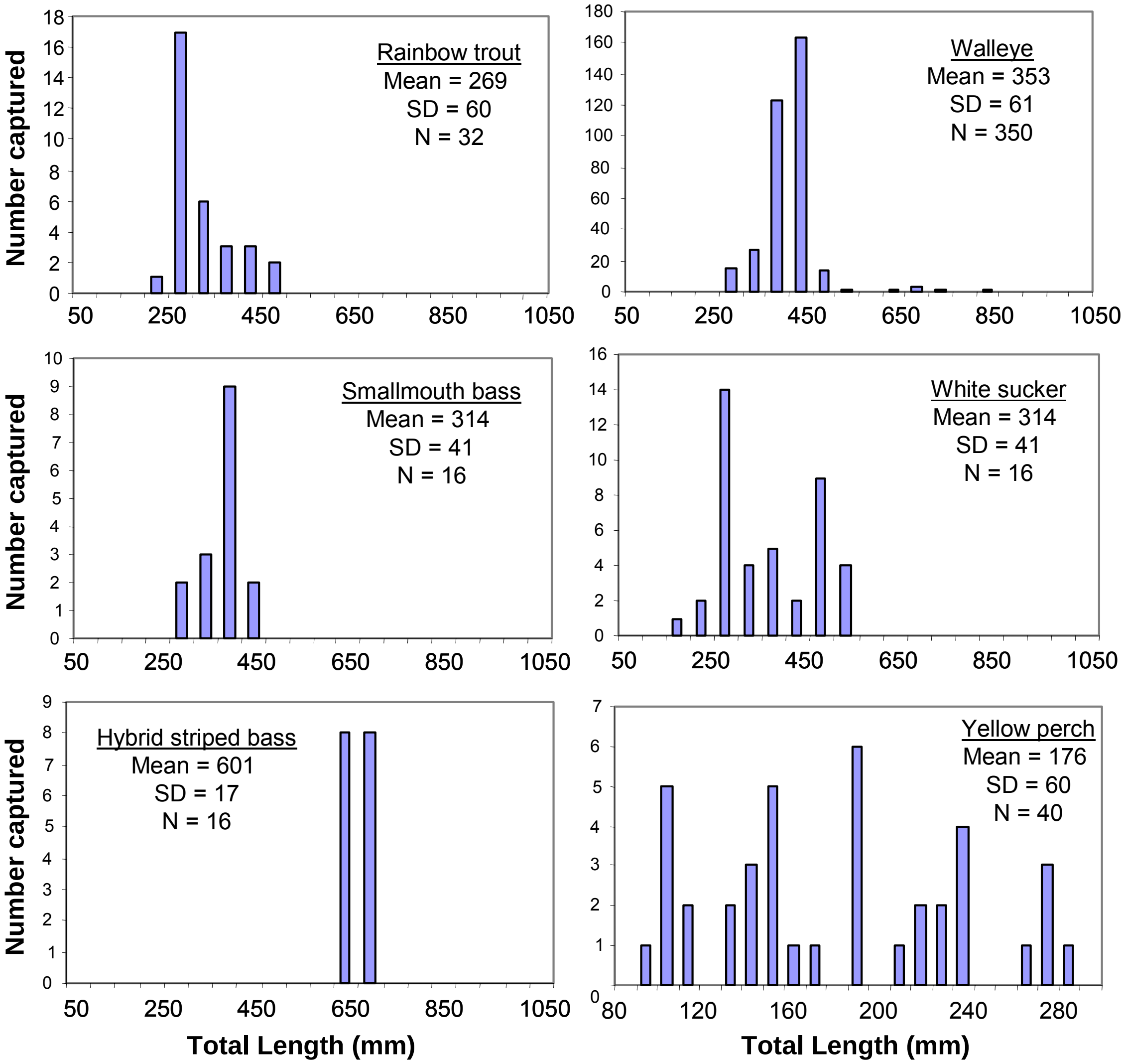

**Figure 16. Length-frequency histograms of six fishes captured in gill nets set in the end of May, 2004.**

**Figure 17. Smallmouth bass (*Micropterus dolomieui*) are popular sport fish in Horsetooth Reservoir (photo: Konrad Schmidt).**

Body condition, as measured by relative weight ($W_{r,}$ where 100 is considered normal condition), of four sport fish species was greater in 2004 (Figure 18) than in 2000 (Ken Kehmeier, CDOW, unpublished data). Body condition of walleyes was substantially greater in 2004 ($W_r$ = 101) than in 2000 ($W_r$ approximately 80), and yellow perch were also in better condition in 2004 ($W_r$ = 105) than in 2000 ($W_r$ = 95). Growth bands on age-3 walleye and yellow perch scales also suggested that 2003 was an excellent year for growth of both species, and that forage availability in 2003 was good. Smallmouth bass and hybrid striped bass condition increased from $W_r \approx 80$ in 2000 to a normal $W_r$ in 2004 (Figure 18).

A total of 52 stomach samples were collected from planktivorous and piscivorous fishes. We also have approximately 100 whole fish to extract stomach contents from. These fish consist mainly of shiners and young walleye and smallmouth bass. Analysis of diet samples continues, supported by funding from the CDOW. Preliminary findings show that the shiners are nearly entirely planktivorous, yellow perch consume more benthic invertebrates than plankton. Piscivore diet data were not available for this report.

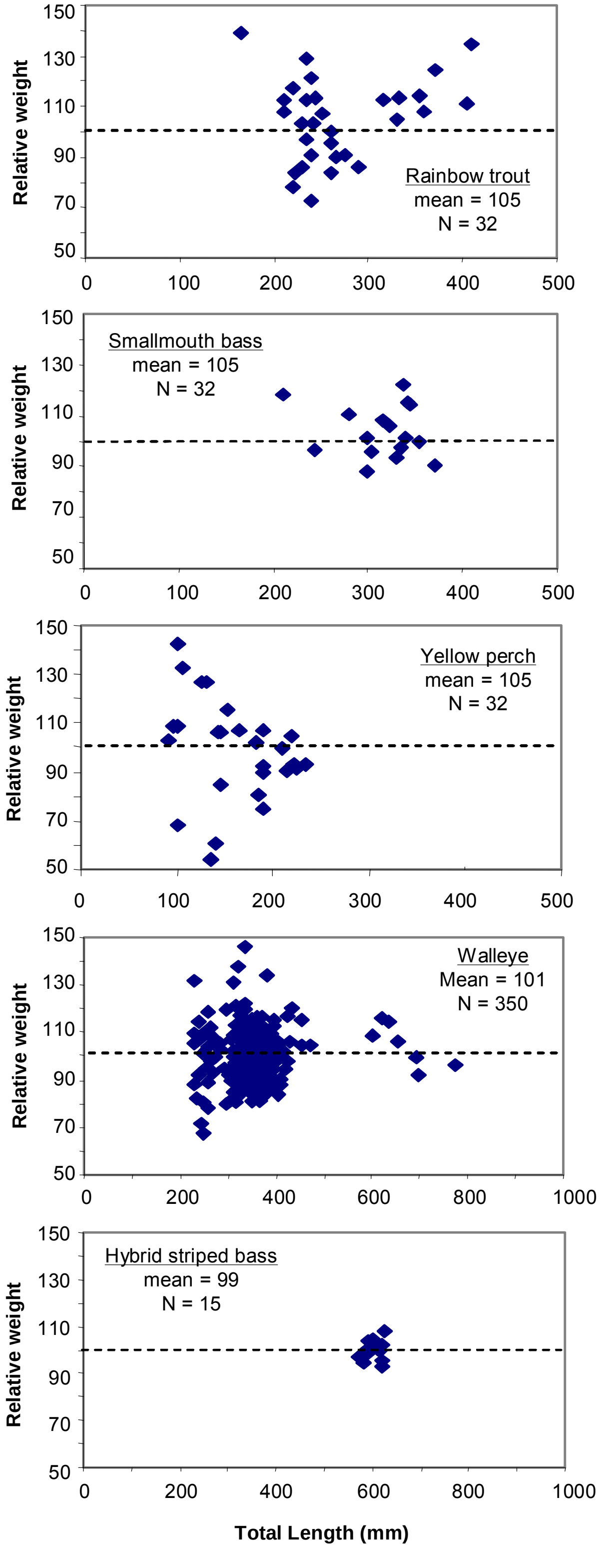

**Figure 18. Relative weight (Wr) of five fish species captured in gill nets set in Horsetooth Reservoir during late May 2004. The dashed line represents a relative weight of 100, or 100% of average body condition for the species.**

## Food Web Dynamics

As in the past (Johnson and Goettl 1999), present sport fish growth rates and biomass are dependent, either directly or indirectly, on pelagic production by zooplankton. Four planktivores derive much of their energy from *Daphnia* production (Figure 19) and piscivores rely indirectly on *Daphnia* production through its support of planktivorous prey fish production.

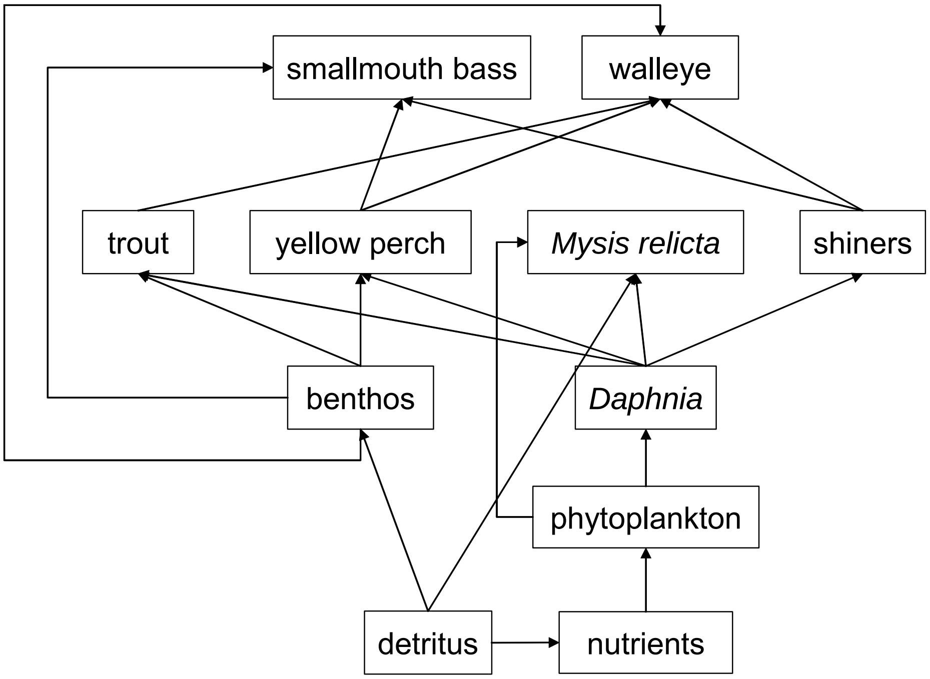

**Figure 19. Primary linkages in the present day food web of Horsetooth Reservoir. Benthos includes crayfish and non-crustacean invertebrates.**

While the drawdown did not appear to negatively impact herbivore, planktivore, or piscivore populations, nor did it appear to stimulate a “trophic upsurge” in pelagic production. Our study did not address changes in the benthic community but effects of the drawdown may have been manifested more strongly in the benthic zone than in the pelagic. Historically, annual water level fluctuations during the course of normal water operations in Horsetooth Reservoir have greatly limited production in the littoral zone. However, sustained drawdown for dam repairs resulted in a large influx of organic matter to the benthos, which could provide energy to support benthic invertebrates and hence, fishes. Presently the relative importance of benthic and pelagic energy sources to the food web can not be assessed. Analysis of growth rates and diets of fishes such as yellow perch, and young walleyes and bass in the future would make such an assessment possible.

The establishment of planktivorous shiners and the resurgence of the yellow perch population has dramatically improved body condition of piscivorous walleyes and hybrid striped bass. The extent to which smallmouth bass rely on these planktivores is not currently known, but in other systems smallmouth bass are highly piscivorous, consuming large numbers of cyprinids (Vander Zanden et al. 2004). However, if planktivore populations continue to expand, the predation demand exerted by *Mysis relicta* and planktivorous fish on zooplankton, and the consequent depletion of grazing pressure, may increase phytoplankton biomass. Ungrazed phytoplankton would add to the pool of organic matter derived from the flooding of terrestrial vegetation. This could lead to water quality issues such as increased TOC, reduced dissolved oxygen concentrations and increased metal concentrations in the hypolimnion, and poorer water clarity.

It has been suggested that food web effects on water quality may be operating at Horsetooth Reservoir (Jassby and Goldman 1996). Thus, fishery managers are challenged by the need to balance predator and prey populations to maintain a food web configuration that supports a desirable sport fishery without contributing to water quality issues. If food web effects indeed appear to be degrading water quality, an understanding of the relative predation demand by Mysis and planktivorous fishes will allow fishery managers to assess how their actions may be used to manipulate the food web to benefit water quality (for example, by biomanipulation).

## CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

The drawdown affected several of the reservoir's physicochemical characteristics to varying degrees but overall, the effects of the drawdown on the food web appear to have been moderate up to this point in time. Based on the findings of this study, and the results of past research at Horsetooth Reservoir, we can draw conclusions that lead to a set of management recommendations regarding limnological conditions and food web dynamics in the reservoir.

1. Drawdown resulted in a large input of organic matter to the reservoir when it filled. It was estimated that approximately 2,200,000 kg of terrestrial vegetation was submerged when the reservoir was re-filled and that that vegetation contributed approximately 5,800 kg of phosphorus to the reservoir.

2. Variation in summertime turbidity was greatest during the first three years of the drawdown, and turbidity increased throughout the summer. A turbidity spike was recorded in July 2002 during a period of rapid drawdown.

3. Hydrological effects of the drawdown contributed to differences in the physicochemical characteristics observed in Horsetooth Reservoir's three main pools.

4. Drawdown transported epilimnial water from Spring Canyon and Dixon pools to the Soldier Canyon pool and the hypolimnetic outlets then depleted the hypolimnion of the Soldier Canyon pool. The result was a lack of stratification at Soldier Canyon and warm water throughout the water column. The epilimnions of Spring Canyon and Dixon pools were deeper in 2003 than in 2004, thus, warm water persisted to a greater depth.

5. Dissolved oxygen concentration below 12 m dropped to levels unsuitable for fishes by late summer in 2003, and there was a significant dissolved oxygen minimum in the metalimnion after July, 2004.

6. *Daphnia* density appeared to drop slightly during the drawdown but returned to pre-drawdown levels by 2004. The effects of the drawdown and refilling on *Daphnia* were much less than the effects of predation by an abundant planktivore population (rainbow smelt) during the late 1980s and early 1990s.

7. Coolwater fish populations did not appear to be hampered by the drawdown. In fact, the yellow perch population expanded and stocking of forage fishes during the drawdown was highly successful. Body condition of perch, walleye, smallmouth bass and hybrid striped bass improved from 2000 to 2004.

8. The present study provided an opportunity to further our understanding of biotic and abiotic drivers of water quality in the reservoir, and to better understand

how knowledge of food web configuration and its dynamics can aid fishery managers in maintaining a desirable sport fishery.

9. It appears that inorganic turbibity plays an important role in determining water clarity in Horsetooth Reservoir, and it would be inadvisable to draw inferences about algal productivity here based on surrogate measures such as secchi depth. More direct measures of algal biomass such as chlorophyll-a concentration would be much more reliable.

10. It remains to be seen how the input of organic matter from flooded vegetation will affect TOC and dissolved oxygen in the hypolimnion as that material decomposes. Because of the implications of these parameters for water treatment and food web dynamics, regular limnological sampling would be prudent.

11. An evaluation of the relative contributions of external TOC loading from inflows and internal loading resulting from decomposition of terrestrial vegetation and inputs from the food web would be an important first step to managing TOC.

12. Standardized monitoring of zooplankton density gives fishery managers an "early warning" sign that the carrying capacity of planktivorous fishes and ultimately, piscivores, is declining and that stocking rates and harvest regulations may need to be adjusted to maintain acceptable growth rates of sport fishes.

13. Continued monitoring of zooplankton biomass and walleye recruitment should be conducted to evaluate the potential indirect effects of forage fish introductions on walleye recruitment. Knowledge of these relationships can guide stocking policy to maintain a fishable stock of walleyes.

14. *Mysis relicta* has recently reinvaded the reservoir. This species is a very potent predator on zooplankton and has been shown to compete strongly for food with planktivorous fishes. While this species has proven to be very difficult to eliminate, stocking of sport fishes that prey on *Mysis* (e.g., splake) may reduce *Mysis* biomass and contribute to sport fish production.

15. Because of the predation demand exerted by *Mysis relicta* and planktivorous fish on zooplankton, and the consequent depletion of grazers, it is possible that phytoplankton biomass will increase. Ungrazed phytoplankton would add to the pool of organic matter that came from the flooding of terrestrial vegetation. This could lead to water quality issues such as reduced water clarity, increased TOC, and low dissolved oxygen levels.

16. If top-down effects appear to be degrading water quality, an understanding of the relative predation demand by *Mysis* and planktirovous fishes will allow

fishery managers to assess how their actions may be used to manipulate the food web to benefit water quality (for example, by biomanipulation).

17. Ultimately, water quality and fisheries in Horsetooth Reservoir are driven by a combination of biotic and abiotic forces and appropriate management initiatives depend on our understanding of the relative contributions of each. Knowledge of food web's configuration and its dynamics is necessary to interpret water quality trends. This understanding can be achieved through cooperation among water quality personnel, limnologists, fishery biologists. Mutual learning about the factors driving Horsetooth Reservoir's dynamics would be facilitated by future collaborative studies among universities, agencies and the private sector.

**Figure 20. Horsetooth Reservoir at close to full pool conditions (photo: City of Fort Collins).**

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# APPENDICES

Table A1. Stations sampled for *Mysis relicta* at Horsetooth Reservoir in September 2003 and 2004. Map datum: Continental U.S., 1927 North American Datum (CONUS NAD27).

| Depth (m) | Station name | UTM coordinates | | |
|---|---|---|---|---|
| | | Zone | East | North |
| | | September 2003 | | |
| 25 | HTRMY1 | 13T | 0485797 | 4493098 |
| 30 | HTRMY2 | 13T | 0486043 | 4492920 |
| 14 | HTRMY3 | 13T | 0486489 | 4490380 |
| 30 | HTRMY4 | 13T | 0487152 | 4489291 |
| 26 | HTRMY5 | 13T | 0487033 | 4488759 |
| 26 | HTRMY6 | 13T | 0487798 | 4486400 |
| 26 | HTRMY7 | 13T | 0487502 | 4486197 |
| 14 | HTRMY8 | 13T | -- | -- |
| | | September 2004 | | |
| 10 | HSTMYSIN1 | 13T | 0487303 | 4486094 |
| -- | HSTMYSIN2 | 13T | 0486788 | 4485991 |
| -- | HSTMYSIN3 | 13T | 0487036 | 4486009 |
| 13 | HSTMYSSP1 | 13T | 0487438 | 4485711 |
| 12 | HSTMYSSP2 | 13T | 0487357 | 4486330 |
| 27 | HSTMYSSP3 | 13T | 0487776 | 4486322 |
| 13 | HSTMYSDC1 | 13T | 0486777 | 4488904 |
| 32 | HSTMYSDC2 | 13T | 0487270 | 4489102 |
| 14 | HSTMYSSO1 | 13T | 0485722 | 4492759 |
| 31 | HSTMYSSO2 | 13T | 0486086 | 4492883 |

Table A2. Location of stations sampled by Colorado Division of Wildlife with experimental gill nets in May, 2004. Map datum: WSG-84.

| | UTM coordinates | | |
|---|---|---|---|
| Net number | Zone | East | North |
| 1 | 13T | 487125 | 4484510 |
| 2 | 13T | 487069 | 4485414 |
| 3 | 13T | 486662 | 4486049 |
| 4 | 13T | 487707 | 4486794 |
| 5 | 13T | 487157 | 4486520 |
| 6 | 13T | 487600 | 4486886 |
| 7 | 13T | 486918 | 4487841 |
| 8 | 13T | 486504 | 4488444 |
| 9 | 13T | 487341 | 4489059 |
| 10 | 13T | 486390 | 4489458 |
| 11 | 13T | 486631 | 4490839 |
| 12 | 13T | 485788 | 4491533 |
| 13 | 13T | 486464 | 4491808 |
| 14 | 13T | 485668 | 4492259 |
| 15 | 13T | 484971 | 4492361 |
| 16 | 13T | 486222 | 4492826 |
| 17 | 13T | 485418 | 4492979 |
| 18 | 13T | 485536 | 4493282 |
| 19 | 13T | 486069 | 4493587 |
| 20 | 13T | 485258 | 4493850 |

Table A3. Temperature (°C) measured at three stations on Horsetooth Reservoir during May through September, 2003. HST1 = Soldier Canyon station, HST2 = Dixon station, and HST3 = Spring Canyon station.

| Depth (m) | HST1 5/15 | HST2 5/15 | HST3 5/15 | HST1 6/11 | HST2 6/11 | HST3 6/11 | HST1 7/24 | HST2 7/24 | HST3 7/24 | HST1 8/14 | HST2 8/14 | HST3 8/14 | HST1 9/12 | HST2 9/12 | HST3 9/12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 12.5 | 12.8 | 13.2 | 18.8 | 18.2 | 18.5 | 24.3 | 23.6 | 23.2 | 23.8 | 22.8 | 22.0 | 20.1 | 19.8 | 19.5 |
| 1 | 12.3 | 11.9 | 12.5 | 18.0 | 17.2 | 17.5 | 24.0 | 23.5 | 23.0 | 23.7 | 22.7 | 21.8 | 19.8 | 19.3 | 19.2 |
| 2 | 11.8 | 11.3 | 12.0 | 17.8 | 16.9 | 17.2 | 23.7 | 23.1 | 22.4 | 23.6 | 22.4 | 21.6 | 19.4 | 18.8 | 18.8 |
| 3 | 11.6 | 11.2 | 11.4 | 17.7 | 16.9 | 17.1 | 23.6 | 22.9 | 21.2 | 23.5 | 22.3 | 21.4 | 19.2 | 18.7 | 18.5 |
| 4 | 11.5 | 11.2 | 11.2 | 17.1 | 16.7 | 16.8 | 22.9 | 21.3 | 20.4 | 23.0 | 22.3 | 20.8 | 19.2 | 18.6 | 18.1 |
| 5 | 11.3 | 11.1 | 11.0 | 15.9 | 16.0 | 15.8 | 20.7 | 20.2 | 19.6 | 21.6 | 21.9 | 20.3 | 19.1 | 18.6 | 17.6 |
| 6 | 11.2 | 11.0 | 10.9 | 14.8 | 15.1 | 14.7 | 19.7 | 19.0 | 19.2 | 21.0 | 20.9 | 20.0 | 19.1 | 18.5 | 17.4 |
| 7 | 11.2 | 10.8 | 10.7 | 13.4 | 14.2 | 13.4 | 18.9 | 18.5 | 18.7 | 20.6 | 20.3 | 19.7 | 19.1 | 18.5 | 17.2 |
| 8 | 10.8 | 10.6 | 10.5 | 12.8 | 13.4 | 12.7 | 18.0 | 18.0 | 18.2 | 20.3 | 19.8 | 19.6 | 19.1 | 18.5 | 17.0 |
| 9 | 10.5 | 10.5 | 10.3 | 12.4 | 12.4 | 12.3 | 17.5 | 16.7 | 16.4 | 20.0 | 19.4 | 19.1 | 19.1 | 18.3 | 16.9 |
| 10 | 10.3 | 10.4 | 10.1 | 12.2 | 11.9 | 11.8 | 16.7 | 15.7 | 13.6 | 19.6 | 19.1 | 18.9 | 19.1 | 18.3 | 16.5 |
| 11 | 10.2 | 10.3 | 10.0 | 11.7 | 11.4 | 11.0 | 15.8 | 14.7 | 12.4 | 19.4 | 18.7 | 18.0 | 19.0 | 17.9 | 16.2 |
| 12 | 9.9 | 10.2 | 9.8 | 11.3 | 11.0 | 10.4 | 15.6 | 13.1 | 11.4 | 19.1 | 17.2 | 13.8 | 18.9 | 17.6 | 15.7 |
| 13 | 9.6 | 10.2 | 9.3 | 11.0 | 10.6 | 9.8 | 15.2 | 11.7 | 10.6 | 18.9 | 15.2 | 11.7 | 18.8 | 17.2 | 15.1 |
| 14 | 9.5 | 10.2 | 9.0 | 10.7 | 10.4 | 9.6 | 14.7 | 11.3 | 10.0 | 18.6 | 13.2 | 10.8 | 18.7 | 16.6 | 13.4 |
| 15 | 9.3 | 9.9 | 8.8 | 10.4 | 10.2 | 9.4 | 14.2 | 10.8 | 9.7 | 18.3 | 12.2 | 10.2 | 18.7 | 15.8 | 11.7 |
| 16 | 9.1 | 9.7 | 8.5 | 10.0 | 10.1 | 9.2 | 13.9 | 10.6 | 9.5 | 18.1 | 11.5 | 9.7 | 18.6 | 13.4 | 10.3 |
| 17 | 8.9 | 9.5 | 8.2 | 10.0 | 10.0 | 9.0 | 13.6 | 10.4 | 9.2 | 17.7 | 10.8 | 9.3 | 18.5 | 11.4 | 9.9 |
| 18 | 8.8 | 9.3 | 7.9 | 9.9 | 9.9 | 8.8 | 13.2 | 10.3 | 9.1 | 17.2 | 10.5 | 9.2 | 18.4 | 11.0 | 9.7 |
| 19 | 8.7 | 9.2 | 7.8 | 9.8 | 9.8 | 8.7 | 12.8 | 10.0 | 9.0 | 16.4 | 10.3 | 9.1 | 18.3 | 10.7 | 9.5 |
| 20 | 8.6 | 9.0 | 7.7 | 9.7 | 9.6 | 8.6 | 12.3 | 9.9 | 9.0 | 15.7 | 10.2 | 9.0 | 18.2 | 10.4 | 9.3 |
| 21 | 8.5 | 8.9 | 7.6 | 9.6 | 9.5 | 8.5 | 12.0 | 9.9 | 8.9 | 15.3 | 10.1 | 8.9 | 18.1 | 10.3 | 9.2 |
| 22 | 8.5 | 8.8 | 7.6 | 9.6 | 9.4 | 8.4 | 11.9 | 9.8 | 8.8 | 14.7 | 10.0 | 8.9 | 18.0 | 10.2 |  |
| 23 | 8.5 | 8.8 | 7.6 | 9.5 | 9.4 | 8.3 | 11.6 | 9.8 | 8.8 | 14.6 | 9.9 | 8.8 | 17.9 | 10.1 |  |
| 24 | 8.5 | 8.7 | 7.5 | 9.5 | 9.4 | 8.3 | 11.5 | 9.7 | 8.7 | 14.2 | 9.8 | 8.8 | 17.8 | 10.0 |  |
| 25 | 8.5 | 8.7 | 7.5 | 9.5 | 9.3 | 8.2 | 11.4 | 9.7 | 8.7 | 13.7 | 9.7 | 8.7 | 17.7 | 10.0 |  |
| 26 | 8.5 | 8.6 |  | 9.4 | 9.3 | 8.2 | 11.1 | 9.6 | 8.6 | 13.5 | 9.7 | 8.7 | 17.5 | 9.9 |  |
| 27 | 8.4 | 8.5 |  | 9.4 | 9.2 |  | 11.1 | 9.6 |  | 13.1 | 9.6 | 8.6 | 17.4 | 9.9 |  |
| 28 | 8.4 | 8.5 |  |  | 9.2 |  |  | 9.6 |  | 12.8 | 9.6 |  | 16.7 | 9.9 |  |
| 29 |  | 8.5 |  |  | 9.2 |  |  | 9.5 |  | 12.7 | 9.6 |  |  | 9.8 |  |
| 30 |  | 8.5 |  |  |  |  |  | 9.5 |  |  | 9.6 |  |  | 9.8 |  |
| 31 |  |  |  |  |  |  |  |  |  |  | 9.6 |  |  | 9.8 |  |
| 32 |  |  |  |  |  |  |  |  |  |  |  |  |  | 9.8 |  |

Table A4. Temperature (°C) measured at three stations on Horsetooth Reservoir during May through July, 2004. HST1 = Soldier Canyon station, HST2 = Dixon station, and HST3 = Spring Canyon station.

| Depth | HST1 | HST2 | HST3 | HST1 | HST2 | HST3 | HST1 | HST2 | HST3 |
|---|---|---|---|---|---|---|---|---|---|
| (m) | 5/18 | 5/18 | 5/18 | 6/8 | 6/8 | 6/8 | 7/16 | 7/16 | 7/16 |
| 0 | 13.7 | 13.1 | 12.9 | 19.0 | 18.8 | 17.7 | 22.0 | 22.3 | 21.8 |
| 1 | 13.7 | 13.1 | 12.9 | 18.5 | 18.6 | 17.5 | 21.8 | 22.1 | 21.8 |
| 2 | 13.7 | 13.1 | 12.9 | 18.0 | 17.8 | 17.2 | 21.7 | 21.7 | 21.6 |
| 3 | 13.7 | 13.1 | 12.8 | 15.8 | 17.4 | 16.9 | 21.0 | 21.6 | 21.5 |
| 4 | 13.7 | 13.1 | 12.8 | 15.1 | 17.3 | 16.8 | 20.2 | 21.5 | 21.5 |
| 5 | 13.7 | 13.0 | 12.8 | 13.4 | 16.1 | 16.6 | 19.6 | 21.3 | 21.4 |
| 6 | 13.7 | 12.8 | 12.7 | 12.8 | 15.7 | 16.4 | 19.2 | 20.0 | 20.9 |
| 7 | 13.6 | 12.6 | 11.3 | 12.4 | 15.2 | 16.2 | 17.2 | 16.2 | 17.1 |
| 8 | 13.6 | 12.6 | 10.2 | 11.8 | 13.8 | 16.1 | 16.1 | 14.1 | 13.2 |
| 9 | 12.1 | 11.7 | 10.0 | 11.5 | 13.1 | 14.7 | 14.8 | 13.1 | 11.8 |
| 10 | 10.7 | 9.6 | 9.0 | 10.9 | 12.7 | 13.2 | 14.2 | 12.0 | 11.1 |
| 11 | 8.6 | 8.5 | 8.6 | 10.2 | 11.5 | 12.6 | 12.5 | 11.1 | 10.6 |
| 12 | 8.3 | 8.0 | 8.0 | 9.4 | 9.7 | 11.5 | 11.2 | 10.4 | 9.2 |
| 13 | 7.9 | 7.8 | 7.5 | 8.9 | 8.4 | 10.2 | 10.0 | 9.4 | 8.9 |
| 14 | 7.5 | 7.6 | 7.3 | 8.3 | 8.2 | 9.5 | 9.4 | 8.7 | 8.8 |
| 15 | 7.3 | 7.3 | 7.2 | 8.1 | 7.9 | 8.0 | 8.9 | 8.6 | 8.5 |
| 16 | 7.2 | 7.2 | 7.1 | 7.9 | 7.7 | 7.6 | 8.7 | 8.3 | 8.3 |
| 17 | 7.1 | 7.1 | 7.0 | 7.8 | 7.6 | 7.5 | 8.4 | 8.2 | 8.1 |
| 18 | 7.0 | 7.0 | 6.9 | 7.7 | 7.5 | 7.4 | 8.2 | 8.1 | 8.0 |
| 19 | 7.0 | 6.9 | 6.9 | 7.6 | 7.5 | 7.3 | 8.1 | 8.1 | 8.0 |
| 20 | 6.9 | 6.8 | 6.9 | 7.5 | 7.4 | 7.3 | 8.1 | 8.1 | 8.0 |
| 25 | 6.7 | 6.8 | 6.7 | 7.2 | 7.2 | 7.1 | 7.8 | 7.9 | 7.8 |
| 30 | 6.5 | 6.7 | 6.5 | 7.0 | 7.1 | 6.9 | 7.5 | 7.7 | 7.7 |
| 35 | 6.4 | 6.6 | 6.4 | 6.9 | 7.0 | 6.8 | 7.3 | 7.6 | 7.6 |
| 40 | 6.1 | 6.5 | 6.3 | 6.7 | 7.0 | 6.8 | 7.2 | 7.6 | 7.5 |
| 45 |  | 6.5 | 6.1 | 6.6 | 6.9 |  | 7.1 | 7.5 |  |

Table A5. Dissolved oxygen (mg/L) measured at three stations on Horsetooth Reservoir during May through September, 2003. HST1 = Soldier Canyon station, HST2 = Dixon station, and HST3 = Spring Canyon station.

| Depth (m) | HST1 | HST2 | HST3 | HST1 | HST1 | HST2 | HST3 | HST1 | HST2 | HST3 | HST1 | HST2 | HST3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5/15 | 5/15 | 5/15 | 6/11 | 7/24 | 7/24 | 7/24 | 8/14 | 8/14 | 8/14 | 9/12 | 9/12 | 9/12 |
| 0 | 13.2 | 8.8 | 7.6 | 7.7 | 7.6 | 8.6 | 7.6 | 7.8 | 6.1 | 7.1 | 5.6 | 6.5 | 7.5 |
| 1 | 13.3 | 10.4 | 8.6 | 12.0 | 8.5 | 9.4 | 8.9 | 7.8 | 6.2 | 10.4 | 5.7 | 6.3 | 7.1 |
| 2 | 12.4 | 11.3 | 10.0 | 12.2 | 9.0 | 9.6 | 8.6 | 9.3 | 9.0 | 11.3 | 5.6 | 6.2 | 7.1 |
| 3 | 12.6 | 11.7 | 10.5 | 11.7 | 9.1 | 9.3 | 13.1 | 9.8 | 8.6 | 10.0 | 5.5 | 6.1 | 7.0 |
| 4 | 12.4 | 11.4 | 10.8 | 8.4 | 8.5 | 8.1 | 11.4 | 8.6 | 7.8 | 9.5 | 5.3 | 6.0 | 6.3 |
| 5 | 12.4 | 11.5 | 10.8 | 8.2 | 7.3 | 7.7 | 11.7 | 8.0 | 7.2 | 9.5 | 5.3 | 5.9 | 5.7 |
| 6 | 12.4 | 11.4 | 10.5 | 7.7 | 6.8 | 7.6 | 12.0 | 7.0 | 6.4 | 9.5 | 5.2 | 5.8 | 5.7 |
| 7 | 12.4 | 11.5 | 10.2 | 7.8 | 6.4 | 7.6 | 12.2 | 6.8 | 6.0 | 9.2 | 5.2 | 5.7 | 5.7 |
| 8 | 12.1 | 10.9 | 10.2 | 7.5 | 6.0 | 8.0 | 12.4 | 6.7 | 6.8 | 9.0 | 5.2 | 5.6 | 5.8 |
| 9 | 12.3 | 11.0 | 10.1 | 7.3 | 5.8 | 7.7 | 12.3 | 6.2 | 5.6 | 8.7 | 5.2 | 5.4 | 5.9 |
| 10 | 12.4 | 10.9 | 10.1 | 7.2 | 5.8 | 7.0 | 12.2 | 6.5 | 5.5 | 8.1 | 5.2 | 5.4 | 5.8 |
| 11 | 12.2 | 11.4 | 10.0 | 6.7 | 6.4 | 6.8 | 11.5 | 6.5 | 5.5 | 7.4 | 4.6 | 5.1 | 5.8 |
| 12 | 12.1 | 11.3 | 10.2 | 6.7 | 6.3 | 6.7 | 10.7 | 6.1 | 5.3 | 6.2 | 4.3 | 5.1 | 5.4 |
| 13 | 12.0 | 11.3 | 10.3 | 6.6 | 6.2 | 6.8 | 10.1 | 6.4 | 5.2 | 5.4 | 4.3 | 5.0 | 4.9 |
| 14 | 12.0 | 10.5 | 10.5 | 6.6 | 6.3 | 6.7 | 9.3 | 5.3 | 5.3 | 5.1 | 4.3 | 4.5 | 2.5 |
| 15 | 11.9 | 10.8 | 10.5 | 7.3 | 6.3 | 6.7 | 8.7 | 5.4 | 5.4 | 4.7 | 4.5 | 4.1 | 1.9 |
| 16 | 11.5 | 10.9 | 10.5 | 7.9 | 6.4 | 6.7 | 7.9 | 5.6 | 5.6 | 4.3 | 4.6 | 3.2 | 1.4 |
| 17 | 10.6 | 10.9 | 10.5 | 7.8 | 6.4 | 6.7 | 7.2 | 5.1 | 5.7 | 4.1 | 4.5 | 2.9 | 1.1 |
| 18 | 10.2 | 10.9 | 10.6 | 8.2 | 6.5 | 6.6 | 6.7 | 5.2 | 5.6 | 3.6 | 4.1 | 2.9 | 0.9 |
| 19 | 9.9 | 10.7 | 10.5 | 8.6 | 6.7 | 6.4 | 6.2 | 5.3 | 5.6 | 3.6 | 3.8 | 2.8 | 0.7 |
| 20 | 9.7 | 11.3 | 10.4 | 10.1 | 6.8 | 6.2 | 5.8 | 5.2 | 5.4 | 3.4 | 3.8 | 2.8 | 0.5 |
| 21 | 9.3 | 10.9 | 10.1 | 9.9 | 7.0 | 6.1 | 5.4 | 5.2 | 5.4 | 3.0 | 3.8 | 2.7 | 0.3 |
| 22 | 8.9 | 10.8 | 9.9 | 9.7 | 7.0 | 6.2 | 4.9 | 5.7 | 5.6 | 2.8 | 3.6 | 2.5 | |
| 23 | 8.6 | 10.6 | 9.8 | 9.7 | 7.0 | 6.1 | 4.5 | 4.8 | 5.5 | 2.6 | 3.7 | 2.4 | |
| 24 | 8.4 | 10.8 | 9.6 | 9.8 | 6.9 | 6.0 | 4.2 | 5.0 | 5.3 | 2.4 | 3.5 | 2.2 | |
| 25 | 8.2 | 10.6 | 9.2 | 9.6 | 7.0 | 5.7 | 3.9 | 5.0 | 5.1 | 2.0 | 3.1 | 2.1 | |
| 26 | 8.2 | 10.3 | | 9.4 | 7.0 | 5.6 | 3.6 | 4.8 | 4.9 | 2.1 | 2.8 | 1.9 | |
| 27 | 8.1 | 10.2 | | 9.3 | 7.0 | 5.5 | | 4.9 | 4.8 | 1.9 | 2.6 | 1.8 | |
| 28 | 8.0 | 9.8 | | | | 5.5 | | 4.8 | 4.7 | | 2.0 | 1.6 | |
| 29 | | 9.6 | | | | 5.3 | | 3.8 | 4.6 | | | 1.5 | |
| 30 | | 9.4 | | | | 5.4 | | | 4.4 | | | 1.5 | |
| 31 | | | | | | | | | 4.3 | | | 1.4 | |
| 32 | | | | | | | | | | | | 1.4 | |

Table A6. Dissolved oxygen (mg/L) measured at three stations on Horsetooth Reservoir during May through July, 2004. HST1 = Soldier Canyon station, HST2 = Dixon station, and HST3 = Spring Canyon station.

| Depth | HST1 | HST2 | HST3 | HST1 | HST2 | HST3 | HST1 | HST2 | HST3 |
|---|---|---|---|---|---|---|---|---|---|
| (m) | 5/18 | 5/18 | 5/18 | 6/8 | 6/8 | 6/8 | 7/16 | 7/16 | 7/16 |
| 0 | 8.3 | 8.4 | 8.2 | 7.6 | 7.6 | 7.4 | 7.6 | 7.1 | 6.9 |
| 1 | 8.5 | 8.2 | 8.1 | 7.9 | 7.9 | 7.5 | 8.5 | 8.4 | 7.1 |
| 2 | 9.0 | 8.4 | 8.2 | 8.3 | 8.2 | 7.8 | 9.0 | 8.1 | 6.9 |
| 3 | 9.4 | 8.6 | 8.4 | 8.4 | 8.5 | 7.9 | 9.5 | 8.3 | 7.2 |
| 4 | 9.7 | 8.8 | 8.5 | 8.7 | 8.7 | 8.0 | 9.3 | 7.7 | 7.4 |
| 5 | 9.8 | 9.1 | 8.6 | 9.0 | 8.7 | 8.1 | 9.6 | 7.4 | 6.9 |
| 6 | 10.1 | 9.2 | 8.8 | 9.2 | 8.8 | 8.2 | 9.4 | 6.5 | 7.0 |
| 7 | 10.1 | 9.3 | 8.8 | 9.3 | 8.9 | 8.2 | 8.3 | 6.0 | 5.8 |
| 8 | 10.1 | 9.4 | 8.9 | 9.4 | 8.8 | 8.3 | 8.0 | 5.8 | 5.6 |
| 9 | 10.1 | 9.4 | 8.9 | 9.6 | 9.0 | 8.2 | 7.6 | 6.0 | 5.6 |
| 10 | 10.1 | 9.3 | 9.1 | 9.7 | 9.2 | 8.3 | 7.5 | 6.2 | 5.8 |
| 11 | 10.4 | 9.6 | 9.1 | 9.9 | 9.3 | 8.3 | 7.5 | 6.3 | 5.8 |
| 12 | 10.4 | 9.9 | 9.2 | 10.1 | 9.5 | 8.5 | 7.7 | 6.4 | 6.1 |
| 13 | 10.5 | 10.0 | 9.2 | 10.3 | 9.6 | 8.6 | 8.1 | 6.6 | 6.3 |
| 14 | 10.5 | 10.0 | 9.3 | 10.4 | 9.7 | 8.8 | 8.2 | 6.9 | 6.4 |
| 15 | 10.6 | 10.0 | 9.5 | 10.5 | 9.9 | 9.0 | 8.1 | 6.9 | 6.4 |
| 16 | 10.6 | 10.1 | 9.5 | 10.6 | 10.1 | 9.1 | 8.0 | 7.0 | 6.5 |
| 17 | 10.6 | 10.1 | 9.6 | 10.6 | 10.2 | 9.3 | 8.4 | 7.1 | 6.6 |
| 18 | 10.6 | 10.0 | 9.6 | 10.6 | 10.3 | 9.3 | 8.2 | 7.0 | 6.6 |
| 19 | 10.4 | 10.0 | 9.6 | 10.6 | 10.2 | 9.3 | 8.1 | 6.9 | 6.7 |
| 20 | 10.4 | 10.0 | 9.8 | 10.7 | 10.3 | 9.4 | 8.3 | 6.8 | 6.7 |
| 25 | 10.5 | 10.0 | 9.8 | 10.8 | 10.3 | 9.4 | 9.4 | 6.3 | 6.7 |
| 30 | 10.3 | 9.7 | 9.9 | 11.0 | 10.4 | 9.6 | 10.2 | 5.6 | 6.8 |
| 35 | 10.3 | 9.7 | 9.8 | 11.2 | 10.5 | 9.5 | 10.7 | 5.5 | 6.9 |
| 40 | 10.2 | 9.6 | 9.8 | 11.3 | 10.6 | 9.3 | 11.1 | 5.1 | 6.8 |
| 45 |  | 9.7 | 9.6 | 11.1 | 10.8 |  | 10.4 | 4.7 |  |

Table A7. Catch of mysids and their estimated density (mean = 0.068 mysids • $m^{-3}$, SD = 0.166) from sampling in September 2004. No mysids were captured in 2003.

| Date | Station | Haul depth (m) | Time of haul | Mysids caught | Volume sampled ($m^3$) | Density (no./$m^3$) |
|---|---|---|---|---|---|---|
| 09/09/04 | HSTMYSSP1 | 26 | 20:45 | 1 | 20.4 | 0.049 |
| 09/09/04 | HSTMYSSP1 | 28 | 21:10 | 0 | 22.0 | 0.000 |
| 09/09/04 | 105 | 22 | 21:30 | 4 | 17.3 | 0.232 |
| 09/09/04 | 105 | 21 | 21:38 | 12 | 16.5 | 0.728 |
| 09/09/04 | 106 | 24 | 21:52 | 1 | 18.8 | 0.053 |
| 09/09/04 | 106 | 24 | 22:00 | 2 | 18.8 | 0.106 |
| 09/09/04 | HSTMYSIN1 | 26 | 22:10 | 0 | 20.4 | 0.000 |
| 09/09/04 | HSTMYSIN1 | 26 | 22:20 | 0 | 20.4 | 0.000 |
| 09/20/04 | HSTMYSSP3 | 45 | 21:00 | 3 | 35.3 | 0.085 |
| 09/20/04 | HSTMYSSP3 | 45 | 21:10 | 3 | 35.3 | 0.085 |
| 09/20/04 | HSTMYSSP2 | 26 | 20:24 | 0 | 20.4 | 0.000 |
| 09/20/04 | HSTMYSSP2 | 25 | 22:36 | 0 | 19.6 | 0.000 |
| 09/20/04 | HSTMYSSO2 | 46 | 21:30 | 0 | 36.1 | 0.000 |
| 09/20/04 | HSTMYSSO2 | 46 | 21:40 | 1 | 36.1 | 0.028 |
| 09/20/04 | HSTMYSSO1 | 23 | 21:50 | 0 | 18.1 | 0.000 |
| 09/20/04 | HSTMYSSO1 | 23 | 22:00 | 0 | 18.1 | 0.000 |
| 09/20/04 | HSTMYSDC1 | 28 | 22:06 | 0 | 22.0 | 0.000 |
| 09/20/04 | HSTMYSDC1 | 27 | 22:13 | 0 | 21.2 | 0.000 |
| 09/20/04 | HSTMYSDC2 | 48 | 22:20 | 0 | 37.7 | 0.000 |
| 09/20/04 | HSTMYSDC2 | 45 | 22:25 | 0 | 35.3 | 0.000 |

Table A8. Catch per seine haul of six species sampled at seven sites in Horsetooth Reservoir by Ken Kehmeier, Colorado Division of Wildlife. Sampling occurred on August 8, 2004. "Juv." are juveniles.

| | Spottail shiner | | Emerald shiner | | Yellow perch | | Bluegill | | Smallmouth bass | | Crappie | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Adult | age-0 | Adult | age-0 | Adult | age-0 | Adult | age-0 | Juv. | age-0 | Juv. | age-0 |
| South boat ramp, east Side of lake | 1 | 12 | 8 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Swim beach | 1 | 51 | 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dixon Cove | 11 | 6 | 487 | 0 | 4 | 40 | 4 | 0 | 1 | 0 | 1 | 2 |
| Dixon Dam- north corner | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| W. side b/t Dixon and Soldier dams | 25 | 6 | 166 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| North of Dixon Dam sand beach | 65 | 25 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Eltuck Cove | 39 | 11 | 650 | 1 | 5 | 777 | 67 | 21 | 1 | 10 | 0 | 0 |
| Totals | 141 | 112 | 1346 | 5 | 9 | 817 | 71 | 21 | 3 | 11 | 1 | 2 |
| Percent composition | 5.6 | 4.4 | 53.0 | 0.20 | 0.37 | 32.2 | 2.81 | 0.83 | 0.12 | 0.45 | 0.03 | 0.08 |

# Horsetooth Reservoir Vegetation Survey

## Sampling Strata

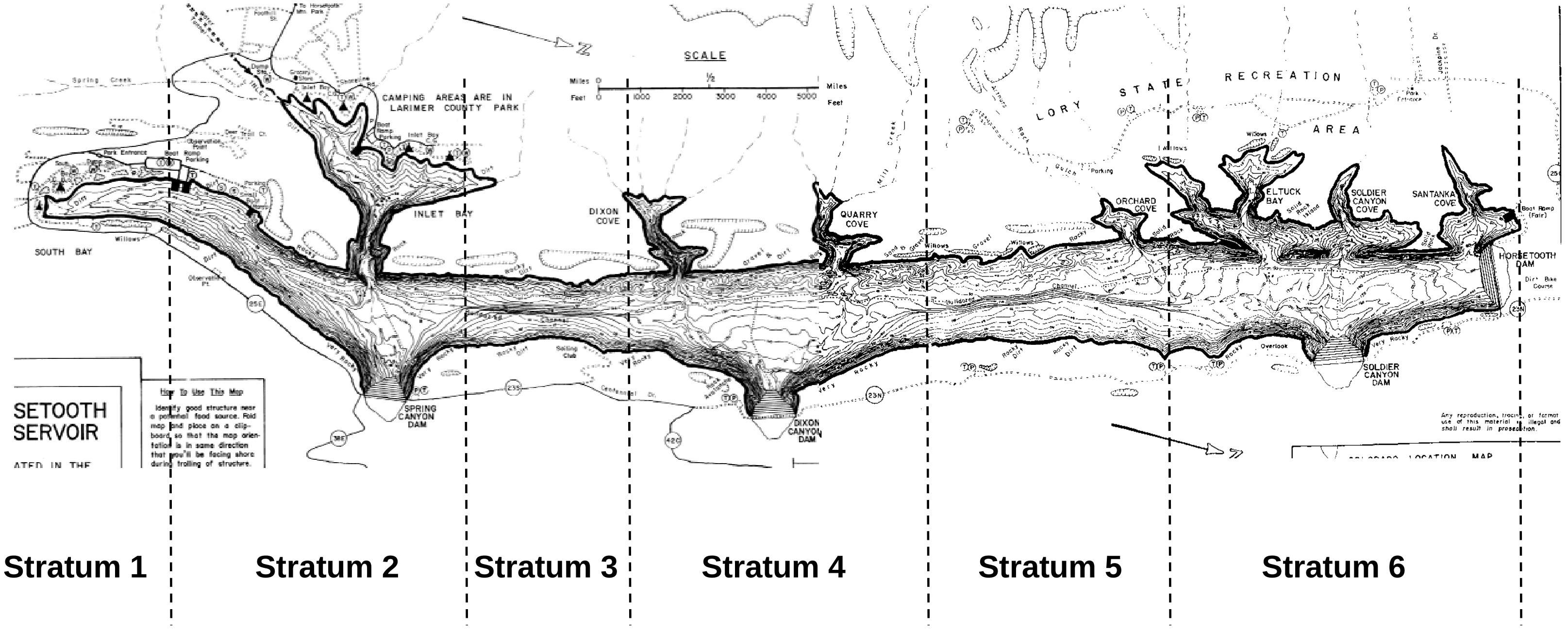

**Figure A1. Sampling strata used in the survey of terrestrial vegetation biomass in the lakebed during August 2003 in Horsetooth Reservoir.**

Table A.9. Survey details and specifications of equipment used in whole-reservoir hydroacoustics surveys conducted at Horsetooth Reservoir (HTR) by Colorado Division of Wildlife in 2003 and 2004.

**HTR 2003 Hydroacoustics Survey -- 9-29-03**

($15^o$ down-looking conical transducer)

| Pings/second | Pulse width | GPS interval | Transect 1: 2225-2348 |
|---|---|---|---|
| 5 | 1.25 ms | 5 sec. | Start: 13T 0485537 UTM 4493979 |
| **Notes:** personnel: Sullivan, Richens, Hicks. Transect 1 File# K2722230; Transect 2 File# K2722357 | | | Stop: 13T 0487431 UTM 4486363 |
| | | | **Transect 2: 2351-0007** |
| | | | Start 13T 0487424 UTM 4486348 |
| | | | Stop 13T 0487217 UTM 4485154 |

**HTR 2004 Hydroacoustics Survey -- 10-6-04**

(Multi-plexed $15^o$ down-looking & $6^o$ side-looking conical transducers (XD))

| Pings/second | Pulse width | GPS interval | Transect 1: 2003-2015 |
|---|---|---|---|
| 10/s, 5/per XD | 1.25 ms | 5 sec. | Start: 13T 0487058 UTM 4485010 |
| **Notes:** personnel: Martinez, Rehder, Vigil. Transect 1 File# K2802003; Transect 2 should be the same as in 2003, but in 2004, it was broken into 4 sub-transects, each about 2-km in length. Transect 2A File# K2802025; Transect 2B File# K2802049; Transect 2C File# K2802112; Transect 2D File# K2802136 | | | Stop: 13T 0487472 UTM 4485850 |
| | | | **Transect 2A: 2025-2048** |
| | | | Start: 13T 0487483 UTM 4485858 |
| | | | Stop: 13T 0487161 UTM 4487808 |
| | | | **Transect 2B: 2049-2110** |
| | | | Start: 13T 0487161 UTM 4487808 |
| | | | Stop: 13T 0486856 UTM 4489761 |
| | | | **Transect 2C: 2112-2134** |
| | | | Start: 13T 0486854 UTM 4489775 |
| | | | Stop: 13T 0486352 UTM 4491675 |
| | | | **Transect 2D: 2136-2159** |
| | | | Start: 13T 0486352 UTM 4491679 |
| | | | Stop: 13T 0485798 UTM 4493628 |