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ANNUAL PROGRESS REPORT
F-47-R: SEGMENT 4

SURVIVAL OF TROUT STRAINS AS AFFECTED BY LIMNOLOGICAL PARAMETERS

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PERFORMANCE REPORT

Project Number: F-47-R

Study Number: 1

Segment Number: 4

Title: Importance of fish predators, cover and feeding conditions for the survival of juvenile trout in Utah Reservoirs

Project Date: January 1-December 31, 1989.

Objective 1: To measure densities of piscivores at our study site (Causey Reservoir).

Progress Summary: A normal mark-recapture experiment was unsuccessful because we could not capture adequate numbers of piscivorous fish to mark. In lieu of the standard methodology, we used a "plant-recapture" technique that uses stocked catchable trout as the marked population. This estimate indicated that there were 4980 piscivorous cutthroat trout, and 620 brown trout in the reservoir. Diet analysis showed that the brown trout were piscivorous by the time they reached 200 mm, whereas cutthroat trout fed some on fishes, but consumed primarily zooplankton and insects. Rainbow trout also ate primarily zooplankton and insects. See Appendix 4.

Objective 2: To estimate digestion rates of fingerling trout in piscivores in order to calculate predation losses.

Progress Summary: A literature survey established a good relationship between temperature (T) and digestion rate (R) in piscivorous fishes. ($\text{Log } R = -1.742 + 0.044\ T$; $r^2 = 0.79$). Digestion rates of brown and rainbow trout measured in our laboratory, however, indicated that these species have somewhat higher rates than indicated by this equation. See Appendix 5.

Objective 3: To determine the interaction of predators, cover, and food in laboratory experiments.

Progress Summary: Experiments in 3-m diameter pools demonstrated that predation rates by brown trout on fingerling rainbow trout were significantly higher in treatments without cover than those with cover. Behavioral observations indicated that the fingerling trout ignored brown trout predators during the day. When large rainbow trout were used as the predator, however, the fingerlings used cover extensively throughout the day. See Appendix 3.

Objective 4: To measure feeding rates and use of cover by fingerling trout in reservoirs with both low and high food abundance.

Progress Summary: Snorkeling observations demonstrated that during the day fingerling rainbow trout were significantly more abundant around complex substrates such as boulders and inundated vegetation, than in simple substrates such as sand and gravel. At night, however, fish dispersed from the complex habitats and did not show any significant micro-habitat selection (Appendix 1). Rainbow trout in Causey reservoir, where Daphnia biomass was moderate, required 8-10 hours to reach peak fullness, whereas fish in East Canyon Reservoir, where large

Daphnia were abundant, fed more rapidly. Wind events may advect large zooplankton to the littoral zone habitats of the fingerling trout and promote feeding (Appendix 1). Comparison of growth rates of trout in East Canyon and Causey Reservoirs with a bioenergetic model indicated that fish in the former site were feeding near repletion rates and growing maximally for much of the year. In contrast, consumption and growth rates of fish in Causey reservoir were high in the spring, but slower in the fall and winter (Appendix 2).

Principal Investigator: Wayne Wurtsbaugh

APPENDIX 1

MICROHABITAT SELECTION AND DIEL FEEDING PATTERNS OF RAINBOW TROUT IN RESERVOIRS

by

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ABSTRACT

Juvenile rainbow trout Oncorhynchus mykiss, (ca. 80 mm S.L.) stocked into mid-elevation reservoirs in Utah are vulnerable to predation from piscivorous fish and birds. I determined how effectively juvenile trout used cover to avoid these predators by using direct observations (snorkel transects) on habitat selection in two reservoirs. Observations of juvenile trout were conducted within five weeks of stocking in 1988 and 1989. During the day juvenile trout were abundant in complex inshore habitats. Juvenile trout actively fed during the day but the time of peak feeding was variable. Large Daphnia made of > 95% of the diet of juvenile trout. Because large Daphnia was often higher offshore than inshore in both reservoirs, selection of inshore cover is believed to be primarily a response to lessen predation risk. At night, trout in both reservoirs selected more exposed areas and rested on the bottom.

INTRODUCTION

To avoid predation fish often move to structurally complex habitats where predators can not forage effectively (Glass 1971; Savino and Stein 1982; Werner and Hall 1988). Because of this, complex habitats that provide cover are often important nursery areas for the young of many fish species (Hall and Werner 1977; Orth et al. 1984; Lowe-McConnell 1987), and this cover may significantly increase the survival of juvenile fish (Aggus and Elliot 1975; Werner and Hall 1988). In lentic systems structurally complex habitats, such as aquatic macrophyte beds (Hall and Werner 1977; Mittelbach 1986), inundated vegetation (Aggus and Elliot 1975), and large boulders (Trendall 1988), are often important habitat of juvenile fish.

Wild populations of lake-dwelling rainbow trout Oncorhynchus mykiss normally have nursery areas in small streams and emigrate to a lake after growing for one to three years in the streams (i.e. Kwain 1983). In contrast, juvenile rainbow trout stocked directly into a lake or reservoir must contend immediately with lacusarine predators. These juvenile fish frequently inhabit the littoral zone until they reach lengths of 100-120 mm S.L. before moving offshore to the pelagic zone (Wurtsbaugh and Tabor 1988). Although, many diurnally active fish in temperate lakes inhabit complex habitats, most of these fish shift from a daytime feeding area near cover to resting on the bottom at night in relatively exposed locations (Emery 1978; Helfman 1981). Others have a strong affinity for shelter sites at night (Helfman 1981). In many reservoirs adult brown trout Salmo trutta are both nocturnally active (Eriksson 1978; Oswald 1978) and important predators of juvenile trout (Sharpe 1957; Stuber et al. 1985; Wurtsbaugh 1986). Because of nocturnal brown trout as well as diurnal predators (i.e. piscivorous birds and other adult trout), juvenile trout may select habitats which provide cover during both day and night.

In lentic systems little is known, however, about use of cover by juvenile rainbow trout or their ability to use cover effectively. To estimate the importance of cover, we designed this study to measure day and night habitat selection of juvenile rainbow trout in two Utah reservoirs and to experimentally test if cover allows them to avoid predation from brown trout.

METHODS

We studied the behavior of trout in two northern mid-elevation Utah reservoirs. The first, East Canyon Reservoir, is a 277 hectare impoundment located at 40°54'20"N and 111°35'20" at an elevation

of 1,734 m. It has a mean depth of 23 m and a 16 km long shoreline. The littoral zone is composed primarily of small substrates such as sand. There are some patches of boulders and inundated vegetation, but little aquatic macrophytes. East Canyon Reservoir is meso-eutrophic with abundant large Daphnia that allow juvenile trout to grow at or near maximal rates (Marine et al. 1986). The Utah Division of Wildlife Resources stocks the reservoir each spring with 300,000 rainbow trout with a mean weight near 6 g. For the first two months after stocking the juvenile trout are preyed on by adult brown trout Salmo trutta, cutthroat trout Oncorhynchus clarki, and rainbow trout O. mykiss (Wurtsbaugh 1986). Juvenile trout are also vulnerable to predation by several species of piscivorous birds that frequent the reservoir (predominantly western grebe Aechrophorus occidentalis, Forsters tern Sterna forsteri, and common merganser Mergus merganser). Redside shiners Richardsonius balteatus are the most numerous fish in this reservoir and are also important forage for adult trout. Kokanee salmon O. nerka, Utah sucker Catostomus ardens, speckled dace Rhinichthys osculus, and fathead minnow Pimephales promelas are also present in the reservoir.

The second field site, Causey Reservoir has an area of 58 ha. This mesotrophic reservoir is at 41°17'55"N and 111°35'13"W at an elevation of 1,735 m. It has a mean depth of 20 m, and a 11.8 km shoreline. Substrates in the littoral zone are similar to East Canyon Reservoir except that there are more medium-sized substrates such as cobble. Due to the steepness of its shore, the littoral zone is generally smaller than at East Canyon Reservoir. Zooplankton is abundant, but densities of large Daphnia are usually lower than in East Canyon Reservoir. The Utah Division of Wildlife Resources has stocked a variety of salmonids in the reservoir, but during the two years of this study only juvenile rainbow trout were stocked. In 1988 30,000 3.2 g fish and 22,300 8.2 g fish were stocked on June 6th. In 1989, 61,000 5.7 g trout were stocked on May 15. In Causey Reservoir, juvenile trout are vulnerable to adult brown, cutthroat and brook trout Salvelinus fontinalis (Wurtsbaugh and Tabor 1989). However, unlike East Canyon Reservoir, few piscivorous birds have been observed at Causey Reservoir. The only other fish species known to occur in Causey Reservoir, mottled sculpin Cottus bairdi, is also forage for adult trout.

Habitat selection was determined through direct observation along shoreline transects. Sampling began one week after the fish were stocked to allow them to acclimate and disperse away from the stocking site. All transects were completed within five weeks of stocking when the fish ranged from approximately 60 to 120 mm standard length. Because planted trout dispersed slowly around the reservoirs, transects were only done along portions of the shorelines (48% in East Canyon and 36% in Causey Reservoir). Within these sampling areas, locations of individual transects were chosen by randomly selecting shoreline sections from a map. At the beginning of the study in 1988 30 m transects were used in East Canyon Reservoir, but subsequently 100 m transects were used to increase sample sizes. Forty-three transects (27 in 1988, 16 in 1989) were done in East Canyon Reservoir and 44 transects (22 in 1988 and 22 in 1989) were done in Causey Reservoir. Sixty five percent of the transects were done during day and 35% at night.

Observations of juvenile trout and their habitat were made by a swimmer, equipped with snorkel and mask, swimming at the surface along shoreline transects. The depth surveyed ranged from the surface to about a depth of 2 m, depending on water clarity. Earlier transects (using SCUBA equipment) were done at depths of 2.5 and 6 m but no juvenile trout where seen. The distance of each transect was measured by swimming along with a 30 or 100 m rope with the other end attached to the boat. Observations consisted of counting fish and noting the closest habitat type for each fish. Other behavioral observations included schooling activity, feeding activity, and distance from substrate.

While swimming back to the boat habitat characteristics were measured. At intervals of 5 m (100 m transects) or 2 m (30 m transects) the percent of different habitat types was estimated within a one meter diameter circle. Habitat was classified into seven categories: bedrock, sand/mud (sediment size <2 mm), gravel (2-20 mm), cobble (20-200 mm), small boulders (200-500 mm), large boulders

(>500 mm), and inundated vegetation. Selectivity for each substrate type was calculated using Manly's α (Manly 1974):

$$\alpha = \frac{r_i/n_i}{\sum_{i=1}^{k} r_i/n_i} \quad \text{where;}$$

r_i = proportion of fish associated with habitat i,
n_i = proportion of habitat type i in the environment,
k = total number of habitat categories.

Random use of habitat types occurs when $\alpha_i = 1/k$. Significant differences of habitat selection within time periods were tested with a chi-square goodness of fit test (Manly 1974).

Abundance of Daphnia, the predominant prey item of juvenile trout, was estimated at both reservoirs in 1989. Zooplankton was collected periodically for two months after trout stocking. Vertical zooplankton tows were done near the stocking sites with a 30 cm diameter plankton net (153 μm mesh). Inshore samples were taken from the bottom to surface where the depth was 1.5 m (≈ 2 to 3 m from shore). Offshore sites were at depths of 10 m (≈ 20 m from shore) in Causey Reservoir and 10 m and 45 m in East Canyon Reservoir (≈ 20 and 200 m from shore). Only the upper 5 m were sampled at the offshore sites because trout were located primarily in the epilimnion when they were offshore. Two or three replicate samples were taken on each date at each site. The zooplankton was identified, enumerated, and the first 50-100 Daphnia encountered in each sample were measured to the nearest 0.03 mm with an ocular micrometer. Food available to juvenile trout was estimated by the biomass of Daphnia > 1.0 mm in length (93% of daphnids found in juvenile trout stomachs were > 1.0 mm). Dry weights (W; mg) of individual daphnids were calculated from lengths (L; mm) with the formulas: 1) D. galeata, ln W = -4.83 + 2.53 ln L; 2) D. schodleri and D. pulex, ln W = -5.04 + 2.83 ln L;adapted from McCauley (1984).

In 1989, diel cycles of gut fullness were determined in each reservoir after the fish had been present for 7-10 days and again after 17-21 days. Ten to twelve juvenile trout were sampled approximately every 3 hr for 24 hr. All fish were sampled within 10 m of shore, near the stocking site. At East Canyon Reservoir trout were collected with either boat mounted electrofishing gear or a 23 m beach seine (5 mm sq. mesh). At Causey Reservoir, trout were collected during the day by setting gill nets (13 and 10 mm sq. mesh) for 5-10 minute periods. At night, a 23 m beach seine or a dip net was used. Within 5-20 minutes after capture, fish were anesthetized with MS-222, weighed to the nearest 0.1 g and measured to the nearest mm. Stomachs were removed and placed in 95% ethyl alcohol. At the laboratory, stomach contents were removed, visually inspected to estimate the relative volumetric composition of prey taxa, dried for 18 h, and weighed to the nearest 0.0001 g. "Gut fullness indices" (GFI) were calculated as:

$$\text{GFI} = \frac{100{,}000\ [\text{dry wt. of stomach contents (mg)}]}{[\text{fish standard length (mm)}]^{3.05}}$$

The factor 3.05 was an empirically derived constant of the length-weight relation of juvenile rainbow trout in both reservoirs.

RESULTS

During the day juvenile rainbow trout that were in the littoral zone of both East Canyon and Causey Reservoir selected the most structurally complex habitats: large boulders, inundated vegetation, and small boulders (P <.001), while other substrates such as sand and gravel were avoided (Fig. 1A,B). Although boulders and inundated vegetation combined made up approximately 20% of the nearshore habitat, most of it was scattered along the shore in small patches and not used by juvenile trout. Juvenile trout preferred to be on the offshore side of large patches of boulders, inundated willows Salix sp., or fallen trees.

During the day juvenile rainbow trout were in the water column from a few centimeters to 2 m above the substrate. Usually juvenile trout were observed in schools by themselves or occasionally in schools with redside shiners. Fish near cover were usually in loose aggregations and not strongly oriented to one another. When fish were seen away from cover they were usually in schools of > 30 fish and appeared to be strongly oriented to one another.

The average number of juvenile trout observed during the day in East Canyon Reservoir was not significantly different between the two years (0.53/m in 1988 and 0.43/m in 1989; p = 0.4; Wilcoxon rank sum test). In Causey Reservoir I observed few fish (0.13/m) in the littoral zone during 1988, but in 1989 juvenile trout were significantly more abundant in this area (0.53/m; p = .008).

In both reservoirs, nighttime habitat of juvenile rainbow trout changed significantly from that in the daytime (p = < .001; goodness of fit test). At night juvenile trout no longer strongly selected structurally complex habitats, but were often found in exposed areas such as sand, gravel, and cobble (Fig. 1C,D). Trout observed at night had moved from the water column to within 10 cm of the substrate. They were easily approached and motionless or "resting". No feeding or schooling activity was detected. Juvenile trout appeared to be distributed randomly along the bottom. For example, at Causey Reservoir along a 200 m shoreline section (composed primarily of gravel and cobble except a 10 m section of large boulders) 290 juvenile trout were distributed along the entire section at night. In contrast, during the day 305 trout were observed along the same section (swam 36 hours earlier) but all were located within the narrow section of large boulders.

In East Canyon Reservoir the average number of trout observed at night was the same in both years (0.57/m) and not significantly different from numbers seen during the day (Fig. 2; p = .07, 1988; p = .16, 1989, Wilcoxon rank sum test). In contrast to trout in East Canyon Reservoir, the abundance of trout in the littoral zone of Causey Reservoir increased significantly from the day to the night during both years (Fig. 2; p = .0002, 1988; p = .005, 1989). The differences between day and nighttime densities were more distinct in 1988 than in 1989.

In both reservoirs the abundance of Daphnia in the littoral zone was low when trout were stocked but numbers increased greatly within one to two weeks. Daphnia sampled offshore were usually larger and accounted for more biomass than Daphnia found inshore (Fig 3, 4). Except for a spring bloom of large Daphnia close to shore, biomass of Daphnia was 2.6 to 23 times higher 20 m offshore than in the swallow littoral zone of Causey Reservoir (Fig. 3). In East Canyon Reservoir abundance of large Daphnia was often much higher 20 to 200 meters offshore (Fig. 4) but wind events appeared to bring large Daphnia close to shore. For example, at another sampling site in East Canyon Reservoir, biomass of Daphnia (> 1.0 mm) inshore was 6.5 times greater than Daphnia 50 m offshore on 30 May after sustained onshore afternoon winds. Ten days later (June 9) with calm weather few large Daphnia were inshore and biomass was 19 times greater offshore.

Underwater observations as well as stomach samples demonstrated juvenile trout were actively feeding during the day. During the diel sampling periods, Daphnia (primarily D. pulex and D. galeata)

made up >99% and 95.5% of the diet of juvenile trout in East Canyon and Causey Reservoir, respectively. Gut fullness decreased at night, with the lowest levels occurring around dawn (Fig. 5). At Causey Reservoir fish began feeding at dawn and gut fullness did not peak until the late afternoon at 1900 h on both sampling days (Fig.5A). Although gut fullness of East Canyon Reservoir trout was variable between the two sampling periods (Fig. 5B), feeding occurred mostly during the day with gut fullness declining throughout the night.

Peaks in gut fullness in East Canyon Reservoir appeared to occur during daytime wind events which generated 0.3-0.7 m waves at the sampling station. On 9 May a wind storm occurred from 1700 to 1730. Average GFI of juvenile trout increased from 2.1 before the storm to 5.8 after the storm. Juvenile trout switched from eating small Daphnia ($\bar{x}$ length = 1.2 mm) before the storm to eating large Daphnia (mean length = 2.2 mm) when sampled 30 min after the winds subsided. The estimated difference in weight of individual Daphnia between these two groups was over seven-fold. On 18 May strong winds started during mid morning ≈ 9:00, before we started sampling, slowly subsided in the late afternoon, and became calm at dusk. Peak gut fullness may have occurred before our sampling. During the remainder of May 18 gut fullness slowly decreased and was close to zero by dawn the following day. Shortly after dawn gut fullness increased rapidly, peaking at 0910 h. The reservoir was calm on the morning of May 19 but unusually high concentrations of zooplankton were observed at the sampling station. The wind storm the preceding day may have advected the large offshore Daphnia into the littoral zone.

DISCUSSION

The distribution and behavior of fish in both the reservoirs was consistent with the foraging return-predation risk hypothesis of Werner et al. (1983). In the two reservoirs juvenile trout were often near cover during the day. Diurnal predators (cutthroat trout and piscivorous birds) were present in both reservoirs and were observed pursuing juvenile trout. Because the abundance of large Daphnia was often higher offshore than inshore in both reservoirs (Fig. 3,4), selection of inshore cover is believed to be primarily a response to lessen predation risk. Therefore, juvenile trout may face tradeoffs between foraging in risky offshore areas or foraging inshore where food levels were lower but predation risk is low. Research with bluegill Lepomis macrochirus (Werner et al. 1983), blacksmith Chromis punctipinnis (Bray 1981), and wrasse Pseudolabrus celidotus (Jones 1984), have also demonstrated that juvenile fish inhabit areas which are suboptimal for foraging but provide sufficient cover from predators.

The change in the use of littoral zone habitats in Causey Reservoir between 1988 and 1989 was also consistent with the foraging return-predation risk hypothesis. During 1988, observations suggested juvenile trout in Causey Reservoir foraged offshore where predation risk was presumably higher and returned inshore after dusk. In contrast, trout were abundant inshore during both day and night in 1989 (Fig. 2). Population estimates of piscivorous size fish (cutthroat and brown trout ≥ 270 mm S.L.) were 1140 and 4229 for 1988 and 1989 respectively. The large disparity in abundance was due to a large cohort of stocked cutthroat trout that attained piscivorous size between the 1988 and 1989 stocking of juvenile rainbow trout. Although we took relatively few zooplankton samples in 1988, results did indicate that Daphnia biomass was 56% lower during the summer in 1988 than 1989. Thus, a combination of lower predation risk and lower prey abundance in 1988 than in 1989 may have caused juvenile trout to move offshore to forage. Likewise, Werner and Hall (1988) found that the distance which juvenile bluegill moved out of macrophyte beds to forage on the abundant pelagic zooplankton was dependent on the abundance of predaceous largemouth bass.

The schooling by juvenile trout in the reservoirs also appeared to be influenced by predators and the proximity of cover. Trout near inundated vegetation and large boulders were often numerous but they did not appear to be strongly oriented to one another. In contrast, trout above small boulders, cobble, and less complex habitats were usually schooled. Schooling may indicate a shortage of complex habitats (i.e. large patches of inundated vegetation and large boulders). Savino and Stein (1982) found the frequency of schooling for juvenile bluegill decreased with habitat complexity if largemouth bass were present. In other juvenile fish, schooling activity has also been increased by the presence of predators (for reviews Shaw 1978; Pitcher 1986). Schooling fish lessen predation risk by predator detection, evasion, and confusion (Godin 1986). Because predators influence foraging time and food intake of small fish, growth of prey populations can also be affected (Mittelbach 1986). In a pond experiment done during 1988 the presence of brown trout reduced growth rates of fingerling trout by 16% (Tabor and Wurtsbaugh 1988). Likewise, the presence of largemouth bass Micropterus salmoides has been shown to significantly reduce the growth of small bluegills (Werner et al. 1983). If growth rates are reduced, juvenile fish will spend more time vulnerable to predators and survivorship could be reduced. Growth rates and survivorship have been shown to be positively correlated in some fish. Even a small reduction in growth can have a large effect on survivorship especially if survivorship is already low (Werner et al. 1983). In both reservoirs zooplankton levels were relatively high, trout grew rapidly, and trout were vulnerable to most predators for only about two months. In other systems, where growth of trout is slower and predators are abundant, juvenile trout could be restricted to the inshore area for an extended period of time. Survival of juvenile trout could then be too low to make stocking small trout (≈ 70 mm S.L.) economically feasible.

The analysis of diel feeding cycles of juvenile rainbow trout indicated there was one major feeding period during the daytime, but the timing of this period was variable and influenced by wind events. In Causey Reservoir, where little wind was observed, peak feeding occurred in the evening on both sampling dates. In contrast, peak feeding in East Canyon Reservoir appeared to occur during wind storms which generated large waves at the sampling site. Based on visual observations and zooplankton samples at another site, abundant offshore Daphnia were moved close to shore during wind events. Werner and Hall (1988) suggested juvenile bluegill diets occasionally changed when D. galeata were moved close to shore by wind currents. George and Edwards (1976) proposed that zooplankton which prefer surface water will be moved down-wind and will accumulate at the end of the lake. Daytime vertical profiles of zooplankton abundance from East Canyon Reservoir indicated the majority of Daphnia were within the top 5 m (R. Tabor, unpublished data). After winds subside Daphnia are capable of moving horizontally back to pelagic areas (Siebeck 1980). Wave action also increased turbidity in the inshore area. Activity of piscivorous birds (western grebe and Forster's tern) was greatly reduced during the storms. Therefore, increased turbidity and lower predator activity, together with higher food availability probably produced a more profitable time to forage.

At night juvenile rainbow trout in both reservoirs rested in exposed areas in a manner similar to the behavior of other diurnally active freshwater fish (Emery 1978; Helfman 1981). Emery (1978) suggested that the lack of cover use at night was due to the paucity of shelter sites. In both reservoirs, complex habitats had few fish at night and thus, there was apparently no shortage of shelter sites. An alternative explanation proposed by Helfman (1981) was that temperate freshwater systems generally lack abundant nocturnal predators and thus prey have little need to seek cover. Although large predaceous brown trout were present in both reservoirs, they were not abundant. Brown trout are capable of foraging under moonlight and starlight conditions (Oswald 1978; Robinson 1979). However, when brown trout fed most intensively in the study reservoirs is unknown. Although brown trout may be an important source of juvenile trout mortality (Wurtsbaugh 1986; Wurtsbaugh and Tabor 1989), they may not be abundant enough to cause juvenile rainbow trout to select more protective habitats during nighttime or daytime. In a preliminary laboratory experiment, juvenile trout used cover extensively at night when a brown trout predator was present, but were in exposed areas at night when a diurnally active rainbow trout was present (see Appendix 3). This suggests that juvenile rainbow trout use cover

only when abundant predators are active. Other studies have shown that prey occupy habitats of greater complexity during periods when predators are active (Hobson 1972; Stein 1979).

Because cover can increase the survival of juvenile rainbow trout, the augmentation of cover should be considered as a potential management tool. Inundated vegetation and boulders are particularly valuable habitats, and thus their addition may be beneficial. Leaving some inundated trees in new reservoirs may also be useful. Similarly, Brouha and von Geldern (1979) suggested revegetating drawdown zones of western reservoirs with willows for production of centrarchid fishes. Stocking fish when the reservoir is at its highest level will usually maximize the amount of available cover because the high-water level often has more vegetation and structural complexity than deeper parts where sediments accumulate. For example, in East Canyon Reservoir inundated vegetation composed 4% of the nearshore habitat in 1988 (low water year) and 12% in 1989 when water levels were higher. Other studies have shown increases in recruitment of fishes when reservoirs or lakes have risen and inundated large areas of shoreline (Aggus and Elliot 1975; Keith 1975; Bayley 1977). The importance of submerged aquatic macrophtyes as cover for trout is questionable, as I seldom saw fish associated with the limited amount of this cover. In another Utah reservoir, juvenile rainbow trout avoided areas dominated by aquatic macrophytes (A. F. Wasowicz, Utah St. Univ., personal communication).

An important consideration for fishery managers is how much habitat structure is needed and how dense it must be to increase juvenile trout survival. In our pond experiment (Wurtsbaugh and Tabor 1988) dense cover made up ≈10% of the total surface area and mortality was significantly reduced. In both reservoirs dense cover such as boulders and inundated vegetation made up ≈20% of the shoreline habitat. The amount of cover in the reservoirs may have increased trout survival, but even higher survival may be expected if cover was more abundant. Durocher et al. (1984) found a highly significant, positive relationship between percent submerged vegetation (up to 20%) of the total lake surface and recruitment of largemouth bass. Gotceitas and Colgan (1989) proposed a certain "threshold" level of complexity (density of aquatic macrophytes) is necessary before predator foraging success is reduced significantly. Both boulders and inundated vegetation should provide dense enough cover to reduce predator foraging success. An increase in juvenile survival may be expected if these habitats are abundant along the shoreline.

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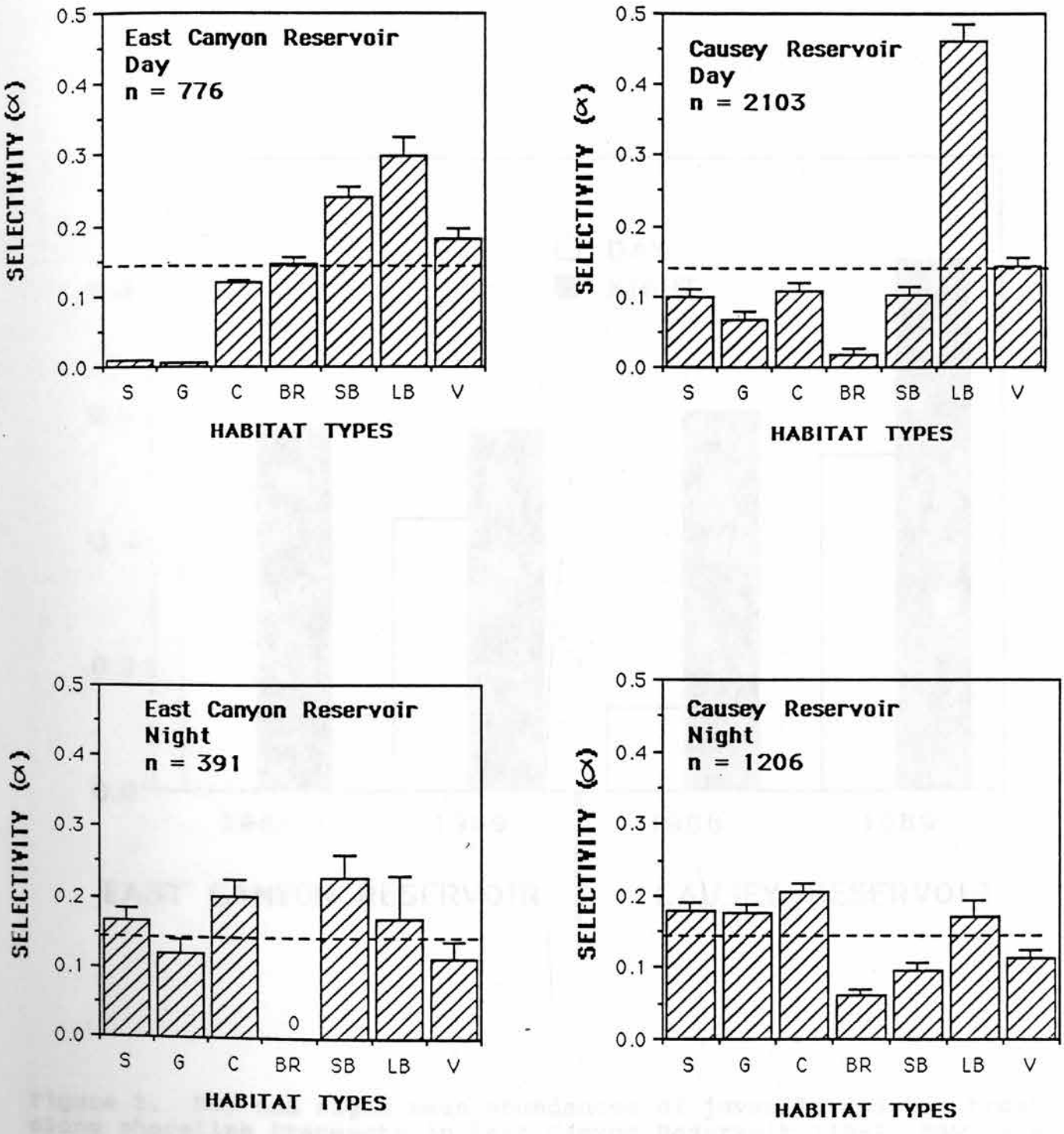


Figure 1. Mean (+ 1 S.E.) selectivity values (Manly's α) for habitat types used by juvenile rainbow trout during the day and night in East Canyon Reservoir (19-25 May 1988 and 16-31 May 1989) and Causey Reservoir (17 June - 12 July 1988 and 31 May - 19 June 1989), Utah. The dashed lines indicate the level of selectivity if all habitat types were used at random. Habitat complexity increases from left to right; sand (S); gravel (G); cobble (C); bedrock (BR); small boulders (SB); large boulders (LB); inundated vegetation (V). Number of trout sampled is also indicated.

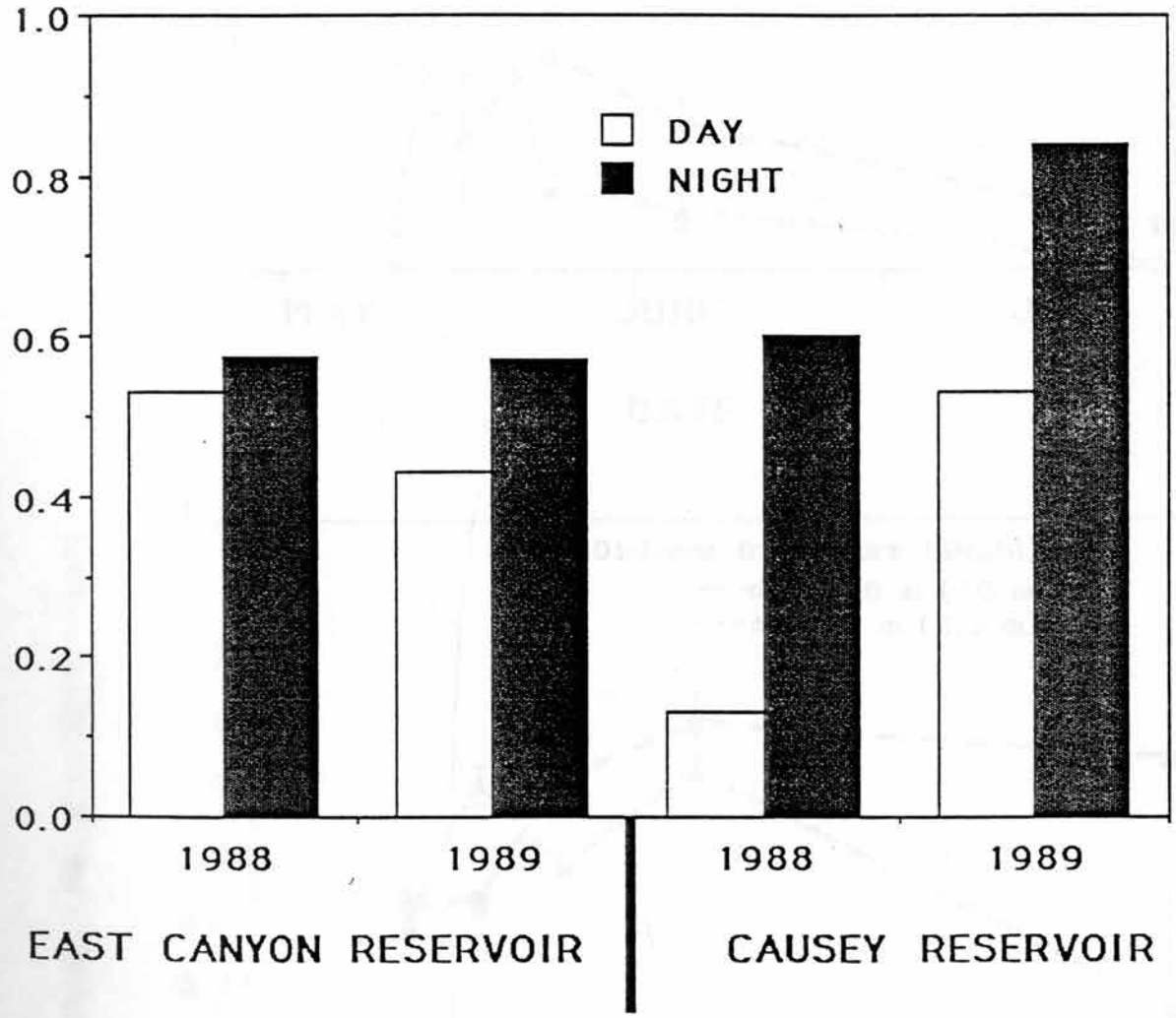


Figure 2. Day and night mean abundances of juvenile rainbow trout along shoreline transects in East Canyon Reservoir (19-25 May 1988 and 16-31 May 1989) and Causey Reservoir (17 June - 12 July 1988 and 31 May - 19 June 1989), Utah. Observations of juvenile trout were made by a swimmer, equipped with snorkel and mask, swimming at the surface. The depth surveyed ranged from the surface to about a depth of 2 m.

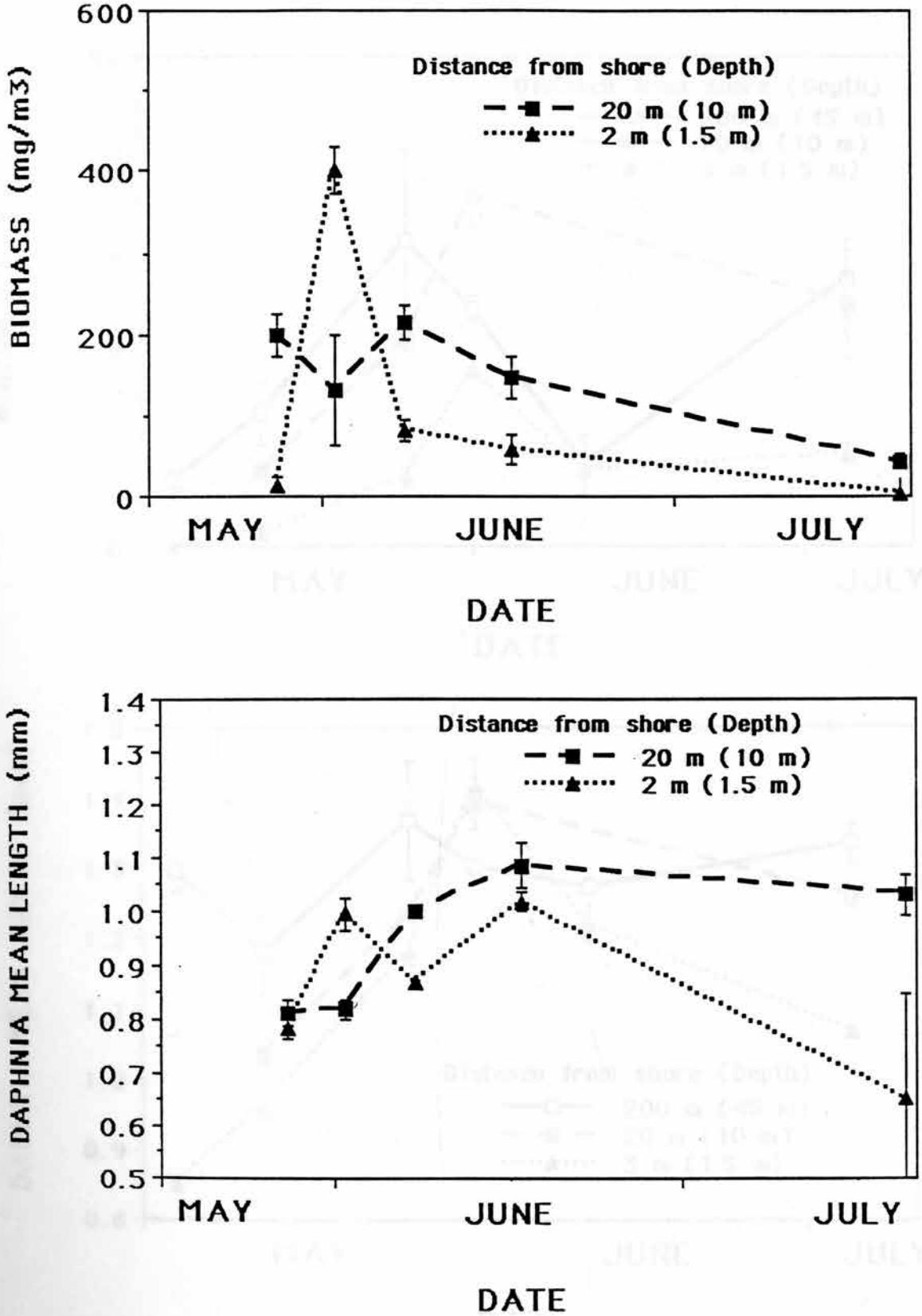


Figure 3. Biomass (± 1 S.E.) and mean length (± 1 S.E.) of Daphnia collected with vertical zooplankton hauls in Causey Reservoir, 1989. Biomass represents dry weight of Daphnia ≥ 1.0 mm. Mean and standard errors were calculated from two to three samples taken at the same site. At the 2 m site samples were taken from 0-1.5 m and at the 20 m site the top 5 m was sampled.

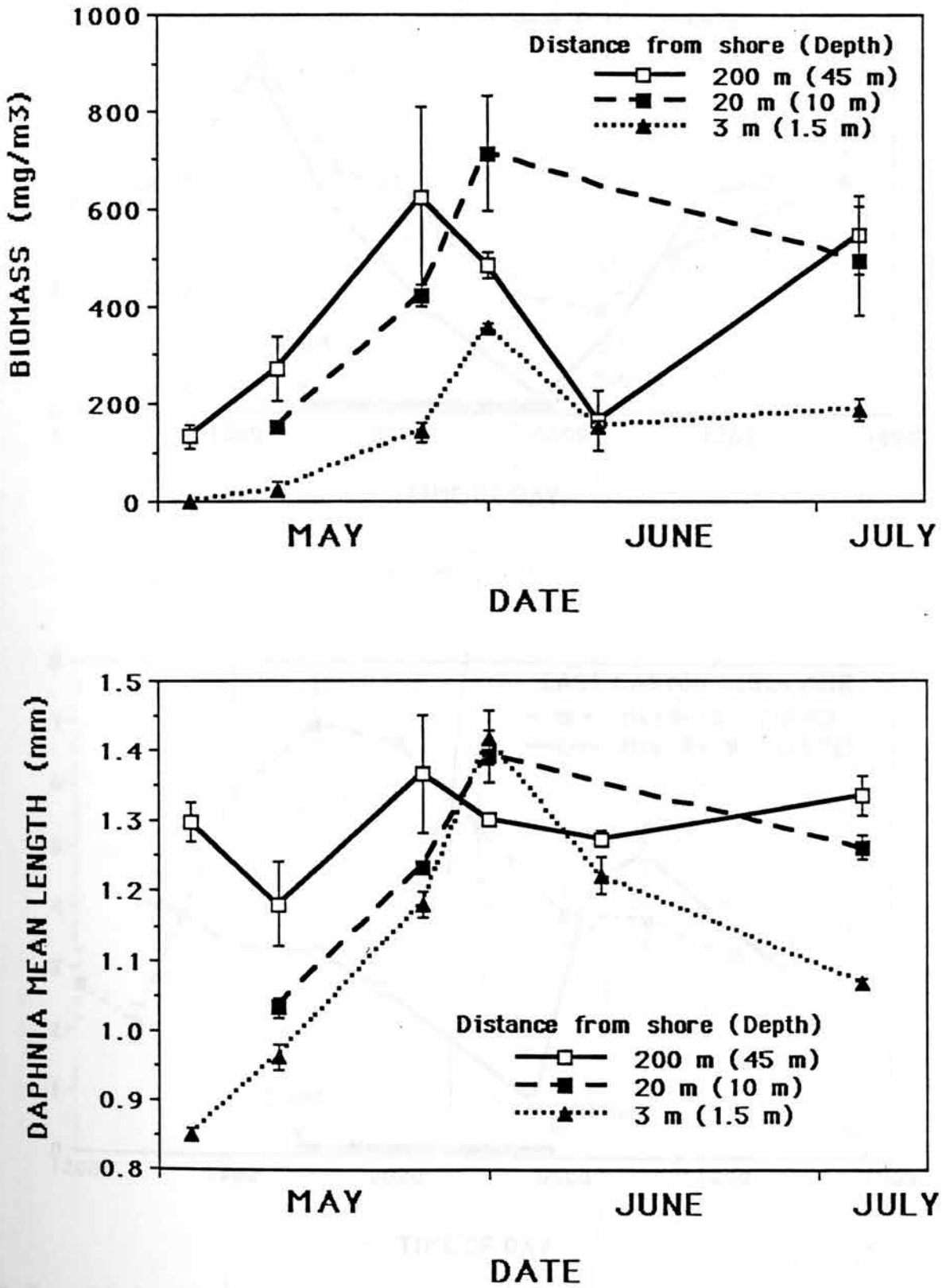
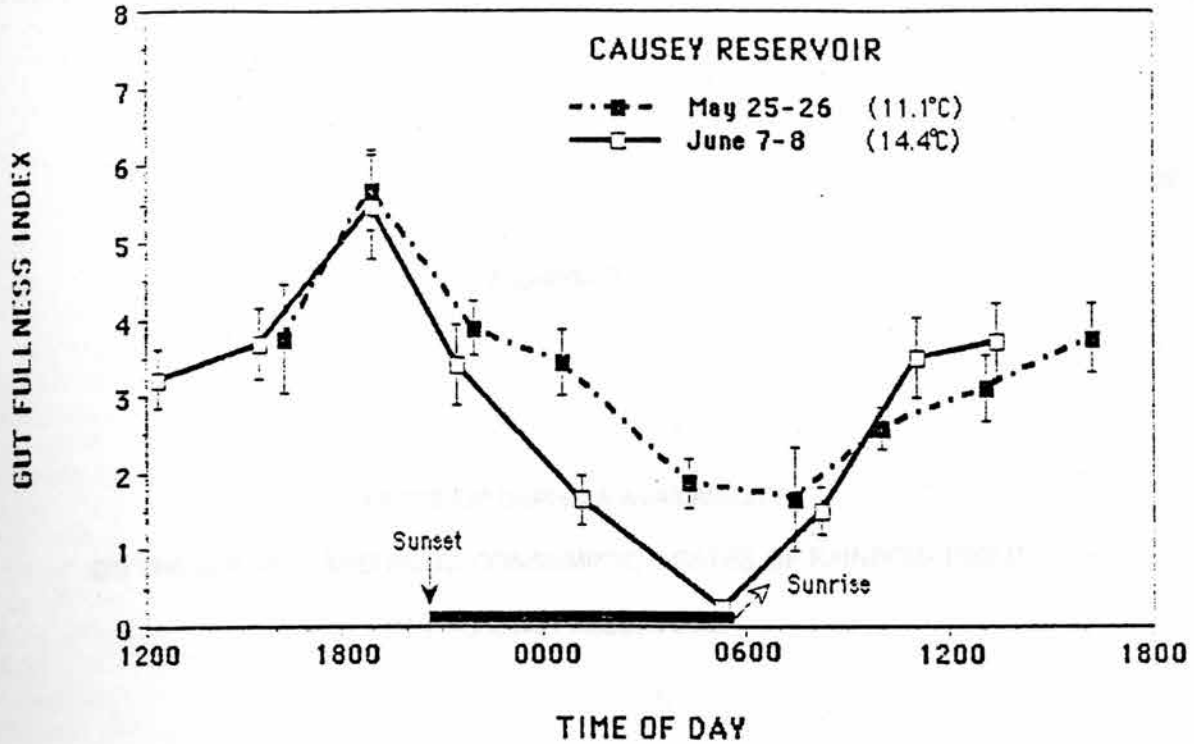


Figure 4. Biomass (± 1 S.E.) and mean length (± 1 S.E.) of Daphnia collected with vertical zooplankton hauls in East Canyon Reservoir, 1989. Biomass represents dry weight of Daphnia ≥ 1.0 mm. Mean and standard errors were calculated from two to three samples taken at the same site. At the 3 m site, samples were taken from 0-1.5 m. At the 20 m and 200 m sites the top 5 m were sampled.



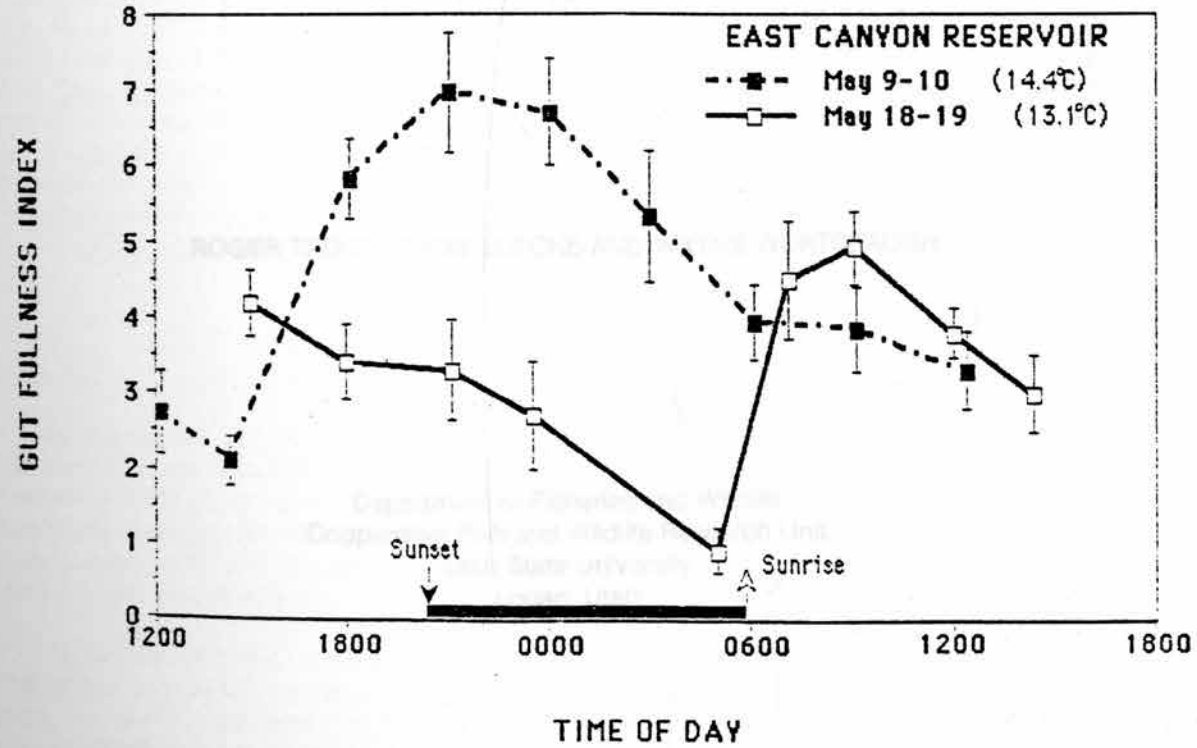


Figure 5. Diel changes in gut fullness of juvenile rainbow trout in Causey (A) and East Canyon Reservoir (B) during their second and third weeks after stocking in 1989. Time of day is given in Daylight Saving Time. Daytime temperatures at 1 m depth during each period are given in parentheses. Two wind events occurred during the sampling at East Canyon Res.: on May 9 from 1700 to 1730 h and on May 18 from 0900 to 1900 h. Mean standard length of juvenile trout for each diel sample was A) Causey Res.: 25-26 May, 78 mm; 7-8 June, 89 mm; B) East Canyon Res.: 9-10 May, 71 mm; 18-19, May 76 mm. All fish were sampled within 10 m of shore, near the stocking site. Error bars indicate ± 1 SE of the mean.

Appendix 2

EFFECTS OF DAPHNIA AVAILABILITY ON THE GROWTH AND FOOD CONSUMPTION RATES OF RAINBOW TROUT IN TWO UTAH RESERVOIRS

by

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ABSTRACT

We monitored the diet and growth of stocked rainbow trout in two Utah reservoirs during 1989-90. For the first month after stocking, juvenile trout in both reservoirs fed extensively on large Daphnia. In East Canyon Reservoir, where Daphnia were abundant, this pattern continued throughout the summer, fall, and winter. In Causey Reservoir, where Daphia were less abundant and smaller, rainbow trout fed progressively on smaller Daphnia throughout the summer, while other prey items (snails, aquatic insects, and algae) became more important. Concurrent with the shift to other prey, condition factors of trout in Causey R. declined gradually after August. We used a bioenergetic approach to examine growth and consumption patterns. Trout in Causey Reservoir grew well from May through August, but in late summer, fall, and winter, growth and estimated consumption rates were low. In contrast, growth of rainbow trout in East Canyon Reservoir was generally good throughout 1989-1990. Bioenergetic modelling of trout studied in 1983-1984 in East Canyon Reservoir, however, suggested that growth rates may be reduced substantially in late summer, when prey abundance is low and environmental conditions poor. Growth during the winter was variable from year to year.

INTRODUCTION

Rainbow trout Oncorhynchus mykiss stocked in fluctuating reservoirs often forage extensively on Daphnia. Galbraith (1975) suggested that the abundance of large Daphnia was related to both the survival of trout and the quality of fishing. Rapid growth of rainbow trout has also been associated with abundant Daphnia. (Becker 1983). Preliminary work at Causey Reservoir and East Canyon Reservoir indicated that the size and biomass of Daphnia available to trout was significantly different between the reservoirs. Daphnia in Causey Reservoir were often more numerous than in East Canyon Reservoir but they were smaller and comprised less biomass (Tabor and Wurtsbaugh 1989). The objective of this study was to determine how variations in the abundance of large Daphnia affected the diet, condition, and growth of stocked rainbow trout.

METHODS

We studied the diet, condition, and growth of trout in two northern mid-elevation Utah reservoirs. The first, East Canyon Reservoir, is a 277 hectare impoundment located at 40°54'20"N and 111°35'20" at an elevation of 1,734 m. It has a mean depth of 23 m. East Canyon Reservoir is meso-eutrophic with abundant large Daphnia that allow juvenile trout to grow at or near maximal rates (Marine et al. 1986). The Utah Division of Wildlife Resources stocked the reservoir on May 2-3, 1989 with 300,000 rainbow trout with a mean weight of 5.3 g.

The second field site, Causey Reservoir has an area of 58 ha. This mesotrophic reservoir is at 41°17'55"N and 111°35'13"W at an elevation of 1,735 m, Its mean depth is 20 m. Zooplankton is abundant, but densities of large Daphnia are usually lower than in East Canyon Reservoir. The Utah Division of Wildlife Resources stocked the reservoir on May 15,1990 with 61,000 rainbow trout with a mean weight of 5.7 g.

Rainbow trout were sampled periodically during 1989 and 1990 with variable mesh gill nets. Nets were usually set in the evening and retrieved 1-2 hours after dusk. During the winter, angler-caught trout were also sampled. Juvenile trout collected during the diel feeding analysis (May-June) were also included. Fish were placed on ice and within approximately 4 h of capture, fish weights and standard

lengths were measured. Fat levels were estimated with the mesenteric fat index (Goede 1989). Stomach contents were visually inspected to determine relative volume of major food items. Stomachs from ten randomly selected trout were preserved in ethanol for laboratory analysis to estimate the mean length of Daphnia ingested. The first 10 Daphnia encountered in each sample were measured from the top of their heads to the base of their tail spine with an ocular micrometer (0.033 mm resolution).

In order to normalize growth rates for differences in temperature and fish size, growth data was analyzed with a bioenergetic model (Hewett and Johnson 1987). We parameterized the model using information for sockeye salmon, but modified the respiration function intercept using rainbow trout data from Wieser (1985). Temperatures selected by trout were estimated from vertical gill netting samples done at East Canyon Reservoir in 1986 and 1987.

Estimates of food consumption (P-values) generated by the model were used to compare growth between reservoirs and at different times of the year. The P-value is a proportionality constant representing the proportion of maximum ration actually consumed by the fish. The P-value can be used to represent food availability. If a P-value is 1, then the fish is feeding at its maximum rate, while a value of 0.5 represents a fish feeding at one-half its maximum rate.

Zooplankton was collected periodically after trout stocking. Vertical zooplankton tows were done with a 30 cm diameter plankton net (153 μm mesh). Samples taken from May to November were collected at one offshore site near the dam in each reservoir. Later samples, December-February, were taken at three offshore sites. Two or three replicate samples were taken on each date at each site. The zooplankton was identified, enumerated, and the first 20-60 Daphnia encountered of each of three species were measured to the nearest 0.03 mm with an ocular micrometer.

Food available to juvenile trout was estimated by the biomass of Daphnia > 1.0 mm in length (≈97% of daphnids found in juvenile trout stomachs were > 1.0 mm). Dry weights (W; mg) of individual daphnids were calculated from lengths (L; mm) with the formulas: 1) D. galeata, $\ln W = -4.83 + 2.53 \ln L$; 2) D. schodleri and D. pulex, $\ln W = -5.04 + 2.83 \ln L$ (adapted from McCauley 1984).

Basic limnological data was also collected periodically in both reservoirs. Temperature (YSI probe), Secchi depths, and chlorophyll a were measured. Water samples for chlorophyll analysis were collected with a 9 m tube sampler, transported to the laboratory in a cooler, filtered, frozen and subsequently analyzed flurometrically (Holm-Hansen and Riemann 1978).

RESULTS

Throughout the year Daphnia was the predominant prey item of rainbow trout in both reservoirs (Fig. 1). In East Canyon Reservoir trout fed extensively on Daphnia between 1.5 and 2.5 mm (Fig. 2). The trout consumed approximately 95% D. pulex and 5% D. schodleri. Aquatic and terrestrial insects were preyed on during the summer and fall but they comprised only a small fraction of the diet. The size of Daphnia ingested by trout in Causey Reservoir declined throughout the year (Fig. 2) and was composed of 58% D. pulex, 20% D. schodleri, and 22% D. galeata. As Daphnia became progressively less important in the diet of trout in Causey Reservoir (Fig. 1), snails, aquatic and terrestrial insects, tubifid worms and algae became more important. Woody debris and rocks were also present in many rainbow trout stomachs.

Condition factors (K) and fat indices also varied between reservoirs and time of year. In Causey Reservoir condition and fat declined during the fall and winter (Fig. 3). In contrast, condition and fat of

trout in East Canyon Reservoir improved substantially during the fall and winter after being low during the summer (Fig. 3).

During 1989-90 growth rates of trout in East Canyon Reservoir were high throughout the year (Fig. 4). Results from the bioenergetic model indicated that food consumption rates of rainbow trout were high most of the year (Fig. 5). We also modelled growth rates of three strains of trout stocked in East Canyon Reservoir in 1983 (Shrader 1988). Fish weights were taken at more frequent intervals than in our study, thus allowing better temporal resolution of growth and consequently, consumption rates (Fig. 6). From May to September estimated consumption rates were similar for all three strains of trout. Growth rates and consumption rates were high in the late spring but declined substantially during the late summer and winter.

During 1989-90 the growth of rainbow trout in Causey Reservoir during the spring was high. Trout growth, however, was minimal in the fall and winter, thus contrasting with the rapid trout growth of East Canyon Reservoir during the same time period (Fig. 4). We also modelled trout growth data from 1988 at Causey Reservoir, which indicated a similar trend of good growth during June and July, but poor growth from August through November (Fig. 7).

The biomass of Daphnia > 1.0 mm and growth of rainbow trout followed the same general trends (c.f. Fig. 8 and Fig. 4). During late spring and early summer in both reservoirs, biomass of Daphnia was high and growth of trout was rapid. As biomass declined during the fall and winter in Causey Reservoir, growth rates also declined. In contrast, the biomass of Daphnia in East Canyon Reservoir increased during the fall and winter, and growth rates of rainbow trout rose accordingly.

In both reservoirs, Secchi depth measurements indicated turbid water in the spring with a clear water phase during the early summer, followed by reduced water clarity in the late summer (Fig. 9). Water clarity improved after the formation of ice during the winter. Chlorophyll a levels in Causey Reservoir were high in the spring and fall with lower levels during the summer (Fig. 10). During July and August abundant Dinobryon was collected in the zooplankton nets. According to Lee (1980) Dinobryon is usually abundant when phosphorus is limiting. In East Canyon Reservoir chlorophyll a levels peaked in the fall (Fig. 10) when macroscopic blue-green algae (Aphanizomenon flos-aquae and Anabaena) were abundant. Results of temperature profiles are listed on Table 1.

DISCUSSION

The lack of large Daphnia and the common occurrence of algae, woody debris, and rocks in the diet of rainbow trout in Causey Reservoir may indicate that food is often limiting there. Large Daphnia were unavailable for most of the year and subsequently many trout switched to larger prey of lower quality. Many trout were ingesting large quantities of mollusks (primarily snails, with some clams). Because the mollusks were often intact in the large intestine, its difficult to estimate how much nutrition a trout can obtain from eating mollusks. Hyatt (1980) portrays rainbow trout as predators that are adapted to prey on large, dispersed prey and poorly adapted to exploit small, morphologically-uniform, prey (i.e. small zooplankton < 1.0 mm). Therefore, rainbow trout may have to switch to alternative prey if Daphnia size is below a certain critical size. In Causey Reservoir few appropriate alterative prey are apparently available.

Based on diet and zooplankton analysis, low availability of large Daphnia may limit the growth of rainbow trout in Causey Reservoir during the fall and winter. The small Daphnia consumed by trout in Causey Reservoir have a lower caloric value per unit weight (Richman 1958) and are harder to detect (Confer et al. 1978, O'Brien 1979) than the larger Daphnia preyed on in East Canyon Reservoir.

According to equations developed by Kerr (1971) planktivorous fish feed and grow more efficiently on large-bodied rather than small-sized prey. Therefore, if Daphnia biomass was equal between the two reservoirs, trout in East Canyon Reservoir could still have potentially higher growth rates than in East Canyon Reservoir due to the presence of abundant large Daphnia.

Growth of rainbow trout in East Canyon Reservoir was reduced during the late summer and fall, which may be due to low food availability and/or poor environmental conditions. The biomass of large Daphnia was low but trout still consumed relatively large Daphnia. Due to high epilimnetic temperatures and low oxygen levels in the hypolimnion, rainbow trout can get squeezed into a narrow thermocline. In addition, trout in East Canyon Reservoir are often heavily parasitized by Lernaea cyprinacea and water quality may be further reduced by blue-green algae blooms.

Although we did not directly measure trout survival, results from gill netting indicated rainbow trout in East Canyon Reservoir had higher survival rates during 1989-1990 than fish in Causey Reservoir. The same strain of rainbow trout was stocked in both reservoirs at approximately the same density and similar time of the year. The catch per unit effort of variable mesh gill nets was much higher in East Canyon Reservoir in samples taken from November, 1989 to February, 1990 than in Causey. Certainly, natural mortality factors such as predation and emigration may cause the observed differences, but they are often interrelated with growth and food availability. Both reservoirs have heavy angling pressure. We do not have adequate data to estimate harvest to anglers but angling pressure per surface area did not appear to be significantly different.

Although the bioenergetic model proved to be useful in comparing growth rates, P-values could be biased due to model error, sampling error, or size selective mortality. On occasion, P-values exceeded 1.0 thus indicating some type of error. The model parameters were developed for sockeye salmon and many model parameters could be modified slightly for rainbow trout, but this probably would not change the results significantly. We did detect a sampling error in angler surveys, where anglers were keeping larger rainbow trout than we caught in our survey nets (Fig. 11). Angler surveys would then have the potential of overestimating growth rates of the fish. Size selective mortality by anglers and piscivorous fish and birds may also produce biased growth rates. If anglers are harvesting a significant number of the largest trout throughout the winter then growth rates may be underestimated. Juvenile trout are preyed on by other predators such as cutthroat trout which may be size selective for the smaller trout. In this case, growth rates may be overestimated. Although there was some potential bias, comparisons could be made because the modelling and sampling procedures were consistent between reservoirs.

RECOMMENDATIONS

Earlier studies (Galbraith 1975; Mills and Schiavone 1982) have demonstrated the value of estimating Daphnia size and abundance in fishery management. This study suggests the biomass of Daphnia > 1.0 mm may provide a useful index for predicting trout growth and condition in fluctuating systems like East Canyon and Causey Reservoirs. The mean size of cladocerans (Mills and Schiavone 1982) and number per liter > 1.3 mm (Galbraith 1975) may also be reliable indices. Diet analysis of rainbow trout can also give useful information concerning size of Daphnia available.

Bioenergetic modelling is a valuable method for comparing growth data. Taking trout samples every three to four weeks would provide insight into times of the year when growth is slow. Periods of slow growth may also be times of significant mortality. Stocking times and rates may then be altered to offset these times of slow growth.

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1. Temperature profiles in East Canyon Reservoir and Causey Resevoir during 1989-90

East Canyon Reservoir

PTH M)	MAY 9	MAY 16	JULY 3	JULY 17	AUG 10	SEPT 7	SEPT 21	NOV 2	DEC 4	JAN 6	FEB 3	FEB 20
0	14.6	13.9	19.3	20.6	22.9	17.1	17.0	8.3	4.4	0.0	0.0	0.0
1	14.4	13.0	18.9	20.6	21.2	17.0	15.8	8.4	4.4	0.9	0.1	0.5
2	13.9	12.6	18.2	20.3	20.9	16.7	15.7	8.4	4.4	1.2	1.1	0.9
4	12.7	12.4	17.8	20.1	20.6	16.5	15.3	8.4	4.4	1.2	1.8	1.2
6	10.2	12.3	17.2	18.7	20.5	16.3	15.1	8.4	4.3	1.4	1.9	1.4
8	9.0	10.6	15.5	16.4	18.7	15.8	15.0	8.4	4.3	1.8	2.1	1.5
10	7.4	7.8	11.8	13.1	10.8	10.6	12.5	8.4	4.3	2.1	2.3	1.8
12	6.2	6.5	9.3	9.9	7.3	7.0	8.0	8.4	4.3	2.3	2.4	1.9
14	5.2	5.3	7.3	7.3	6.2	6.1		8.4	4.3	2.4	2.6	2.0
16	4.4	4.9	5.6	6.0	5.7	5.9	6.9	8.3	4.3	2.7	2.7	2.1
18	4.1	4.2	5.2	5.3	5.4	5.4		7.0	4.2	2.8	2.7	2.1
20	3.7	3.9	4.9	5.1	5.0	5.2	5.8	6.4	4.2	2.9	2.8	2.1
25	3.4	3.6	4.4	4.7	4.6	4.2	5.3	5.7	4.3	2.8	2.9	1.8
30	3.2	3.3	4.1	4.3	4.1	3.8	4.7	5.2	4.2	3.1	2.7	1.5
35	2.9	2.9	3.6	3.7	3.6			5.0	4.5		2.4	1.3
40	2.9	2.8	3.3	3.4	3.5			4.8	4.2		2.2	1.3
45				3.3							2.7	1.7

Causey Reservoir

EPTH (M)	MAY 25	MAY 31	JUNE 8	JUNE 22	JULY 3	JULY 18	AUG. 18	SEPT. 20	NOV. 2	DEC. 16	JAN 13	FEB. 10
0	11.2	11.7	14	15.5	18.3	20.4	19.4	13.4	6.1	0.5	1	1
1	11.1	11.6	14.4	15	17.6	19.6	19	13.5	6.1	2.5	2.5	0.9
2	11	11.4	14	14.8	17.1	19.2	18.8	13.5	6	3.5	3.7	2.4
4	9.9	10.3	10.6	13.7	16.1	18	18.7	13.3	5.9	4	3.9	3.4
6	8.2	9.4	9.4	11.9	13.6	16.3	18	12.7	5.9	4	3.9	3.8
8	7.5	8.4	9	11.1	12.4	15.1	16.9	12.5	5.9	4	3.9	4.2
10	7.5	8	8.5	9.8	11.4	14.3	16.3	12	5.8	4	3.8	4.3
12	7.3	7.6	8.1	8.8	10.5	13.4	15.7	11.5	5.7	3.9	3.8	4.2
14	7.3	7.4	7.8	8.4	9.5	12.2	15.5	9.6	5.7	3.9	3.8	4.2
16	7.2	7.3	7.7	8	8.8	11.6	15.1	7.8	5.6	3.9	3.8	4.1
18	7.2	7.2	7.7	7	8.4	11.1	14.8	7.2	5.5	3.9	3.9	4.2
20	7.2	7.3	7.7	7	8	10.6	9.9	7	5.5	4	3.9	4.2
25	7.1	7.2		7.3	7.5	8.9	6.6	6.1	5.5		4	4.3
30	6.8	6.4		6.6	6.7	6.6	5.6				4	4.3
35	4.8	5.2		5.8	5.9	5.5					4	4.3
40	4.7											

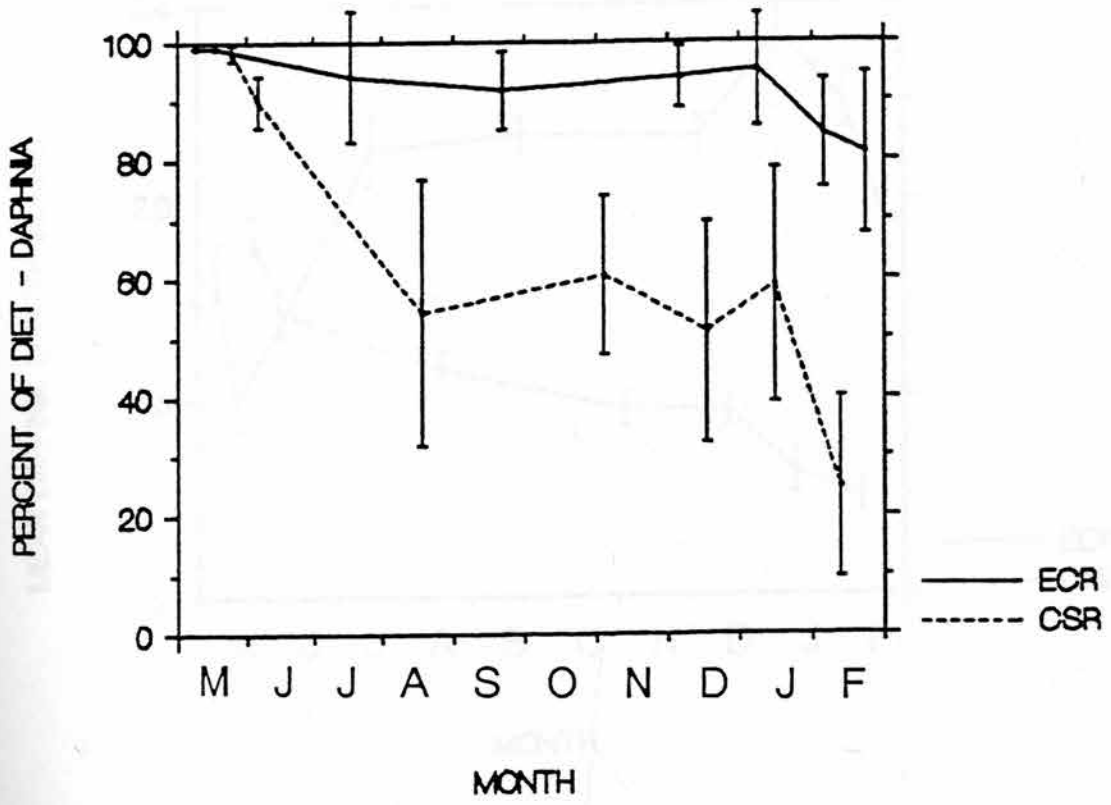


Figure 1. Percent (± 2 S.E.) of rainbow trout diet that was composed of Daphnia. Gill net, angler survey, and electrofishing samples were taken from May, 1989 to February, 1990 at East Canyon Reservoir (ECR) and Causey Reservoir (CSR). Stomach contents were visually estimated to determine relative volume of major food items.

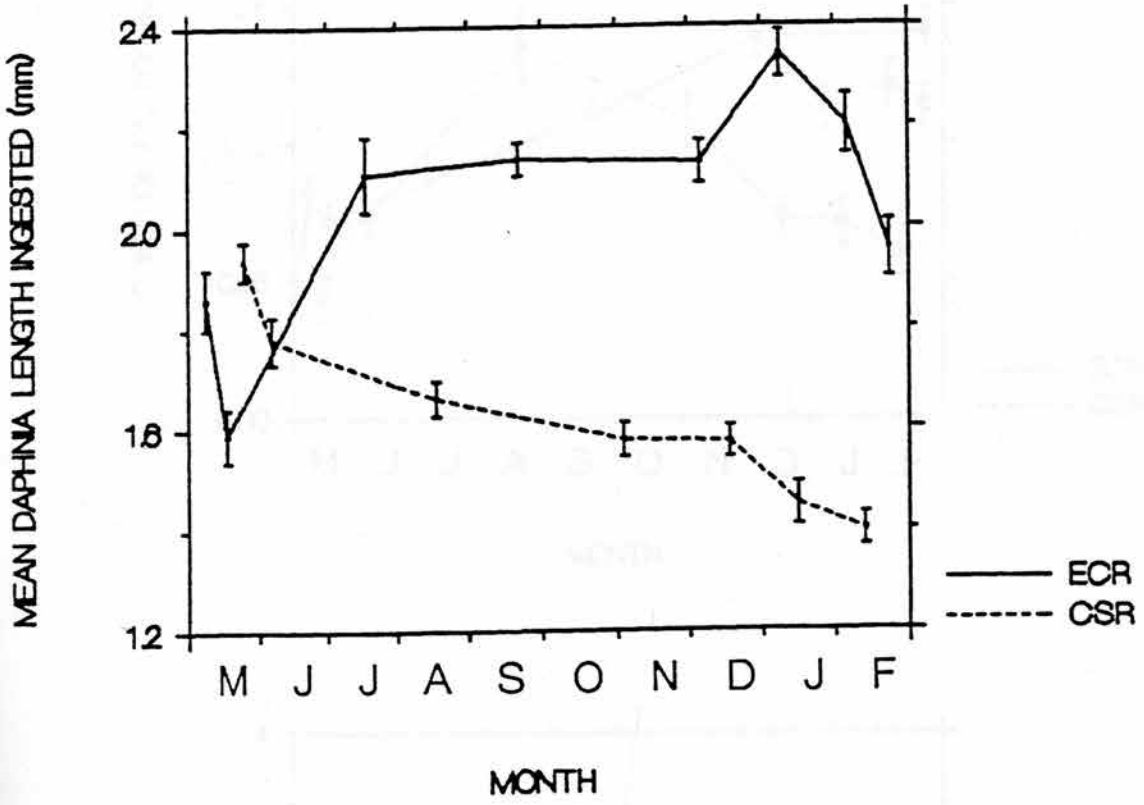


Figure 2. Mean length (± 2 S.E.) of Daphnia ingested by rainbow trout in East Canyon Reservoir (ECR) and Causey Reservoir (CSR) from May, 1989 to February, 1990.

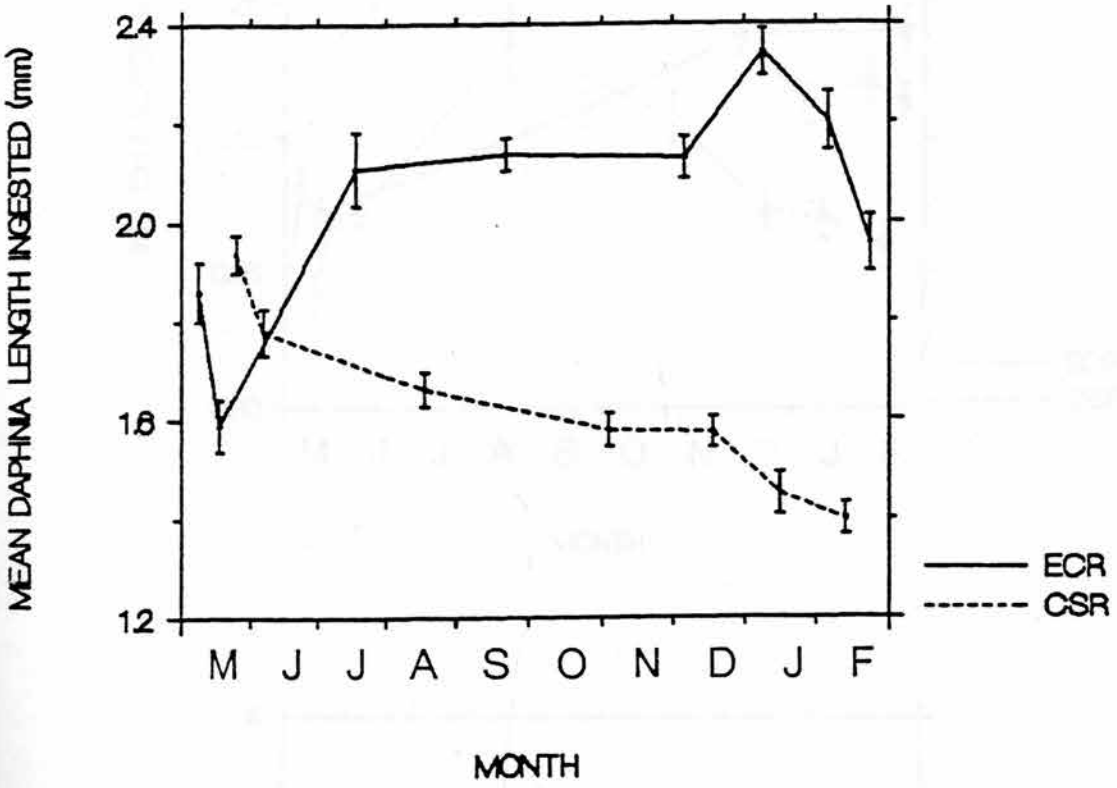


Figure 2. Mean length (± 2 S.E.) of Daphnia ingested by rainbow trout in East Canyon Reservoir (ECR) and Causey Reservoir (CSR) from May, 1989 to February, 1990.

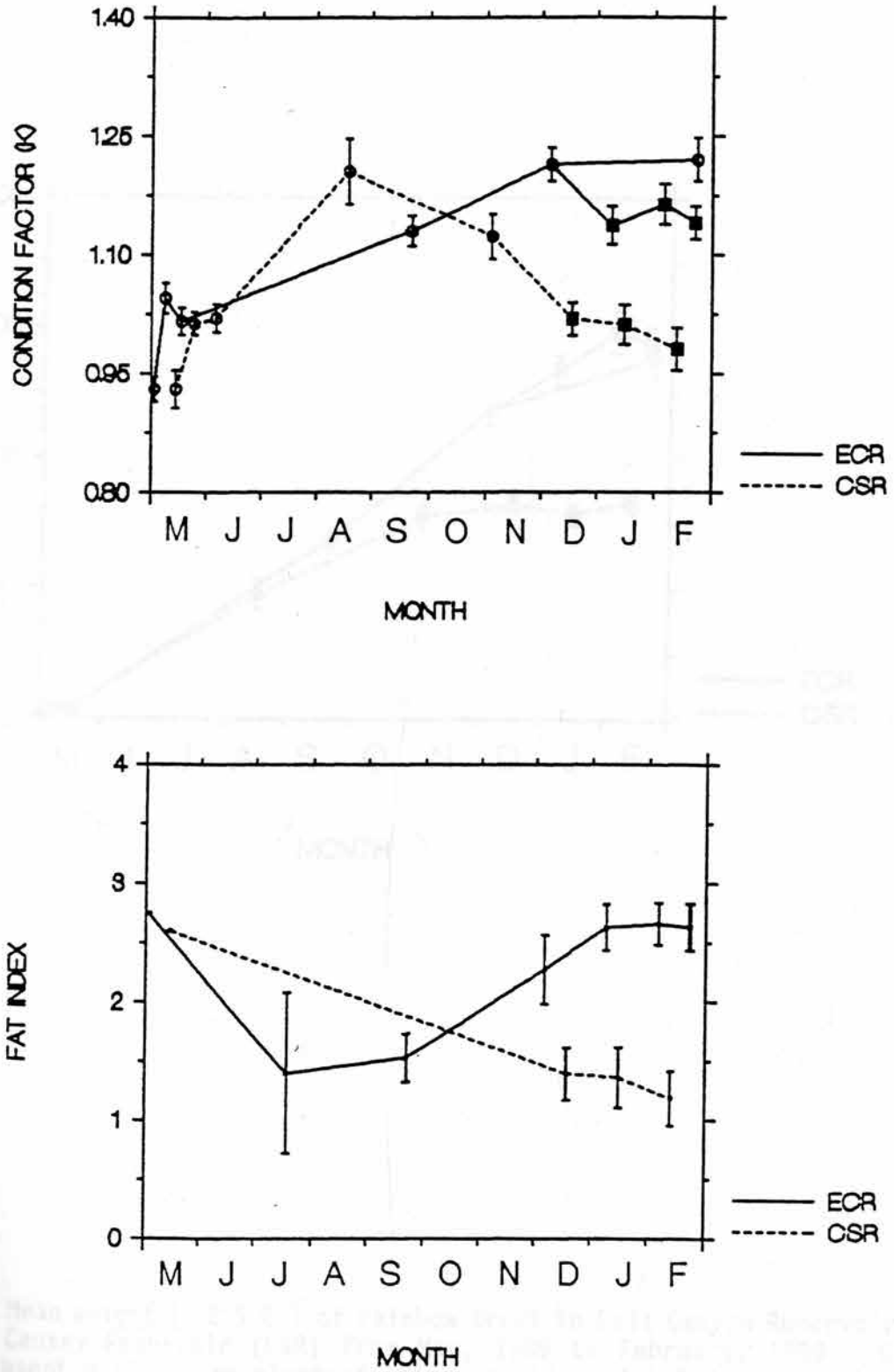


Figure 3. Mean condition factor (K; ± 2 S.E.) and mean mesentery fat index (± 2 S.E.) of rainbow trout in East Canyon Reservoir (ECR) and Causey Reservoir (CSR) from May, 1989 to February, 1990. Condition factor symbols: circles are gill net or electrofishing samples and solid squares are for fish sampled in angler surveys.

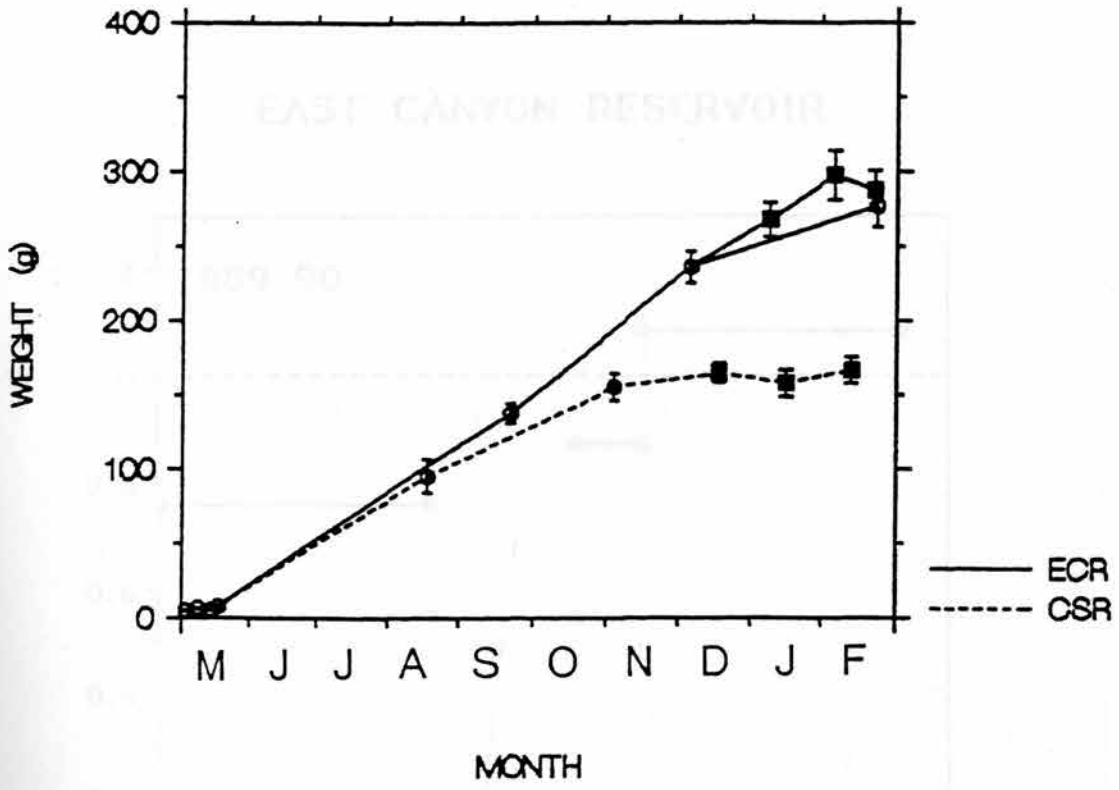


Figure 4. Mean weight (± 2 S.E.) of rainbow trout in East Canyon Reservoir (ECR) and Causey Reservoir (CSR) from May, 1989 to February, 1990. Circles represent gill net or electrofishing samples and solid squares represent fish from angler surveys.

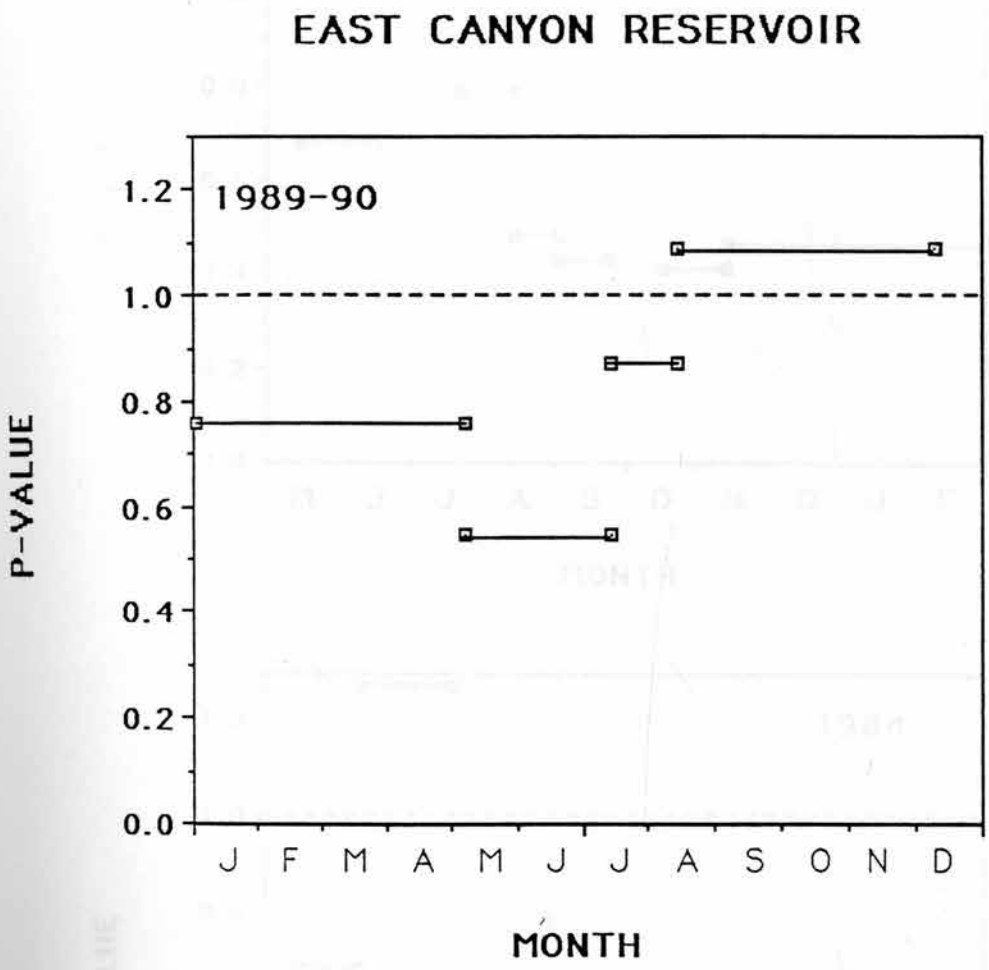


Figure 5. P-values from a bioenergetic model of one rainbow trout growth in East Canyon Reservoir from May, 1989 to February 1990. P-values represent the proportion of maximum ration actually consumed by the fish. The dashed line (P-value = 1.0) represents a fish feeding at its maximum rate.

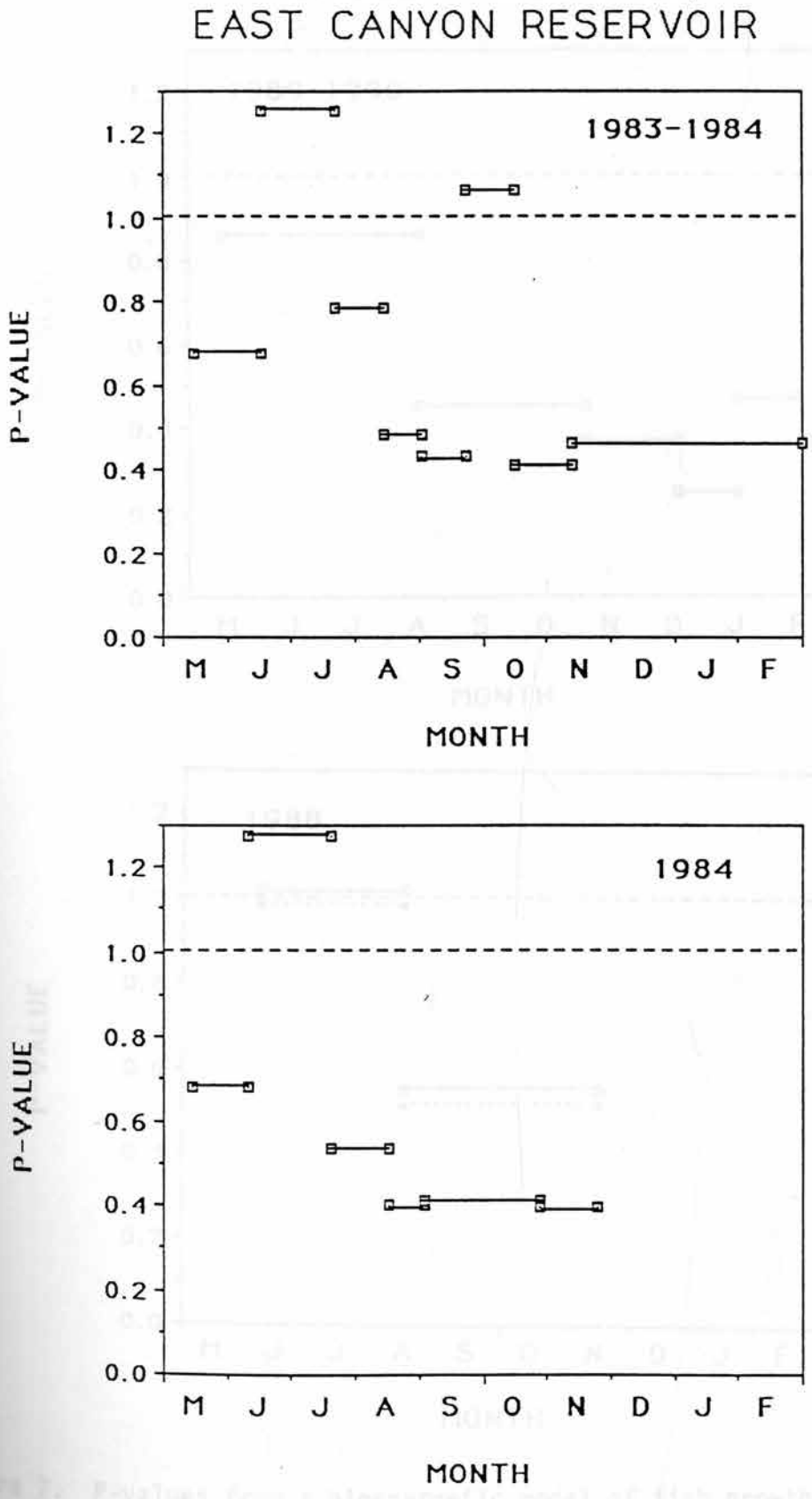


Figure 6. P-values from a bioenergetic model of fish growth of two cohorts of rainbow trout in East Canyon Reservoir from May, 1983 to November 1984. P-values represent the proportion of maximum ration actually consumed by the fish. The dashed line (P-value = 1.0) represents a fish feeding at its maximum rate.

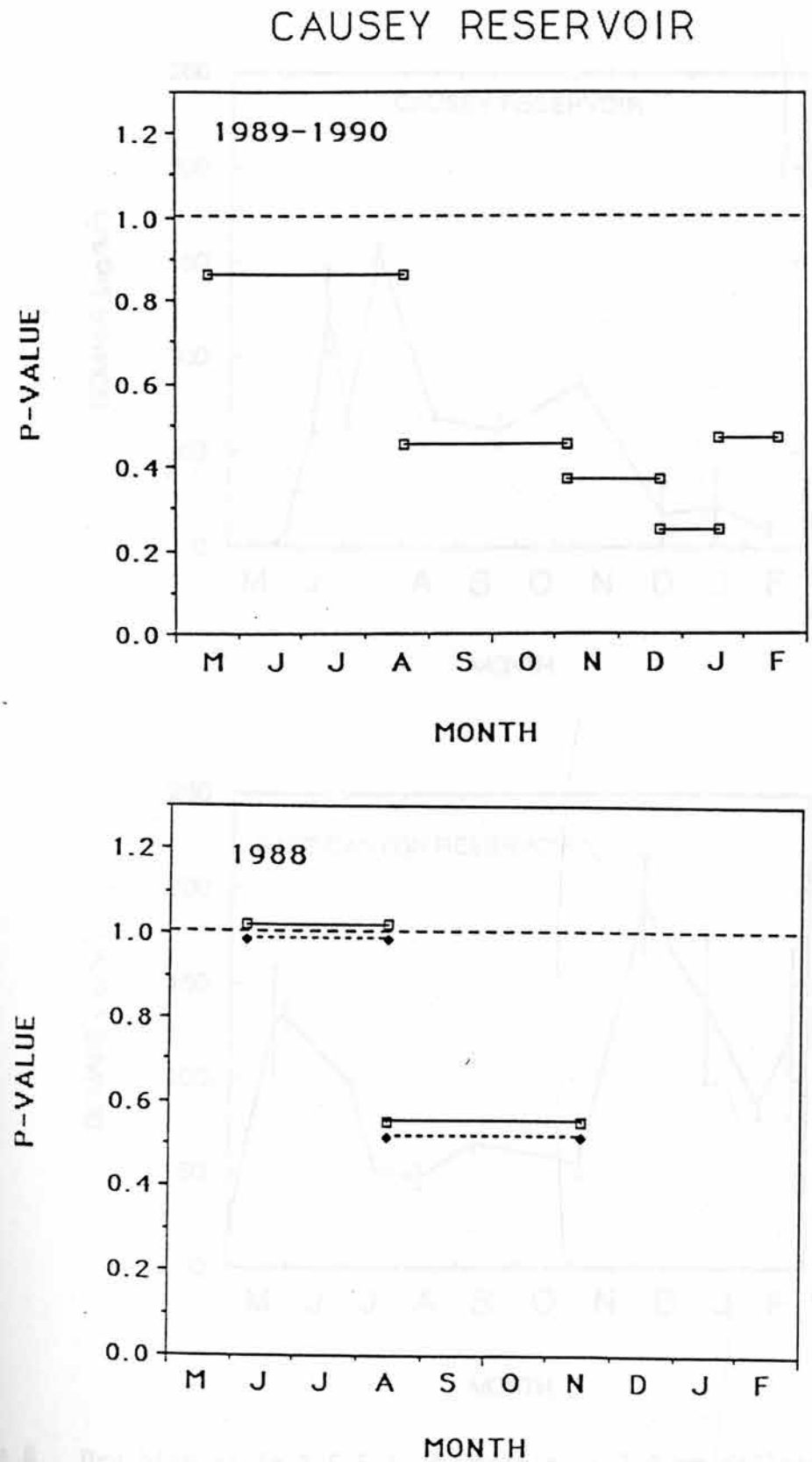


Figure 7. P-values from a bioenergetic model of fish growth. Data represents three cohorts (2 in 1988 and 1 in 1989-90) of rainbow trout in Causey Reservoir. P-values represent the proportion of maximum ration actually consumed by the fish. The dashed line (P-value = 1.0) represents a fish feeding at its maximum rate.

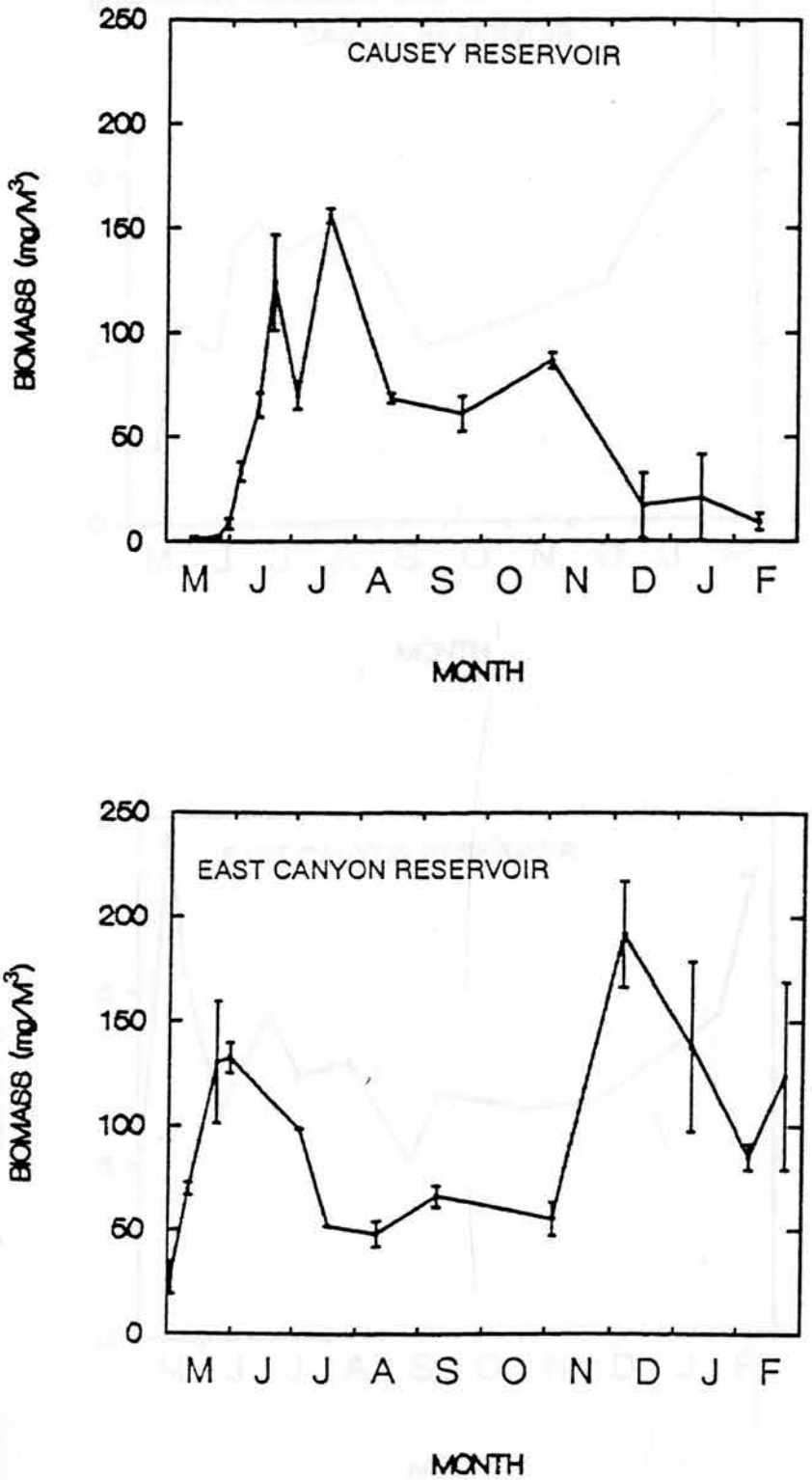
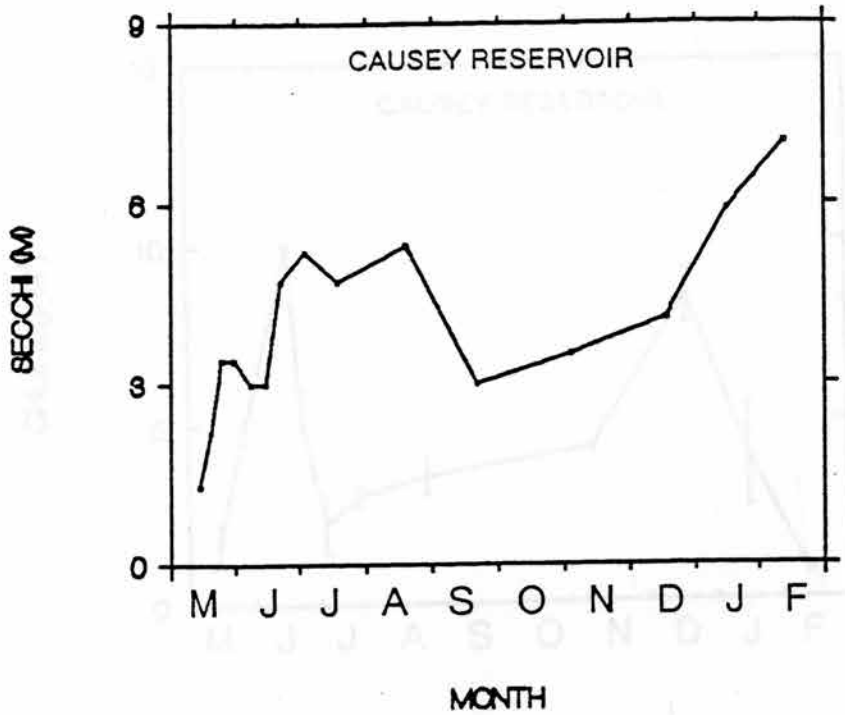


Figure 8. Dry biomass (± 2 S.E.) of Daphnia ≥ 1.0 mm collected with vertical zooplankton hauls in Causey Reservoir and East Canyon Reservoir, 1989. Mean and standard errors were calculated from two to three samples taken at the same site. Vertical hauls were collected at offshore sites where depths sampled ranged from 21 to 40 m.



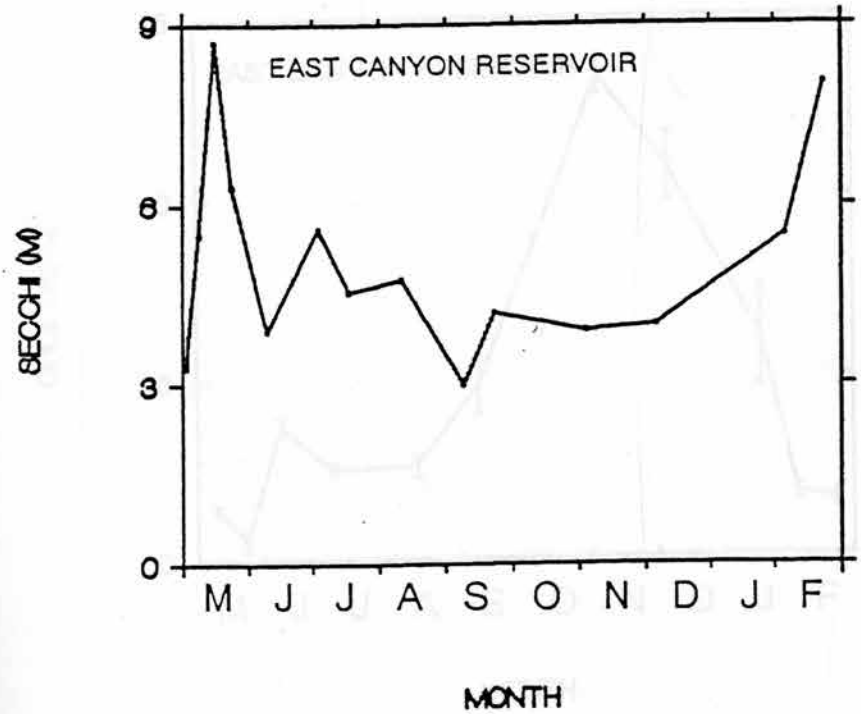


Figure 9. Secchi depths (m) from East Canyon Reservoir and Causey Reservoir from May, 1989 to February, 1990.

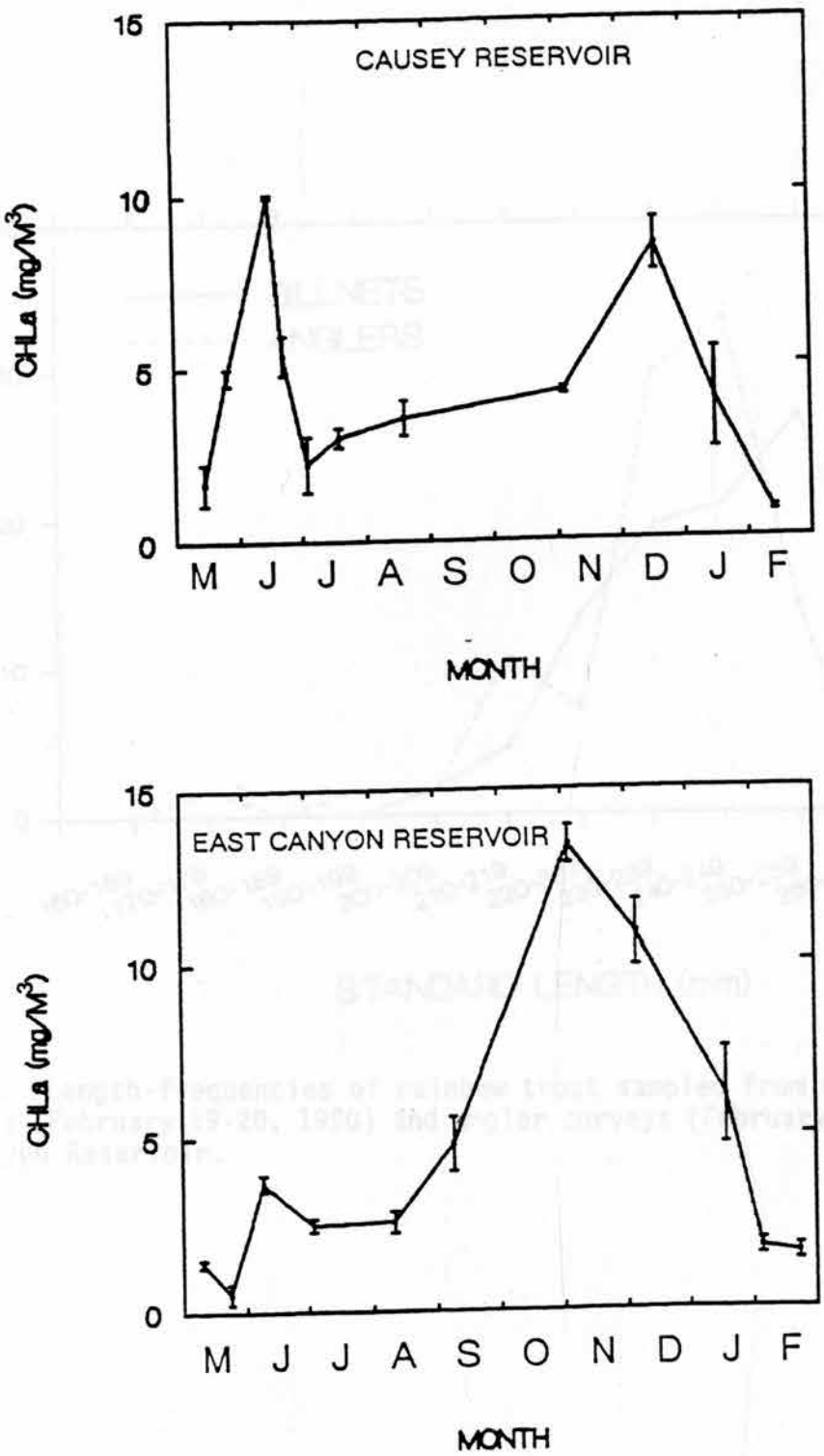


Figure 10. Chlorophyll a concentrations in the top 9 m of East Canyon Reservoir and Causey Reservoir from May, 1989 to February, 1990.

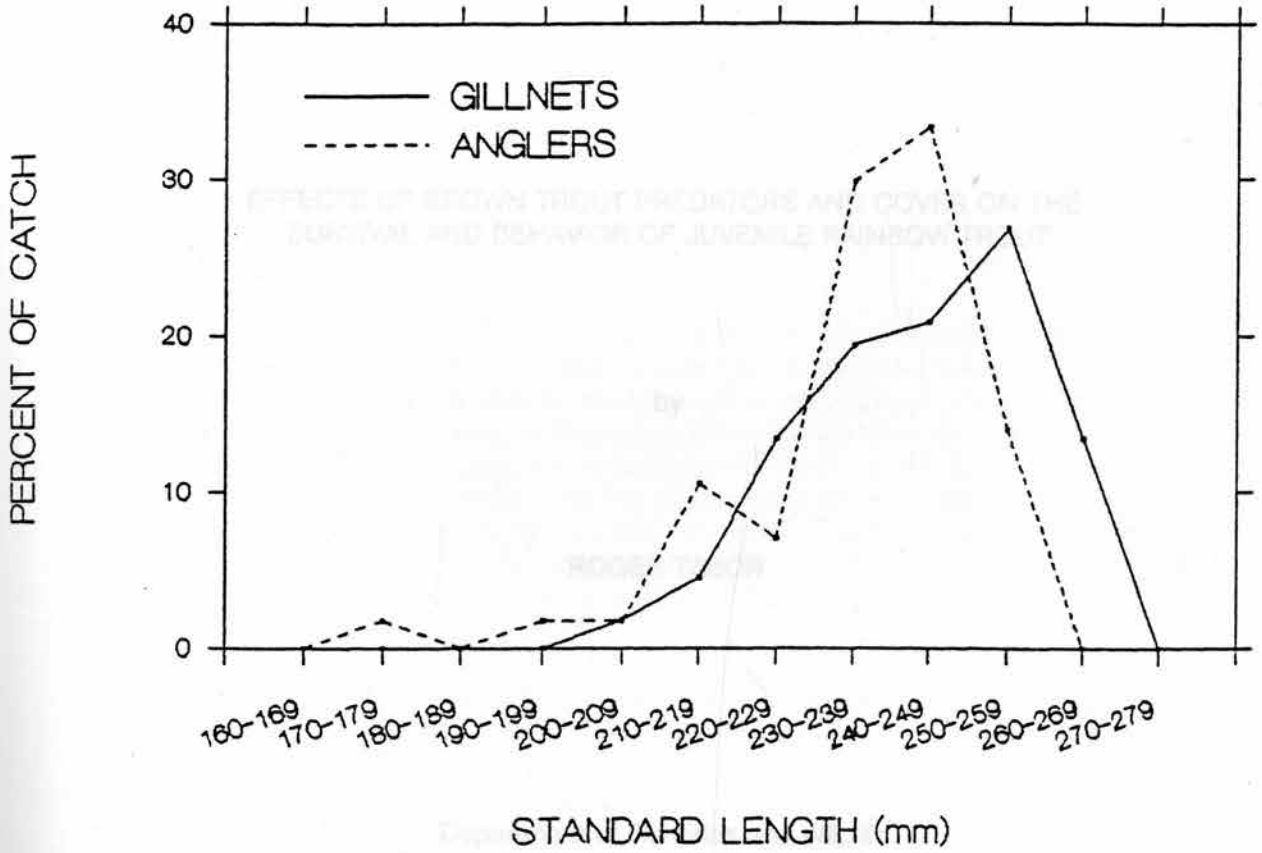


Figure 11. Length-frequencies of rainbow trout sampled from variable mesh gill nets (February 19-20, 1990) and angler surveys (February 19, 1990) at East Canyon Reservoir.

Appendix 3

EFFECTS OF BROWN TROUT PREDATORS AND COVER ON THE SURVIVAL AND BEHAVIOR OF JUVENILE RAINBOW TROUT

by

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15 March 1990

INTRODUCTION

Pond experiments in 1988 indicated that juvenile rainbow trout could use cover to avoid predation by piscivorous brown trout (Tabor and Wurtsbaugh 1989). In that experiment there was some question as to the degree of protection afforded by cover, and of the behavioral responses of the predator and prey over the diel cycle. In order to resolve these questions I conducted a controlled laboratory experiment to look at the interaction of predators, prey and cover.

METHODS

The experiment was conducted in a 4.6 m^2, 0.4 m deep circular wading pool. The bottom was painted dark brown and the sides were left as light blue. The pool was divided in half with small mesh netting. Eighteen to twenty juvenile rainbow trout (ca. 5.5 g) were placed in one half of the pool and allowed to acclimate to pool conditions for two days before the predator was stocked. Juvenile trout were fed brine shrimp 3 times each day from a feeder at the center of the pool. One 320 mm S.L. brown trout was used for the experiment. The brown trout was placed in the other half of the pool and allowed to acclimate to pool conditions for one day. The divider was removed at night to minimize disturbance to the fish. Six treatments were conducted, with three with cover added and three with no cover. Seven stacked cinder blocks were used as cover. Total area of cover represented approximately 10% of the total pool area.

Observations of predator and prey were taken from behind a plastic divider during the day. Night observations were done with red light to minimize disturbance. Predator and prey were together for 2 days, afterwards the predator was removed, the pool drained and remaining prey counted. Instantaneous mortality rates (Z) were calculated as:

$$Z\ (\%/\text{day}) = \frac{(\ln N_o - \ln N_t) \times 100}{t}, \quad \text{where;}$$

N_t = final population size
N_o = initial population size
t = duration of experiment (2 days)

RESULTS AND DISCUSSION

Mortality rates (Z) for the laboratory pool experiments were:

	MORTALITY RATE	
TRIAL #	COVER	NO COVER
1.	.173	1.498
2.	.144	.178
3.	.029	1.10
mean	.115	.925
st. dev.	.076	.677

The brown trout predator was largely inactive during the day with increased swimming at dusk and at night. Juvenile rainbow trout did not increase their use of cover during the day without or with the brown trout present. At night few juvenile trout were observed away from cover when the brown trout was present. I also did one experimental trial with a rainbow trout predator. This predator was active during the day and inactive at night. In this trial, juvenile trout used cover extensively during the day and were in exposed areas at night. My results suggest that rainbow trout can effectively use cover to avoid predators and move to cover only when predators are active.

REFERENCE

Tabor R.A. and W.A. Wurtsbaugh. 1989. The use and importance of cover by juvenile rainbow trout to reduce piscine predation: field observations and pond experiment. Utah Division of Wildlife Resources, Federal Aid in Fish Restoration, Project F-47-R-3, 1988 Annual Progress Report, Salt Lake City.

APPENDIX 4

DENSITY ESTIMATES AND DIETS OF PISCIVOROUS FISH IN CAUSEY RESERVOIR

by

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15 March 1990

ABSTRACT

The population size of piscivores was measured in Causey Reservoir, Utah with the plant-recapture methodology. Catchable trout were planted as the "marked" population and recaptures were made with multi-meshed gill nets. The estimated populations of piscivorous cutthroat and brown trout were 4,980 and 180, respectively. Brown trout > 200 mm S.L. were piscivorous, feeding on juvenile rainbow trout and sculpins. Cutthroat trout fed primarily on zooplankton and insects, but small numbers of fish were consumed after the fish reached 250 mm. Rainbow trout, in contrast, fed entirely on invertebrates. The large cohort of cutthroat trout in the reservoir, that reached piscivorous size in 1989, is expected to cause substantial mortality of fingerling trout planted in 1990.

INTRODUCTION

To estimate the number of fingerling rainbow trout consumed by piscivorous fishes, we must know the number of predators in the system. This number, multiplied by the daily consumption rate of fingerlings provides us with an estimate of fish lost to predation. In 1989 we used two types of mark-recapture methods to estimate the densities of piscivorous cutthroat and brown trout in Causey Reservoir.

METHODS

A standard mark-recapture experiment was attempted in the spring of 1989. We initially attempted to capture trout with fyke nets near the spawning tributaries in April. This method was abandoned, however, as only 1.8 fish were captured per net-night. The use of electrofishing equipment was considered but not tried because: (1) Causey Reservoir does not have a ramp where the large boat necessary for this work could be launched, and; (2) the banks in the reservoir are very steep so that the shocker's electrical field would have been dispersed too rapidly.

Because these methods did not work, we captured trout in trammel nets that were set overnight in June. Preliminary netting indicated that many fish would survive this treatment and recover. During the actual experiment reasonable numbers of live fish were captured with this method, but less than 20% survived overnight after they were placed in live-cages. We believe that the high mortality was due to surface water temperatures near 18°C, which undoubtedly placed additional stress on the netted fish. This method was consequently abandoned.

In lieu of a traditional mark-recapture experiment we used the "plant-recapture" method of Hepworth and Modde (in review). Two thousand 150 g rainbow trout were planted on 19 June to serve as the "marked" population. The fish were planted at two sites in order to facilitate dispersal. Recaptures were made with overnight sets of gill nets on 20-22 June. Sinking gill nets with mesh sizes of 0.5, 0.75, 1, 1.25, 1.5, 2 and 2.5 inches were set perpendicular to shore. Additional floating nets were set offshore. The sites for the nets were chosen randomly from 49 lake sections (34 shoreline and 15 offshore), resulting in a total of 9 net-nights along the shoreline and 3 net-nights offshore. Captured fish were identified, measured, weighed and their stomach removed for subsequent analyses. Stocked trout could easily be distinguished from other rainbow trout by erosion of fins and coloration. Population estimates (N) of each species and size class were made with the following formula:

$$N = \frac{n(c + R + 1)}{R + 1} - n$$

where: N = estimated population size
n = number of trout stocked = 2000
c = number of unmarked fish captured
R = number of stocked trout captured = 44

Confidence intervals normally used for mark-recapture methods are not appropriate for this method.

The diets of fish captured in the various mark-recapture experiments were analyzed. Guts of gill netted fish were examined in the field or preserved and analyzed latter in the laboratory. The percent a diet item represented in the gut of each fish was estimated visually. Diets over the summer (June-August) were calculated by equally weighting the percent composition on the three sampling periods (8, 14, 20-21 June 1989)

RESULTS

The stocked rainbow trout dispersed rapidly, but we still had higher catch rates in nets set close to the stocking sites than in more distance locations. A total of 220 fish were recaptured of the following taxa:

Taxa	Captured	Estimated Population size	
		Number	Percent
Rainbow (feral)	21	930	12
Cutthroat <250	28	1240	16
Cutthroat >250	112	4980	63
Brown <300	10	440	6
Brown >300	3	180	2
Brook	2	90	1
Total	176	7860	

Cutthroat trout greater than 250 mm were the most numerous fish in the reservoir and brown trout were about an order of magnitude less abundant. Length-frequency distributions demonstrated that most of the cutthroat trout are from a single cohort of fish that were stocked in the reservoir in 1987 (Fig. 1). Eighty percent of the cutthroat trout captured in 1989 were larger than 250 mm, the approximate size that they become piscivorous (see below; Wurtsbaugh and Tabor 1989). Although catches were low, the data suggest that a new cohort of piscivorous brown trout may also be present in the reservoir (Fig. 2).

DIETS

The limited numbers of fish analyzed for diet information provided useful information, even though a food analysis was not one of our original objectives. Although the sample size of brown trout was very low (N=16) it appears that by the time they reached 200 mm standard length these fish became piscivorous, and fed extensively on rainbow trout and sculpins (Fig. 3). In contrast with the other trout in the reservoir, the browns ate relatively little zooplankton. Cutthroat trout between 200 and 375 mm ate primarily zooplankton, insects and snails, but small amounts of fish were consumed. Small rainbow trout exploited zooplankton even more than cutthroat trout, but then began consuming substantial numbers of insects by the time they reach 250 mm. Rainbow trout larger than 275 mm were not captured during 1989, so the degree of piscivory of this species could not be determined. The diet results from 1989 are consistent with the more extensive dietary analysis done in 1988 (Wurtsbaugh and Tabor 1989).

DISCUSSION

Our population estimate of 4980 cutthroat trout > 250 mm and 620 brown trout suggests that there may be considerable predation pressure on fingerling trout planted in Causey Reservoir. This year we did not attempt to measure temporal changes in predation on the newly-stocked fish. Nevertheless, we found that cutthroat and brown trout were preying on the fingerlings up to four weeks after they were stocked.

Our population estimates, however, are only crude measures of abundance because of the method employed. The use of hatchery rainbow trout to provide the "marked" population may violate several key assumptions of a mark recapture experiment: (1) that the marked and unmarked fish have similar distribution patterns; (2) that catchability of the two groups is identical, and; (3) that activity of the two groups is identical. We do not know how severely these assumptions were violated. Although the other attempted methods would have given better estimates, the plant-recapture method provides us with an approximate density of predators in the system.

The growth and abundance of the single large cohort of cutthroat trout may have important consequences for the management of Causey Reservoir. In 1988 most of these fish were less than 250 mm, and consequently fed very little on the stocked fingerling trout. In 1989, however, 80% of the cutthroat were larger than 250 mm and they were still preying on the fingerling trout one month after stocking. Additionally, the population estimates of this cohort in 1988 and 1989 suggested that only 43% of them had died. This is consistent with the low angler catch rates for this species in the reservoir. If the growth rates of this cohort continue, and mortality rates are low, a very large population of piscivores will be present when fingerling fish are stocked in 1990. A hypothetical example will demonstrate the potential magnitude of this effect. If 4,000 piscivorous cutthroat trout are present in 1990, and if they ate 0.2 fingerling trout/day for a period of 30 days, they would consume 24,000 trout. Additional losses could occur after this period, and from piscivorous brown trout. Consequently, we predict that juvenile trout stocked in 1990 will have low survival rates.

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Cushing, D.H. 1981. Fisheries biology: a study in population dynamics. University of Wisconsin Press, Madison, WI.

Hepworth, D., and T. Modde. In Review. Use of hatchery fish to estimate population size and survival of fingerling rainbow trout stocked in a reservoir. N. Am. J. Fisheries Manag.

Wurtsbaugh, W.A., and R.A. Tabor. 1989. Effects of fish predation on the survival of rainbow trout fingerlings in Causey Reservoir, Utah. Utah Division of Wildlife Resources, Federal Aid in Fish Restoration, Project F-47-R-3, 1988 Annual Progress Report, Salt Lake City.

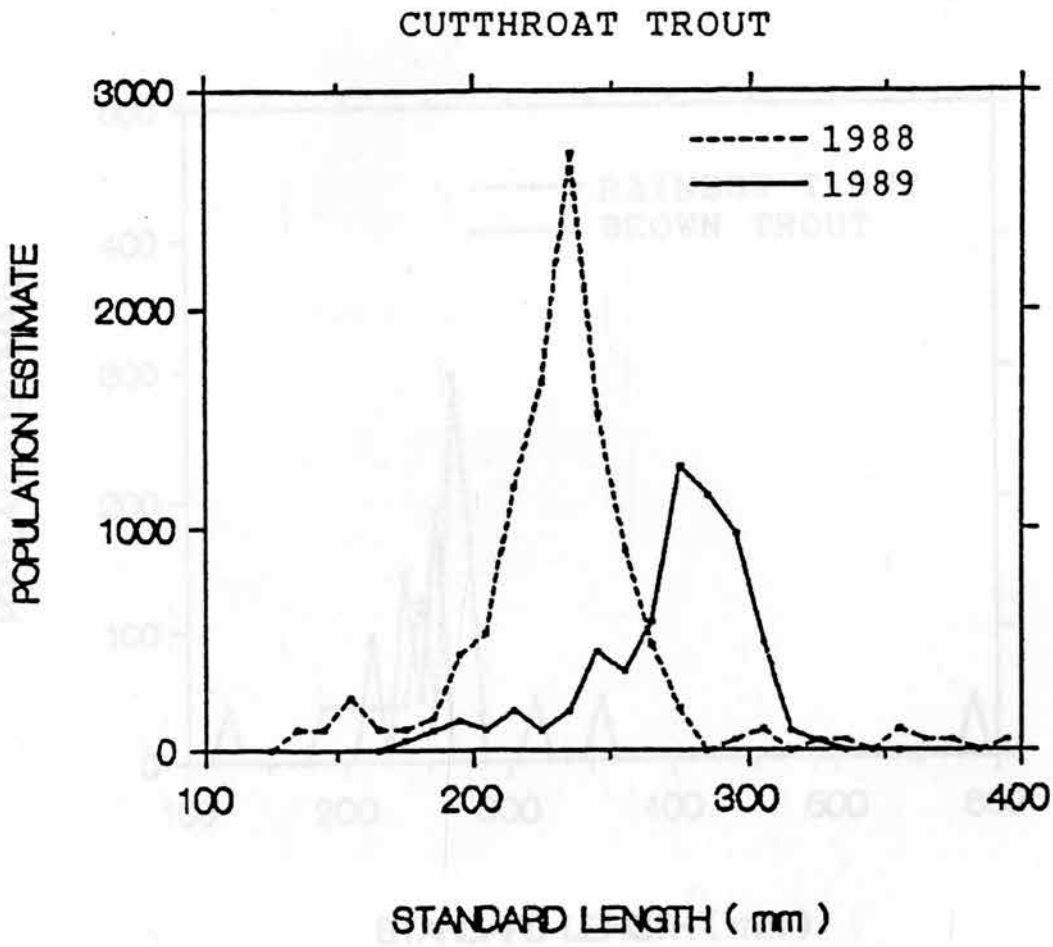

Figure 1. Length-frequency distributions of cutthroat trout measured in Causey Reservoir in June 1988 and 1989. Multi-meshed gill nets were used to capture the fish. Population sizes were estimated with a plant-recapture method (see text).

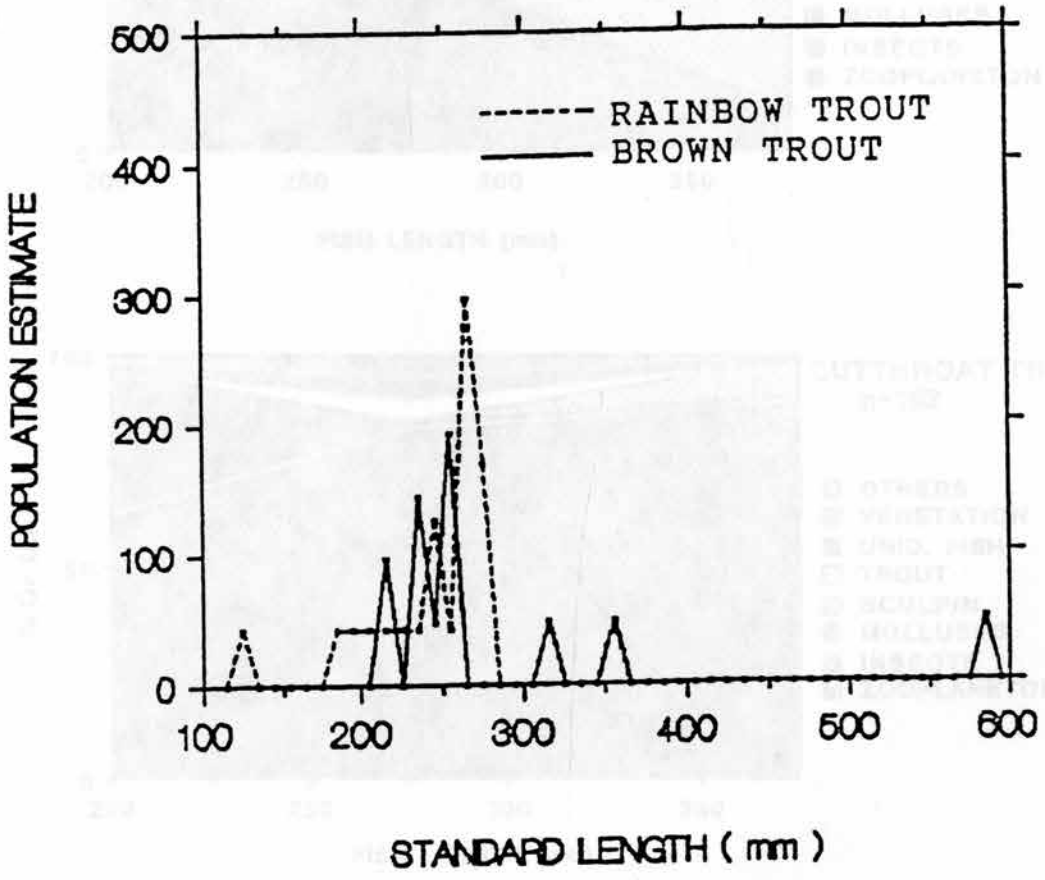

Figure 2. Length-frequency distributions of brown and rainbow trout measured in Causey Reservoir in June 1989. Population sizes were estimated with a plant-recapture method (see text).

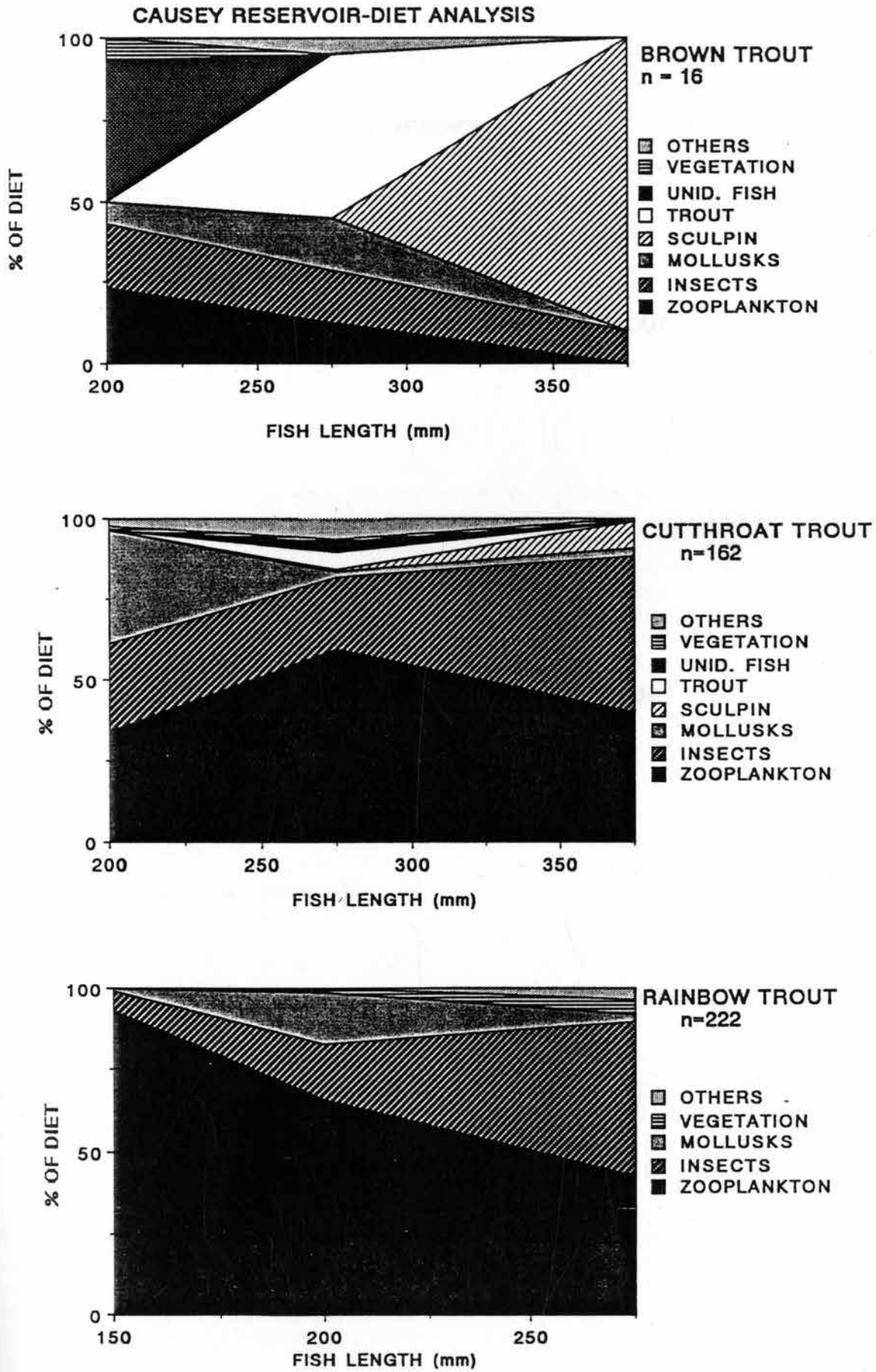

Figure 3. Effects of fish size on diet composition (% by volume) of brown, cutthroat and rainbow trout in Causey Reservoir during June 1989.

APPENDIX 5

DIGESTION RATES OF PISCIVOROUS TROUT

by

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ABSTRACT

A literature review and laboratory experiments demonstrated the relationship between temperature and digestion rates of piscivorous fish and of fish fed invertebrates or pellet rations. Digestion rates increase exponentially with temperature, so that rates are about 10-fold higher at 25° than at 3°C. Temperature increased digestion equally for piscivores and fish eating smaller items. Digestion rates of brown trout and rainbow trout tested at 9° and 14°C were somewhat higher than rates of most other piscivores. The importance of digestion rates of piscivores in determining predation losses of fingerling trout is discussed.

INTRODUCTION

Fish digestion has been studied and documented for decades. It has important implications for the management of pond, stream, lake and reservoir fisheries (Alexander 1977; Windell 1966, 1967; Warren et al. 1964; Brocksen et al. 1968; and Brett et al. 1969). In lakes and reservoirs where fish stocking is needed to maintain sport fisheries, fisheries workers are concerned about the number of juvenile fish eaten by piscivorous fishes. This is a particular concern when fingerling trout are stocked in reservoirs containing piscivorous brown, cutthroat and rainbow trout.

Field work conducted in the earlier phase of the Trout Survival Project has shown that the stocked fingerling trout are frequently found in the stomachs of adult trout (Wurtsbaugh 1987). In order to determine the total mortality rates due to predation, we need to know how fast the prey are digested in the predators' stomachs. This report summarizes the relationship between temperature and digestion rates of piscivorous fishes taken from the literature, and from our experiments on the digestion rates of brown and rainbow trout.

The Gastric Evacuation Model

The general model of gastric evacuation rates is:

$$dW/dT = -RW^b$$

where W is weight of the stomach contents, T is time after feeding, R is gastric evacuation rate, and b is a constant.

When b=0.0, the model becomes linear: $dW/dT=-R$ (Hunt 1960; Seaburg & Moyle 1964; Swemson & Smith 1973; and Daan 1973). When b=0.5, the model follows a square root function: $dW/dT=-RW^{0.5}$ (Kariyaet et al. 1969; Jobling & Davies 1979; and Jobling 1981). When b=1.0, the model is exponential: $dW/dT=-RW$ (Cochran & Adelman 1982; Brett & Higgs 1870; Thorpe 1977; MacDonald et al. 1982; Persson 1979, 1981, 1982, and 1986; and Elliott 1972). Which of these models best describes fish digestion has received considerable attention and discussion in the literature.

Factors Affecting Digestion Rates

Major factors affecting gastric evacuation rates are: (1) characteristics of the predators themselves, e.g. predator size, species, acclimation state and time since last feeding; (2) prey types and sizes; (3) environmental factors such as temperature.

Several studies on the effects of predator size and species on the rates of gastric evacuation (R) have been conducted. Jobling et al. (1977) fed Limanda of different body weights with flatfish paste diet and found that the time (T) for emptying gastric contents varied with (fish weight)$^{0.39}$. Pandian (1967) ran a similar experiment on Megalops fed on prawns which shows that R varies with (fish weight)$^{0.47}$. These two experiments indicate that as fish sizes increase, gastric evacuation rates do not increase proportionally. The reason may be due to the fact that large fish have larger food boluses than small ones (although the percentage of the food to their body weight is the same) and have relatively smaller surface areas than small fish. It may therefore take longer for the gastric enzymes to penetrate into the bolus and consequently gastric evacuation could be slowed.

Different species have different gastric evacuation rates. This can be attributed to the differences in their diet, morphology of the gastrointestinal tract, size, and perhaps other factors such as enzyme activity. Windell (1978) compared the gastric evacuation rates among several species. For example, at 15°C largemouth bass (Micropterus salmoides) required 32h to fully evacuate a meal of minnows, whereas walleye (Stizostedion vitreum) required only 16h. Similarly, Molnar et al. (1967) found that largemouth bass (Micropterus salmoides) evacuated their stomach contents more than two times faster than pike-perch (Lucioperca).

Fange and Grove (1979) classified fish into 3 groups based on the types of food eaten: microphagous (plantivores and insectivores), mesophagous (eating larger invertebrates such as mollusks, annelids and shrimps) and macrophagous (taking crabs, fish or other vertebrates). He found that microphagous fish evacuated food much faster than macrophagous fish, with mesophagous fish in between them. The fact that macrophagous fish take longer to digest and evacuate their food from their stomachs is because they consume more protein and fat in their diets than microphagous fish. These components need more time and more gastric enzymes to break them down.

Piscivorous fish have considerably slower gastric evacuation rates than fish consuming invertebrates or pellet diets. This may be due to the fact that large particles, such as a whole fish, have a relative small surface area which does not facilitate mechanical and chemical breakdown (Swenson & Smith 1973; Windell 1978). Additionally, prey fish have skin, and skeletons that may digest slowly.

Long period of starvation may reduce gastric evacuation rates. Windell (1978) reported that a 7-day fast decreased gastric evacuation by as much as 22%: after 25-days it was reduced to 51% of the rate with 2-days of starvation. In addition, a long fast can also cause striking morphological changes in the pyloric caeca (Windell 1978; Elliott 1972).

Temperature is the major environmental factor affecting digestion. At low temperatures gastric evacuation rates are greatly depressed, especially near 0°C. As the water temperature rises, gastric evacuation rate increases exponentially until reaching a maximum near the upper temperature tolerance of the species. Beyond this temperature the evacuation rate decreases considerably (Elliott 1972, 1975a, b; Molnar & Tolg 1962a, b; Smith 1967; Molnar et al. 1967; Shorable et al. 1969; Brett & Higgs 1970; Tyler 1970).

Surprisingly, meal size has relatively little affect on digestion rates. Windell (1978) indicates that most data show relatively little effects of meal size on the time necessary for 50% or 100% gastric evacuation, unless abnormally small meals area eaten. He found that the gastric evacuation rate of

rainbow trout (Oncorhynchus mykiss) was independent of the meal size except at ration levels below 0.7% body weight. When the ration levels dropped below 0.7% body weight, fish evacuated their stomach contents very fast. Elliott (1972) also found that there was no significant effect of meal size on the rates of gastric evacuation. One of the reasons for the rapid digestion of small meals is that they have a relatively large surface area to volume ratio, and consequently enzymes can attack the material rapidly. Another reason may be that ration levels below 0.7% body weight can be readily digested by the gastric juice already present in the stomach rather than requiring new gastric enzymes.

Feeding technique also affects fish digestion in experimental studies. There are two major techniques available: force-feeding and voluntary feeding. Handling fish during force-feeding may stress fish. Alexander (1977) pointed out that force-feeding trout decreased their gastric digestion rates 38% below that of fish feeding voluntarily. Similarly, Swenson and Smith (1973) found that force-feeding species decreased digestion rates by 50% (Table 2). Because of this effect, most researchers have turned to voluntary feeding to reduce stress.

LABORATORY METHODS

Rainbow trout and brown trout originally obtained from State hatcheries were held at 10°C water in our laboratory for about two years. These fish were over 400 mm standard length. They were maintained on pellet diets but occasionally fed live rainbow trout. Prior to a digestion experiment they were trained to feed readily on live fish.

The predator fish were acclimated in groups by increasing temperatures upward 2.0°C or downward 1.0°C per day until the experimental temperatures were reached. The predators were then transferred into individual tanks and acclimated to the experimental conditions for 5 additional days during which the fish were fed fingerling trout. The digestion experiments were conducted in round tanks, as preliminary work demonstrated that brown trout become stressed in small, square tanks, and do not feed actively.

Digestion rates of both rainbow and brown trout were measured. When the experiments are completed, we will have tested the former at 14•C and the latter at temperatures of 4°, 9°, 14°, 19°, and 23°C. To date, we have completed experiments at 9°C with brown trout and at 14°C with both species.

Prior to an experiment the trout were starved for periods ranging from 24 to 72 h, as temperatures varied from 4° to 23°C. The piscivorous trout were fed rainbow trout weighing approximately 5g (75 mm total length). This is a size commonly consumed by wild trout (Wurtsbaugh, 1987). The initial dry weight of a prey was estimated by determining the dry:wet weight ratio of ten individual fingerling trout, and multiplying this ratio times the wet weight of the prey.

At the start of a feeding experiment, the prey were weighed and then put into tanks with the predator and the time recorded when the fingerling trout was eaten. At 1-64 hour intervals after the ingestion, prey remains were removed from three predators by gastric levage (Foster 1977), dried and weighed. Preliminary experiments comparing stomach removal and the gastric levage method demonstrated that the flushing technique was 100% effective when used carefully. At a given temperature we measured (or will measure) evacuation rates at the following intervals:

Temperatures (°C)	Intervals (hours after feeding)
4	4, 10, 20, 40, 80
9	4, 8, 16, 32, 64
14	2, 4, 8, 16, 32
19	1, 2, 4, 8, 16
22.5	.8, 1.5, 3, 6, 12

Fifteen fish were tested at each temperature (5 intervals x 3 fish/interval). Gastric evacuation rates were estimated at each temperature by calculating the slope of the regression between time after feeding, and the natural log of percent of the prey remaining in the fishes stomachs. Gut evacuation rates in our experiments were compared to values available in the literature to determine if trout digestion differs substantially from that of other piscivores.

RESULTS AND DISCUSSION

The literature review of gastric evacuation of fifteen species of fish demonstrates that digestion rates increase exponentially with temperature (Figure 1). For piscivorous fish, rates are near 0.02 at 3°C, and increase 10-fold as temperatures reach 25°C. Although there is a good deal of scatter in the data, the relationship between temperature (T) and digestion rate (R) can be fit well by the equation:

$$\text{Log (R)} = -1.742 + 0.044\ (T)$$

$$r^2 = 0.79,\ \ p < 0.000$$

The literature review also demonstrated that small particles are evacuated much faster from guts than are prey fish. The regression for invertebrates or pelleted food showed that these items were evacuated at about twice the rate of prey fish (Figure 1). The fitted regression for the digestion rate of the small food items was:

$$\text{Log (R)} = -1.506 + 0.045\ (T)$$

$$r^2 = 0.56,\ \ p < 0.000$$

Note that the slope coefficients for both types of prey were nearly identical (0.044, 0.045), indicating that temperature increases stimulate digestion similarly in both cases.

Our experiments on brown and rainbow trout suggest that these fish have somewhat higher digestion rates than most piscivorous fish (Figure 1). In part, however, this may be due to the fact that many of the studies reported in the literature have used force-feeding which may have depressed

digestion rates. In addition, we will need to conduct experiments at several other temperatures before we can draw strong conclusions about the relative digestion rates of piscivorous trout.

The rates we have measured for rainbow and brown trout suggest that it takes about 24 hours for a fingerling trout to be evacuated at temperatures of 9 and 14°C, assuming that prey would be completely undetectable after they were 95% digested. (Table 1). In a model to estimate losses of fingerling trout to piscivores, Wurtsbaugh (1987) assumed that prey fish would be evacuated from predators in 24 hours. Consequently, it appears that the gut evacuation parameter used in that model is approximately correct.

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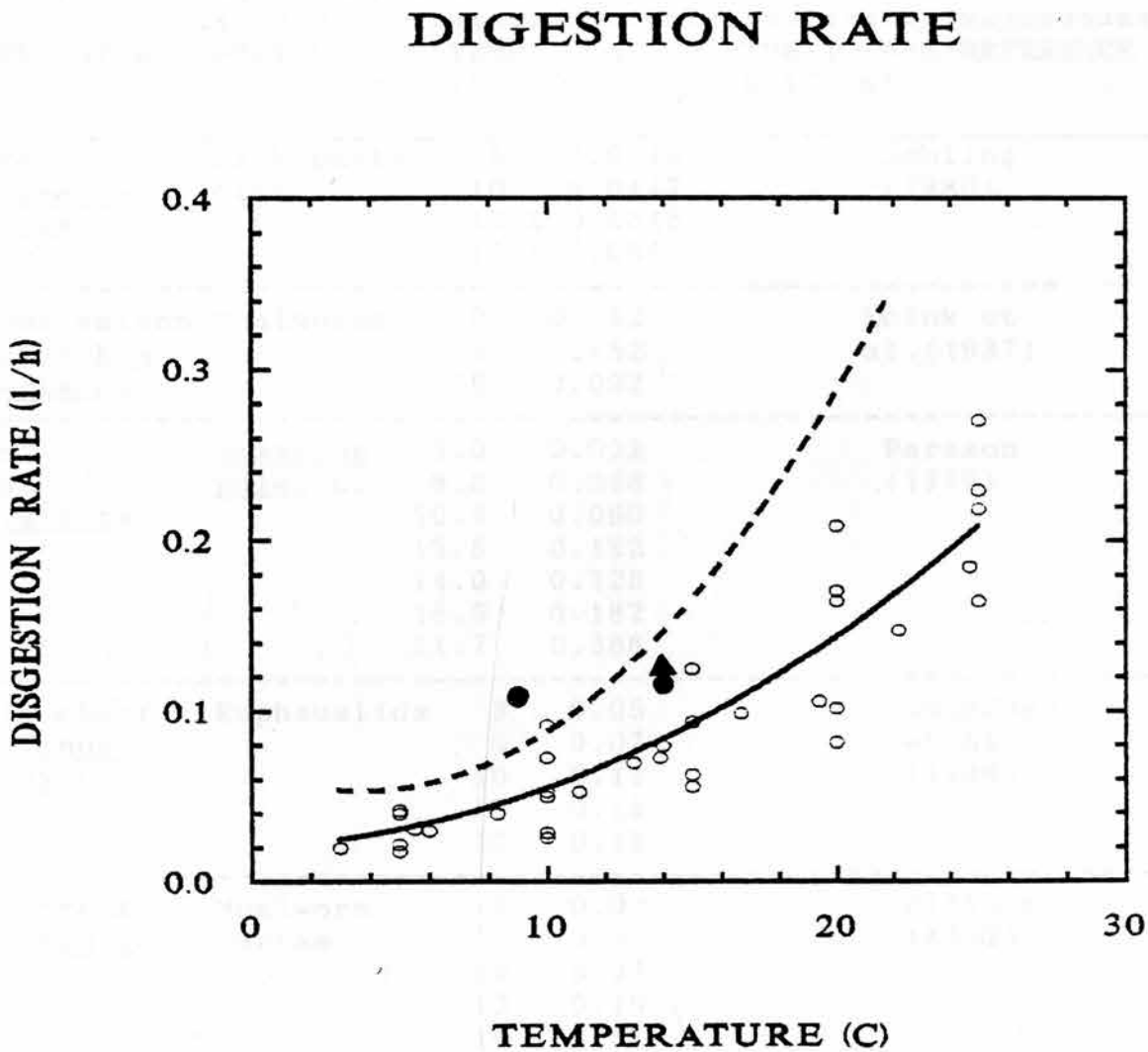


Figure 1. Relationship between temperature and digestion rates in fish. The solid line and data points show the digestion rates of piscivorous fish. Digestion rates of trout measured in our laboratory are shown with solid circles (brown trout), or the solid triangle (rainbow trout). The relationship for fish fed invertebrates or pelleted rations is shown with the dashed line for comparison. The graph was derived from the data given in Table 1.

Table 1. Rates of gastric evacuation of fishes reported in the literature and in our study.

STUDY #	PREDATOR	PREY	TEMP (°C)	R	TIME TO 95% EVAC.(h)	REFERENCE
A	Plaice *Pleuronectes platessa* L.	Fish-paste diet	5	0.0249		Jobling (1980)
			10	0.0447		
			13.5	0.0545		
			15.5	0.0557		
B	Chinook salmon *Oncorhynchus tshawytscha*	Mealworms	10	0.142		Kolok et al.(1987)
			14	0.152		
			15	0.092		
C	Perch *Perca fluviatilis*	*Gammarus pulex* L.	4.0	0.032		Persson (1979)
			8.3	0.058		
			10.4	0.080		
			13.5	0.122		
			14.0	0.125		
			16.5	0.182		
			21.7	0.386		
D	Arctic charr *Salvelinus alpinus* L.	Euphausiids	3	0.05		Amundsen et al. (1988)
			6	0.07		
			10	0.11		
			13	0.16		
			14	0.18		
E	Brown trout *Salmo trutta*	Mealworm larvae	3	0.03		Elliott (1972)
			6	0.05		
			10	0.07		
			13	0.10		
			14	0.12		
F	Brown trout *Salmo trutta*	Gammarus baetis, Chironomidae, Oligochaeta	3	0.07		Elliott (1972)
			6	0.10		
			10	0.16		
			13	0.23		
			14	0.25		
G	Roach	*Chaoborus* sp., *Daphnia* sp.	3	0.05		Persson (1982)
			6	0.06		
			10	0.10		
			13	0.14		
			14	0.16		
H_1	Rainbow trout (*Oncorhynchus mykiss*)	trout fingerling	14	0.126	24	This experiment

H_2	Brown trout *Salmo trutta*	trout fingerling	9	0.11	27	This experiment
			14	0.12	25	
I	Perch *Perca fluviatilis*	Fish larvae	3	0.02	149	Persson (1981)
			6	0.03	100	
			10	0.05	60	
			13	0.07	43	
			14	0.08	37	
J	Sacramento squawfish *Ptychocheilus grandis*	Juvenile chinook salmon	5	0.018	166	Vondracek (1987)
			10	0.026	115	
			15	0.063	48	
			20	0.082	37	
K	Pike-perch *Lucioperca lucioperca*	Fish	5	0.018	257	Molnar et al. (1967)
			10	0.029	157	
			15	0.056	83	
			20	0.102	45	
			25	0.165	28	
L	Sheat-fish *Silurus glanis*	Fish	5	0.022	206	Molnar et al. (1967)
			10	0.053	87	
			15	0.094	49	
			20	0.165	28	
			25	0.230	20	
M	Perch *Perca fluviatilis*	Fish	5	0.040	115	Molnar et al. (1967)
			10	0.073	63	
			15	0.094	49	
			20	0.171	27	
			25	0.219	21	
N	Largemouth bass *Micropterus salmoides*	fish	5	0.042	110	Molnar et al. (1967)
			10	0.092	50	
			15	0.125	37	
			20	0.209	24	
			25	0.271	19	
O	Walleye *Stizostedion vitreum vitreum*	Minnows	5.5	0.031	147.2	Hofmann (1969)
			8.3	0.040	114.7	
			11.1	0.053	86.3	
			13.9	0.073	63.3	
			16.7	0.099	46.6	
			19.4	0.106	43.4	
			22.2	0.148	31.1	
			24.7	0.185	24.9	

Table 2. Effects of force-feeding and voluntary feeding on digestion rates of walleye (Stizostedion vitreum vitreum). Numbers in the parentheses are sample sizes.

Feeding Techniques	% of digestion		Sources
	After 4h	After 8h	
Voluntary feeding	36.0 (30)	60.1 (30)	Swenson &
Force-feeding	18.2 (20)	32.4 (20)	Smith (1972)

PERFORMANCE REPORT

Project Number: F-47-R

Study Number: 2

Segment Number: 4

Title: Evaluation of predation and outmigration upon the loss of juvenile trout from Utah reservoirs.

Project Date: January-December 1989

Purpose: The purpose of this segment was to determine the factors contributing to the loss of juvenile rainbow (Onchorhynchus mykiss) trout stocked into Rockport Reservoir. This project is a continuation of studies which have investigated piscivorous predation, avian predation, and emigration in an effort to explain juvenile trout loss from Utah reservoirs. The first year of this study was designed to identify the major factors contributing to fingerling losses and provide a focus for explaining why these losses occur in Rockport Reservoir.

Study area: Rockport Reservoir was divided into three approximately equal sampling areas. Each area was then divided into sampling units. Littoral units were established parallel to shoreline, 100 meters long and 100 meters wide (Figure 1). Pelagic sampling units were developed as 325 m^2 grids. A total of 27 littoral and 36 pelagic units were established for the entire reservoir.

Methods: Fingerling rainbow trout were planted into Rockport Reservoir in July and September of 1989. Each fingerling stocking was spray-marked with various-colored pigments prior to stocking to identify individual plants. Approximately 100,000 fingerling rainbow trout were planted on each date in 1989. All fish were planted at the boat ramp near the middle of the reservoir at both dates.

The relative abundance and distribution of planted fingerling trout throughout the reservoir was determined by shoreline electrofishing, using a pulsed DC electroshocker mounted on a 16 ft flat-bottom boat. Collections were made weekly following the July stocking and continued until September 18. Seven shoreline sections, distributed among all three areas, were sampled per night (two each in areas 1 and 2 and one in area three). Each section sampled was selected at random and no two sections in a single area were sampled consecutively. Electrofishing began approximately one hour after sunset and typically lasted about 4 hours. Sampling effort was set at 10 minutes of electrofishing per site, and all sampling was done as close to shore as possible. All fish captured were counted, measured for total length, stocking date determined, and returned to the water.

Distribution of adult and sub-adult rainbow trout in Rockport Reservoir was determined by sampling with experimental gill nets monthly between May and September and again in November. Nets were set at in late afternoon and fish were collected the following morning. In 1989 nine nets were set per sampling date: one floating net in an inshore section and a floating and diving net pair in an offshore section within each of the three reservoir study areas. Stomachs of all adult and sub-adult trout and a random sample of Utah chub were collected and preserved in 5% formalin. In addition to lengths and total weight, the number of external parasites and visceral fats were recorded from all trout. On

the same date that gill nets were set, temperature profiles and zooplankton collections were made from offshore and inshore sites within each study area. Duplicate samples were taken from each zooplankton collection site.

The abundance of avian piscivores at Rockport Reservoir in 1988 were determined by visual counts. Counts were made in the evening, twice a week between mid March and mid September 1989. All observations were made through a tripod-mounted 16 x 60X spotting scope from the same four sites overlooking the entire reservoir. A fish trap was constructed and used to sample the reservoir spillway to determine the incidence of out-migration of fingerling rainbow trout. The apparatus consisted of two panels which directed all incoming fish into a center trap with a removable top. Fish were netted from the trap, identified, and counted and the apparatus checked for maintenance at least once daily. The trap was installed on March 21 and dismantled on September 14.

Findings:

Thermal stratification occurred in Rockport Reservoir through July and August (Figure 2). Thermocline depths were near 10 meters in areas 1 and 2 and approximately 3 meters deep in the upper end of the reservoir (area 3). Zooplankton densities were highest in spring and fall and exhibited similar trends among areas (Figure 3). Lowest Daphnia spp. densities were observed in area 1 for the two months following the July fingerling trout stocking. Little differences in offshore and inshore number of Daphnid spp. occurred between May and November. The slight differences in spring and early summer may be attributed to differences in thermocline depth.

Gill net catch rates varied by species and time throughout the lake (Figure 4). Adult rainbow trout were captured in greatest numbers in the upper end of the reservoir (area 3) May through November excluding June when abundance was highest in the deepest end of the reservoir (area 1). Gill net catches of adult rainbow trout were greater during the cooler months of May, June, and November and lower during the warmer months of July and August. Adult Utah chub numbers were consistently high from May through September. Capture rates of chub were lowest in November. The highest abundance of chub occurred in area 3 from May through November with increasing numbers of chub being sampled from areas 1 and 2 as the summer progressed.

Electrofishing indicated that fingerling trout utilized area 1 at a greater rate than areas 2 or 3 during the summer months. Numbers of stocked fish declined weekly from 49 fish in August to 9 fish per electrofishing effort in the first week of September (Figure 5). Following the decline of the July stocking, planted rainbow trout were found in the Weber River which flows into Rockport Reservoir. These fish were first observed in mid-September and monitored through December. Fish from the July stock dominated the population of stocked fish found in the Weber River even though fish from the September stock were present. Although the stocked fish were found in the inflowing river, they tended to inhabit a small stretch (100 yards) of the river approximately 1 kilometer from the lake. Stream electrofishing indicated that trout stocked into Rockport Reservoir did not move further up the Weber River.

Mean lengths of stocked rainbows ranged from approximately 120 mm to 170 mm during a 2-month period from August through September (Figure 6). Growth of fingerling trout in Rockport Reservoir occurred at a rate similar to that observed by Wurtsbaugh and Tabor (USU, personal communication) in East

Canyon and Causey Reservoirs (Figure 7). Visceral fat content dropped throughout the summer for the planted fingerlings. Adult trout increased fat levels from May until July at which time fat levels began to decrease until September (Figure 8). From September until November fat levels increased. September population estimates of the July stock and adult rainbow trout in the reservoir using Peterson's mark and recapture methods were 16,800 and 16,000 fish respectively. However, because of population estimates utilized the September plant as the marked component, if many of the July plant had migrated offshore the population estimate of fingerling trout would be underestimated.

Bird counts taken throughout the summer indicated moderate numbers of gulls and western grebes utilizing the lake. Grebes were observed feeding at most times of the day. The majority of the gulls observed on the reservoir were resting on the large mud flats area of the reservoir. The only indication of gull predation on the stocked fish occurred during a 12-24 hour period following stocking. The highest density of western grebes occurred during May with < 100 birds/day (Figure 9). The highest densities of gulls occurred in September with < 400 birds/day. Average bird numbers were approximately 200 gulls and 30 western grebes per day.

Fish trap capture rates indicated that few if any adult rainbow trout left the reservoir between May and September. The highest number of rainbow trout caught in the trap occurred during June when 5 fish were collected on a single date. Juvenile rainbow trout were too small to be collected by the trap and thus emigration could not be determined.

Future direction: The past year's study plans deviated from the approved project plan by the failure to determine vertical and horizontal distribution of fingerling trout with fine mesh gill nets. Greater effort than was expected was directed toward acquiring and maintaining the fish trap below the reservoir. The first year's data suggested that bird predation was not a factor contributing to fingerling trout loss. In addition, brown trout were not collected in large numbers and those that were did not have fingerling trout in their stomachs. However, zooplankton collections did indicate that tropic resources may be low during the summer months in those areas that fingerling trout occupy most frequently. Efforts in the coming year will be focused upon zooplankton availability, vertical and horizontal distribution of fingerling trout, and methods for determining the extent of emigration.

Principal Investigator: Timothy Modde.

FIGURE LEGENDS

Figure 1. Rockport Reservoir study areas boundaries with sampling grids delineated within areas.

Figure 2. Monthly temperature profiles within study areas at Rockport Reservoir during the spring, summer, and fall of 1989.

Figure 3. Numbers of Daphnia spp. by area and between inshore and offshore (among all areas) collection sites from Rockport Reservoir during 1989.

Figure 4. Distribution of rainbow trout and Utah chub by area and month from Rockport Reservoir during 1989.

Figure 5. Distribution and relative abundance of rainbow trout fingerlings stocked in Rockport Reservoir 29 July 1989.

Figure 6. Summer growth (total length) of rainbow trout fingerlings stocked into Rockport Reservoir 29 July 1989.

Figure 7. Growth of fingerling rainbow trout from Rockport, East Canyon, and Causey Reservoirs.

Figure 8. Visceral fat index of fingerling and adult rainbow trout collected from Rockport Reservoir during 1989.

Figure 9. Abundance of western grebe and California gulls on Rockport Reservoir during the spring and summer months of 1989.

Figure 1

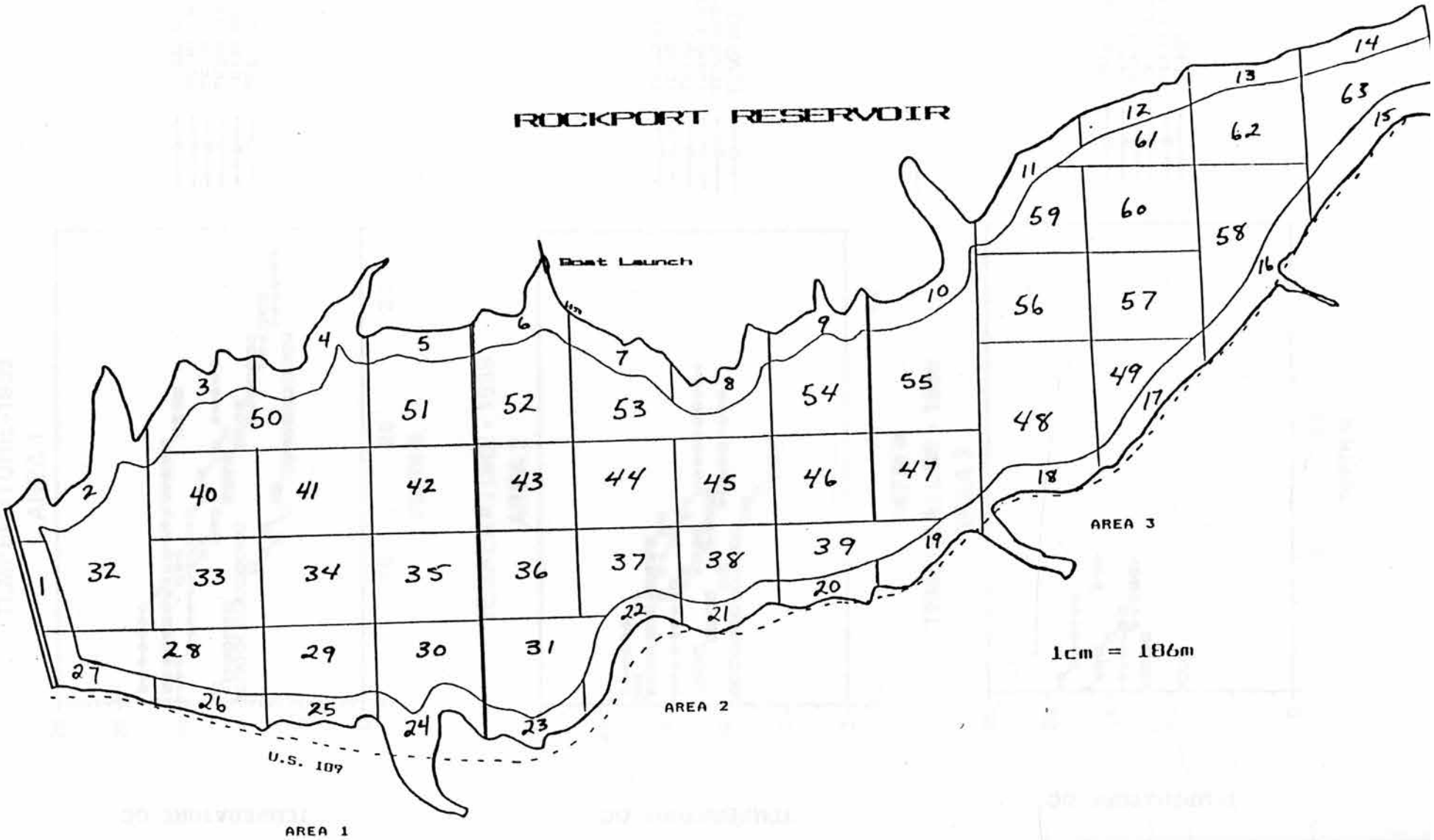
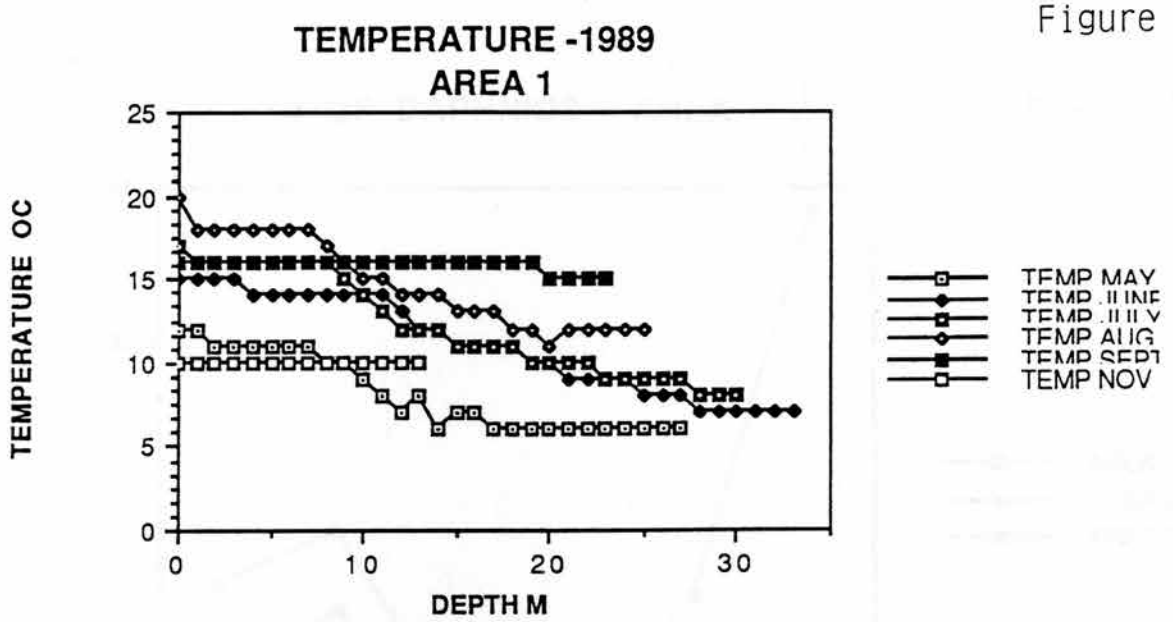

ROCKPORT RESERVOIR
Boat Launch
AREA 1
AREA 2
AREA 3
U.S. 109
1cm = 186m

Figure 2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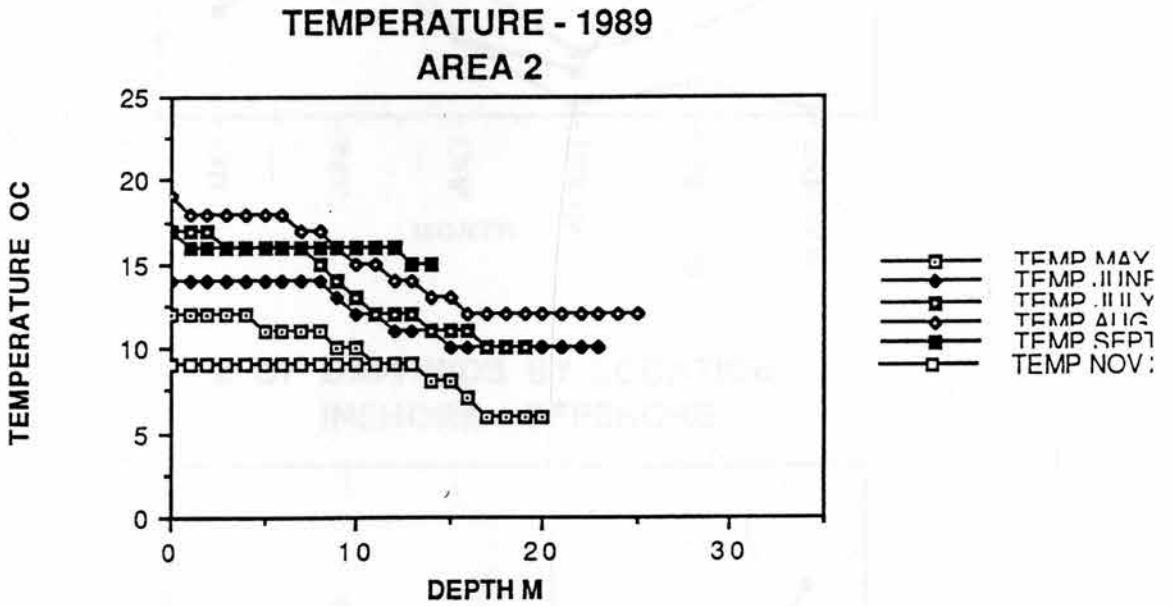
TEMPERATURE OC
DEPTH M
TEMP MAY
TEMP JUNE
TEMP JULY
TEMP AUG
TEMP SEPT
TEMP NOV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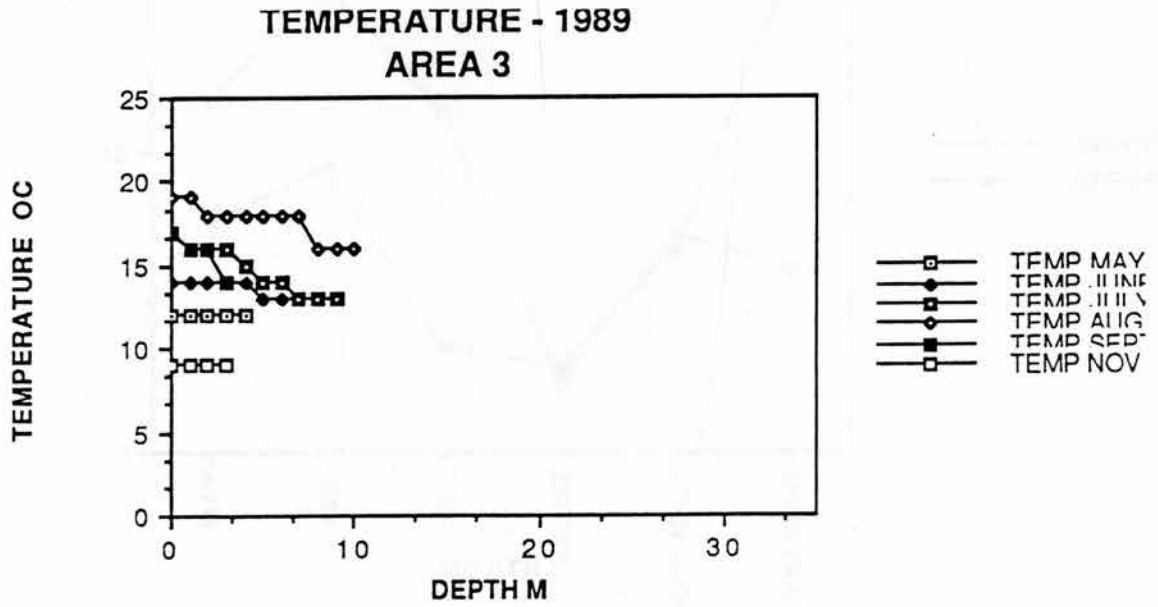
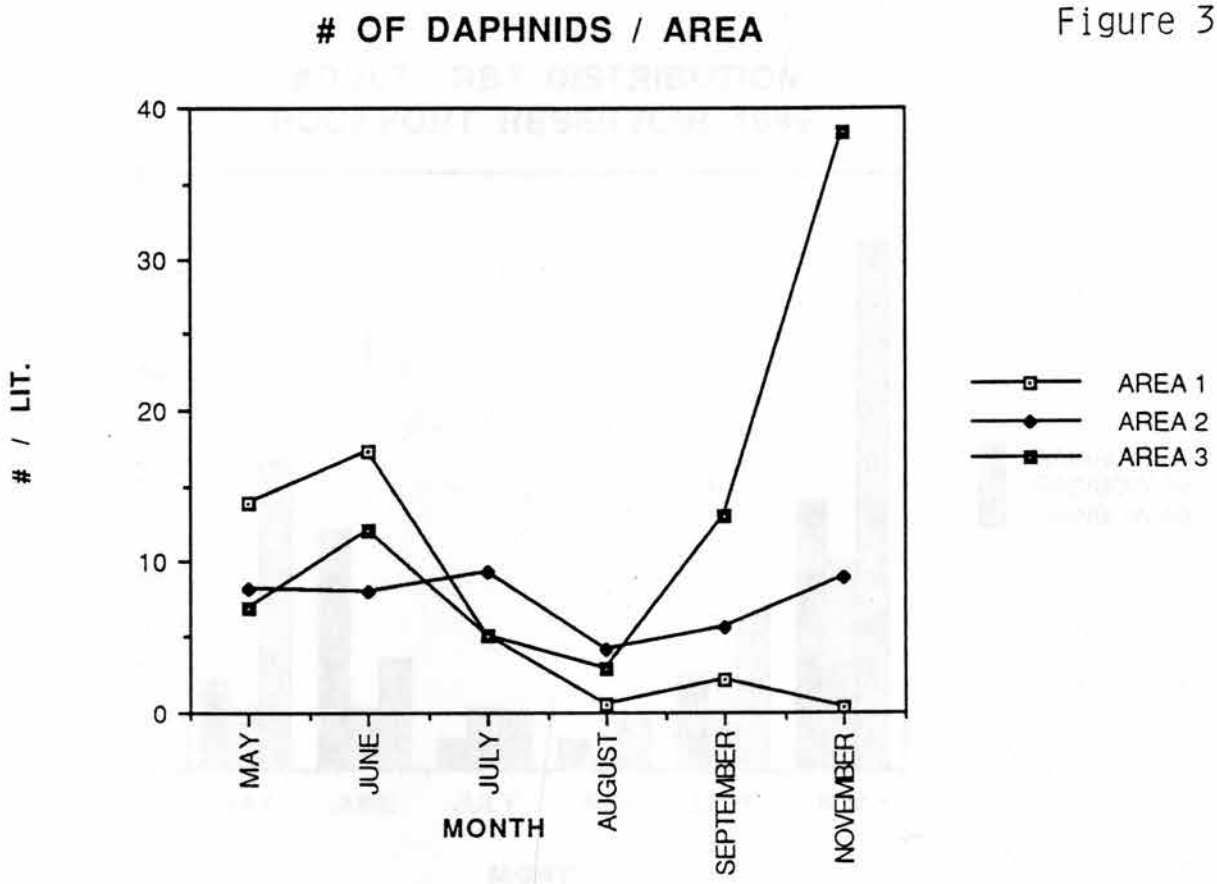
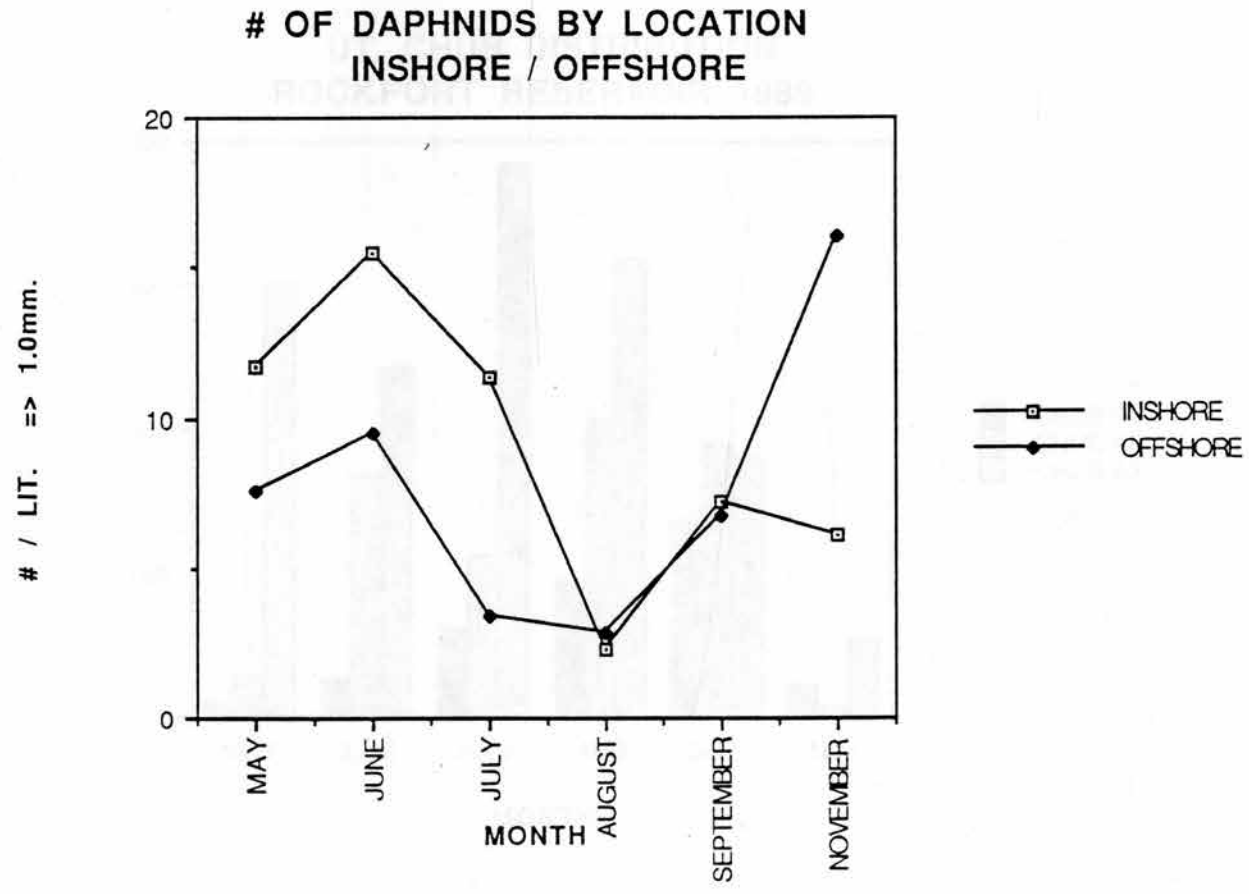

TEMPERATURE - 1989
AREA 3
TEMPERATURE OC
DEPTH M
TEMP MAY
TEMP JUNE
TEMP JULY
TEMP AUG
TEMP SEPT
TEMP NOV

Figure 3


OF DAPHNIDS / AREA
/ LIT.
40
30
20
10
0
MAY
JUNE
JULY
AUGUST
SEPTEMBER
NOVEMBER
MONTH
AREA 1
AREA 2
AREA 3


OF DAPHNIDS BY LOCATION
INSHORE / OFFSHORE
/ LIT. => 1.0mm.
20
10
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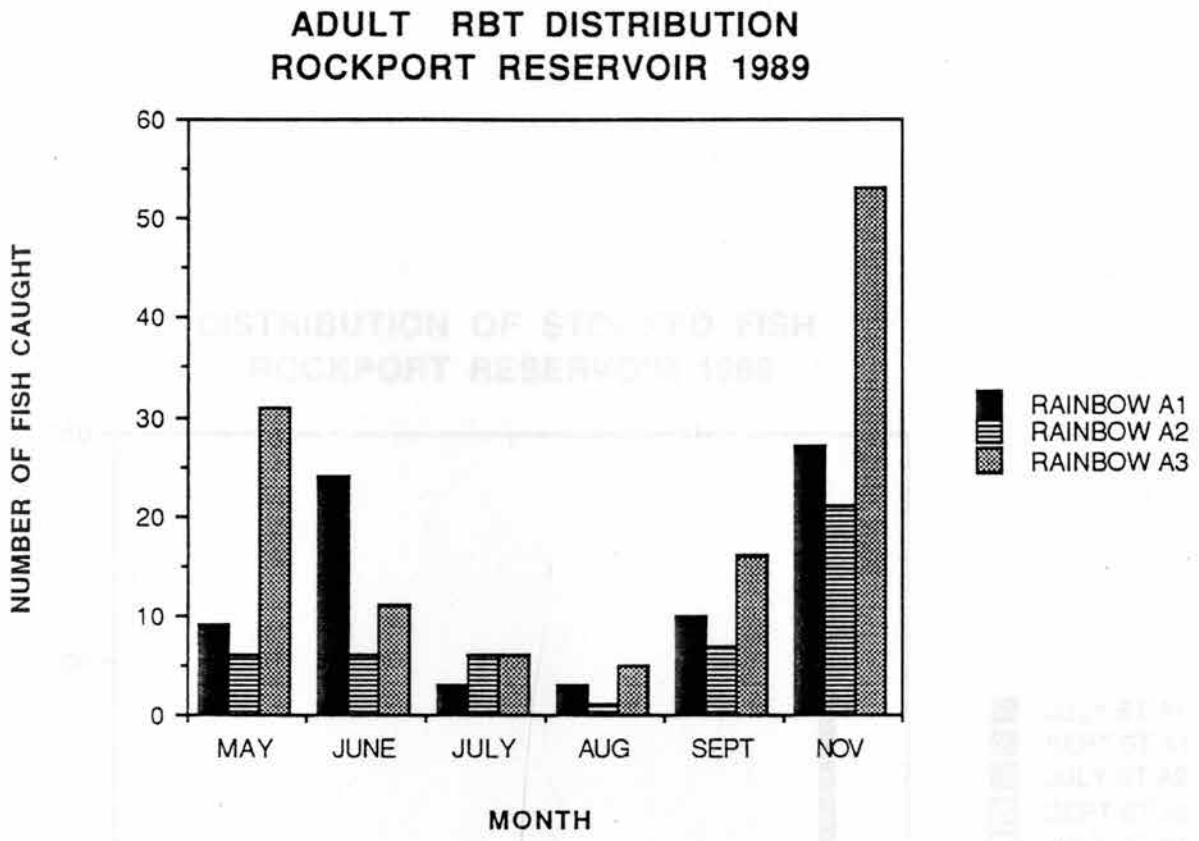
MAY
JUNE
JULY
AUGUST
SEPTEMBER
NOVEMBER
MONTH
INSHORE
OFFSHORE

Figure 4


ADULT RBT DISTRIBUTION
ROCKPORT RESERVOIR 1989
NUMBER OF FISH CAUGHT
60
50
40
30
20
10
0
MAY
JUNE
JULY
AUG
SEPT
NOV
MONTH
RAINBOW A1
RAINBOW A2
RAINBOW A3

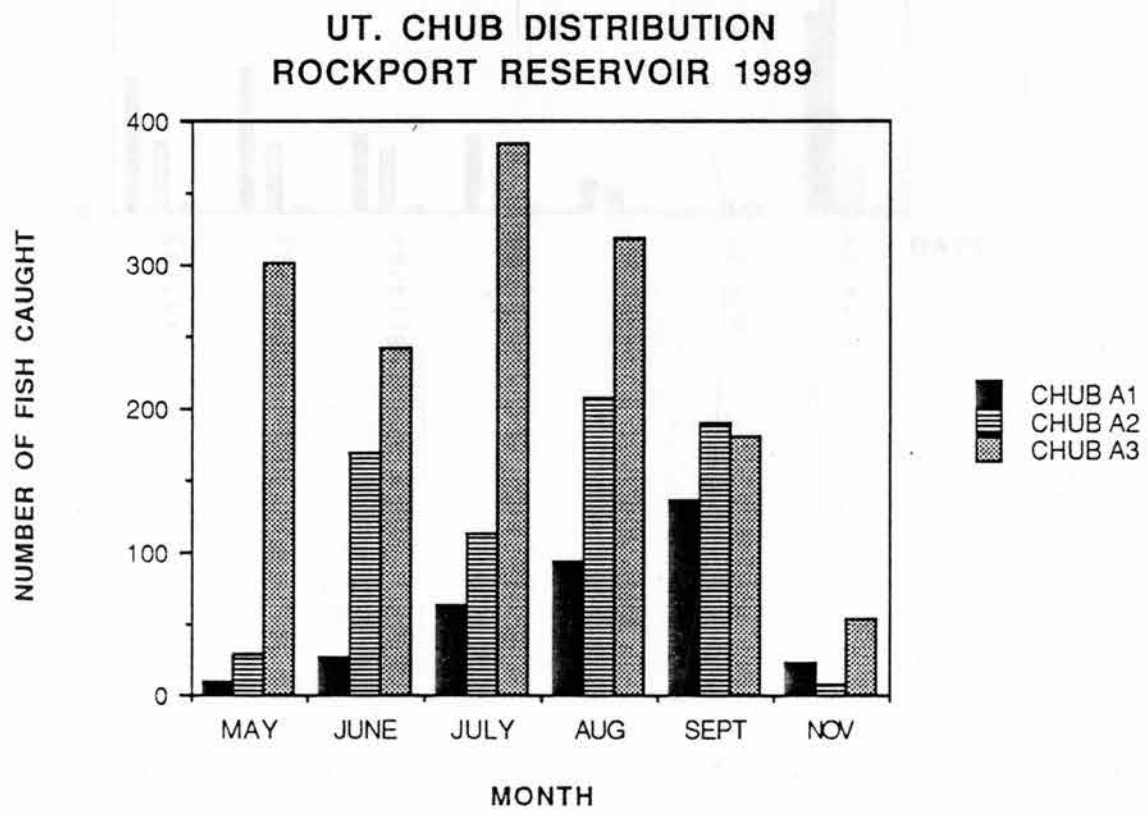
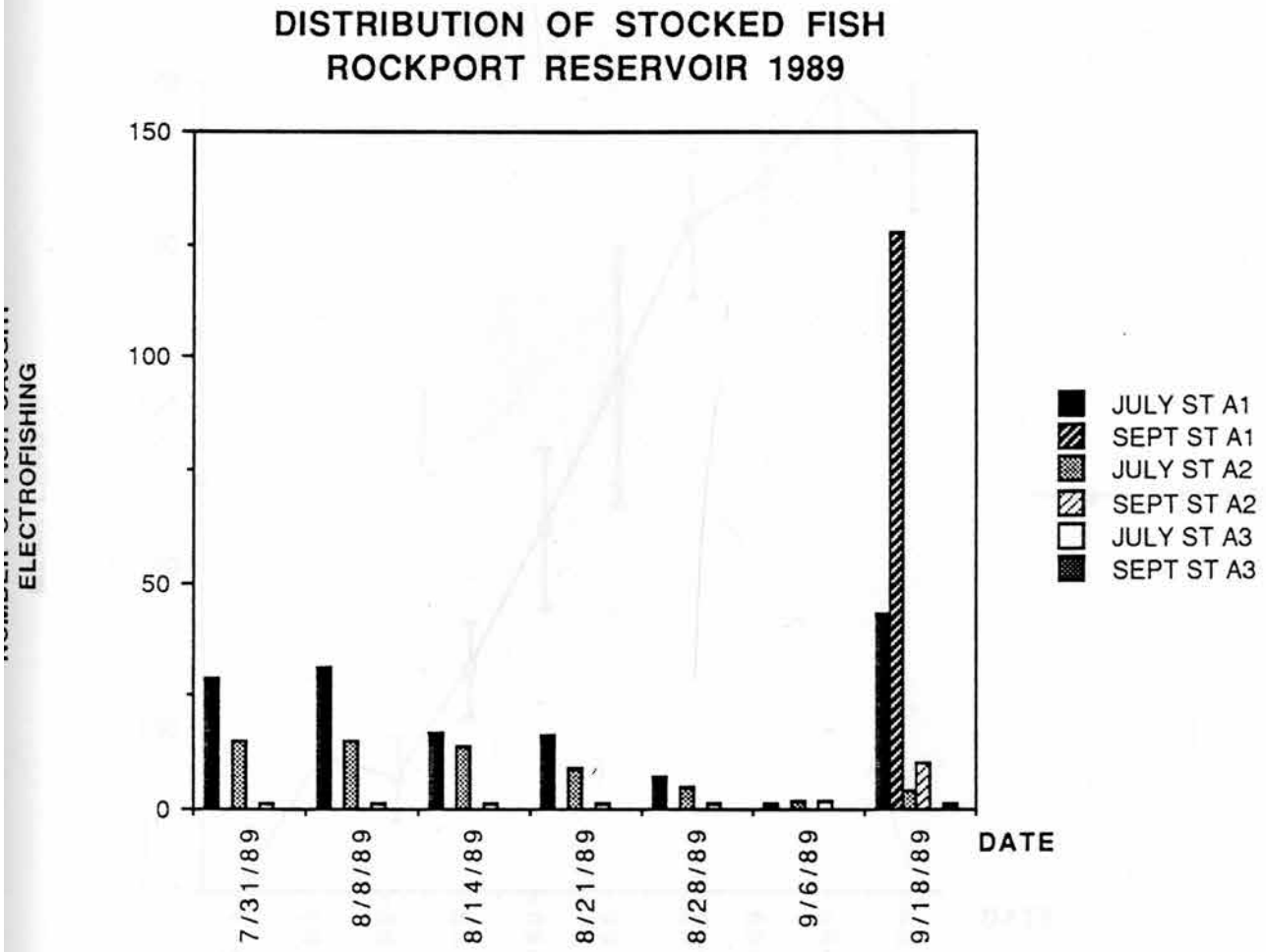

UT. CHUB DISTRIBUTION
ROCKPORT RESERVOIR 1989
NUMBER OF FISH CAUGHT
400
300
200
100
0
MAY
JUNE
JULY
AUG
SEPT
NOV
MONTH
CHUB A1
CHUB A2
CHUB A3

Figure 5


DISTRIBUTION OF STOCKED FISH
ROCKPORT RESERVOIR 1989
ELECTROFISHING
150
100
50
0
7/31/89
8/8/89
8/14/89
8/21/89
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JULY ST A1
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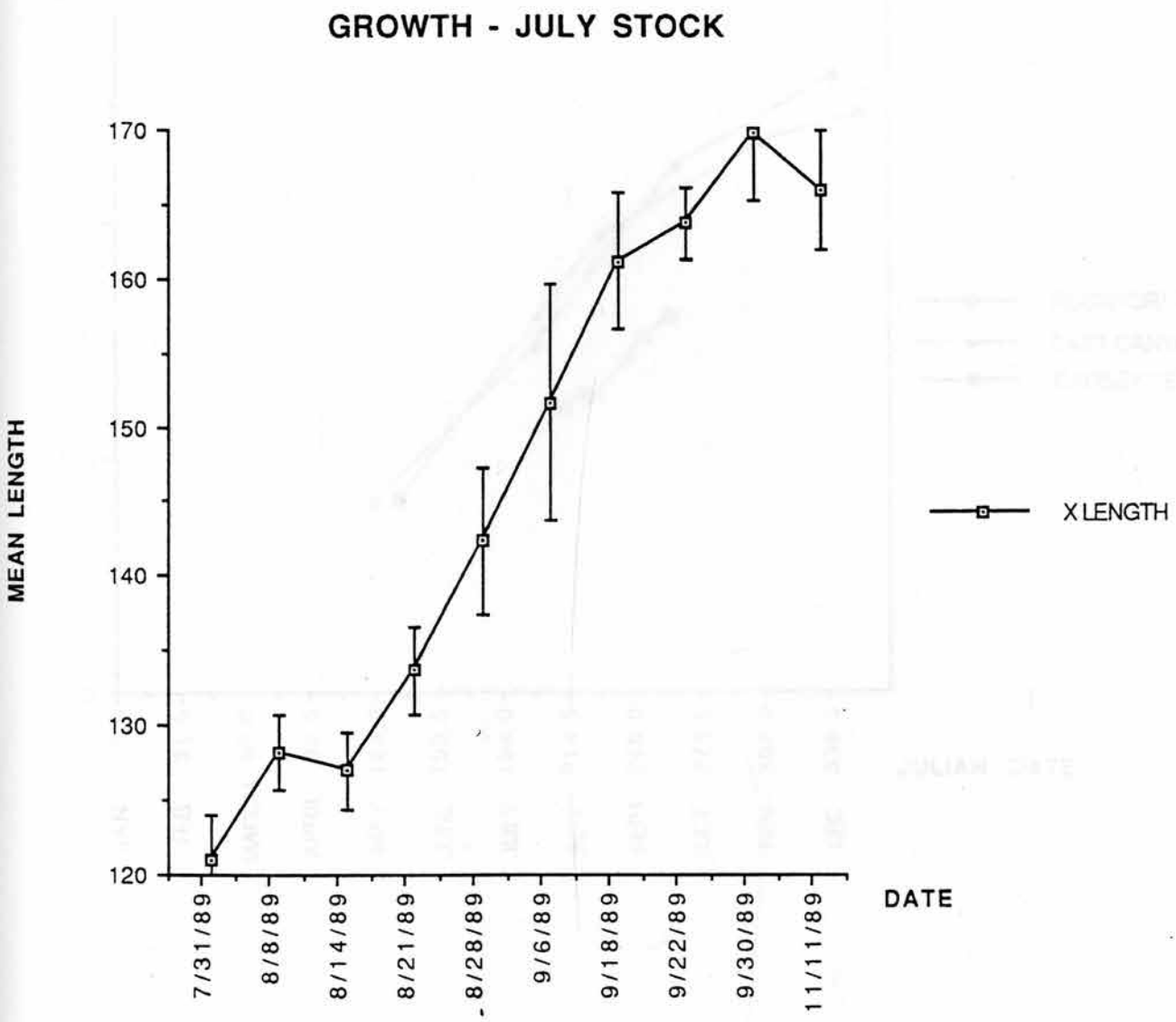
Figure 6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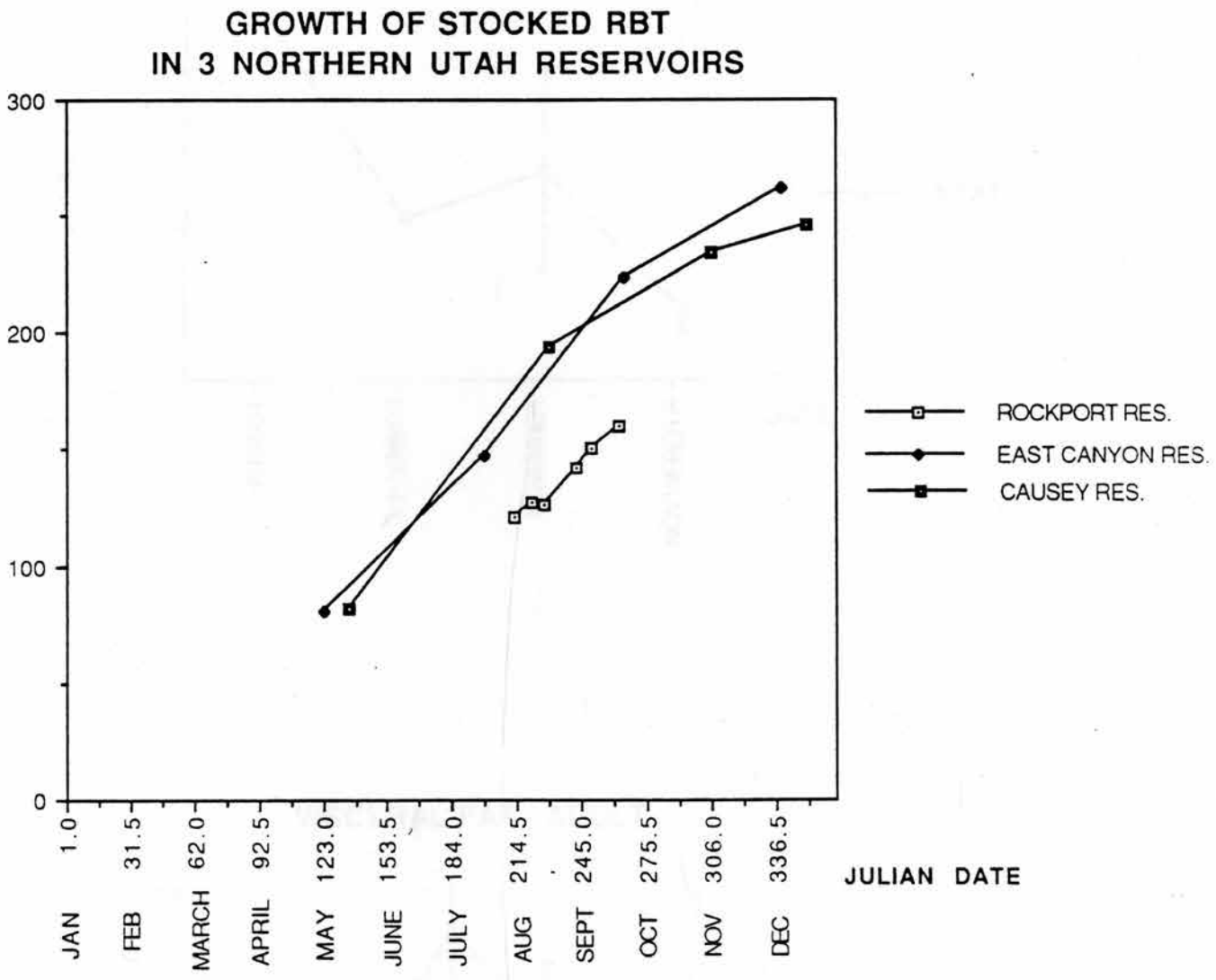
X LENGTH

Figure 7


GROWTH OF STOCKED RBT
IN 3 NORTHERN UTAH RESERVOIRS
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100
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62.0
92.5
123.0
153.5
184.0
214.5
245.0
275.5
306.0
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JAN
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ROCKPORT RES.
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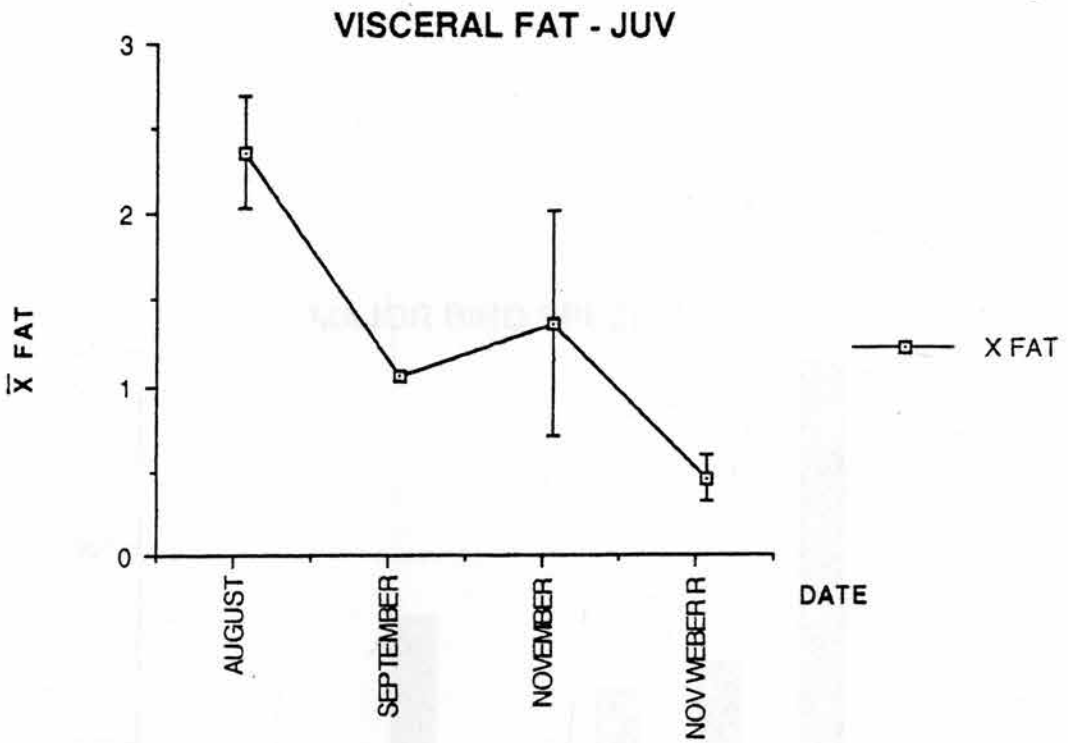
Figure 8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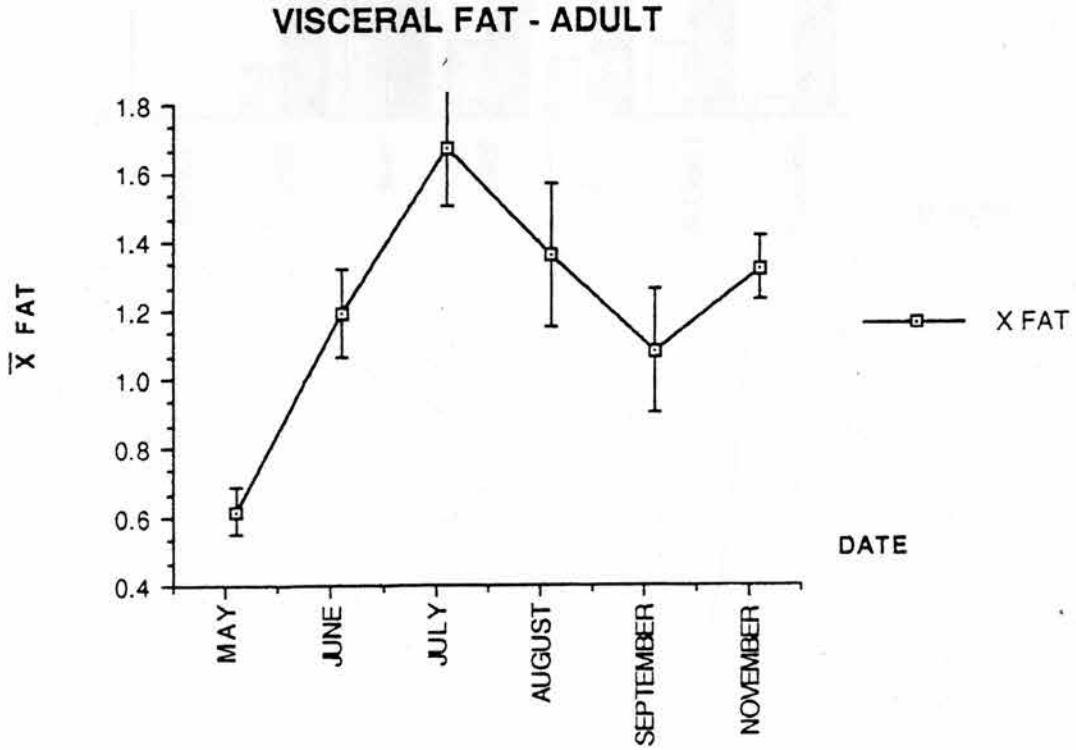
VISCERAL FAT - ADULT
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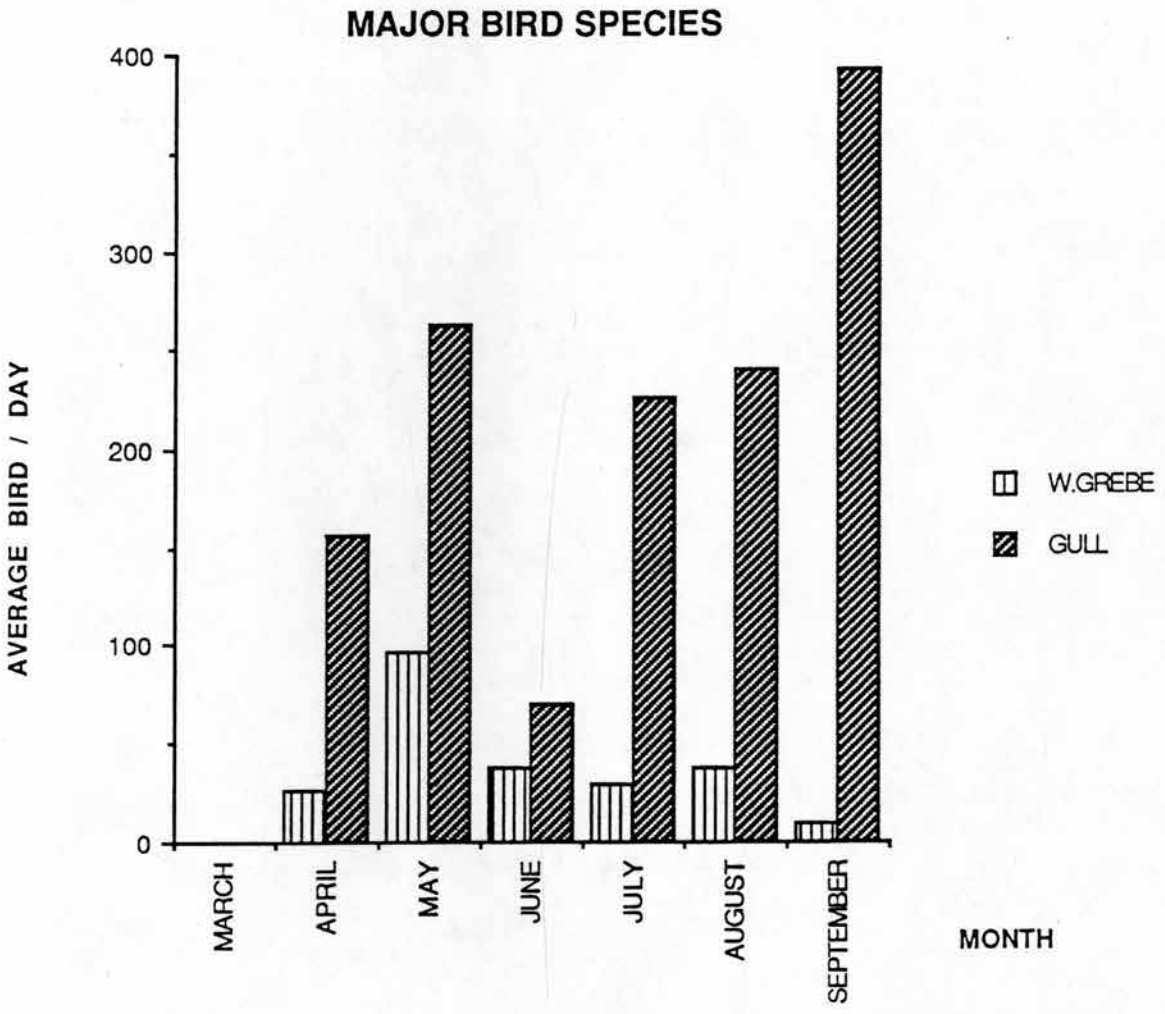
Figure 9


MAJOR BIRD SPECIES
AVERAGE BIRD / DAY
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300
200
100
0
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
MONTH
W.GREBE
GULL

PERFORMANCE REPORT

Project Number: F-47-R

Study Number: 3

Segment Number: 4

Title: Evaluation of reservoir fish stock assessment methodologies

Project Date: January 1-December 31, 1989

Purpose 1: Explore feasibility of using hydroacoustics and trawling to assess forage stocks

Progress Summary: A hydroacoustics survey of Flaming Gorge Reservoir conducted in August by towing a surface transducer along 42 transects. Forage fish densities were high in epilimnetic regions of the canyon and inflow area, averaging approximately 8 fish per 1000 m^3. Abundance of forage fish was 75% lower in the open hills area. Very few fish were found below 30 m in any area. A trawling and hydroacoustics study was conducted in September and indicated that these two gears provide similar density estimates, but that the hydroacoustics was only moderately successful at discriminating sizes of fish.

Purpose 2: Predict lake trout responses to restrictive regulations.

Progress Summary: Simulations using Taylor's Generalized Inland Fisheries Model indicated that all proposed regulations would result in greater numbers of trophy fish caught, lower overall yields, and higher consumption of forage fishes. Slot length restrictions of 28-36" and 26-36" provided near maximum trophy fish and had the least reductions in yield and in forage consumption.

Purpose 3: Compare forage abundance with lake trout consumption.

Progress Summary: Bioenergetics models of lake trout growth dynamics are being formulated. Initial simulations indicated that additional data concerning diet were needed. Plans are being made to collect this data.

Principal Investigator: Chris Lueke

Cooperator/ project support: Utah Division of Wildlife Resources

Schedule: 1989

Investigator: Chris Luecke

Objectives:

1. Explore the feasibility of using hydroacoustics and trawling to assess prey stocks for lake trout in Flaming Gorge Reservoir

2. Develop methods for modeling and predicting lake trout responses to restrictive harvest regulations

3. Compare abundance of prey for lake trout in Flaming Gorge Reservoir to potential consumption demand

Results: This study utilizes population and energetics modeling techniques to estimate how consumption of prey fishes by lake trout will change under various harvest regulations. Results from this first year indicate that total food consumption by lake trout was 20% of biomass of small fishes in the lake, estimated from samples of 40 hydroacoustic transects conducted in August.

Future plans: Yearly assessment of forage fishes will continue to examine how prey availability will change in future years.

SURVIVAL OF TROUT STRAINS AS AFFECTED BY LIMNOLOGICAL PARAMETERS

PROJECT #F47-R, Segment #4, Study #4

EVALUATION OF RESERVOIR STOCK ASSESSMENT METHODOLOGIES

ANNUAL REPORT

CHRIS LUECKE

DEPARTMENT OF FISHERIES AND WILDLIFE

UTAH STATE UNIVERSITY

December 12, 1989

This annual report is broken down into three sections. The first concerns the response of the lake trout populations to various harvest restrictions. The second section deals with assessment of forage fish populations using hydroacoustics. And the third section discusses the calibration of hydroacoustics with data collected from a midwater trawl. Figures and tables are numbered consecutively within each section.

RESPONSE OF THE LAKE TROUT POPULATION TO HARVEST RESTRICTIONS

An age structured population model (GIFSIM, Taylor 1981) was used to assess potential changes in lake trout population abundance and size structure to changes in the harvest regulations in Flaming Gorge Reservoir. In this model, an initial recruitment of fishes is followed as mean size of individuals changes resulting from a growth function and numbers decrease resulting from natural and fishing mortality. We examined 7 harvest scenarios, including the previous two fish limit and 6 slot limits whereby fish could not be harvested if their lengths fell within the slot (Table 1).

A number of assumptions were made in these simulations. Recruitment of age 3 fish was assumed to be 10,000 individuals per year. Because we were interested in relative changes in harvest of lake trout, any initial number could have been used. The value chosen is probably smaller than what occurs in the reservoir (Wengert et al. 1985). Both growth and mortality rates are density independent, and fish caught and then released suffer a 15% mortality rate (Loftus et al. 1988).

Natural and fishing mortality was estimated by counting returns of marked fish in the creel according to the methodology of Ricker (1975). Annual natural mortality was estimated at 0.22 for all age classes and fishing mortality for non-protected age classes was 0.12.

Growth rate of individuals fish was estimated by comparing the lengths and weights of marked fish during initial capture and subsequent recapture. A length-weight regression was calculated from fish collected in gill nets during 1981-1988.

$$W = 1.54 \times 10^{-7} L^{3.65}$$

Results from the GIFSIM model were used as input to a bioenergetics model to estimate how likely changes in population structure would result in changes in the consumption dynamics of the lake trout. The bioenergetics model for lake trout was developed by Stewart et al. (1983), and is based on the following mass balance equation:

$$C = G + R + F + U + SDA$$

where C is total consumption in grams, G is growth in grams, R is losses due to respiration populations, F represents egestion and U is excretion. The unit for each term is grams. The currency of the model is calories and thus caloric equivalents for food items and lake trout varied. The model runs on a daily time step.

Growth rates for lake trout were estimated from changes in weights of individual marked fish that were recaptured. Respiration varied as a function of fish weight and temperature. F, U, and SDA varied as functions of food ingested and temperature. Lake trout were assumed to occupy water with temperatures as close to 12°C (the optimum for growth) as possible. Temperature information for Flaming Gorge Reservoir comes from Schmidt et al. (1982). Lake trout diets were assumed to consist entirely of fish.

Results of the GIFSIM simulations (Table 1) indicated that abundance of older age lake trout would be higher under all of slot limits proposed (Fig. 1). The 24-36" slot would likely result in the greatest increase in lake trout biomass as a large proportion of the catchable population would be protected.

Yield from the fishery (biomass of fish harvested) would decrease with the imposition of all slot restrictions (Fig. 2). Reductions in yield would be greatest under the 24-36" slot limit. Harvest of

lake trout over 20 lbs would be higher over all slot regulations with the greatest increase occurring with the 24-36" regulations.

Bioenergetics simulations of lake trout populations indicated that the consumption of forage fishes was greater under all slot restrictions due to the increase in lake trout biomass (Fig. 2). Forage available to individual lake trout increased with fish length (Table 2). Yearly consumption of forage by individual lake trout increased and conversion efficiency decreased with lake trout size.

Two benefit-cost curves were derived from the information in the simulations. If decrease in yield and increase in trophy fish harvested are weighted equally (based on proportional change from the previous conditions), the 26-36" slot restrictions provide the greatest benefit per cost (Fig. 3). The 24-36 and 28-36" slots are also highly valuable. If the proportional increase in forage demand is included as a cost of the management restrictions, the 28-36" slot restrictions provide the highest benefit (Fig. 3).

The relative weightings of changes in yield, harvest of trophy fish and pressure on the forage base have not been specified. Surveys of lake trout fisherman have indicated a bimodal populations with many fisherman indicating a preference for more smaller fish and others indicating a preference for a few trophy fish (Schneidervinn, pers. comm.). We presently have no information concerning the recreational value these two groups of fisherman place on their fishing trips. Additional survey work could be conducted to determine these values and give appropriate weight to the variables. Evaluating the costs of increasing the forage demand is more problematic. Yearly assessment of forage demand compared with estimates of forage fish abundance could provide a sliding scale whereby consumption demand becomes more important as available forage declines. Weighting consumption demand equally with yield and trophy harvest is a conservative approach, decreasing the potential for trophy harvest but lessening the consumption demand placed on the forage base for lake trout in Flaming Gorge Reservoir.

Table 1. Variables use in GIFSIM simulations, except for growth (see Table 2).

Simulation type	Previous conditions (2 fish limit) 20-30" slot limit 24-32" slot limit 24-34" slot limit 24-36" slot limit 26-36" slot limit 28-36" slot limit
Initial Population Size	10,000 age 3 fish
Recruitment	10,000 age 3 fish per year
Natural mortality	0.22
Fishing mortality	0.12
Hooking mortality	0.15

Table 2. Growth parameters used in Gifsim and bioenergetics simulations.

Age Class	Length (mm)	Weight (g)	P-value
3	378	388	0.369
4	429	601	0.323
5	442	680	0.447
6	493	1013	0.560
7	577	1798	0.580
8	650	2972	0.674
9	729	4217	0.574
10*	763	4999	0.6
11*	796	5842	0.6
12*	824	6615	0.6
13*	854	7356	0.6
14*	882	7865	0.6
15*	908	8316	0.6

* indicates weight was estimated from bioenergetics models assuming a P-value of 0.6.

Fig. 1. Changes in abundance of different age classes of lake trout in Flaming Gorge Reservoir under different regulation type derived from GIFSIM output. Previous refers to havest regulations present prior to 1989, 20-30 refers to a slot limit of 20-30 inches; other slot limits are also shown. Simulations based on adding 10,000 3+ recruts per year.

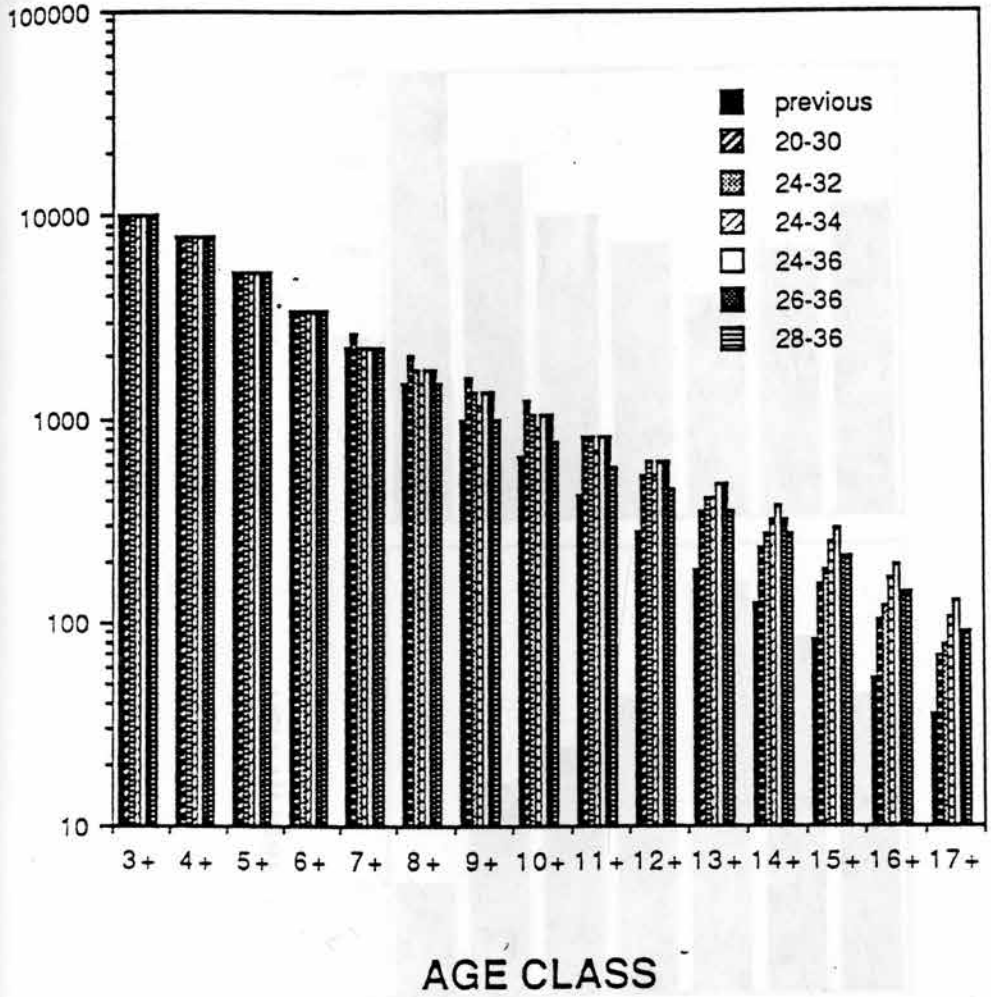


Fig. 2. Changes in total yield (top), harvest of trophy fish (middle), and consumption of forage fishes under different types of harvest regulations. Regulation types as in Fig. 1. Trophy fish are those greater than 20 lbs. Yeild is in kilograms, consumption in kg x 1000, and trophy fish in numbers. Yeild and trophy fish are from GIFSIM simulations; consumption from bioenergetics simulations. Results are based on adding 10,000 recruits per year; actual values are roughly twice that amount.

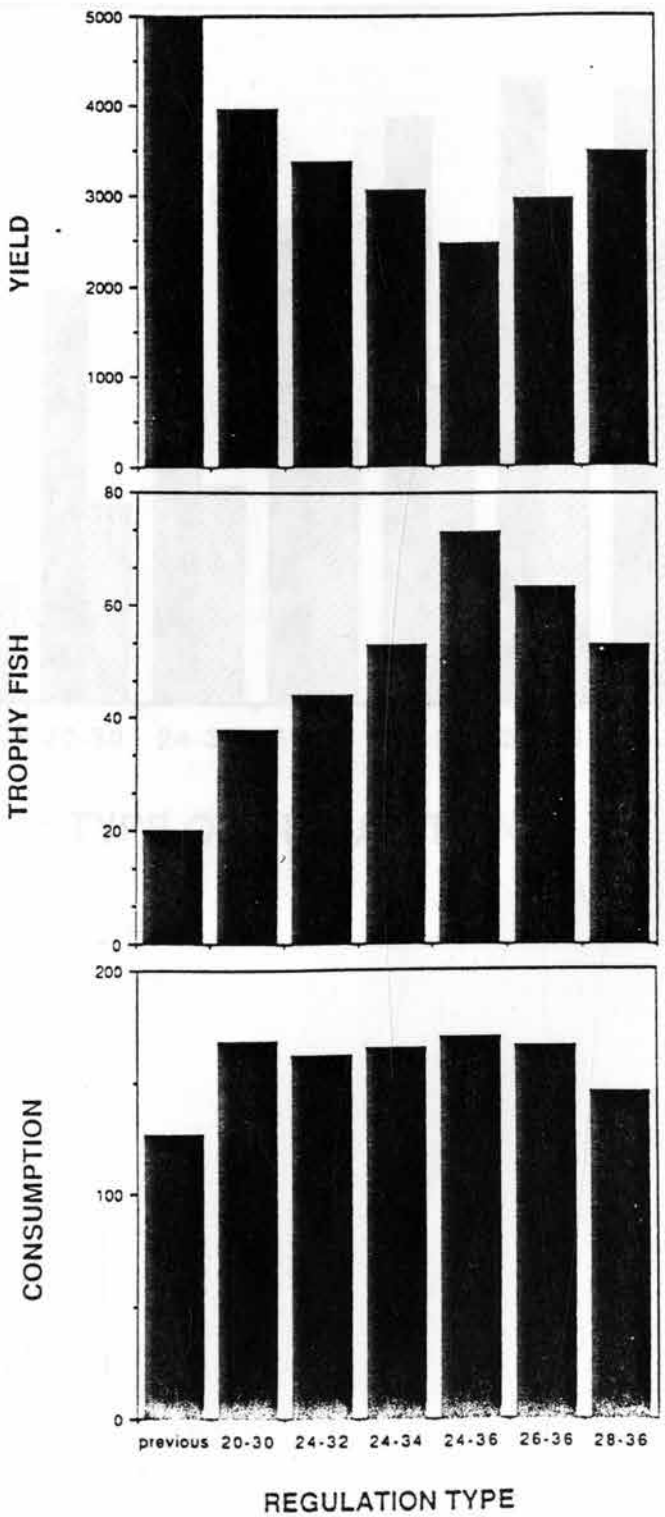
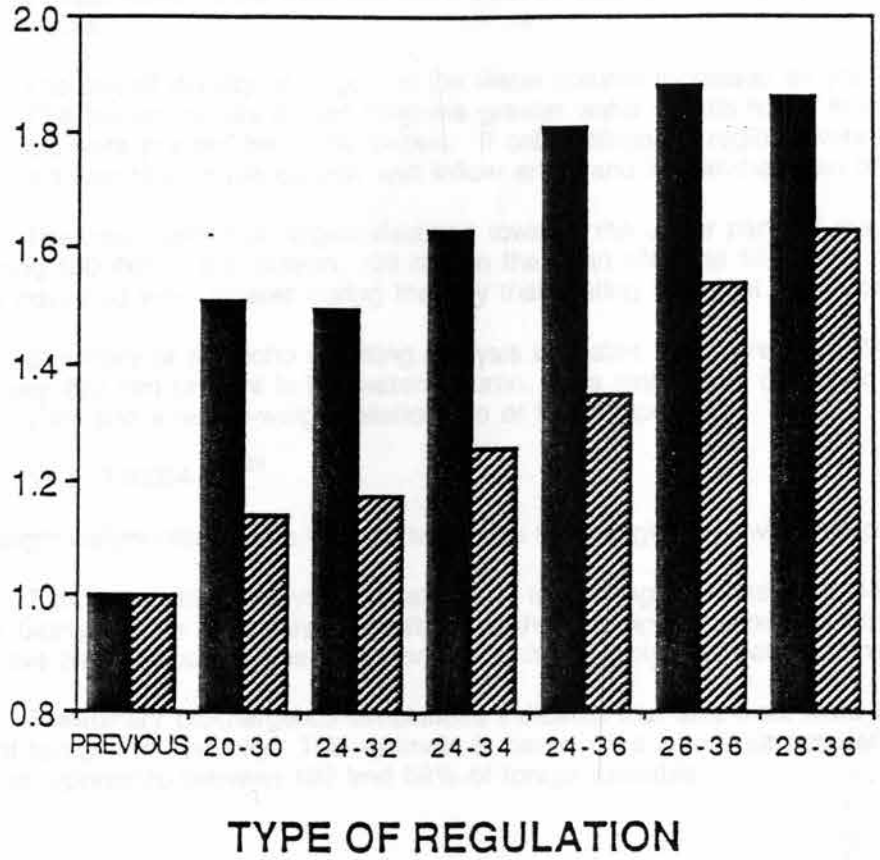


Fig. 3. Relative benefits per cost for implementing different harvest regulations based on GIFSIM and bioenergetics simulations. Solid bars represent benefits/cost if decreases in yield and increases in trophy fish harvested are used. Stipled bars represent benefits/cost when proportional increase in forage demand is included as a cost.



ACOUSTICS ASSESSMENT OF FORAGE FISHES IN FLAMING GORGE RESERVOIR

Between July 31 and August 9, 1989 a hydroacoustics survey of fish was conducted in Flaming Gorge Reservoir. Cross-reservoir transects were conducted in the canyon (23 sites), open hills (12 sites) and inflow areas (6 sites) by running a surface-towed dual beam transducer (420 kHz, 6 and 15°) off the front of the boat. Data were analyzed using echo counting techniques. The target strength of each echo returned was calculated and converted to fish length using Love's (1971) empirical relationship. Data were collected from all transects at night and from 8 transects during daylight hours.

The overall density of targets in the water column increased as you move up the reservoir (Fig.1) This pattern results in part from the greater water depths found in the canyon area, as few fish targets were present below 30 meters. If only epilimnetic regions were examined, the density of fish targets was high in the canyon and inflow areas and low in the open hills (Fig. 2).

The mean length of targets declined towards the upper parts of the reservoir (Fig. 3), averaging 130 mm in the canyon, 100 mm in the open hills and 58 mm in the inflow area. Lengths of fish insonified were smaller during the day than during the night in the canyon and open hills area.

Summary of the echo counting analysis indicated that there were 244.3 metric tons of forage fish under 200 mm present in the water column. This estimate is based on a reservoir volume of $3.722 \times 10^9 m^3$ and a length-weight relationship of forage species.

$$W = 0.00054\ L^{2.29}$$

The length weight-relationship was derived from fish caught in trawls in September 1989.

Echo integration analysis indicated that total forage biomass was 449.1 metric tons. The higher biomass from this analysis results from the inclusion of schooled fish. Non-fish targets may also have been included. The true biomass estimate likely falls between these two values.

Preliminary bioenergetics simulations indicated that lake trout were consuming 266.7 metric tons of forage fish annually. This estimate is based on a lake trout population of 69,000 catchable fish and represents between 109 and 59% of forage available.

COMPARISON OF HYDROACOUSTICS AND TRAWLING METHODOLOGIES

During September 19-21, 1989, hydroacoustic estimates of fish density and size distributions were made with a Biosonics Dual-beam system and compared with fish density and size estimates collected with a 3.2 m x 3.2 m midwater trawl.

For most runs the trawl was kept at a single depth and run for 15 minutes. In some instances the trawl was run for several minutes at one depth and then moved to a depth where fish biomasses were higher as indicated on the acoustics paper chart. Trawl densities assumed 100% net efficiency and a trawl velocity of 3 km/s. Acoustics density estimates were made for only the strata of water in which the trawl was present.

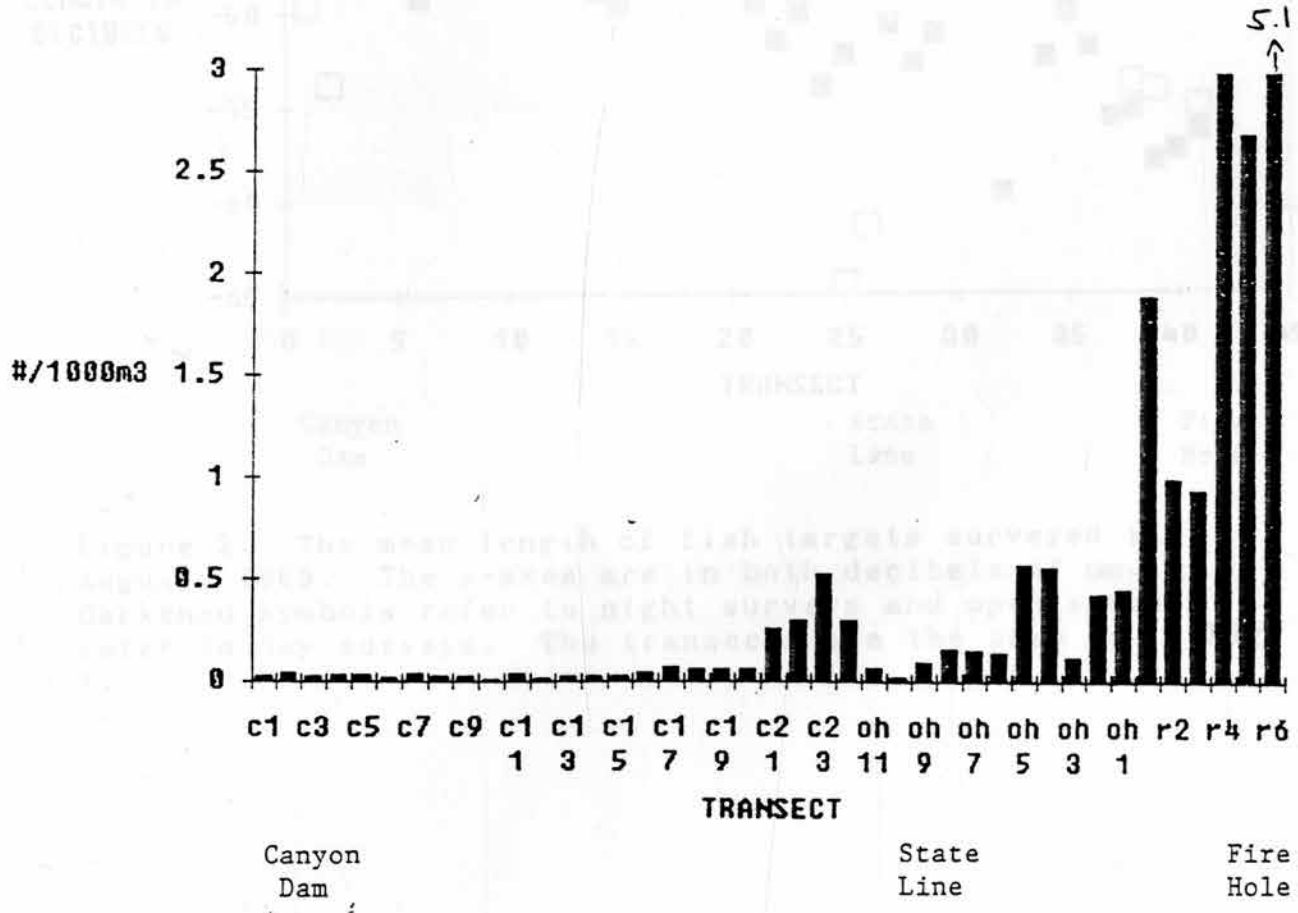
Estimates of total fish density were correlated between the two methods of sampling (Fig. 1). Density estimates from the trawl averaged 65% of acoustic estimates. If only runs in which fish were sampled with the trawl are included, a significant correlation between trawl and acoustic density was present ($r=0.91$, $p<0.05$, $n=8$). Addition of all the data improves this correlation ($r=0.94$, $p<0.01$, $n=17$). The line drawn in Fig. 1 represents the 1:1 line between trawl and hydroacoustics estimates. The trawl was not effective at catching fish when acoustic densities were below 0.0005 fish per cubic meter.

Estimates of fish size distribution were compared between the two methods of sampling (Fig. 2). Catches from the trawl indicated three distinct size classes of Utah chub (20-50, 90-130, and 250-300 mm). Analysis of the acoustic targets indicated three possible modes (45 mm, 70 mm, and 295 mm), but there was not good separation between the two smallest size classes. A close correspondence between the relative abundance of the size classes in trawl and acoustics samples was not found. The trawl catch indicated a greater number of large fish; whereas the acoustic sampling indicated a more uniform distribution of the three size classes. These differences may be due to undersampling of smaller fishes by the trawl, or due to the blurring of the size distribution by the acoustics. Calibration of the acoustics methodology for individual fish indicated that a range of lengths (approximately equal to - 40% to +10% of measured length) was found for any individual.

Most fish captured with the trawl were Utah chub from the inflow area. Total counts were 68 Utah chub, 3 redside shiner, 2 sucker, 1 kokanee, and 2 rainbow trout.

The hydroacoustics system appears to give reliable estimates of fish density and can continue to be used to estimate forage abundance. It will not be possible to distinguish species based on their differences in size. Some additional means of fish collection will have to be done in order to attain the size and species composition information needed for a multi-year trend analysis. We plan to collect hydroacoustics data during the purse seining next spring and will want to proceed with additional trawling or perhaps gill netting next August. The low number of fish caught in the trawl in the lower portions of the reservoir made comparisons difficult. The use of vertical gill nets would probably assure greater catches of fish, and provide the necessary information on species composition and size distributions. We would lose any ability to verify the density estimates made with acoustics. If we decide to continue trawling, it is likely that we will do better next August. Acoustic densities were approximately five times higher in the canyon area in August compared with September. Fish density in the Open Hills area was low in both August and September. Fish in this region may not be accessible to the trawl.

Figure 1. The density of fish targets (number per 1000 cubic meters) along 43 transects in Flaming Gorge Reservoir surveyed during the first two weeks in August, 1989. C1-C24 refers to transects in the Canyon area; OH1-OH11 refers to transects in the Open Hills area; and R1-R6 refers to transects in the Inflow area.



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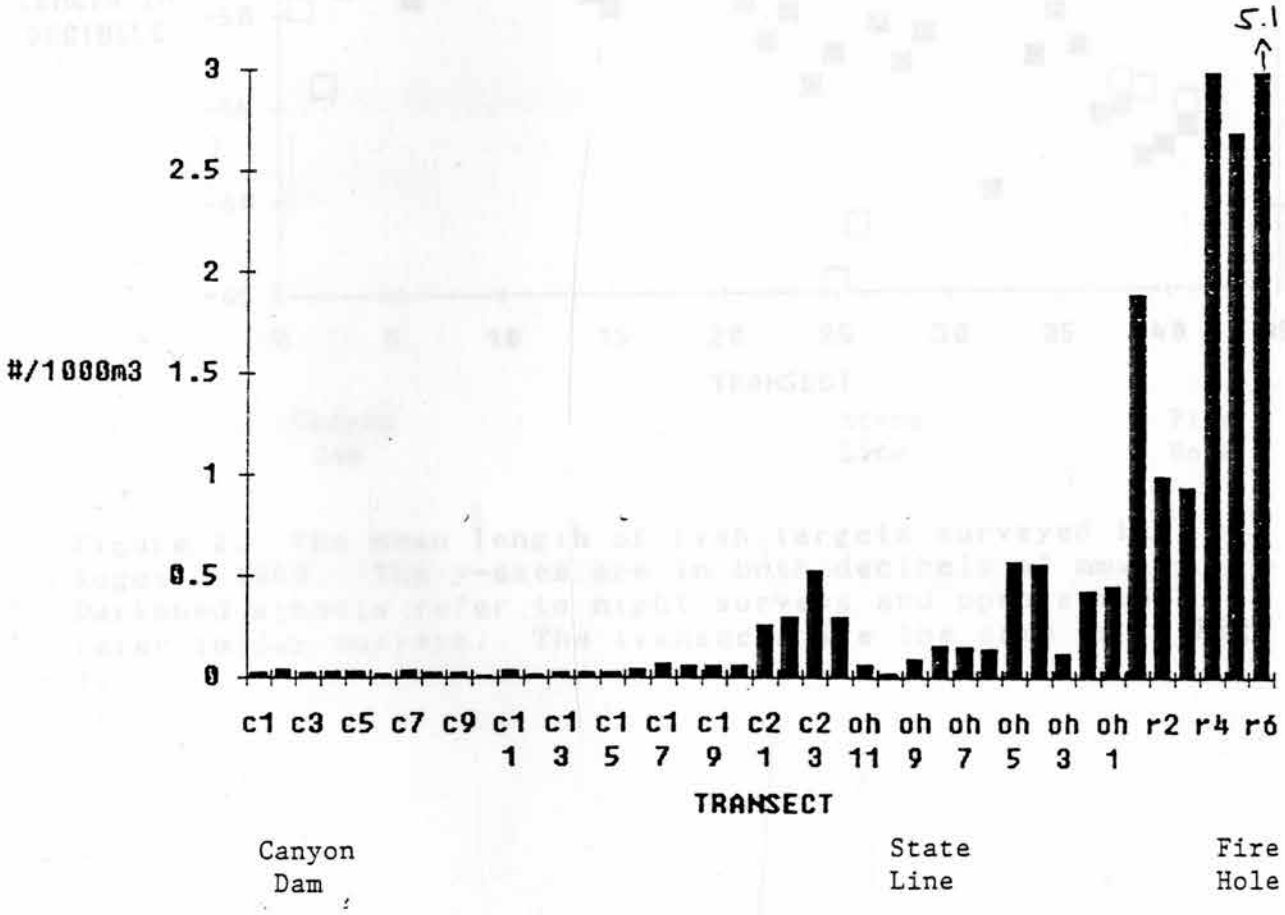


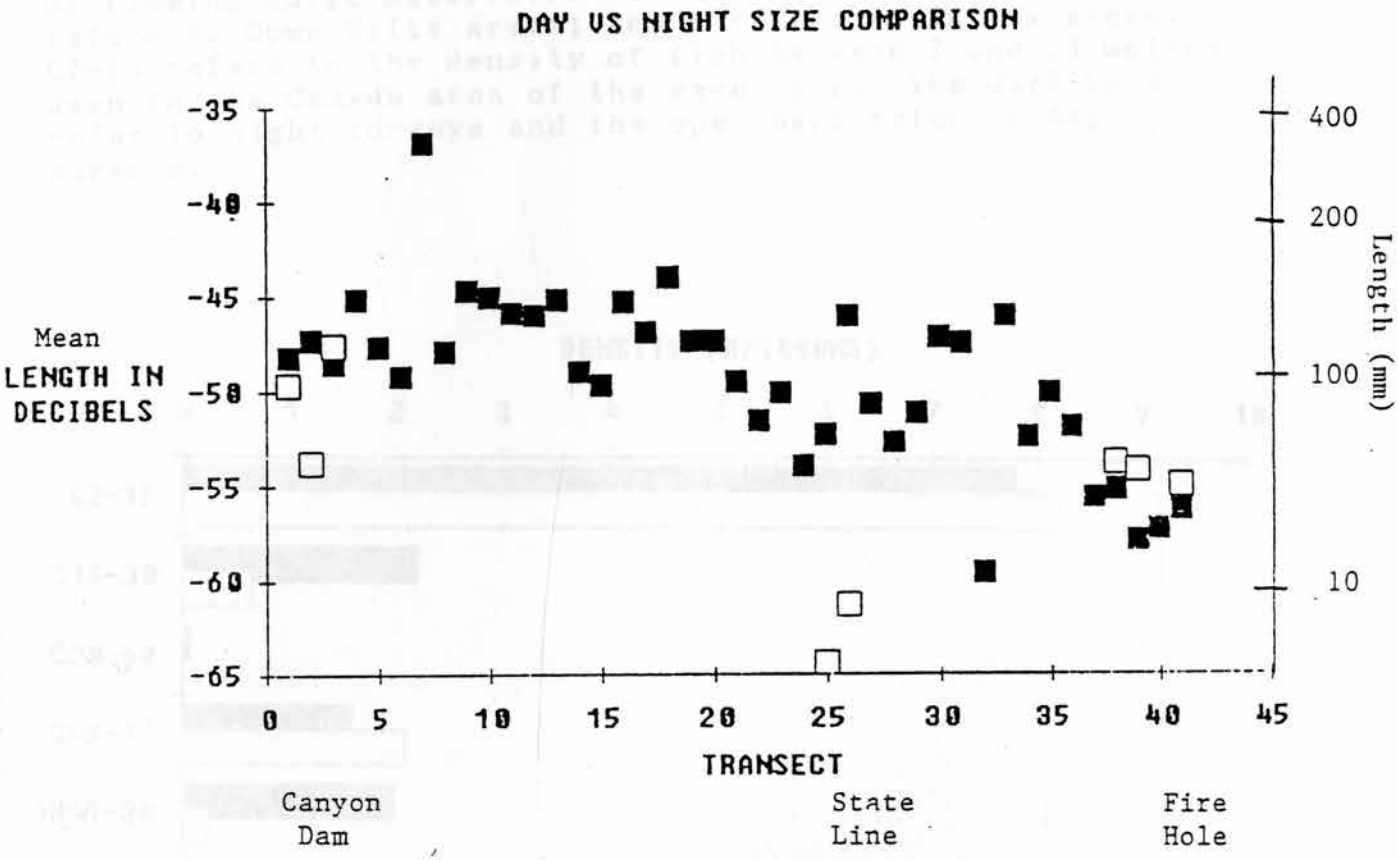


Figure 2. The mean length of fish targets surveyed in August, 1989. The y-axes are in both decibels of mm. Darkened symbols refer to night surveys and open symbols refer to day surveys. The transects are the same as in Fig. 1.

Figure 3. The density of fish targets (numbers per 1000 cubic meters) in different depth strata in the three regions of Flaming Gorge Reservoir. C refers to Canyon areas; OH refers to Open Hills areas; and R refers to Inflow areas. C2-15 refers to the density of fish between 2 and 15 meters deep in the Canyon area of the reservoir. The dark bars refer to night surveys and the open bars refer to day surveys.

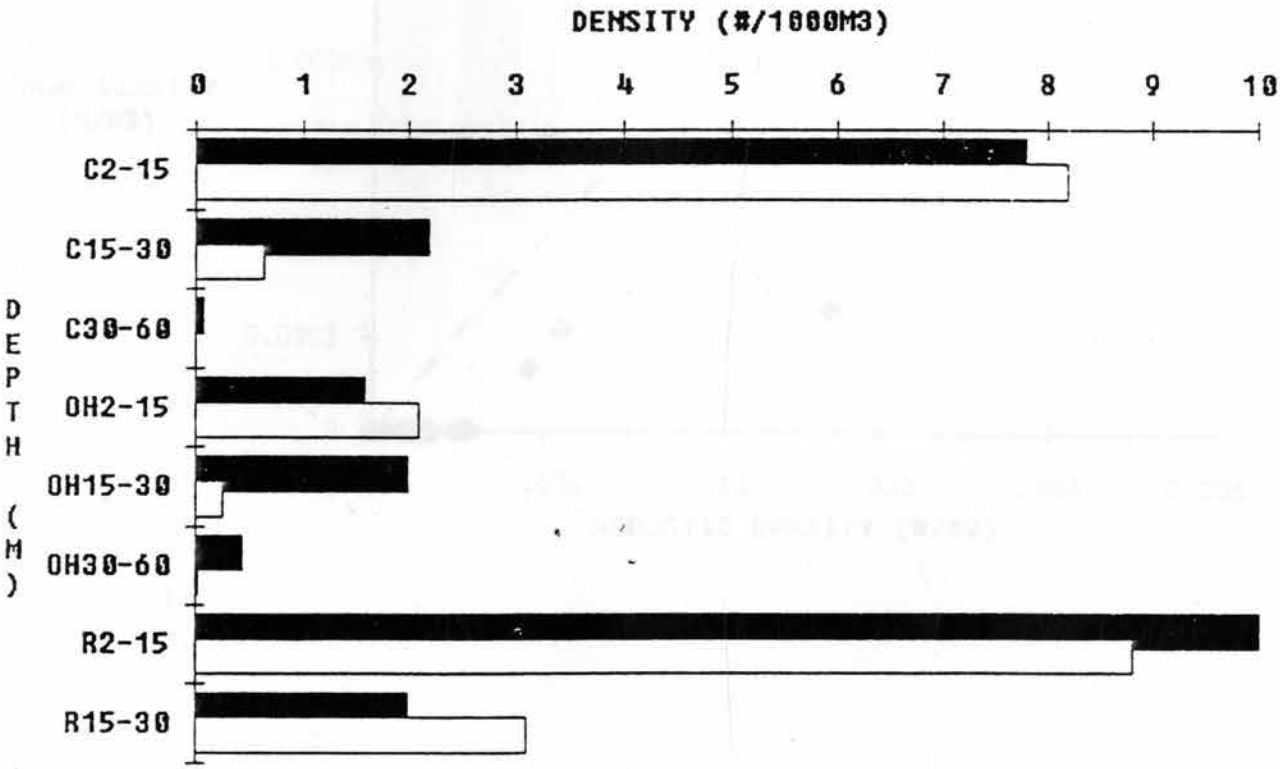


Figure 1. Comparison of hydroacoustics and trawl data collected during September 1989. In nine runs the trawl captured no fish while acoustics data indicated some fish were present. The dotted line is the 1:1 correspondence between the two types of gears

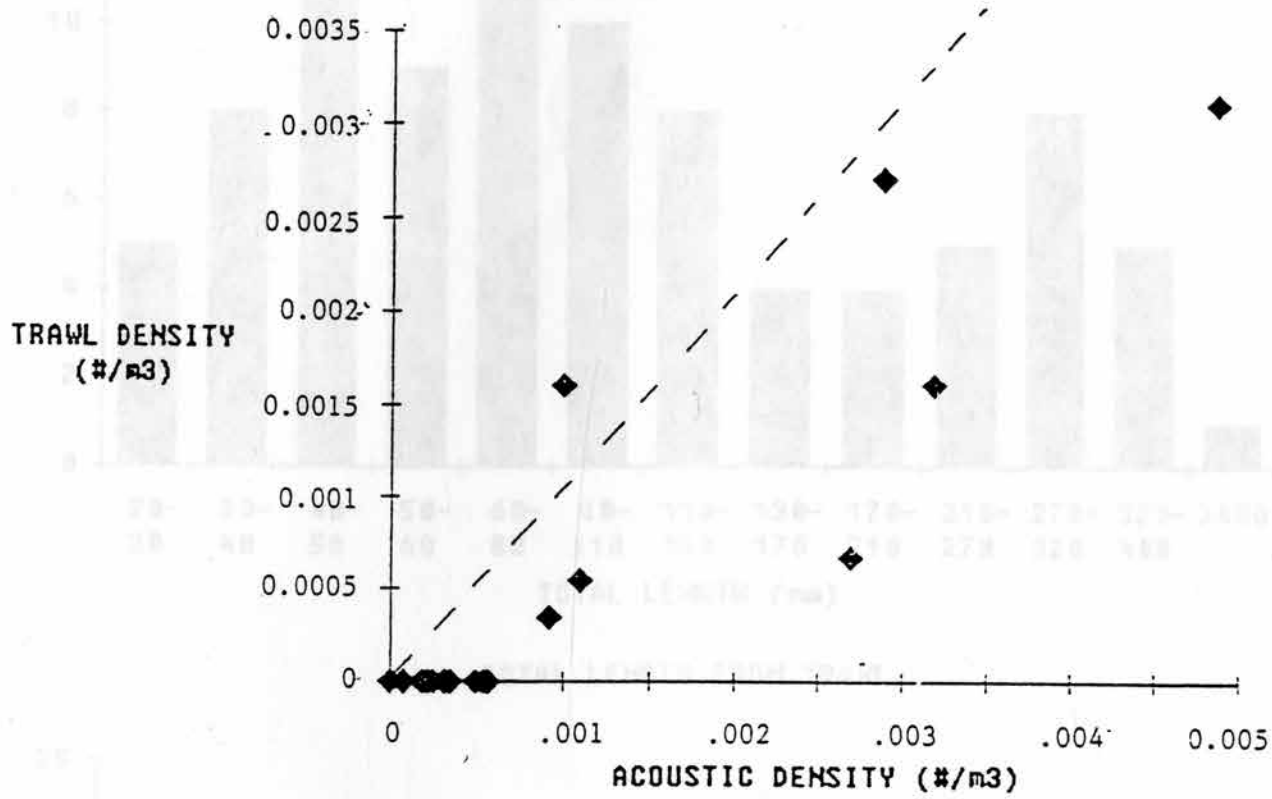
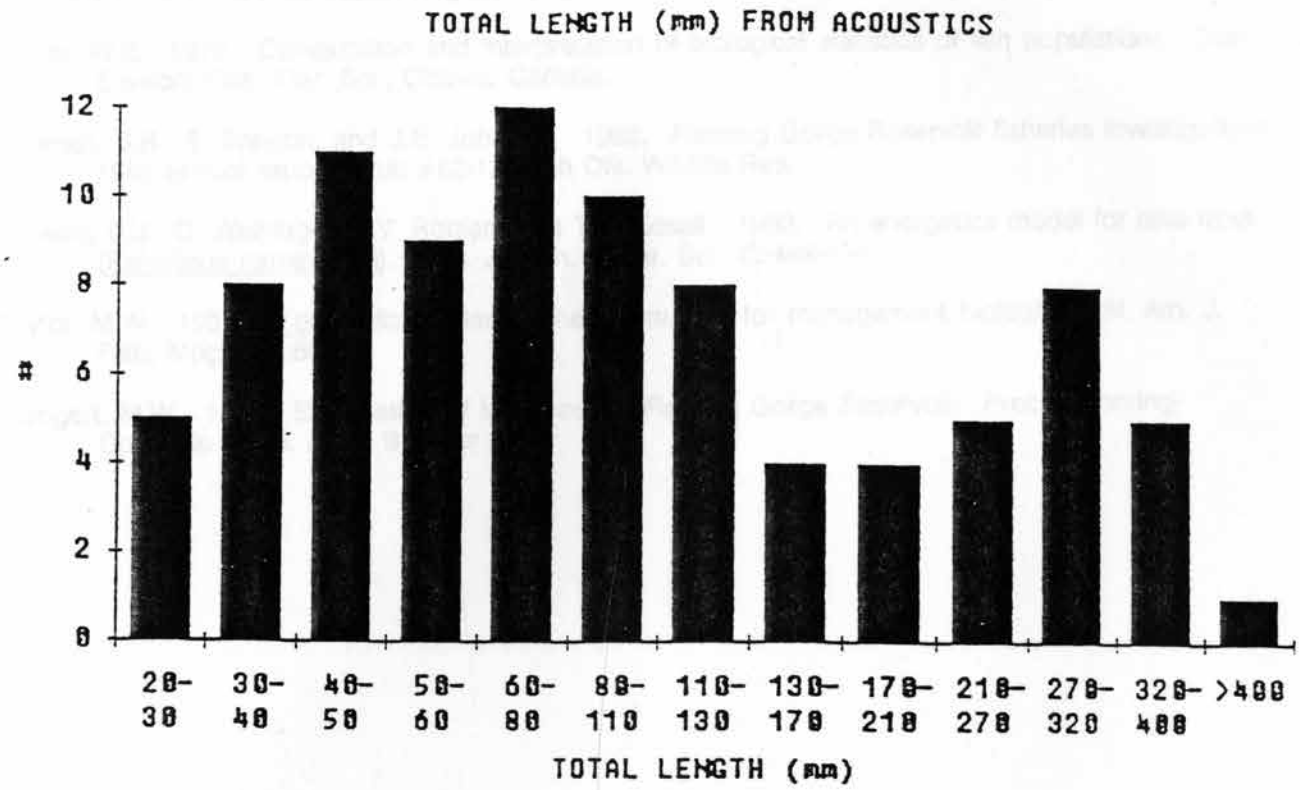
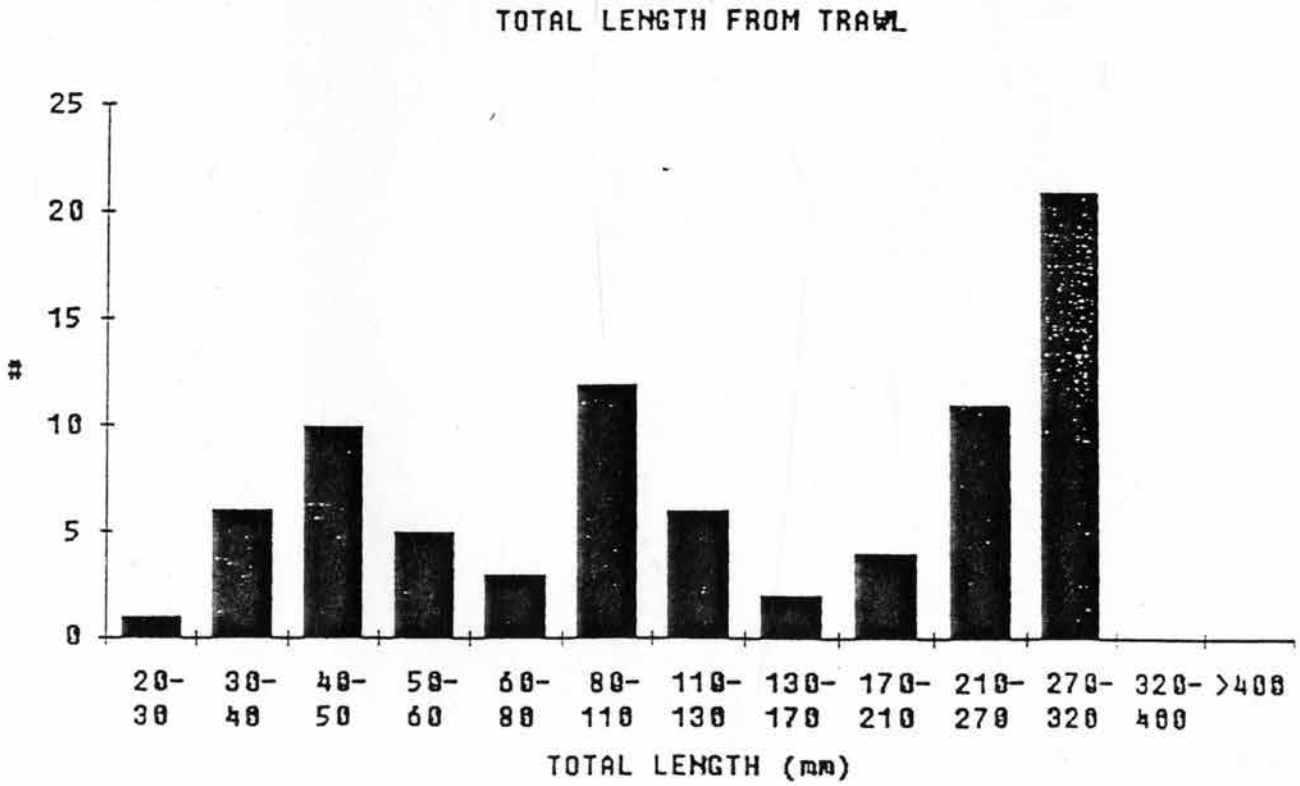


Figure 2. Comparison of the lengths of fish sampled with acoustics (top) and with a midwater trawl (bottom).





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PERFOMANCE REPORT

Project Number: F-47-R

Study Number: 4

Segment Number: 4

Title: Behavioral Responses of Utah Chub and Rainbow Trout to Rotenone

Project Date: January 1-December 31, 1989

Purpose: The purpose of this segment was to determine whether Utah chub and rainbow trout actively avoid the substances associated with both powdered and emulsified forms of rotenone.

Progress Summary: The sportfishery of Strawberry Reservoir, one of Utah's most important coldwater fisheries, is presently threatened by a rapidly expanding nongame fish population. The Utah Division of Wildlife Resources plans to chemically treat the entire epilimnion of Strawberry Reservoir with rotenone in August 1990 to eliminate the rough fish population. Fish are thought to avoid piscicides, rotenone in particular; however there have been no controlled studies testing this assumption. The primary objective of this project is to ascertain whether Utah chub (Gila atraria) and rainbow trout (Oncorhynchus mykiss) avoid applications of powdered or emulsified rotenone. This information will be useful in assessing the effectiveness of chemical treatments with these two formulations of the piscicide.

A behavioral trough to test the response of Utah chub and rainbow trout to rotenone was constructed. Preliminary studies to determine concentrations and duration of exposure for 3 formulations of rotenone (liquid rotenone, powdered rotenone, active ingredients only) were completed. Data from preliminary trials with liquid rotenone showed significant differences in fish distribution before and after exposure to the piscicide. Final experiments are currently in progress. A separate analysis of the response of each fish species to rotenone will be done. Test fish are being subjected to 12 treatments: three concentrations each of liquid rotenone, powdered rotenone, and the active ingredients in rotenone, one concentration of liquid carrier, one concentration of inert powder and a water control. A complete report of the research accomplishments in 1989 is found in Appendix I.

Principal Investigator: Cheryl Courtney

APPENDIX I

BEHAVIORAL RESPONSES OF UTAH CHUB AND RAINBOW TROUT TO ROTENONE

Cheryl C. Courtney

USFWS Utah Cooperative Fish and Wildlife Research Unit
Department of Fisheries and Wildlife
Utah State University
Logan, Utah 84322-5210

March 12, 1990

INTRODUCTION

Strawberry Reservoir, located in Wasatch County, contains one of Utah's most important coldwater fisheries. This sportfishery is presently threatened by a rapidly expanding nongame fish population that is dominated by Utah chub, Gila atraria. The Utah Division of Wildlife Resources plans to chemically treat the entire epilimnion of Strawberry Reservoir with rotenone in August 1990 to eliminate the rough fish population. The reservoir will then be stocked with salmonid species. Fish are thought to avoid piscicides, rotenone in particular; however there have been no controlled studies testing this assumption. The objective of this study is to determine experimentally whether Utah chub and rainbow trout (Oncorhynchus mykiss) exhibit an avoidance response to powdered or emulsified rotenone. This information will be useful in assessing the effectiveness of chemical treatments with these two formulations of the piscicide in Strawberry Reservoir.

The first year of this study resulted in the development of a behavioral trough to test the response of Utah chub and rainbow trout to rotenone. Additionally, preliminary studies to determine concentrations and duration of exposure for the rotenone formulations were completed.

METHODS

Three criteria that are usually employed to determine preference or avoidance responses to toxicants are: time spent in treated water, number of entries into treated water, and fish distribution in relation to treated water over time (Giattina and Garton 1983). The measure of avoidance that is used in the present study is the amount of time a fish spends in treated water as opposed to untreated water.

Test trough

A behavioral trough was developed to test the response of Utah chub and rainbow trout to various formulations of the piscicide rotenone and its carriers. This apparatus is a modification of the behavioral trough used by Jones and Hara (1985) to study behavioral responses of whitefish (Coregonus clupeaformis) and arctic char (Salvelinus alpinus) to chemical cues. It is constructed of plexiglass, measures 200 x 38 x 18 cm, and holds approximately 85 l of water. Two perforated plastic plates divide the trough into 3 sections: an influent side partitioned into 6 cells (each receiving its own water supply), a central chamber where the fish swims, and an effluent side containing 6 drains corresponding to the 6 cells on the influent side. Water coming into a cell passes through the perforated plate, and exits via 1 of the 6 drains on the effluent side. Fish swim perpendicular to the current in this trough and are able to sample the water masses in all 6 cells.

Study design

Two fish species are currently being studied, Utah chub and rainbow trout. A separate analysis of the response of each fish species to rotenone will be done. Test fish are subjected to 12 treatments: three concentrations each of liquid rotenone, powdered rotenone, and the active ingredients in rotenone, one concentration of liquid carrier, one concentration of inert powder and a water control. Individual fish are introduced into the center of the central chamber of the behavioral trough and acclimated for 1 hour. This allows the fish to exhibit random exploratory activity. A control period follows, with no chemical treatment introduction. Next the chemical treatment is introduced randomly into cell 1 and cell 6 via a separatory funnel, buret or syringe. After the introductory period, an exposure period follows which is equal in duration to the control period. In preliminary trials with liquid rotenone, the introductory period was 5 minutes. Six time intervals for the control and exposure period were done (5, 10, 15, 20, 25, and 30 minutes). The time spent in each cell of the behavioral trough throughout the experiment is recorded with video equipment (Panasonic color video camera, VCR, and monitor). Treated water containing rotenone is detoxified with potassium permanganate.

An analysis of variance test is used to analyze the data collected in this study. In the final experiments, a total of 10 replicates will be done for each treatment. Thus, 120 fish of each species will be tested. The number of times that the treatment will be introduced into cell 1 and cell 6 of the behavioral trough will be equal, 5 for each.

RESULTS AND DISCUSSION

Concentration and duration of exposure trials

Individual rainbow trout were exposed to a total of 7 mixtures of liquid rotenone containing 0.075, 0.15, 0.5, 1.0, 1.5, 3.0 and 5.0 mg/l of rotenone for various time intervals (5, 10, 15, 20, 25, and 30 minutes). The amount of time spent in each cell of the behavioral trough was recorded onto VHS video cassettes. Analysis of variance was used to assess the effect of 3 factors (cell position, concentration and treatment period) on the dependent variable, percent time (initially measured in seconds) for the 10, 15 and 20 minute exposure trials for the 7 concentrations of rotenone. Cell position refers to the division of the behavioral trough into 6 cells. Cell 1 is designated as the cell into which liquid rotenone was introduced; whereas, cell 6 was relatively free of rotenone. The treatment period was divided into 2 categories: before rotenone introduction (control period) and after rotenone introduction (exposure period).

A significant interaction between cell position and treatment period was seen in all 3 exposure trials (for the 10 minute trial, variance ratio, $F = 6.438$, $P < 0.05$; for the 15 minute trial, $F = 3.859$, $P < 0.05$; and for the 20 minute trial, $F = 2.135$, $P < 0.05$). No significant interaction was found between cell position, concentration and treatment period in any of the exposure trials.

Average time spent by rainbow trout in each cell of the behavioral trough before and after exposure to liquid rotenone in the 10, 15 and 20 minute trials is shown in Tables 1, 2, and 3, respectively. A pairwise comparison of the cell position means using the least significant statistic was also done. In all exposure trials a significant interaction was found between the means for cell 1 and 6 after rotenone introduction at 0.5 and 3.0 mg/l, but not at 1.5 mg/l (Figures 1-3).

Chemical analysis trials

Chemical analyses of rotenone-treated water was done by the Utah Water Research Laboratory. These analyses revealed the concentration of rotenone that must be introduced into an inflow cell and the duration of that introduction to achieve a particular concentration of rotenone in the central chamber of the behavioral trough. These analyses showed that 0.2, 0.5 and 1.5 mg/l mixtures of rotenone resulted in 0.045, 0.075 and 0.15 mg/l of rotenone in cell 1, respectively. No rotenone was found in cell 6 at 0.2 and 0.5 mg/l, but approximately .010 mg/l of rotenone was found in cell 6 after 20 minutes with the 1.5 mg/l mixture.

Both the 3.0 and 5.0 mg/l mixtures did not allow for a rotenone-free area in the trough. Almost .040 mg/l of rotenone was found in cell 6 using the former concentration. In addition, the 5.0 mg/l mixture proved to be too toxic for test fish. A non-toxic concentration of rotenone, 0.045 mg/l, and 2 toxic concentrations, 0.075 and 0.15 mg/l rotenone are being used in the final experiments.

LITERATURE CITED

Giattina, J. D., and R. R. Garton. 1983. A review of the preference avoidance responses of fishes to aquatic contaminants. Residue Reviews 87: 43-90.

Jones, K. A., and T. J. Hara. 1985. Behavioral responses of fishes to chemical cues: results from a new bioassay. Journal of Fish Biology 27: 495-504.

Table 1. Mean time (seconds) spent by rainbow trout in each cell of the behavioral trough before and after exposure to liquid rotenone in the 10 minute trial, n=5.

Rotenone Concentration (mg/l)	Cell Position 1★	2	3	4	5	6
0.075	210★★ / 126★★★	97 / 61	92 / 56	20 / 51	25 / 67	156 / 239
0.15	203 / 79	100 / 59	40 / 39	47 / 38	45 / 62	165 / 323
0.5	301 / 30	33 / 25	13 / 29	14 / 25	29 / 88	210 / 403
1.0	117 / 25	44 / 29	50 / 36	86 / 67	94 / 165	209 / 278
1.5	124 / 118	83 / 152	80 / 92	106 / 51	92 / 45	115 / 142
3.0	123 / 51	26 / 40	29 / 28	39 / 39	120 / 166	263 / 276
5.0	235 / 49	53 / 29	33 / 34	38 / 56	43 / 87	198 / 345

★Cell into which liquid rotenone was introduced.
★★Time spent in a cell before liquid rotenone was introduced.
★★★Time spent in a cell after liquid rotenone was introduced.

Table 2. Mean time (seconds) spent by rainbow trout in each cell of the behavioral trough before and after exposure to liquid rotenone in the 15 minute trial, n=4.

Rotenone Concentration (mg/l)	Cell Position 1★	2	3	4	5	6
0.075	391★★ / 96★★★	139 / 79	48 / 59	22 / 54	25 / 107	275 / 505
0.15	305 / 255	102 / 66	74 / 36	60 / 49	58 / 96	301 / 398
0.5	478 / 33	53 / 29	24 / 43	25 / 49	51 / 139	269 / 607
1.0	159 / 42	64 / 46	70 / 56	104 / 107	143 / 293	360 / 356
1.5	251 / 235	138 / 165	130 / 137	128 / 95	106 / 86	147 / 182
3.0	47 / 81	33 / 58	42 / 36	80 / 50	286 / 211	412 / 464
5.0	191 / 46	83 / 52	61 / 55	69 / 149	105 / 122	391 / 476

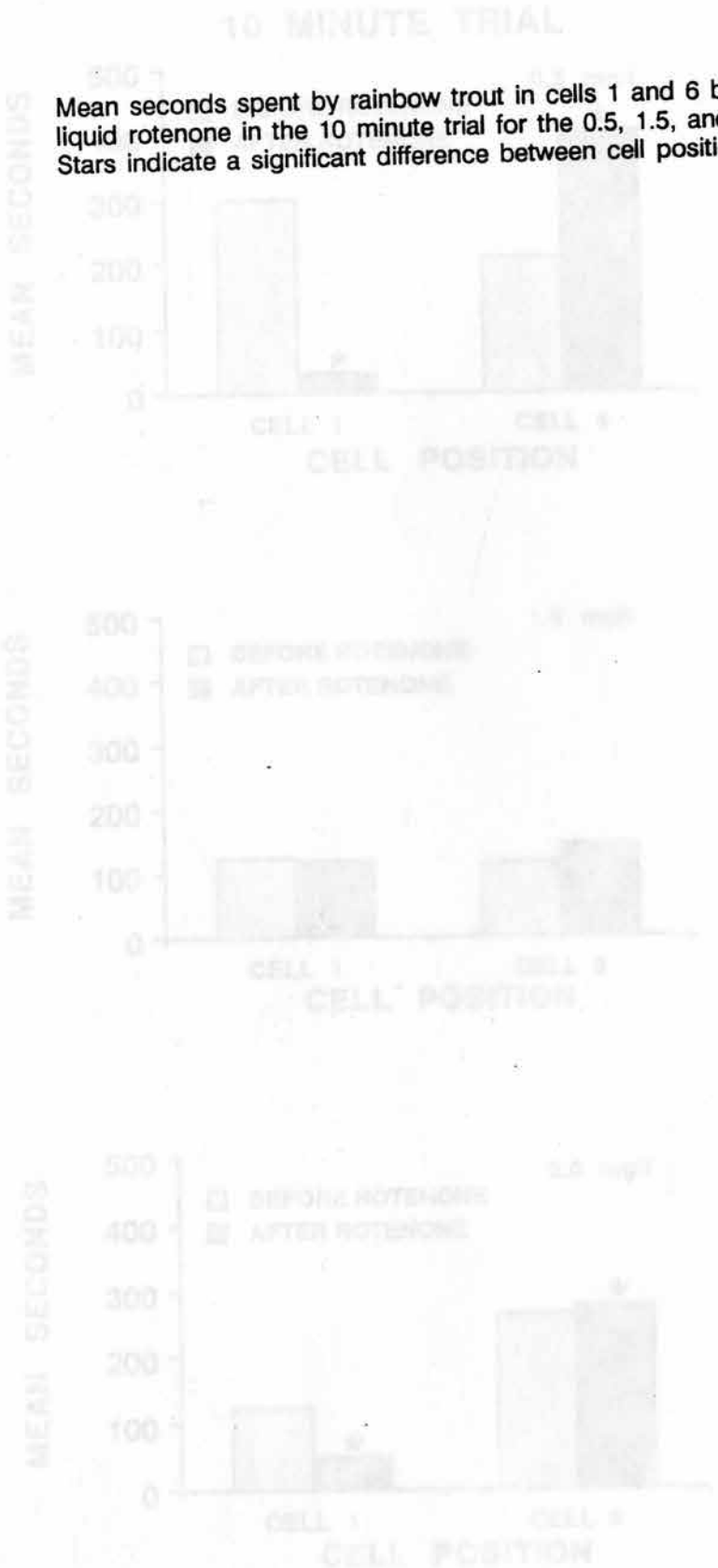
★Cell into which liquid rotenone was introduced.
★★Time spent in a cell before liquid rotenone was introduced.
★★★Time spent in a cell after liquid rotenone was introduced.

Table 3. Mean time (seconds) spent by rainbow trout in each cell of the behavioral trough before and after exposure to liquid rotenone in the 20 minute trial, n=3.

Rotenone Concentration (mg/l)	Cell Position 1★	2	3	4	5	6
0.075[a]	475★★ / 102★★★	315 / 76	128 / 91	61 / 101	42 / 201	179 / 629
0.15	446 / 386	42 / 40	48 / 26	68 / 46	80 / 119	516 / 583
0.5	498 / 40	83 / 34	37 / 53	46 / 61	96 / 210	440 / 802
1.0	123 / 29	84 / 32	95 / 56	139 / 139	214 / 460	545 / 484
1.5	214 / 370	245 / 225	215 / 132	174 / 93	135 / 101	217 / 279
3.0	13 / 98	26 / 117	44 / 47	124 / 53	415 / 258	578 / 627
5.0	138 / 58	95 / 64	86 / 81	95 / 105	173 / 169	613 / 723

★Cell into which liquid rotenone was introduced.
★★Time spent in a cell before liquid rotenone was introduced.
★★★Time spent in a cell after liquid rotenone was introduced.
[a]n=2 for this concentration.

Figure 1. Mean seconds spent by rainbow trout in cells 1 and 6 before and after introduction of liquid rotenone in the 10 minute trial for the 0.5, 1.5, and 3.0 mg/l rotenone mixtures. Stars indicate a significant difference between cell position means 1 and 6, $P < 0.05$.



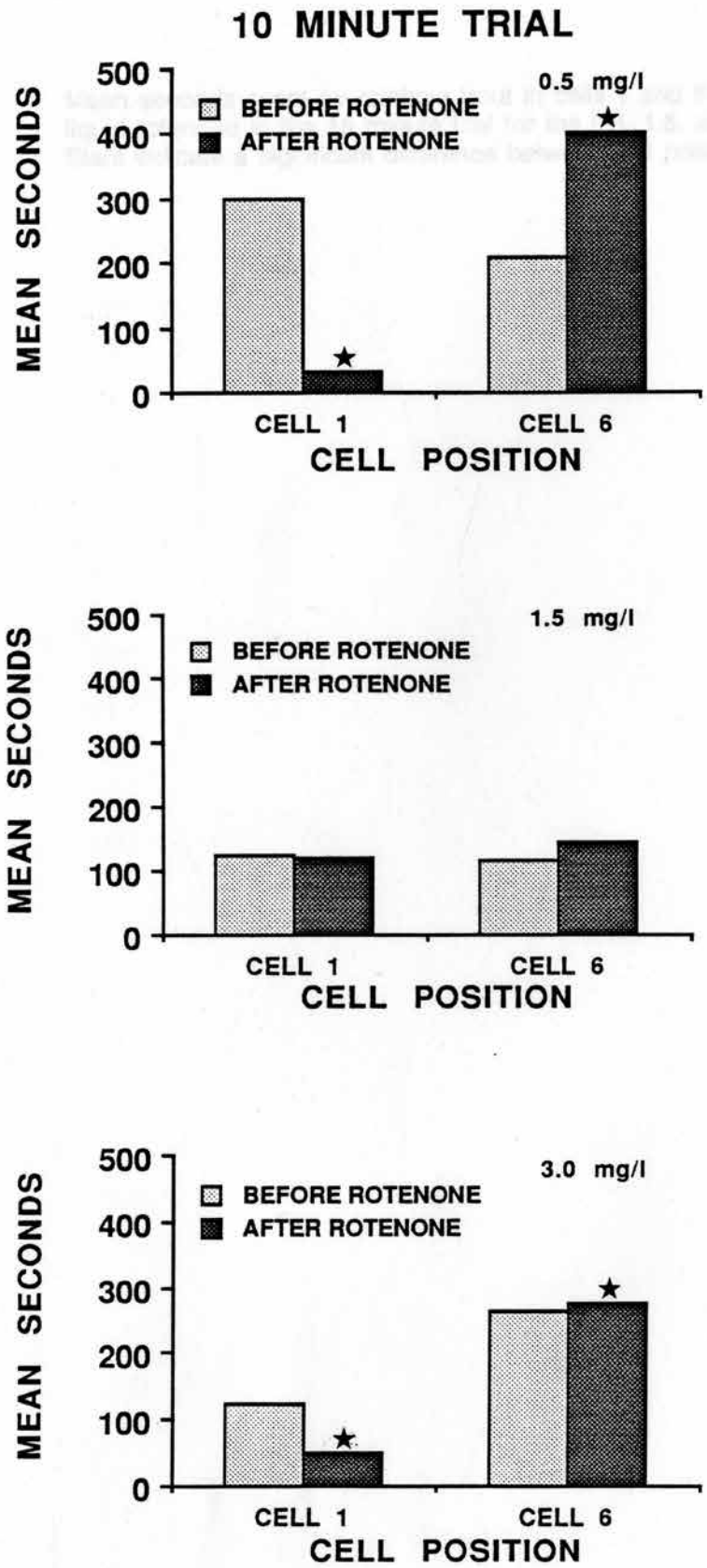
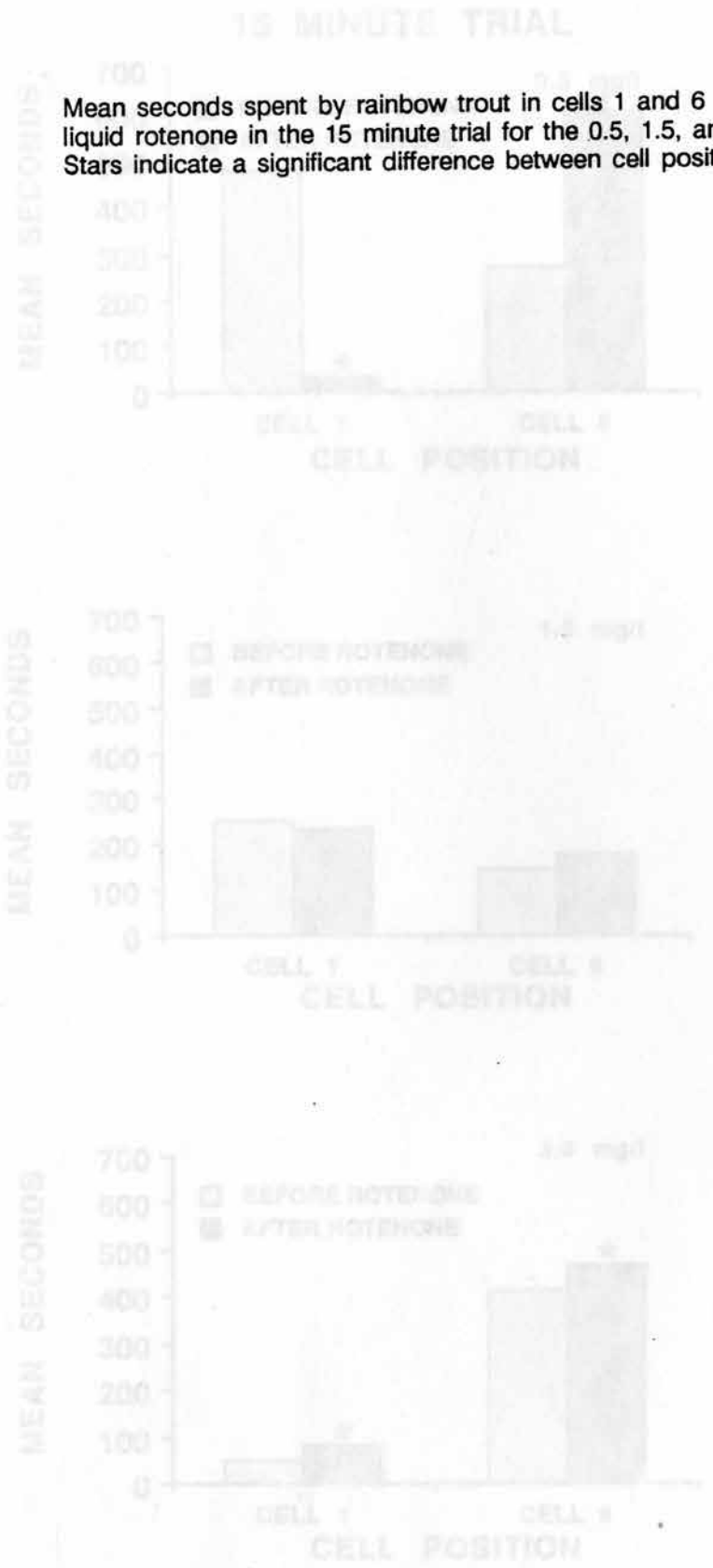
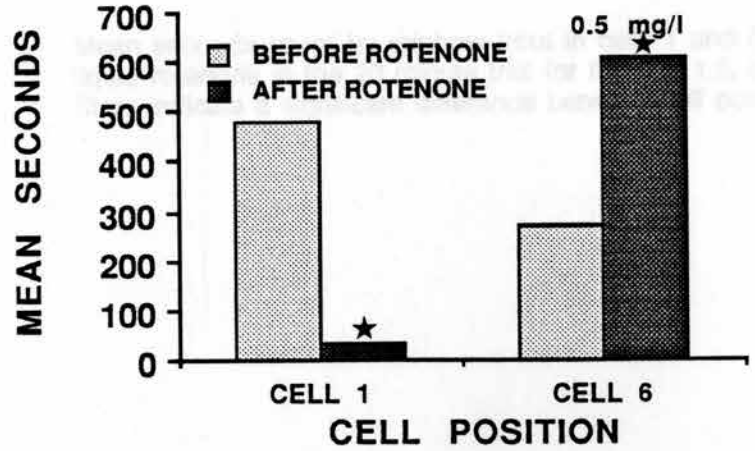
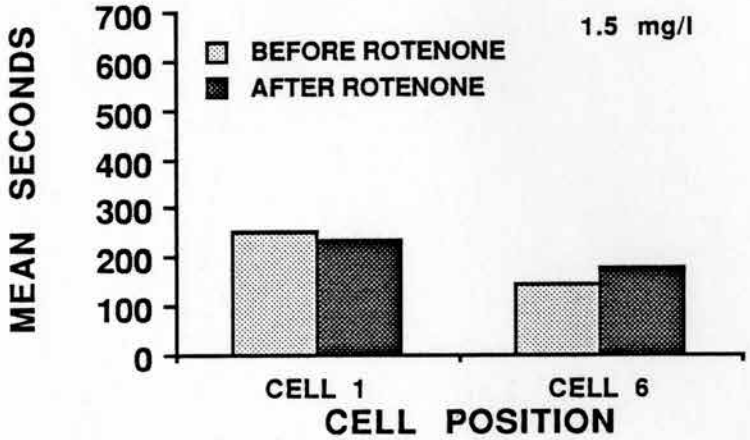

10 MINUTE TRIAL
0.5 mg/l
BEFORE ROTENONE
AFTER ROTENONE
MEAN SECONDS
500
400
300
200
100
0
CELL 1
CELL 6
CELL POSITION
1.5 mg/l
BEFORE ROTENONE
AFTER ROTENONE
MEAN SECONDS
500
400
300
200
100
0
CELL 1
CELL 6
CELL POSITION
3.0 mg/l
BEFORE ROTENONE
AFTER ROTENONE
MEAN SECONDS
500
400
300
200
100
0
CELL 1
CELL 6
CELL POSITION

Figure 2. Mean seconds spent by rainbow trout in cells 1 and 6 before and after introduction of liquid rotenone in the 15 minute trial for the 0.5, 1.5, and 3.0 mg/l rotenone mixtures. Stars indicate a significant difference between cell position means 1 and 6, $P < 0.05$.



15 MINUTE TRIAL





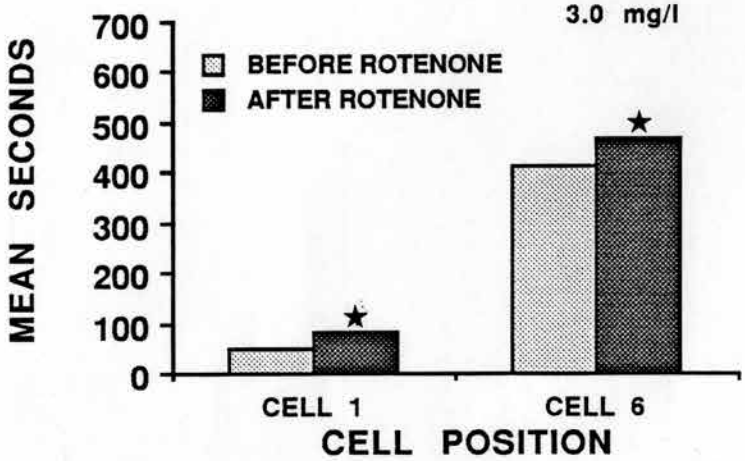


Figure 3. Mean seconds spent by rainbow trout in cells 1 and 6 before and after introduction of liquid rotenone in the 20 minute trial for the 0.5, 1.5, and 3.0 mg/l rotenone mixtures. Stars indicate a significant difference between cell position means 1 and 6, $P < 0.05$.

20 MINUTE TRIAL