Conditions for growth and survival of bull trout in Beulah Reservoir, Oregon

Annual Report for 2001

James H. Petersen and Eric E. Kofoot

U.S. Geological Survey
Western Fisheries Research Center
Columbia River Research Laboratory
5501A Cook-Underwood Road
Cook, WA 98605

Prepared for the:

U.S. Bureau of Reclamation
Pacific Northwest Region
1150 North Curtis Road
Boise, Idaho 83706-1234

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Introduction

The Bureau of Reclamation (BOR) constructed Agency Valley Dam on the North Fork of the Malheur River in 1934-35, creating Beulah Reservoir. The project is operated and maintained by the Vale Irrigation District for irrigation and downstream flood control, with no minimum pool or outflow operational criteria. Although the project is not operated for fish and wildlife values, the reservoir supports a rainbow trout *Oncorhynchus mykiss* fishery and also seasonally harbors an adfluvial population of bull trout *Salvelinus confluentus* (Oregon Department of Fish and Wildlife [ODFW]; Burns Paiute Tribe). Bull trout were listed by the USFWS as a threatened species throughout the Columbia and Klamath river basins in 1998, and Oregon has listed the North Fork Malheur River population “Of Special Concern”.

Reasons for the decline of bull trout in the Malheur River likely include habitat degradation, habitat fragmentation, and downstream loss through entrainment at dams. The construction of dams in the Malheur River drainage isolated formerly connected bull trout metapopulations of the Snake River Basin. Migratory bull trout are important to the persistence and stability of the North Fork Malheur population because they may represent unique genetic resources and because large migratory individuals are more fecund than smaller, resident stream fish. In Beulah Reservoir, water quality (temperature, DO, etc.), forage fish, and bull trout growth may be especially critical limiting factors. There is currently no formal agreement for a minimum pool level at Beulah Reservoir, although project operators of Agency Valley Dam have recently considered pool levels.

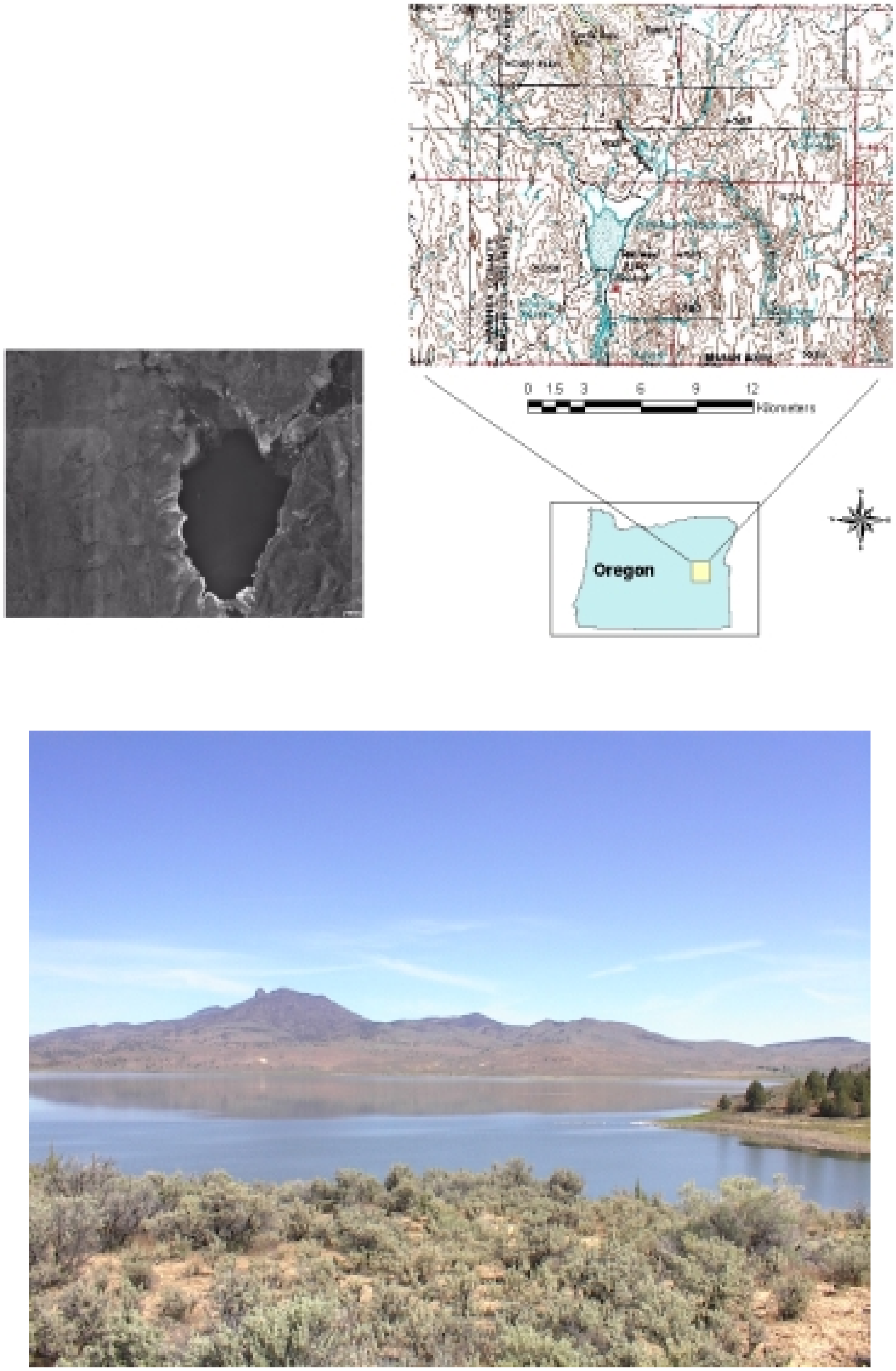

Figure 1. Location of Beulah Reservoir, central Oregon (top). Photo at the top left shows the reservoir and the inflow of the North Fork of the Malheur River (upper left in photo). Photo at the bottom is Beulah Reservoir from the south shore.

The BOR has initiated an investigation of alternatives for creating a conservation fisheries pool in Beulah Reservoir. Water quality monitoring and modeling are underway to describe the seasonal distribution of dissolved oxygen and temperature relative to bull trout needs. General limnological information is also being collected on a regular basis to describe algal and zooplankton standing crops under wet and dry year conditions. A Beulah Reservoir sedimentation survey was initiated in 2000 to provide updated capacity data, and a bathymetric map for use in developing a conservation pool. These investigations are to be completed by December, 2004.

Both subadult and adult bull trout likely reside in Beulah Reservoir for either all (subadults) or part (mature adults) of the year. During residence, bull trout are likely feeding on fish, including stocked rainbow trout, and will be exposed to temperatures, dissolved oxygen, and other conditions that might change with season or reservoir operation.

We are studying the seasonal and interannual variation in food habits and availability of prey for bull trout in Beulah Reservoir. Data will be integrated with water quality work being done in the reservoir and through an energetics model of bull trout. Our long-term goal is to estimate the quality of habitat in the reservoir for bull trout growth and survival, and provide some guidance for reservoir operations and establishment of a conservation pool.

Study Design

The design for this pilot study included three Objectives:

- **Objective 1**. Adult bull trout are presumed to be present in Beulah Reservoir during winter and early spring will migrate to tributaries during early spring, and return to the reservoir during late fall or early winter (Tiley and Schwabe 1999; Wayne Bowers, pers. comm.). No information is available on the occurrence of subadult bull trout in the reservoir (Rick Rieber, BOR, pers. comm.), but subadult bull trout with an adfluvial life history commonly move downstream from tributaries and spend part of their life in lakes or reservoirs (Rieman and McIntyre 1993), so it is likely they occur in this reservoir. During their residence in Beulah Reservoir, both adults and subadults probably feed on small fish (Brown 1995), and possibly some benthic invertebrates. In this Objective, we will develop methods to quantify prey availability through time in the reservoir.

- **Objective 2**. Little is known about the life history, size structure, growth, and diets of bull trout that occur within the reservoir. It is important that we begin to describe the growth rates, condition, and diets for migratory adult bull trout, which could be negatively influenced by low oxygen, high temperature, or other water quality concerns within the reservoir.
- **Objective 3**. Drawdowns and pool-level manipulations can presumably have effects on temperature and the available preyfish within the reservoir, which could greatly influence growth and survival of bull trout. Water quality studies by the BOR may show, for example, that temperatures stratify creating very different environments for bull trout in the reservoir. If the reservoir is drawn down too far, and exchange is low in mid- to late-summer, there might no thermocline and all bull trout will be exposed to lethal or sub-optimal temperatures. Energetics models (e.g., Brandt and Kirsch 1993; Labar 1993; Petersen and Kitchell 2000) have been used to synthesize temperature, diet, water quality, and variations in forage base of a variety of fish species, and to address specific management questions. Such a model for bull trout could be used to estimate changes in specific or total reservoir habitat, and predict the expected growth rates with different management scenarios. Data from Objective 2, especially diet and growth rates, will be explicit inputs to these modeling exercises, along with water quality assessment and modeling done by the BOR/Denver group. During FY01, only preliminary model parameters will be developed and tested for sensitivity. Parameters from Arctic char, brook trout, lake trout, and perhaps other cold-water species in the genus *Salvelinus*, will first be considered in model development (Hanson et al. 1997). After parameters are identified, a model is configured, and software is modified if necessary, sensitivity analyses of consumption, respiration, and swimming parameters will be conducted. Sensitivity analyses can be used to determine whether future laboratory studies may be needed to refine parameters.

Methods

Field studies

Field sampling was conducted from late May to late November, on seven trips (Table 1). Sample times were assigned a trip number that corresponded to the month of sampling (samples collected on June 1, 2001 were assigned to the May trip). Sampling efforts lasted from 2 to 4 days.

Water quality. Water quality parameters were measured at the deepest part of the reservoir. Contour elevation maps of Beulah Reservoir, provided by the Bureau of Reclamation in Boise, ID. indicated an area of deepest water from near the dam face extending north along the original thalwag to approximately mid-reservoir. During the spring, when the water level was near its seasonal peak, we physically located this deep area using a boat and an electronic depth sounder. We recorded GPS coordinates at several of the deepest locations using a PLGR+96 GPS unit; during subsequent monthly sampling visits to Beulah Reservoir, we would return to these locations to collect water quality data.

Dissolved oxygen and water temperature data were collected with a YSI model 57. The YSI had a 14-meter probe cable that limited our sampling depth. Dissolved oxygen was measured in parts per million (PPM) and temperatures was recorded in degrees Celsius. Data were collected at 1-meter intervals from the surface to 14 meters when water depths permitted. Surface measurements were taken at approximately 10 centimeters below the water surface. Turbidity data were collected at about 10 centimeters below the water surface, 1, 5, 10, 15, and 20 meters, water depth permitting. A Van Dorn water sampler was used to collect unmodified water samples at depth. Turbidity samples were processed with a HACH 2100P turbidity meter and data were recorded in National Turbidity Units (NTU's). Data collected during a single week's sampling were combined and then averaged by depth interval.

Fish sampling. Fish were sampled with experimental gill nets fished on the bottom. Each net had six panels (20' long by 10' deep) with mesh sizes of 3.5, 3.0, 2.5, 2.0, 1.5, and 1.0 inches. Gill nets were generally set and fished from late afternoon through early night hours, so day, crepuscular, and dark periods were sampled. Four to six nets were set in a series, and a set ranged from 0.5 to 3.0 hours. Fish captured were identified (see Table 2 for common and specific names used in this report) and measured (forklength; nearest mm). The number of hours fished per set was rounded to the nearest 0.1 h, and catch per unit of effort (CPUE) was calculated as the number of fish caught per hour of fishing. Fyke nets were fished during five trips (May, June, July, October, November). Nets were set along the shore in about 1 m of water and were fished over one or two nights.

Table 1. Inclusive sampling dates at Beulah Reservoir, 2001.

Trip Number	Month designation	Start date	End date
1	May	May 31	June, 1
2	June	June, 26	June, 28
3	July	July, 24	July, 26
4	August	August, 21	August, 23
5	September	September, 18	September, 20
6	October	October, 23	October, 25
7	November	November, 27	November, 28

Table 2. Common and specific names of species or taxa mentioned in the text.

Common name	Specific name or taxa
Bull trout	*Salvelinus confluentus*
Northern pikeminnow	*Ptychocheilus oregonensis*
Redside shiner	*Richardsonius balteatus*
Rainbow trout	*Oncorhynchus mykiss*
Sculpins	Cottidae
Suckers	Catostomidae[1]
White crappie	*Pomoxis annularis*

[1]Species of suckers were not separated during 2001, however, both large-scale *Catostomus occidentalis* and bridgelip suckers *C. columbianus* were observed.

Figure 2. Fyke net sampling at Beulah Reservoir, 2001.

Bioenergetic modeling

The energy-balance bioenergetics model of Beauchamp and van Tassell (2001) was used as a template for developing a bioenergetic model for bull trout. Most parameters in this model were originally developed for lake trout *Salvelinus namaycush* by Stewart et al. (1983).

Sensitivity studies examined the variation in both predicted body size (assuming a fixed prey availability) and predicted consumption (assuming a fixed growth increment). Parameters were varied by ±10% (Bartell et al. 1986 ; Petersen and Ward 1999). For sensitivity analyses, we simulated an age 2 fish that grew from 5 to 87 g (Beauchamp and van Tassel 2001). The diet of these fish was assumed to be 50% invertebrate prey (4000 Joules/g; 15% indigestible), 50% fish prey (5000 Joules/g; 3% indigestible; Beauchamp and van Tassel 2001), and constant throughout the year. Predator energy density was modeled according to Stewart et al. (1983).

Recent data from Selong et al. (2001) were used to help corroborate the performance of the bull trout bioenergetics model. We predicted the growth rate of age-0 bull trout at a range of temperatures and compared these predictions to laboratory measurements in Selong et al. (2001). At each temperature (8, 10, 12, 14, 16, 18, and 20 °C), fish were assigned a start size (1.8 g) and end size (observed by Selong et al.), and allowed to grow for 60 d, analogous to the experiments in Selong et al. (2001). Fish in the Selong et al. (2001) experiments were fed a nutrient-rich diet of krill, fish meal, and supplements; the caloric density of this diet was not given so we arbitrarily assigned a value of 5,500 Joules/g.

Simulations were also run using size-at-age endpoints from Beauchamp and van Tassel (2001). For subadult bull trout, sizes simulated were for age 2 (initial 5 g, final 87 g), age 3 (initial 87 g, final 311 g), and age 4 (initial 311 g, final 1176 g). These size ranges represent fish that are approximately 75 – 450 mm FL (ages 2+ to 4+; Beauchamp and van Tassel 2001).

Results

Field studies

During 2001, Beulah Reservoir filled to a maximum of about 40,000 acre-feet in April and had a minimum of about 2,000 acre-feet in July and August (Figure 3). Water temperature and dissolved oxygen conditions in Beulah Reservoir are summarized in

Figure 4. Average water temperature at the surface increased to over 24 °C in July and then declined steadily. There was no evidence of a thermocline in our sampling, with water temperatures declining steadily with depth, even when the reservoir was moderately empty during August (Figure 3). Dissolved oxygen was highest in surface water during October and lowest during August and September (Figure 4). In July, DO ranged from >9 ppm at the surface to <5 ppm near the bottom of the reservoir (9-10 m depth; Figure 4).

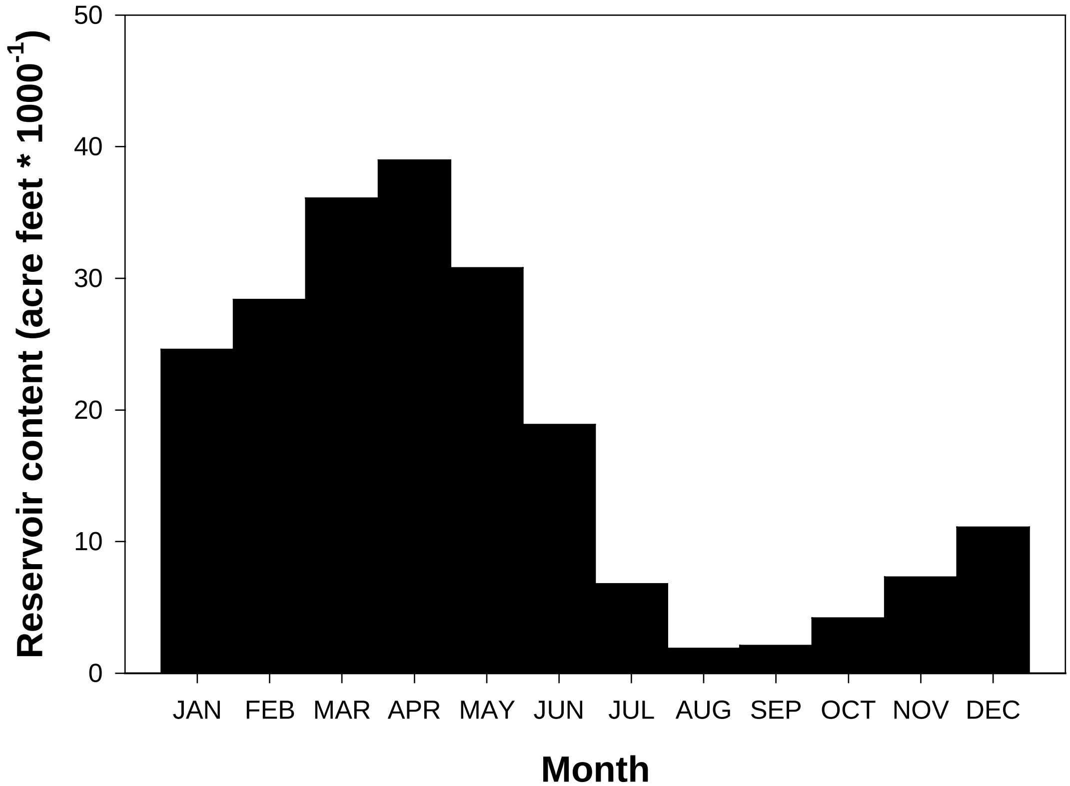

Figure 3. Water content of Beulah Reservoir during 2001.

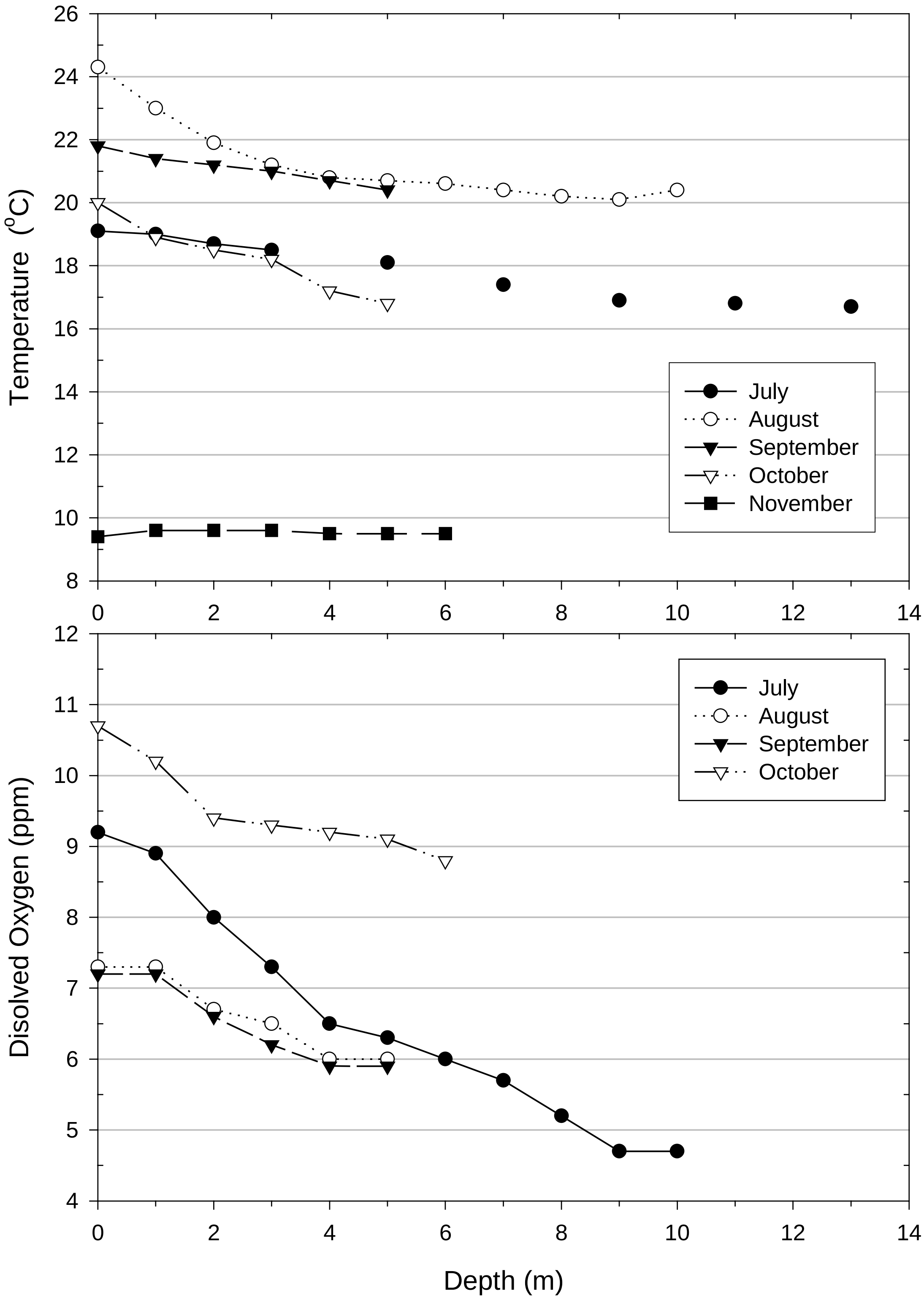

Figure 4. Water temperature and dissolved oxygen in Beulah Reservoir during 2001.

Sampling effort was distributed throughout Beulah Reservoir (Figure 5), but effort was concentrated in the lower third of the reservoir in the deepest water and along the thalweg of the old river, especially during summer months as the water level declined. Fyke net sampling was along the shore as the water level declined in summer (Figure 5). The trip during May was primarily a reconnaissance trip to test gear, and relatively few samples were collected.

We collected 1,145 fish in gill nets and 185 fish in Fyke nets during sampling in 2001 (Table 3), although none of the fish captured were bull trout. In the gill nets, over half of the fish collected (50.3%) were northern pikeminnow, while suckers and rainbow trout were the second and third most common species, respectively (Figure 6). Fyke net sampling was not conducted as intensely as the gill net sampling, thus fewer fish were collected with that gear (Table 3).

The CPUE by species showed relatively few patterns through the season, except somewhat higher densities during late summer and fall months (Table 4). These differences were not tested statistically. Rainbow trout appeared to decline during October and November sampling, compared to August and September densities (Table 4).

The sizes of fish captured in Beulah Reservoir are summarized in Table 5 and Figure 7 Northern pikeminnow averaged 186 mm FL (range 42-404 mm; Table 5). The median size for northern pikeminnow was about 150 mm with relatively few fish over 300 mm (Figure 7). Rainbow trout were the largest fish on average (average 359 mm; maximum 499 mm). Suckers were common across a large size range (Figure 7). Sculpins, redside shiners, and white crappie were small compared to other species, although a moderate number of small northern pikeminnow were also collected (Figure 7). Smaller fish were generally captured in the Fyke nets.

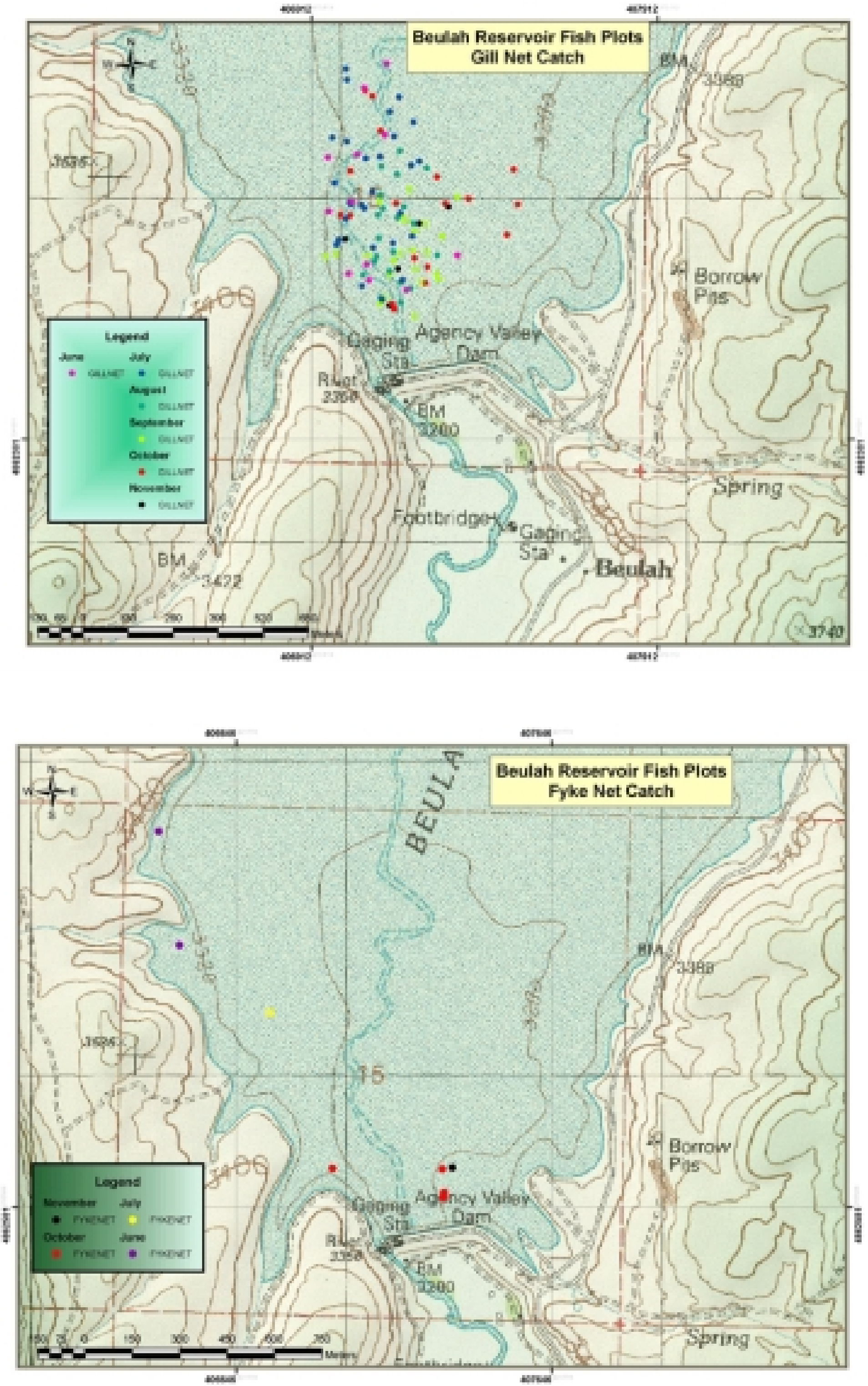

Figure 5. Locations of gill net (top panel) and Fyke net (bottom) samples in Beulah Reservoir, 2001.

For the first time since sampling began in Beulah Reservoir about 60 years ago, an introduced species, white crappie, was found. White crappie were collected in both the September and the October sampling periods (Table 3). The average size of white crappie collected was 92 mm (Table 5) and they comprised about 0.8% of the catch (Figure 6).

We collected a few bottom samples during May and June using a van Veen dredge, but observed very low numbers of bottom invertebrates. Most samples included only dark mud with no macroinvertebrates observable to the naked eye.

Table 3. Number of fish captured at Beulah Reservoir in 2001 by month. NF = not fished.

Species / taxa	Month							
	May	June	July	August	September	October	November	Total
				Gill nets				
Sculpins								
White crappie					2	7		9
Sucker		49	74	132	69	47	9	381
N. pikeminnow	5	143	114	104	58	181	11	616
Redside shiner		1		4	5	9		19
Rainbow trout	1	1	40	63	60	3		168
				Fyke nets				
Sculpins			1	NF	NF	3		3
White crappie				NF	NF			
Sucker		2		NF	NF			2
N. pikeminnow	69	4	1	NF	NF	1	1	76
Redside shiner	62	12		NF	NF	22	16	112
Rainbow trout				NF	NF			

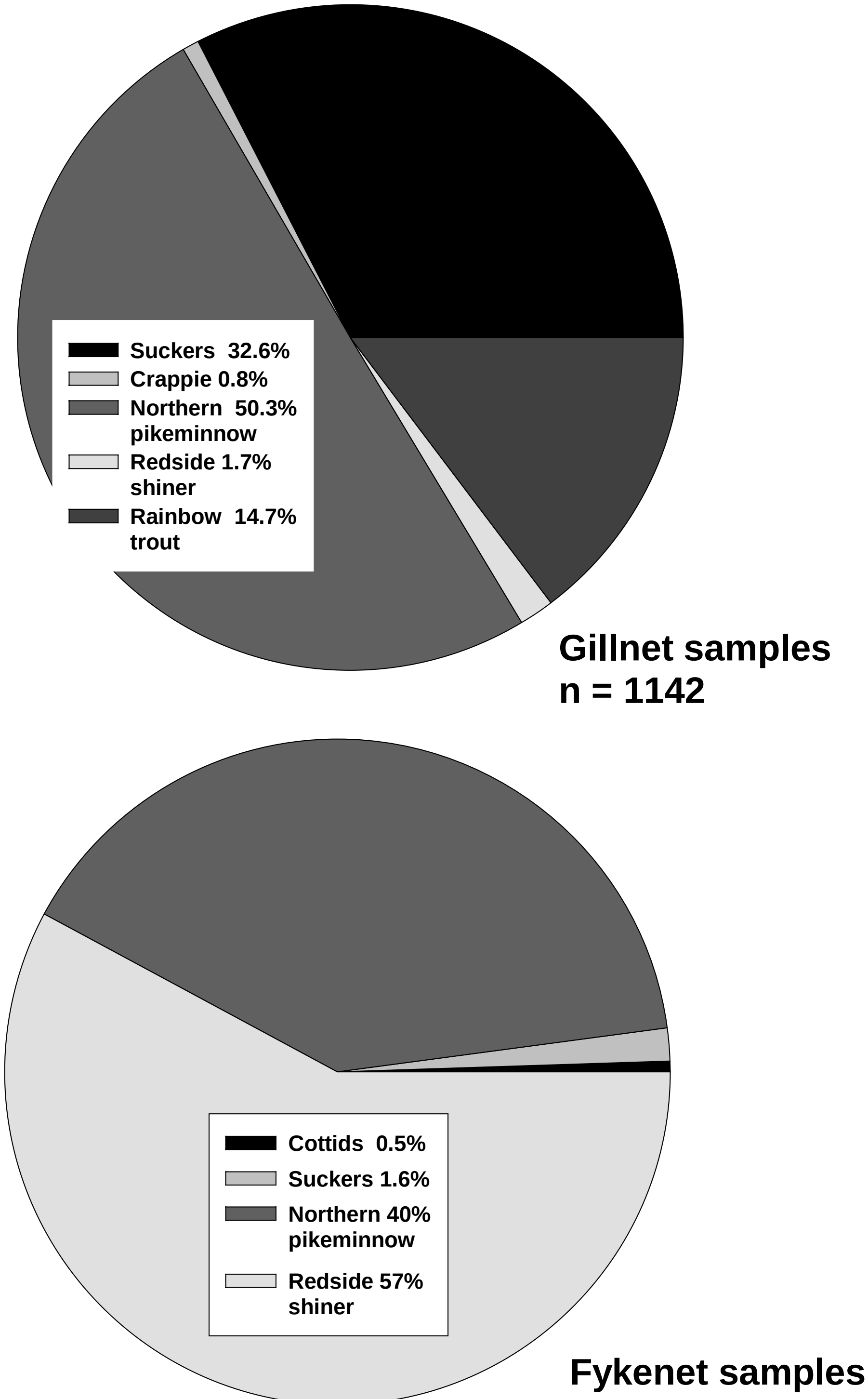

Figure 6. Species composition from gill net and Fyke net samples, Beulah Reservoir, 2001.

Table 4. Average CPUE (catch per hour of soak time for gill nets) for major taxa collected at Beulah Reservoir, 2001. N is the total number of gill net sets per trip.

Month (trip number)	Northern pikeminnow		Rainbow trout		Suckers		Redside shiners		N
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
May (1)	3.0	4.2	0.5	0.7	2.4	3.4	0.0	0.0	2
June (2)	3.8	2.2	0.0	0.1	1.5	0.9	0.0	0.1	12
July (3)	3.5	3.0	1.1	1.6	2.2	1.6	0.0	0.0	28
August (4)	7.3	4.0	4.6	4.1	10.0	4.7	0.2	0.5	22
September (5)	3.2	2.8	3.5	2.6	4.0	2.3	0.2	0.5	25
October (6)	14.0	17.4	0.2	0.6	3.5	2.9	0.6	1.1	18
November (7)	3.8	4.0	0.0	0.0	3.2	2.6	0.0	0.0	5
All months	5.9	8.3	2.0	2.9	4.3	4.0	0.2	0.6	112

Table 5. Average size of fish captured at Beulah Reservoir during 2001.

Species / taxa	Forklength (mm)				
	Mean	Minimum	Maximum	SD	N
Sculpins	56	23	80	27	4
White crappie	92	88	97	3	9
Sucker	284	26	476	90	375
Northern pikeminnow	186	42	404	66	692
Redside shiner	57	22	103	15	131
Rainbow trout	359	131	499	63	168

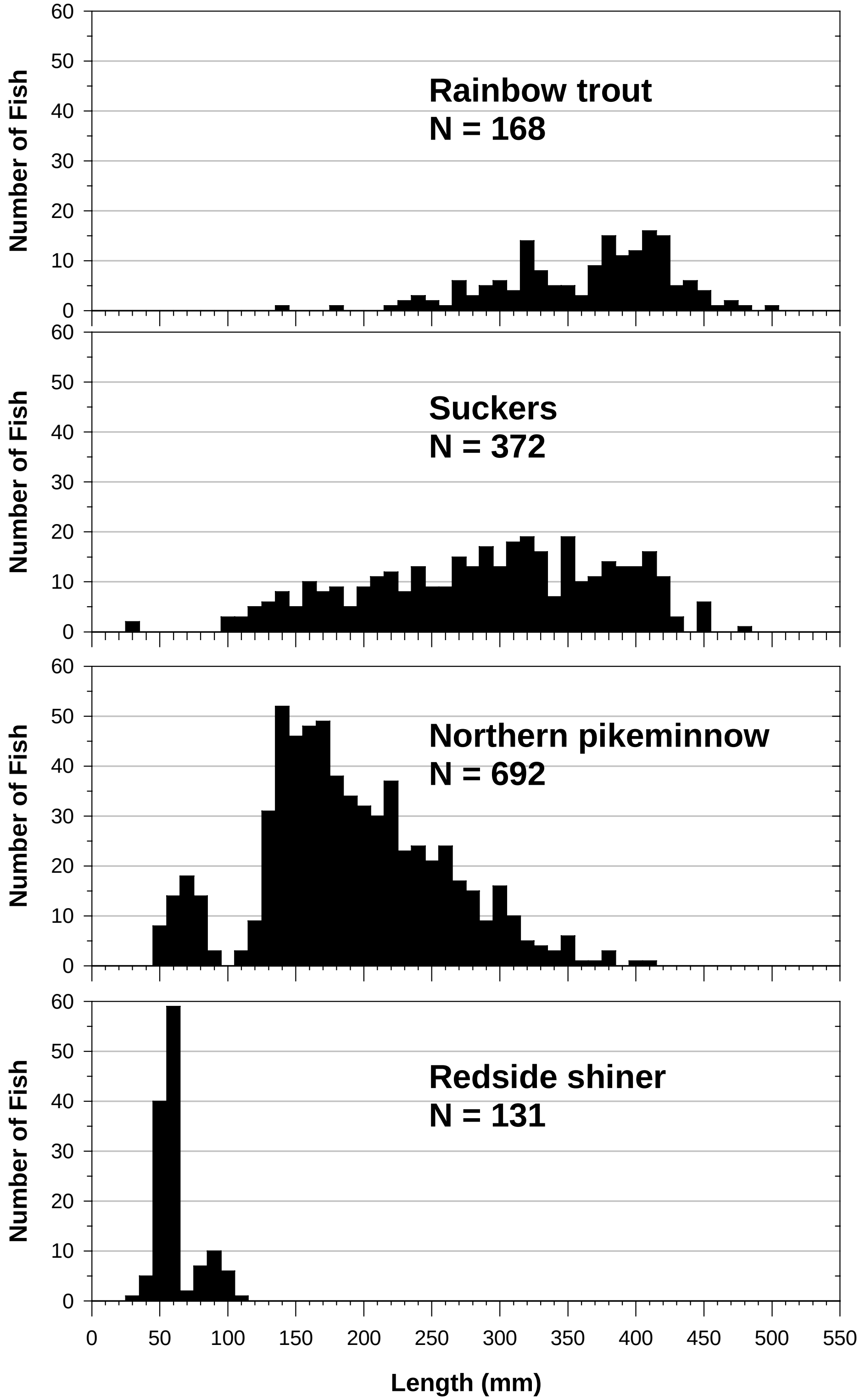

Figure 7. Length-frequency distributions of the most abundant species in Beulah Reservoir, 2001.

Bioenergetic modeling

Parameters used in modeling are shown in Table 6 (see Beauchamp and van Tassel 2001). Seasonal temperature used for modeling was based on BOR information collected in 1999 (Table 7). For the spring through summer period (3/23/99 to 9/27/99), temperatures near the bottom of the reservoir were derived from Figure 2 in BOR (1999). For other parts of the year, we used water temperatures measured in the North Fork Malheur River during (BOR 1999). The temperatures that we used from 1999 were from a "normal" flow year (R. Rieber, pers. comm.). These temperatures are lower than those observed during summer 2001 (Figure 4), which was a drought year. In these analyses, we are concerned with overall model performance rather than to compare different temperature regimes, which can be done later.

The sensitivity of bull trout growth and consumption in the bioenergetics model is given in Table 8. Predicted fish size and consumption were most sensitive to the consumption parameters, especially CQ (Table 8). Increasing the consumption parameters by +10% caused growth to vary between +37 and +53%, while decreasing parameters caused slightly smaller changes in predicted size (-26% to –34%; Table 8). The consumed mass of prey in the model also varied quite significantly with small changes in the consumption parameters. Variations in the respiration and excretion parameters caused considerably less change in predicted growth and consumption, generally less than 15% up or down depending on the direction of change in the parameter (Table 8).

Table 6. Parameter values used in the bull trout bioenergetics model. Parameters in capital letters (e.g., CA and CQ) refer to the formulation in the software of Hanson et al. (1997) for Consumption (their Equation 1), Respiration (their Equation 1), and Egestion-Excretion (their Equation 2). Sources: Beauchamp and van Tassel (2001), Stewart et al. (1983).

Parameter	Parameter description	Parameter values
CA	Intercept: C_{max}	0.059
CB	Coefficient: C_{max} versus mass	-0.307
CQ	Temperature for CK1	0.123
CTO	[Not relevant with Eq. 1 so = 0]	0
CTM	[Not relevant with Eq. 1 so = 0]	0
CTL	[Not relevant with Eq. 1 so = 0]	0
CK1	[Not relevant with Eq. 1 so = 0]	0
CK4	[Not relevant with Eq. 1 so = 0]	0
RA	Intercept: R	0.00463
RB	Coefficient: R versus mass	-0.295
RQ	Coefficient: R versus temperature	0.059
RTO	Activity coefficient	0.0232
RK1	Swimming speed intercept	1
RK4	Swimming speed slope	0.05
RTL	Cuttoff temperature for activity change	11
SDA	Specific dynamic action	0.172
ACT	Activity	11.7
Bact	Temperature dependence coefficient	0.041
FA	Proportion of consumption egested	0.212
FB	Temperature coefficient for egested	-0.222
FG	Feeding level (p-value) coefficient	0.631
UA	Proportion of (consumption - egested)	0.31
UB	Temperature coefficient for excretion	0.58
UG	Feeding level (p-value) coefficient	-0.299

Table 7. Average monthly temperatures used in bioenergetic modeling.

Month	**Temperature (^oC)**
January	2.0
February	2.0
March	4.5
April	6.0
May	8.0
June	9.5
July	12.0
August	16.0
September	16.5
October	9.0
November	5.0
December	2.0

Table 8. Sensitivity of the bull trout bioenergetics model to variations in parameter estimates. Sensitivity is the percentage difference between a nominal simulation and one where the parameter was varied ±10%. Response is shown for the change in predicted growth of the simulated fish (fish size) and for total consumption. The food availability (p-value) was constant for all simulations. Numbers in parentheses are the percent change from nominal. Parameter symbols were defined in Hanson et al. (1997), and are briefly summarized in Table 7 above.

Parameter	Sensitivity by varying parameter			
	+10 %		-10 %	
	Fish size (g)	Consumed mass (g)	Fish size (g)	Consumed mass (g)
Nominal	**87**	**400**	**87**	**400**
Consumption				
CA	119 (+37%)	523 (+31%)	62 (-29%)	300 (-25%)
CB	122 (+40%)	531 (+33%)	64 (-26%)	313 (-22%)
CQ	133 (+53%)	579 (+45%)	57 (-34%)	282 (-30%)
Respiration				
RA	76 (-13%)	371 (-7%)	100 (+15%)	432 (+8%)
RB	76 (-13%)	378 (-6%)	98 (+13%)	423 (+6%)
RQ	81 (-7%)	385 (-4%)	93 (+7%)	416 (+4%)
RTO	83 (-5%)	391 (-2%)	91 (+5%)	409 (+2%)
Excretion				
FA	81 (-7%)	384 (-4%)	94 (+8%)	417 (+4%)
FB	84 (-3%)	394 (-2%)	90 (+3%)	408 (+2%)
FG	85 (-2%)	395 (-1%)	89 (+2%)	406 (+2%)
UA	84 (-3%)	392 (-2%)	90 (+3%)	409 (+2%)
UB	82 (-6%)	388 (-3%)	91 (+5%)	411 (+3%)
UG	86 (-1%)	399 (<1%)	88 (+1%)	402 (+1%)

The predicted growth rate of age-0 bull trout using this model differed considerably from measurements conducted in the laboratory by Selong et al. (2001; Figure 8), except at the highest temperature tested. The pattern of change in growth rates with temperature, however, was similar between the model and the laboratory experiments with maximum growth rates at about 12 – 14 °C.

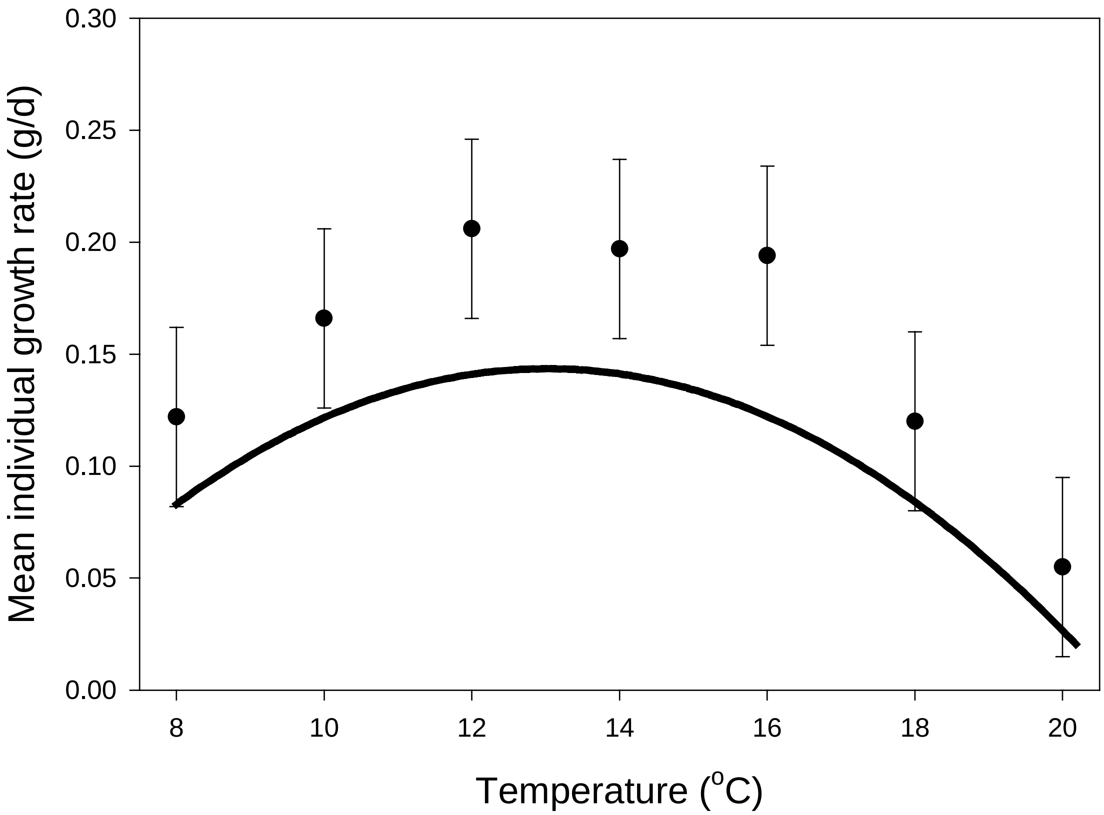

Figure 8. Growth rate for age-0 bull trout at different temperatures, predicted with the bioenergetic model (• ± 1 SD; see text) and fit to laboratory experiments (heavy line; see Selong et al. 2001).

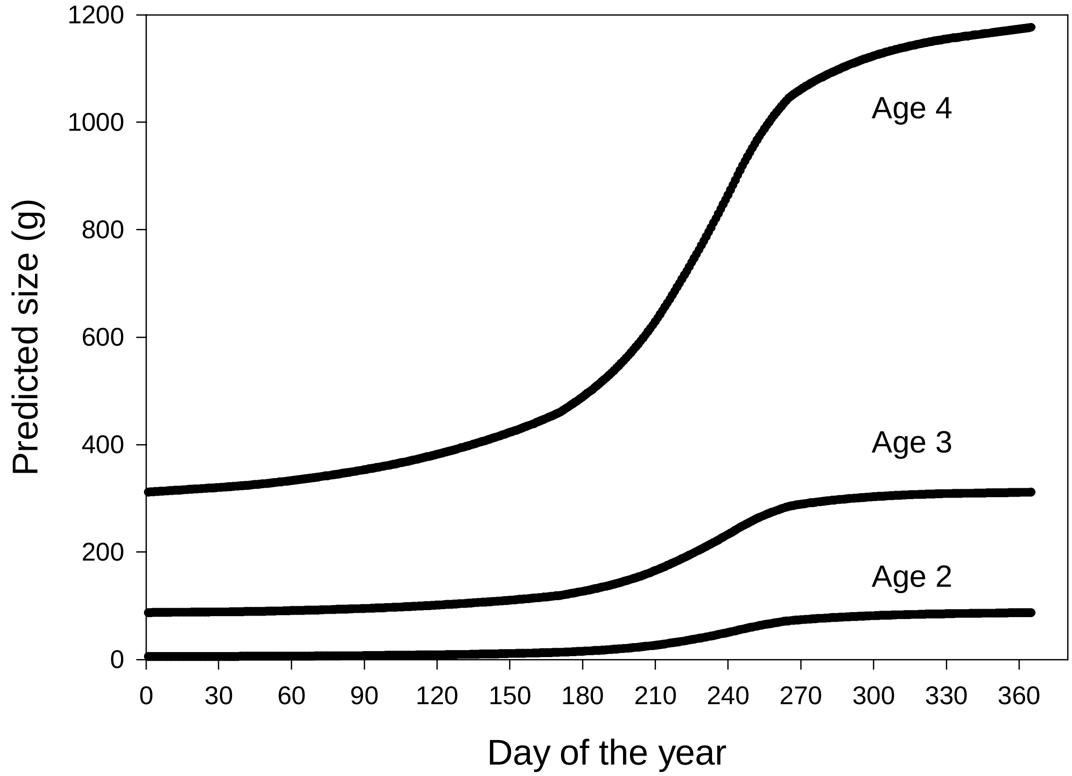

Figure 9. Predicted seasonal growth for subadult bull trout (75 – 450 mm; ages 2-4) using the bioenergetics model.

The daily size and growth rate of subadult bull trout (ages 2-4 years) was predicted with the bioenergetics model (Figure 9). The maximum predicted growth rate occurred on day 214 (August 2) for age 2 (0.023 g/g/d), age 3 (0.017 g/g/d), and age 4 (0.011 g/g/d). The model suggests that relatively little growth occurs prior to about July 1 (day 182; Figure 9) and after October 1 (day 274). Simulations in Figure 9 were conducted with constant p-values (0.69) in the model and growth may occur during other months if forage is sufficient (increase in model p-value). Extremely high temperatures during summer months, which may occur during drought years, could also limit growth.

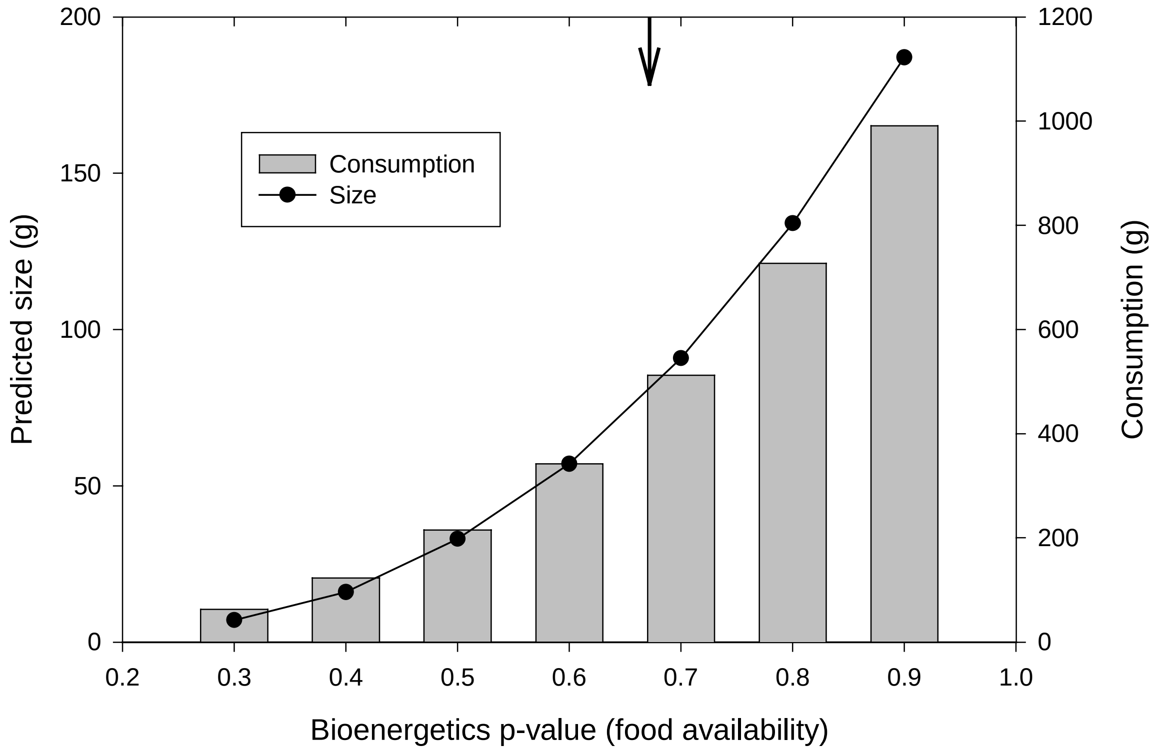

Figure 10. Predicted size and total consumption of prey by an age-1 bull trout feeding at various levels of maximum consumption (p-value in the bioenergetics modeling configuration). Starting bull trout size is 5 g. The arrow indicates the expected growth (87 g; fitted p-value 0.69) and consumption (see text).

The p-value in the bioenergetics model adjusts the proportion of maximum consumption at which the fish feeds to achieve a given growth increment, and p-values are often interpreted as a measure of the amount of food available to fish in a given habitat. Varying the p-value from 0.3 to 0.9 for an age-1 bull trout caused, as expected, considerable changes in the predicted size and consumption of the modeled fish (Figure 10). At very low p-values (<0.5), fish consumed less than 200 g of prey during the year and grew to less than 40 g (Figure 10). When p-values were greater than the fitted p-value (0.69), modeled fish were capable of growing to >100 g and consuming >700 g of prey; some of these higher growth rates and consumption values may be unreasonable in field situations.

Discussion

During summer and fall of 2001, we did not detect any bull trout in Beulah Reservoir, although over 1,400 individuals of other species were collected. We used methods that have been successful during earlier years (ODFW data, e.g.) in collecting bull trout in Beulah Reservoir, so it seems unlikely that our procedures were insufficient to sample bull trout. We also sampled at a variety of water depths and throughout the reservoir. The lack of adult bull trout in our collection is perhaps not unexpected since adfluvial bull trout in the system had likely moved upriver into the North Fork of the Malheur River during late spring. There were also questions from local agencies and biologists about the potential occurrence of subadult bull trout during summer months in Beulah Reservoir. Results from 2001 suggest that subadult bull trout are perhaps not present in Beulah Reservoir during summer months, or were present in very low number. Subadult bull trout may also exhibit the same migratory behaviors as adults, moving out of Beulah Reservoir during the early spring prior to the beginning of our sampling.

Based on temperatures observed and preferences noted in literature for bull trout (see Selong et al. 2001 for a summary), it is not surprising that none were captured. Saffel and Scarnecchiea (1995) noted sharp declines in bull trout abundances at temperatures >13.9 ^{o}C. Many other authors have concluded that temperatures in excess of about 15 ^{o}C limit bull trout distributions (Rieman and McIntyre 1993 and references therein). In Lake Billy Chinook, Oregon, the CPUE of bull trout (by size classes) was zero during July-September and was zero or relatively low during June in the reservoir habitat; CPUE's were generally higher in the river and transition zones (Beauchamp and van Tassel 2001; their Table 4). In Beulah Reservoir during 2001, temperatures <16 ^{o}C were observed only during November and December (Figure 4); however, during these late fall months bull trout may have still been in the upper tributaries rather than in the reservoir. Sampling was scheduled during spring through fall months, rather than winter months, since this is the period during which water management is possible and agencies have concerns about temperature, water quality, and available forage.

Based on the numbers and sizes of fish collected during 2001, redside shiner, northern pikeminnow, suckers, and a few other species were the only fish greater than about 100 mm in length that might have been likely prey for subadult bull trout in Beulah

Reservoir. Rainbow trout are stocked into the reservoir as fingerlings during many years, and these fish may also be preyfish for adult bull trout, and perhaps larger subadult bull trout. Rainbow trout were not stocked into Beulah Reservoir during 2001 since there were concerns about the survival of stocked fish during the severe drought (Wayne Bowers, ODFW, personal communication).

The collection of white crappie in Beulah Reservoir is the first known occurrence of a nonnative species above Agency Valley Dam (Wayne Bowers, ODFW, personal communication).   The means by which white crappie entered the reservoir are unknown. The average length of white crappie was 92 mm and the range was only 88-97 mm, suggesting that all of these fish were from the same cohort.   White crappie become reproductively mature at 2-3 years old when they are about 180-200 mm long (Wydoski and Whitney 1979), suggesting that the population of white crappie in Beulah Reservoir may not be large enough to reproduce.   White crappie were introduced into Oregon and Washington in the late 1800s and are now widespread throughout the two states (Wydoski and Whitney 1979).   White crappie spawn in the spring among vegetation in shallow water, and feed on plankton, insects, and eventually small fish. It seems likely that white crappie will be self-sustaining in Beulah Reservoir.

Introduced species such as the white crappie occasionally alter the food web and predator-prey dynamics in a reservoir system, especially when their populations increase dramatically. Rainbow smelt *Osmerus mordax*, for example, were introduced into Strawberry Reservoir, Colorado, in 1983 to increase the prey availability for walleye *Stizostedion vitreum* (Johnson and Goettl 1999).   The rainbow smelt population increased dramatically within 6 years, but the planktivorous smelt consumed large numbers of zooplankton and the smelt population crashed. Johnson and Goettl (1999) recommended that future efforts to supplement prey populations also requires monitoring of prey, predator, and zooplankton populations. Likewise, the abundance of white crappie in Beulah Reservoir probably deserves monitoring in future years as it may become a prey of bull trout, northern pikeminnow, or rainbow trout, and potentially a predator on juvenile fish in the reservoir.

At this time, we have no information on the diet of bull trout that occur in Beulah Reservoir, and must thus make assumptions using other studies. It is likely that the larger subadults and adults are piscivorous (Brown 1995; Wilhelm et al. 1999; Beauchamp and van Tassel 2001). The diet of smaller bull trout probably includes more invertebrate species, gradually switching to a greater proportion of fishes. In Lake Billy Chinook, Oregon (Beauchamp and van Tassel 2001), the diet of subadult (ages 2-4 years; 75 – 450 mm FL) bull trout may include a large proportion of invertebrates. Beauchamp and van Tassel (2001) noted invertebrates in subadult bull trout in both the reservoir and in the transition zone between the reservoir and in the river during winter and spring. Based on the Beauchamp and van Tassel study, we included invertebrates as 50% of the diet in modeled fish. However, this assumption should probably be changed in the future based on our finding of few invertebrates in Beulah Reservoir. Our efforts to sample invertebrates were minimal, however, and the occurrence of sculpins suggest some invertebrate species may occur in the reservoir. For future work, we might assume that the diet of bull trout is roughly proportional to the species captured throughout the reservoir, particularly the smaller fish species that occur in the deeper, cooler waters where bull trout are most likely to reside.

Sensitivity analyses of the bull trout bioenergetics model suggested that output was most sensitive to the consumption rate parameters (CA, CB, CQ). Varying these parameters by ±10% tended to cause fish growth and consumption to vary ~20-50% (Table 8). Changes in the respiration parameters caused growth and consumption to vary roughly proportional to the parameter change (Table 8), while the model output is not generally sensitive to excretion parameter change. These results are consistent with other sensitivity studies (Bartell et al. 1986; Petersen and Ward 1999). Respiration parameters are generally quite important, and it is possible that the ones for lake trout do not fit bull trout especially well.

Sweka and Hartman (2001) recently estimated consumption rate parameters CA and CB for a congener of bull trout, brook trout *Salvelinus fontinalis.* Their parameter estimates were 0.130 (CA) and –0.201 (CB), compared to lake trout parameters of 0.059 (CA) and –0.307 (CB; Stewart et al. 1983) that we used as proxies for bull trout. Experiments with brook trout, however, were conducted at only one temperature (12.0 ^{o}C) and with relatively small individuals (avg. 37 g). Although brook trout are congeners of bull trout and lake trout, these consumption rate parameters differ considerably from those used in the other models. Beauchamp and van Tassel (2001) argue that parameters from lake trout should suffice in a general way for bull trout, although they likely did not have access to the Sweka and Hartman (2001) values since the two studies were being done at about the same time.

Selong et al. (2001) measured the growth rate of age-0 bull trout at a variety of temperatures. Compared to the Selong et al. (2001) data, the bioenergetics model over-predicted the rate of growth at all temperatures, particularly in the 12-16 ^{o}C range (Figure 8). However, the two analyses matched well in showing that the optimum temperature for growth was likely around 12-14 ^{o}C. This is the lowest optimum temperature for growth among a variety of juvenile salmonids that have been studied (Selong et al. 2001). Other studies have also concluded that adult bioenergetic models may not be appropriate for predicting growth or consumption of larval or juvenile fishes (Rice and Cochran 1984).

Error in the bioenergetic model predictions can also occur through the activity parameter, which is often just an integer multiplier of the standard metabolic rate (Hanson et al. 1997). The model for bull trout is based on the lake trout parameter set where activity is a function of swimming speed, which is a function of mass and water temperature below a cutoff temperature (Stewart et al. 1983). The activity coefficient in this model ranges from about 1.4 at low temperature and small size to 1.9 at high temperature and large size (Stewart et al. 1983). Several studies have suggested that activity is underestimated in many bioenergetic model formulations (e.g., Boisclair and Leggett 1989; Ney 1993; Rowan and Rasmussen 1996). Rowan and Rasmussen (1996) estimated that the activity multiplier for lake trout might be as high as 4 or 5 for mature fish, which could translate into an underestimate of consumption by roughly half. Relatively few field studies have been done to estimate how activity influences field estimates of consumption or growth. If activity is under-estimated in the bull trout model, predictions about the needed prey base to support a bull trout population could be wrong.

Authors often warn against “borrowing” parameters from one species in developing a model for a new species (Ney 1993, e.g.), however, borrowing is a common practice (Beauchamp and van Tassel 2001 and many others) and generally produces satisfactory results between congeners and fish with similar food habits. More often, other unknown parameters, such as prey or predator population sizes, will be poorly estimated and introduce added errors. During 2002, we plan to collect laboratory data on the maximum consumption and respiration rate of bull trout at various temperatures and body sizes. Data will be used to develop species-specific parameters for a bull trout bioenergetics model.

Although we some identified potential problems with the bull trout bioenergetics model, we believe that it can be improved and used as a predictive tool for managing bull trout in Beulah Reservoir. We do not intend to use the model for age-0 fish and the laboratory studies that we have planned will address the issue of “borrowed” parameters. Bull trout activity is problematic; telemetry studies that are being conducted in the North Fork Malheur River by the Burns-Paiute Tribe and in the Boise River by BOR researchers should provide information on the activity of bull trout during summer and fall months. Subadult bull trout have been radiotagged and shown to occur in Arrowrock Reservoir, Idaho, during July and other months (R. Rieber, pers. comm..). Movement data from these fish might be used in modeling of bull trout in Beulah Reservoir.

Once we have improved the bioenergetics model for bull trout we can address question such as: What production in the reservoir (total grams of fish and invertebrates e.g.) would be necessary to maintain bull trout populations of varying sizes during different months of the year? The field and model studies should allow us to estimate whether prey populations for bull trout are limiting during low water conditions at Beulah Reservoir. We have begun collaboration with Alan Harrison and Merlyn Bender (BOR, Denver), who will be providing estimates of the temperature in Beulah Reservoir under different flow and meteorological conditions. These estimates can be used in modeling runs to bound the consumption needs of bull trout. Field studies are also continuing at Beulah Reservoir in 2002 to better characterize the preyfish population, sample bull trout diets, and measure physical conditions.

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Appendices.

Appendix 1. Catch in gill nets by species in Beulah Reservoir, 2001. BLS= Bridgelip sucker; CRA=White crappie; LSS=sucker spp.; NPM=northern pikeminnow; RSS=redside shiner; RT=rainbow trout; UNI=unidentified.

		SPECIES						
		BLS	CRA	LSS	NPM	RSS	RT	UNI
		N	N	N	N	N	N	N
SETDATE	SAMPLE							
05/31/2001	3	.	.	1	5	.	.	.
06/01/2001	5	.	.	.	.	.	1	.
06/26/2001	11	.	.	1	2	.	.	.
	12	.	.	2	2	.	1	.
	13	.	.	3	6	.	.	.
	14	.	.	2	7	.	.	.
06/27/2001	15	.	.	5	9	.	.	.
	16	.	.	8	10	.	.	.
	17	.	.	2	3	.	.	.
	18	.	.	2	7	.	.	.
06/28/2001	21	.	.	4	17	1	.	.
	22	.	.	4	32	.	.	.
	23	.	.	6	30	.	.	.
	24	.	.	10	18	.	.	.
07/24/2001	31	.	.	3	3	.	.	.
	32	.	.	1	5	.	4	.
	33	.	.	1	10	.	1	.
	34	.	.	7	15	.	4	.
	35	.	.	3	1	.	1	.
	36	.	.	6	.	.	1	.

(Continued)

SETDATE	SAMPLE	BLS N	CRA N	LSS N	NPM N	RSS N	RT N	UNI N
07/24/2001	37	.	.	5	2	.	1	.
	38	.	.	3	1	.	.	.
07/25/2001	40	.	.	3	4	.	.	.
	41	.	.	1	13	.	.	.
	42	.	.	1	2	.	.	.
	44	.	.	1	1	.	.	.
	45	.	.	4	5	.	1	.
	46	.	.	6	4	.	.	.
	47	.	.	1	3	.	1	.
	48	.	.	5	6	.	2	.
	49	.	.	3	1	.	.	.
	51	.	.	2	1	.	.	.
	52	.	.	2	3	.	3	.
	53	.	.	1	2	.	.	.
07/26/2001	56	.	.	.	7	.	.	.
	57	.	.	4	3	.	.	.
	58	.	.	1	6	.	2	.
	59	.	.	5	3	.	4	.
	60	.	.	1	4	.	9	.
	61	.	.	2	5	.	.	.

(Continued)

SETDATE	SAMPLE	SPECIES BLS N	CRA N	LSS N	NPM N	RSS N	RT N	UNI N
07/26/2001	62	.	.	1	3	.	4	.
	63	.	.	1	1	.	2	.
08/21/2001	68	.	.	3	4	1	4	.
	69	.	.	5	7	.	1	.
	70	.	.	10	17	.	1	.
	71	.	.	8	3	.	3	.
	72	.	.	5	2	.	3	.
	73	.	.	9	2	.	2	.
	74	.	.	2	1	.	.	.
08/22/2001	79	.	.	5	4	1	6	.
	80	.	.	7	10	2	6	.
	81	.	.	3	7	.	1	.
	82	.	.	4	4	.	3	.
08/23/2001	84	.	.	5	6	.	3	.
	85	.	.	8	7	.	4	.
	86	.	.	6	5	.	2	.
	87	.	.	7	6	.	4	.
	88	.	.	11	3	.	.	.
	89	.	.	5	4	.	.	.
	90	.	.	3	1	.	4	.

(Continued)

SETDATE	SAMPLE	BLS N	CRA N	LSS N	NPM N	RSS N	RT N	UNI N
08/23/2001	91	.	.	10	3	.	1	.
	92	.	.	5	2	.	12	.
	93	.	.	6	5	.	.	.
	94	.	.	5	1	.	3	.
09/18/2001	100	.	.	.	1	.	4	.
	101	.	.	4	2	1	3	.
	102	.	.	1	1	.	.	.
	103	.	.	4	3	.	.	.
	104	.	.	2	1	.	2	.
	105	.	.	1	.	.	2	.
	106	.	.	2	.	.	1	.
	107	.	.	1	.	.	1	.
09/19/2001	112	.	.	2	2	.	2	.
	113	.	.	3	3	.	1	.
	114	.	.	4	4	.	2	.
	115	.	.	4	3	.	2	.
	116	.	.	1	3	.	4	.
	117	.	.	1	.	.	2	.
	118	.	.	3	.	.	4	.
	119	.	.	1	.	.	.	.

(Continued)

SETDATE	SAMPLE	BLS N	CRA N	LSS N	NPM N	RSS N	RT N	UNI N
09/20/2001	120	.	.	3	2	1	1	.
	121	.	1	5	5	1	3	.
	122	.	.	3	2	.	4	.
	123	.	1	5	3	1	2	.
	124	.	.	1	2	.	8	.
	125	.	.	5	6	.	2	.
	126	.	.	2	2	1	5	.
	127	.	.	6	10	.	4	.
	128	.	.	5	3	.	1	.
10/24/2001	157	.	.	1	11	.	.	.
	158	.	.	5	3	.	.	1
	159	.	1	1	13	2	.	.
	160	.	.	1	.	.	.	.
	161	.	1	2	4	.	.	.
	162	.	.	.	2	1	1	.
	163	.	.	2	20	2	.	.
	164	.	.	5	4	.	1	.
10/25/2001	178	.	2	6	42	1	.	.
	179	.	2	1	21	3	.	.
	180	.	.	1	11	.	1	.

(Continued)

		SPECIES						
		BLS	CRA	LSS	NPM	RSS	RT	UNI
		N	N	N	N	N	N	N
SETDATE	SAMPLE							
10/25/2001	181	.	.	2	15	.	.	.
	182	.	.	6	8	.	.	.
	183	.	.	.	2	.	.	.
	184	.	.	2	1	.	.	.
	185	.	.	3	.	.	.	.
	186	.	1	2	18	.	.	.
	187	.	.	7	6	.	.	.
11/27/2001	198	1	.	.	4	.	.	.
	199	2	.	.	1	.	.	.
	200	1	.	.	.	.	.	.
	202	1	.	.	1	.	.	.
	203	4	.	.	5	.	.	.

Appendix 2. Catch in Fyke nets by species in Beulah Reservoir, 2001. COT=cottids; LSS=sucker spp.; NPM=northern pikeminnow; RSS=redside shiner.

SETDATE	SAMPLE	COT N	LSS N	NPM N	RSS N
05/31/2001	1	.	.	10	26
	2	.	.	53	32
	6	.	.	1	4
	7	.	.	5	.
06/26/2001	9	.	1	.	1
	10	.	.	1	.
06/27/2001	19	.	1	2	11
	20	.	.	1	.
07/24/2001	26	1	1	1	.
10/23/2001	131	.	.	.	1
	138	1	.	.	.
	143	.	.	.	15
	145	1	.	.	1
10/24/2001	155	.	.	.	5
	171	.	.	1	.
10/25/2001	190	1	.	.	.
11/27/2001	196	.	.	1	3
	204	.	.	.	13