Coldwater Reservoir Ecology

Federal Aid Project F-242-R13

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Federal Aid in Fish and Wildlife Restoration

Job Progress Report

Colorado Division of Wildlife

Fish Research Section

Fort Collins, Colorado

August 2006

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The results of the research investigations contained in this report represent work of the authors and may or may not have been implemented as Division of Wildlife policy by the Director or the Wildlife Commission.

CONTENTS

LIST OF TABLES

Appendix Tables

LIST OF FIGURES

Appendix Figures

State: Colorado

Project No. F-242-R13 **Name:** Statewide Fish Research

Study No. F-02 **Title:** Coldwater Reservoir Ecology

Period Covered: July 1, 2005 to June 30, 2006

Principal Investigator: Patrick J. Martinez

STUDY OBJECTIVE: To investigate factors which influence or might affect the stability of sport fisheries in Colorado's large (>1,000 surface acres), coldwater (>6,500 feet in elevation) reservoirs and to provide recommendations for the management and monitoring of these and similar reservoirs.

OBJECTIVE 1: HYDROACOUSTIC SURVEYS OF KOKANEE AND PISCIVORE ABUNDANCE IN EXISTING AND PROPOSED BROODWATERS

Perform standardized hydroacoustic surveys to estimate kokanee and piscivore abundance in established (Blue Mesa, Granby, McPhee, Vallecito and Williams Fork) and proposed (e.g. Elevenmile and Ridgeway) kokanee brood stock waters and in other reservoirs as resources allow.

Segment Objective 1: Perform sonar surveys on Blue Mesa, Elevenmile, Granby, McPhee, Ridgeway, Vallecito and Williams Fork reservoirs.

Segment Objective 2: Perform sonar surveys on Dillon, Taylor Park and Ruedi Reservoirs, as feasible.

Introduction

Hydroacoustic surveys have been performed on several coldwater reservoirs annually to follow long-term trends in pelagic fish abundance. Interest remains in discerning predator-sized vs. prey-sized fishes in these sonar data to track and forecast predation demand and it potential impact to overall fishery stability. Efforts to refine this approach (Martinez 2003) are given in Crockett et al. (IN PRESS). Fishery biologists requested that additional waters be surveyed by sonar in 2005. These additional waters had to be prioritized due to time constraints and not all requests could be met. Priority was given to developing kokanee broodstock waters (Elevenmile Reservoir) or to waters with potential lake trout regulation issues (Green Mountain Reservoir). Interest in waters with walleye predation vs. prey scenarios (Carter Reservoir) could not be surveyed in 2005 due to time constraints. I explained to biologists that we may have to move some sonar surveys out of ten day window surrounding the new moon in order to be able to accommodate all additional surveys during the months of July-October in the future.

Methods and Materials

Hydroacoustic surveys were performed on nine reservoirs in 2005. These included: Blue Mesa, 3-4 August; Dillon, 10 August; Elevenmile, 8 August; Granby, 6 September, Green Mountain, 7 September; McPhee, 30 August; Taylor Park, 2 August; Vallecito, 29 August; and Williams Fork, 9 August. All surveys were performed at night and were scheduled around the new moon. A PC controlled HTI 243 digital split-beam scientific echosounder with its 15^{o} down-looking transducer mounted in towed vehicle and deployed using the apparatus described in Martinez (2005) was operated from a 22 foot Hewes SeaRunner powered by an 8-hp Yamaha outboard during the surveys. Standardized transects (Figure 1), typically about 1-mile each in length, depicted in Martinez 2003, were followed using a Garmin 165 GPS that also fed latitude and longitude coordinates to the PC every five seconds.

Results and Discussion

Numbers of pelagic fish estimated in sonar surveys of reservoirs in 2005 were: Blue Mesa, 623,274; Dillon, 254,115; Elevenmile, 172,877; Granby, 323,418; Green Mountain, 75,014; McPhee, 283,022; Taylor Park, 10,747; Vallecito, 37,325; and Williams Fork, 48,325. Trends in pelagic fish abundance for reservoirs with multiple-year sonar survey data are shown in Figure 1 and 2. Noteworthy observations in these trends concern the state’s historic and primary sources of kokanee eggs at Blue Mesa, Granby and Green Mountain reservoirs. All appear to show increasing pelagic fish densities attributable to kokanee. Hopefully, this trend will manifest in adequate kokanee egg numbers in upcoming years. In the recent past, these three reservoirs have produced no, or low numbers of, kokanee eggs.

OBJECTIVE 2: POPULATION DEMOGRAPHICS OF KOKANEE AND LAKE TROUT AND OTHER PISCIVORES THREATENING KOKANEE

Survey key population demographics for kokanee (size and age at maturity) in established and potential brood stock waters, and for lake trout and other piscivores (relative weight and growth rate) where they pose a threat to kokanee populations and their egg production (e.g. Blue Mesa and Granby).

Segment Objective 1: Measure lengths and weights and collect otoliths from mature kokanee at Blue Mesa, Elevenmile, Granby, McPhee, Ridgeway, Shadow Mountain, Vallecito and Williams Fork Reservoirs.

Introduction

The size and age structure of mature kokanee in Colorado’s fall spawn runs continues to be a useful indicator of trends for kokanee populations and egg production (Martinez 2004). Validation of kokanee ages determined by surface aging of otoliths was afforded by tetracycline marked kokanee in Blue Mesa Reservoir.

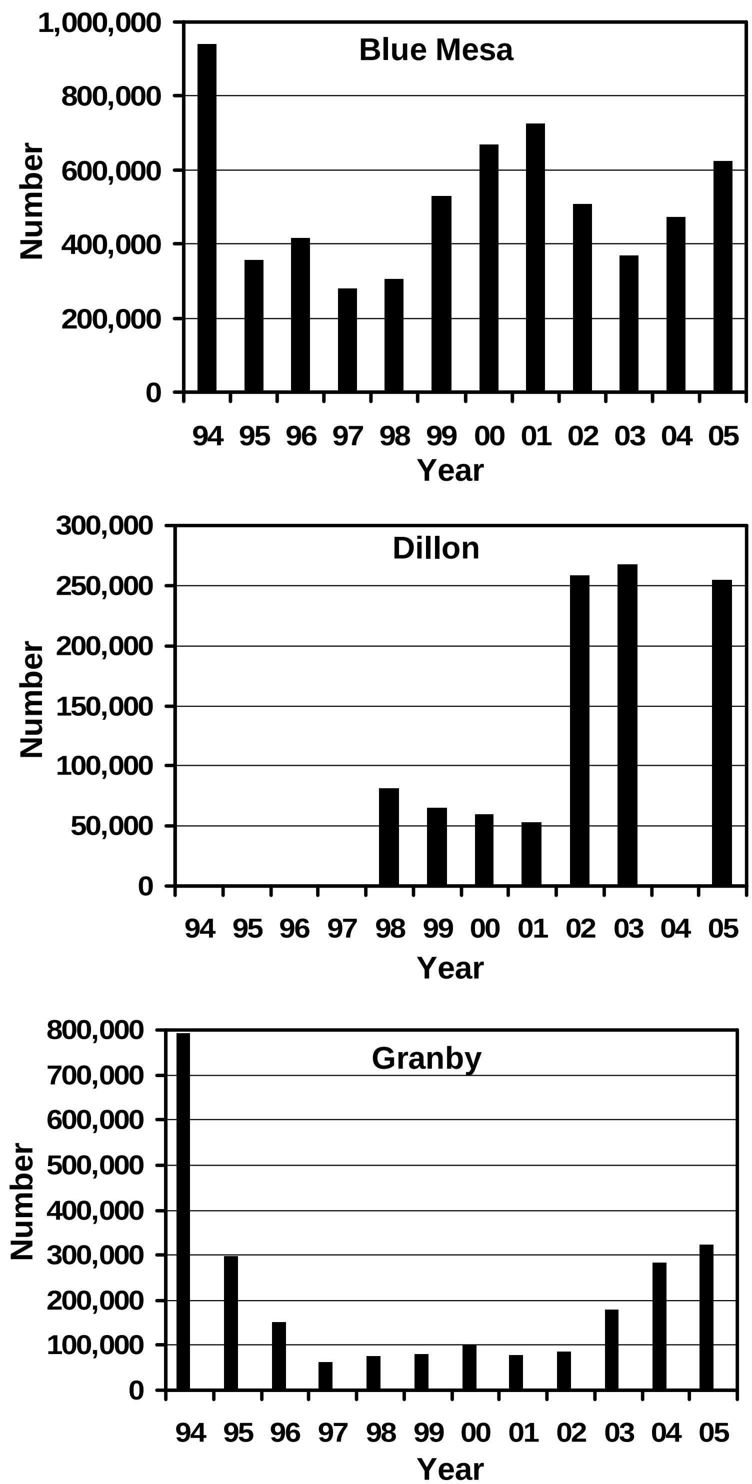

Figure 1. **Comparison of trends in lakewide pelagic fish abundance derived from hydroacoustic surveys performed in Blue Mesa, Dillon and Granby reservoirs, 1994-2005. Missing bars indicate that no sonar survey was performed during that year.**

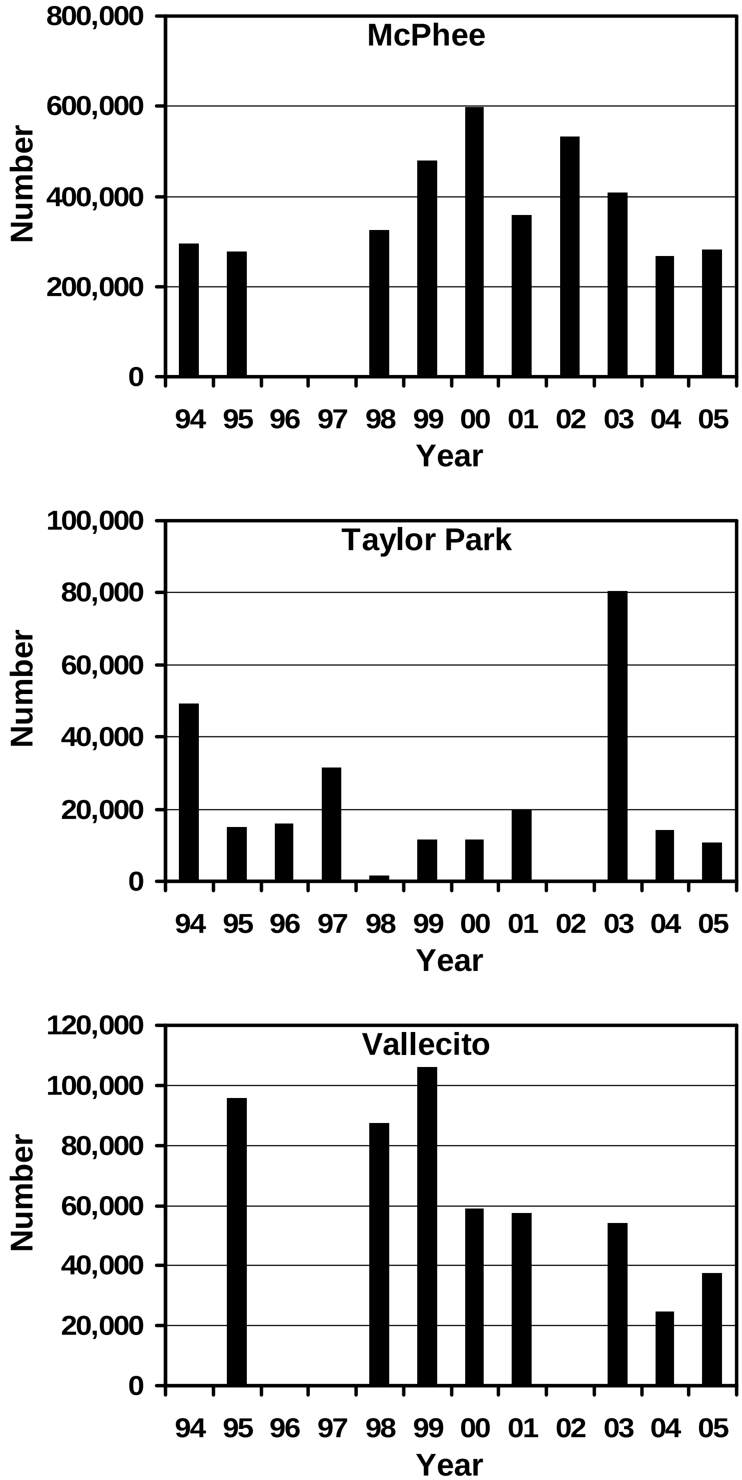

Figure 2. **Comparison of trends in lakewide pelagic fish abundance derived from hydroacoustic surveys performed in McPhee, Taylor Park and Vallecito reservoirs, 1994-2005. Missing bars indicate that no sonar survey was performed during that year.**

Methods and Materials

Length, weight and both otoliths (occasionally only one otolith could be found) were collected from random samples of mature kokanee at several spawn runs in 2005, as follows. The Blue Mesa Reservoir spawn run at the Roaring Judy Hatchery was sampled and otoliths were collected on five dates: 4, 12, 19 and 25 October and 1 November. A portion of the spawn run from Blue Mesa that bypasses the hatchery and enters Slate Creek near Crested Butte was sampled once on 6 October. Otoliths were collected for the first time from the kokanee spawn run at Elevenmile reservoir on four dates: 25 October and 2 and 9 November. The spawn run from Granby Reservoir was sampled at the kokanee trap on the Colorado River below the dam at Shadow Mountain Reservoir on five dates: 7, 10, 14 and 21 November and on 5 December. Otoliths were collected in the Dolores River spawn run from McPhee Reservoir at the Old Dolores Hatchery site on three dates, 24 October and 3 and 10 November. At Vallecito Reservoir, otoliths were collected on one date only, 25 October, due to a limited run. Williams Fork Reservoir was sampled and otoliths collected on three dates: 31 October and 8 and 14 November. The procedure for determining the age of the otoliths is described in Martinez (2002). No otoliths were collected in 2005 from the kokanee originating from Shadow Mountain Reservoir.

Results and Discussion

Length frequencies, mean lengths and sex and age composition of mature kokanee sampled in spawn runs in 2005 are found in Tables 1–14. A key observation made in the age structure of kokanee in individual spawn runs is whether the spawn run is comprised of primarily age 3 and age 4 kokanee. Spawn runs consisting mostly of these age classes indicate that the population is tending toward a desirable status, which occurred for all population in 2005 (Tables 1–14). Spawn runs consisting primarily of age 2 and age 3 or age 4 and age 5 fish tend to indicate an undesirable condition in the kokanee population or its environment. When this occurs, it often manifests in reduced egg production and a declining trend in the kokanee fishery.

Another important index is the mean size of the mature kokanee in the spawn run. Individual spawn runs typically have characteristic size ranges attributable to differences in reservoir productivity and survivability trends for kokanee fry stocked in individual reservoirs. Figure 3 illustrates how the mean size of mature kokanee in individual spawn runs can fluctuate annually. Both smaller-than-normal and larger-than-normal mean sizes for a given kokanee population are typically associated with, or would forecast in upcoming years, declines in kokanee egg production and often a decline in the kokanee fishery. Three populations, Granby, McPhee and Vallecito, are typically characterized by mature kokanee less than 400 mmTL, with a desired range for the mean length of their mature kokanee being between 330-380 mmTL. Three other waters are known for mean spawner sizes often exceeding 400 mmTL, with a desired range being between 380-430 mmTL. These empirical trends can be tested more rigorously in the future after the newer kokanee egg sources, Elevenmile, McPhee and Williams Fork have a longer history of annual kokanee size structures and egg-production records become available.

Table 1. Length frequency, age (determined from otoliths) and sex composition of mature kokanee collected in the Roaring Judy Hatchery's spawn run from Blue Mesa Reservoir on 4, 12, 19 and 25 October and 1 November 2005.

Blue Mesa 2005							
Total Length	Age 3 - 9%		Age 4 - 85%		Age 5 - 6%		Totals
	Female	Male	Female	Male	Female	Male	
320		1					1
330							
340		1	1				2
350							
360			1		1		2
370	1		5				6
380	2	1	8	2	1		14
390	4	1	21	1	1		28
400	8	2	23	11			44
410	7	2	33	6	1		49
420	4	1	27	41			73
430		1	20	49	2		72
440		5	9	58	3	1	76
450		2	2	49	2	1	56
460		1	2	24	2	1	30
470				15	1	4	20
480				8		3	11
490				4		4	8
500				2		2	4
510							
520				1			1
530			1				1
540							
550	1						1
Total Fish	27	18	153	271	14	16	499
	45		424		30		
Mean Length	411	418	414	445	433	480	433
	414		434		458		

Table 2. Length, age (determined from otoliths) and sex composition of mature kokanee collected in the Roaring Judy Hatchery's spawn run from Blue Mesa Reservoir on five dates in 2005.

Blue Mesa Reservoir 2005										
Age	Statistic (total length in mm)	4-Oct-05			12-Oct-05			19-Oct-05		
		Female	Male	Both	Female	Male	Both	Female	Male	Both
3	n	19	7	26	3	1	4	1	1	2
	Mean length	418	424	420	392	427	401	383	401	392
	Length range	395-555	324-458	324 - 555	373-405	427-427	373-427	383-383	401-401	383-401
	Percent	19%	7%	26%	3%	1%	4%	1%	1%	2%
4	n	27	46	73	41	50	91	38	53	91
	Mean length	423	451	441	416	443	431	412	447	432
	Length range	391-531	406-440	391-531	385-465	395-529	385-529	370-447	383-499	370-499
	Percent	27%	46%	74%	41%	50%	91%	38%	53%	91%
5	n				1	4	5	4	3	7
	Mean length				435	486	476	441	489	462
	Length range				435-435	466-501	435-501	412-474	470-508	412-508
	Percent				1%	4%	5%	4%	3%	7%
All	**n**	**46**	**53**	**99**	**45**	**55**	**100**	**43**	**57**	**100**
	Mean length	**421**	**447**	**435**	**415**	**446**	**432**	**414**	**448**	**433**
	Length range	**391-555**	**324-458**	**324-555**	**373-465**	**395-529**	**373-529**	**370-474**	**383-508**	**370-508**
	Percent	**46%**	**54%**	**20%**	**45%**	**55%**	**20%**	**43%**	**57%**	**20%**

Table 2. Continued. Length, age (determined from otoliths) and sex composition of mature kokanee collected in the Roaring Judy Hatchery's spawn run from Blue Mesa Reservoir on five dates in 2005.

Blue Mesa Reservoir 2005										
Age	Statistic (total length in mm)	25-Oct-05			01-Nov-05			All Dates		
		Female	Male	Both	Female	Male	Both	Female	Male	Both
3	n	3	4	7	1	5	6	**27**	**18**	**45**
	Mean length	394	441	421	416	393	397	**411**	**418**	**414**
	Length range	381-405	418-469	381-469	416-416	348-443	348-443	**373-555**	**324-469**	**324-555**
	Percent	3%	4%	7%	1%	5%	6%	**6%**	**3%**	**9%**
4	n	31	48	79	16	74	90	**153**	**271**	**424**
	Mean length	409	437	426	410	445	439	**414**	**445**	**434**
	Length range	345-445	401-484	345-484	374-444	401-492	374-492	**345-531**	**383-529**	**345-429**
	Percent	31%	48%	79%	16%	74%	90%	**33%**	**52%**	**85%**
5	n	7	7	14	2	2	4	**14**	**16**	**30**
	Mean length	434	476	455	415	472	443	**433**	**480**	**458**
	Length range	365-469	441-495	365-495	348-445	453-490	348-492	**365-474**	**441-508**	**365-508**
	Percent	7%	7%	14%	2%	2%	4%	**3%**	**3%**	**6%**
All	n	**41**	**59**	**100**	**19**	**81**	**100**	194	305	499
	Mean length	**412**	**442**	**429**	**411**	**442**	**436**	415	445	433
	Length range	**345-469**	**401-495**	**345-495**	**374-445**	**348-492**	**348-492**	345-555	324-529	324-555
	Percent	**41%**	**59%**	**20%**	**19%**	**81%**	**20%**	39%	61%	100%

Table 3. **Length frequency, age (determined from otoliths) and sex composition of mature kokanee collected in Slate Creek, above Roaring Judy Hatchery's and part of the spawn run from Blue Mesa Reservoir on 6 October 2005.**

Slate River 2005							
Total Length	Age 3 - 7%		Age 4 - 84%		Age 5 - 9%		Totals
	Female	Male	Female	Male	Female	Male	
360			1				**1**
370							
380			2	1			**3**
390	1		9				**10**
400	1		2	2	1		**6**
410	1	1	11	4	1		**18**
420	2		8	6			**16**
430	1		8	10			**19**
440				8	1		**9**
450			1	5		1	**7**
460				4	1		**5**
470				1	1		**2**
480						2	**2**
490						1	**1**
500							
510							
520							
530							
540							
550				1			**1**
Total Fish	**6**	**1**	**42**	**42**	**5**	**4**	**100**
	7		**84**		**9**		
Mean Length	**415**	**410**	**413**	**439**	**440**	**477**	**428**
	414		**426**		**457**		

Table 4. **Length, age (determined from otoliths) and sex composition of mature kokanee collected in Slate Creek, above Roaring Judy Hatchery and part of the spawn run from Blue Mesa Reservoir on 6 October 2005.**

Slate River run 2005				
Age	**Statistic (total length in mm)**	**6-Oct-05**		
		Female	**Male**	**Both**
3	**n**	6	1	7
	Mean length	415	410	414
	Length range	390-435	410-410	390-435
	Percent	6%	1%	7%
4	**n**	42	42	84
	Mean length	413	439	426
	Length range	361-452	386-556	361-556
	Percent	42%	42%	84%
5	**n**	5	4	9
	Mean length	440	477	457
	Length range	404-478	458-491	404-491
	Percent	5%	4%	9%
All	**n**	**53**	**47**	**100**
	Mean length	**416**	**441**	**428**
	Length range	**361-478**	**386-556**	**361-556**
	Percent	**53%**	**47%**	**100%**

Table 5. **Length frequency, age (determined from otoliths) and sex composition of mature kokanee collected in the spawn run at Elevenmile reservoir on 25 October and 2, 9 and 16 November 2005.**

Eleven Mile Reservoir 2005							
Total Length	Age 3 - 42%		Age 4 - 54%		Age 5 - 4%		Totals
	Female	Male	Female	Male	Female	Male	
320	3						3
330	2	1	3				6
340	7	1	1	1			10
350	11	2	5	1			19
360	19	9	9	2			39
370	18	8	10	6			42
380	19	9	11	10			49
390	11	17	10	11			49
400	3	9	9	26	1		48
410	2	9	4	23			38
420		2	2	30			34
430		1	1	16			18
440				7			7
450	1		1	1			3
460			2				2
470			1				1
480		1	1				2
490	1		1		1		3
500					2		2
510			1		2		3
520			2	1	1	2	6
530			1		3		4
540			1	1		1	3
550					1	1	2
560					1		1
570					1		1
Total Fish	97	69	76	136	13	4	395
	166		212		17		
Mean Length	373	391	400	413	519	537	401
	380		408		523		

Table 6. Length, age (determined from otoliths) and sex composition of mature kokanee collected in the spawn run at Elevenmile Reservoir on four dates in 2005.

Eleven Mile Reservoir 2005										
Age	**Statistic (total length in mm)**	**25-Oct-05**			**02-Nov-05**			**09-Nov-05**		
		Female	**Male**	**Both**	**Female**	**Male**	**Both**	**Female**	**Male**	**Both**
3	**n**	8	5	13	18	4	22	36	19	55
	Mean length	363	374	367	371	369	371	376	398	383
	Length range	345-392	362-399	345-399	335-400	356-392	335-400	321-493	360-480	321-493
	Percent	8%	5%	13%	18%	4%	22%	37%	19%	56%
4	**n**	35	47	82	23	45	68	12	31	43
	Mean length	402	411	407	390	412	405	395	418	423
	Length range	339-535	355-520	339-535	351-496	375-457	351-496	352-527	344-549	344-549
	Percent	35%	47%	82%	24%	46%	70%	12%	31%	43%
5	**n**	2	3	5	7	1	8	1		1
	Mean length	485	533	511	532	549	534	498		498
	Length range	400-570	520-554	400-570	502-560	549-549	502-560	498-498		498-498
	Percent	2%	3%	5%	7%	1%	8%	1%		1%
All	**n**	**45**	**55**	**100**	**48**	**50**	**98**	**49**	**50**	**99**
	Mean length	**398**	**422**	**411**	**404**	**412**	**408**	**393**	**410**	**402**
	Length range	**339-570**	**355-520**	**339-570**	**335-560**	**356-549**	**335-560**	**321-408**	**344-549**	**321-549**
	Percent	**45%**	**55%**	**25%**	**49%**	**51%**	**25%**	**49%**	**51%**	**25%**

Table 6. Continued. Length, age (determined from otoliths) and sex composition of mature kokanee collected in the spawn run at Elevenmile Reservoir on four dates in 2005.

Eleven Mile Reservoir 2005							
Age	Statistic (total length in mm)	16-Nov-05			All Dates		
		Female	Male	Both	Female	Male	Both
3	n	35	41	76	**97**	**69**	**166**
	Mean length	373	392	383	**373**	**391**	**380**
	Length range	325-452	339-432	325-452	**321-493**	**339-480**	**321-493**
	Percent	36%	42%	78%	**25%**	**18%**	**43%**
4	n	6	13	19	**76**	**136**	**212**
	Mean length	434	410	417	**400**	**413**	**408**
	Length range	330-549	385-424	330-549	**330-549**	**344-549**	**330-549**
	Percent	6%	13%	19%	**19%**	**34%**	**53%**
5	n	3		3	**13**	**4**	**17**
	Mean length	517		517	**519**	**537**	**523**
	Length range	512-524		512-524	**400-570**	**520-525**	**400-570**
	Percent	3%		3%	**3%**	**1%**	**4%**
All	n	**44**	**54**	**98**	**186**	**209**	**395**
	Mean length	**391**	**397**	**394**	**394**	**408**	**401**
	Length range	**325-549**	**339-432**	**325-549**	**321-570**	**339-549**	**321-570**
	Percent	**45%**	**55%**	**25%**	**47%**	**53%**	**100%**

Table 7. **Length frequency, age (determined from otoliths) and sex composition of mature kokanee collected in the spawn run from Granby Reservoir at the kokanee trap on the Colorado River below the dam at Shadow Mountain Reservoir on 7, 10, 14 and 21 November and 5 December 2005.**

Granby Reservoir 2005					
Total Length	Age 3 - 75%		Age 4 - 25 %		Totals
	Female	Male	Female	Male	
300	2				**2**
310					
320	1	1			**2**
330	4			1	**5**
340	13				**13**
350	16				**16**
360	29	5	1		**35**
370	36	4	1		**41**
380	27	26	2	1	**56**
390	21	26	6		**53**
400	14	29	7	2	**52**
410	9	16	4	2	**31**
420	6	15	14	4	**39**
430	9	3	14	2	**28**
440	14	4	10	3	**31**
450	6	4	6	6	**22**
460	2	3	6	7	**18**
470	3	3		7	**13**
480	1	2		4	**7**
490			1	4	**5**
500		1		3	**4**
510		1	1	1	**3**
Total Fish	**213**	**143**	**73**	**47**	**476**
	356		**120**		
Mean Length	**388**	**408**	**430**	**457**	**407**
	396		**441**		

Table 8. **Length, age (determined from otoliths) and sex composition of mature kokanee collected in the spawn run from Granby Reservoir at the kokanee trap on the Colorado River below the dam at Shadow Mountain Reservoir on five dates in 2005.**

Granby Reservoir 2005										
Age	Statistic (total length in mm)	07-Nov-05			10-Nov-05			14-Nov-05		
		Female	Male	Female	Female	Male	Both	Female	Male	Both
3	n	37	28	65	41	35	76	38	34	72
	Mean length	397	410	403	385	408	396	372	398	384
	Length range	329-463	321-489	329-489	339-482	363-473	339-482	307-471	367-447	307-471
	Percent	37%	28%	65%	43%	37%	80%	41%	37%	78%
4	n	14	21	35	9	10	19	14	7	21
	Mean length	425	455	425	425	463	445	463	445	436
	Length range	388-455	338-516	338-516	383-458	424-502	383-502	390-493	423-492	390-493
	Percent	14%	21%	35%	9%	11%	20%	15%	8%	23%
All	n	**51**	**49**	**100**	**50**	**45**	**95**	**52**	**41**	**93**
	Mean length	**405**	**430**	**417**	**393**	**420**	**406**	**386**	**408**	**396**
	Length range	**329-463**	**321-516**	**321-516**	**339-482**	**363-502**	**339-502**	**307-493**	**367-492**	**307-493**
	Percent	**51%**	**49%**	**21%**	**53%**	**47%**	**21%**	**56%**	**44%**	**20%**
Age	Statistic (total length in mm)	21-Nov-05			05-Dec-05			All Dates		
		Female	Male	Both	Female	Male	Both	Female	Male	Both
3	n	50	16	66	47	30	77	**213**	**143**	**356**
	Mean length	391	407	394	395	416	403	**388**	**408**	**396**
	Length range	305-460	368-479	305-479	332-473	365-510	332-510	**305-473**	**321-510**	**305-510**
	Percent	58%	18%	76%	46%	30%	76%	**45%**	**30%**	**75%**
4	n	16	5	21	20	4	24	**73**	**47**	**120**
	Mean length	439	473	447	431	437	432	**430**	**457**	**441**
	Length range	399-465	419-500	399-500	366-510	404-472	366-510	**366-510**	**338-516**	**338-516**
	Percent	18%	6%	24%	20%	4%	24%	**15%**	**10%**	**25%**
All	n	**66**	**21**	**87**	**67**	**34**	**101**	**286**	**190**	**476**
	Mean length	**402**	**422**	**407**	**406**	**418**	**410**	**399**	**420**	**407**
	Length range	**305-465**	**368-500**	**305-500**	**332-510**	**365-510**	**332-510**	**305-510**	**321-516**	**305-516**
	Percent	**76%**	**24%**	**18%**	**66%**	**34%**	**21%**	**60%**	**40%**	**100%**

Table 9. **Length frequency, age (determined from otoliths) and sex composition of mature kokanee collected in the Dolores River spawn run from McPhee Reservoir at the Old Dolores Hatchery site on 24 October and 3 and 10 November 2005.**

McPhee 2005					
Total Length	Age 3 - 73%		Age 4 - 27%		Totals
	Female	Male	Female	Male	
220	1				1
230					
240					
250					
260					
270					
280					
290		1			1
300	1				1
310	11	2	3	1	17
320	38	5	4	1	48
330	34	13	9	4	60
340	23	22	14	6	65
350	8	30	7	13	58
360	2	15	2	8	27
370		8		4	12
380		5		2	7
390				1	1
Total Fish	118	101	39	40	298
	219		79		
Mean Length	331	351	341	356	342
	340		348		

Table 10. **Length, age (determined from otoliths) and sex composition of mature kokanee collected in the Dolores River spawn run from McPhee Reservoir at the Old Dolores Hatchery site on three dates in 2005.**

McPhee Reservoir 2005										
Age	Statistic (total length in mm)	24-Oct-05			03-Nov-05			10-Nov-05		
		Female	Male	Both	Female	Male	Both	Female	Male	Both
3	n	38	38	76	37	28	65	43	35	78
	Mean length	332	353	343	332	352	341	329	347	337
	Length range	309-358	318-386	309-386	314-364	326-383	314-383	225-360	291-375	225-375
	Percent	38%	38%	76%	38%	29%	66%	43%	35%	78%
4	n	14	10	24	13	20	33	12	10	22
	Mean length	344	359	350	338	355	348	340	355	347
	Length range	315-367	327-396	315-396	316-357	315-382	316-382	317-357	334-382	317-383
	Percent	14%	10%	24%	13%	20%	34%	12%	10%	22%
All	**n**	**52**	**48**	**100**	**50**	**48**	**98**	**55**	**45**	**100**
	Mean length	**336**	**354**	**345**	**334**	**353**	**344**	**332**	**349**	**339**
	Length range	**309-367**	**318-396**	**309-396**	**314-357**	**315-383**	**314-383**	**225-360**	**291-382**	**225-383**
	Percent	**52%**	**48%**	**34%**	**51%**	**49%**	**33%**	**55%**	**45%**	**34%**

Age	Statistic (total length in mm)	All Dates		
		Female	Male	Both
3	n	**118**	**101**	**219**
	Mean length	**331**	**351**	**340**
	Length range	**225-364**	**291-386**	**225-386**
	Percent	**54%**	**46%**	**73%**
4	n	**39**	**40**	**79**
	Mean length	**341**	**356**	**348**
	Length range	**315-367**	**315-396**	**315-396**
	Percent	**49%**	**51%**	**27%**
All	n	**157**	**141**	**298**
	Mean length	**334**	**352**	**342**
	Length range	**225-367**	**291-396**	**225-396**
	Percent	**53%**	**47%**	**100%**

Table 11. Length frequency, age (determined from otoliths) and sex composition of mature kokanee collected in the spawn run at Vallecito Reservoir, 25 October 2005.

Vallecito Reservoir 2005					
Total Length	Age 3 – 23%		Age 4 - 77%		Totals
	Female	Male	Female	Male	
300	1				1
310					
320					
330					
340					
350					
360					
370					
380	2		2		4
390	2		2	1	5
400	3	1	15	1	20
410	2		9	3	14
420	3		10		13
430	2	1	7	6	16
440	1	1	1	1	4
450		3	1	4	8
460			3	6	9
470				2	2
480				1	1
490					
500		1		2	3
Total Fish	16	7	50	27	100
	23		77		
Mean Length	406	450	419	450	427
	419		430		

Table 12. Length, age (determined from otoliths) and sex composition of mature kokanee sampled in the spawn run at Vallecito Reservoir on one date in 2005.

Vallecito Reservoir 2005				
Age	**Statistic (total length in mm)**	**25-Oct-05**		
		Female	**Male**	**Both**
3	**n**	16	7	23
	Mean length	406	450	419
	Length range	311-444	408-503	311-503
	Percent	16%	7%	23%
4	**n**	50	27	77
	Mean length	419	450	430
	Length range	380-463	390-507	380-507
	Percent	50%	27%	77%
All	**n**	**66**	**34**	**100**
	Mean length	**416**	**450**	**427**
	Length range	**311-463**	**408-507**	**311-507**
	Percent	**66%**	**34%**	**100%**

Table 13. Length frequency, age (determined from otoliths) and sex composition of mature kokanee collected in the spawn run at Williams Fork Reservoir on 31 October and 8 and 14 November 2005.

William's Fork Reservoir 2005									
Total Length	**Age 2 - 21%**		**Age 3 - 38 %**		**Age 4 - 40%**		**Age 5 - 1%**		**Totals**
	Female	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	
220			1						**1**
230									
240									
250									
260									
270									
280									
290									
300		2	1						**3**
310		5	2						**7**
320		8	1	5					**14**
330		15	5	3	1	1			**25**
340	1	5	5	6					**17**
350		5	1	5					**11**
360		3	6	3					**12**
370		2	2	4					**8**
380		4		3					**7**
390			4						**4**
400									
410			4		1				**5**
420			5	1	2				**8**
430			1		4				**5**
440			2		6	1			**9**
450			1	3	6				**10**
460			1	5	11	1			**18**
470				4	13	5			**22**
480				3	5	3			**11**
490				1	7	4			**12**
500				1	2	6			**9**
510					1	1			**2**
520					2	3	1		**6**
530						4			**4**
540						3			**3**
550						1			**1**
560						1		1	**2**
570					1				**1**
580									
590									
600								1	**1**
Total Fish	**1**	**49**	**42**	**47**	**62**	**34**	**1**	**2**	**238**
	50		**89**		**96**		**3**		
Mean Length	**340**	**340**	**376**	**397**	**468**	**502**	**523**	**583**	**417**
	340		**387**		**480**		**563**		

Table 14. Length frequency, age (determined from otoliths) and sex composition of mature kokanee collected in the spawn run at Williams Fork Reservoir on three dates in 2005.

William's Fork Reservoir 2005													
Age	**Statistic (total length in mm)**	**31-Oct-05**			**08-Nov-05**			**14-Nov-05**			**All Dates**		
		Female	**Male**	**Both**	**Female**	**Male**	**Both**	**Female**	**Male**	**Both**	**Female**	**Male**	**Both**
2	**n**		14	14	1	35	36				1	49	50
	Mean length		335	335	340	343	343				340	340	340
	Length range		315-372	315-372	340-340	303-387	303-387				340-340	303-387	303-387
	Percent		14%	14%	1%	35%	36%				0%	21%	21%
3	**n**	5	13	18	15	19	34	22	15	37	42	47	89
	Mean length	416	412	413	411	422	417	342	350	346	376	397	387
	Length range	398-429	323-504	323-504	304-466	339-492	304-492	229-371	326-386	229-386	229-466	323-504	229-504
	Percent	5%	13%	18%	15%	19%	34%	58%	39%	97%	18%	20%	38%
4	**n**	47	19	66	14	15	29	1		1	62	34	96
	Mean length	473	501	481	463	504	484	333		333	468	502	480
	Length range	416-474	446-548	416-548	432-492	334-560	334-560	333-333		333-333	333-492	334-560	333-560
	Percent	47%	19%	66%	14%	15%	29%	3%		3%	26%	14%	40%
5	**n**	1	1	2		1	1				1	2	3
	Mean length	523	562	543		604	604				523	583	563
	Length range	523-523	562-562	523-562		604-604	604-604				523-523	562-604	523-604
	Percent	1%	1%	2%		1%	1%				0%	1%	1%
All	**n**	**53**	**47**	**100**	**30**	**70**	**100**	**23**	**15**	**38**	**106**	**132**	**238**
	Mean length	**468**	**428**	**450**	**433**	**403**	**412**	**342**	**359**	**345**	**431**	**406**	**417**
	Length range	**398-523**	**315-562**	**315-562**	**304-492**	**303-604**	**304-604**	**229-371**	**326-386**	**229-386**	**229-523**	**303-604**	**229-604**
	Percent	**53%**	**47%**	**42%**	**30%**	**70%**	**42%**	**61%**	**39%**	**16%**	**45%**	**55%**	**100%**

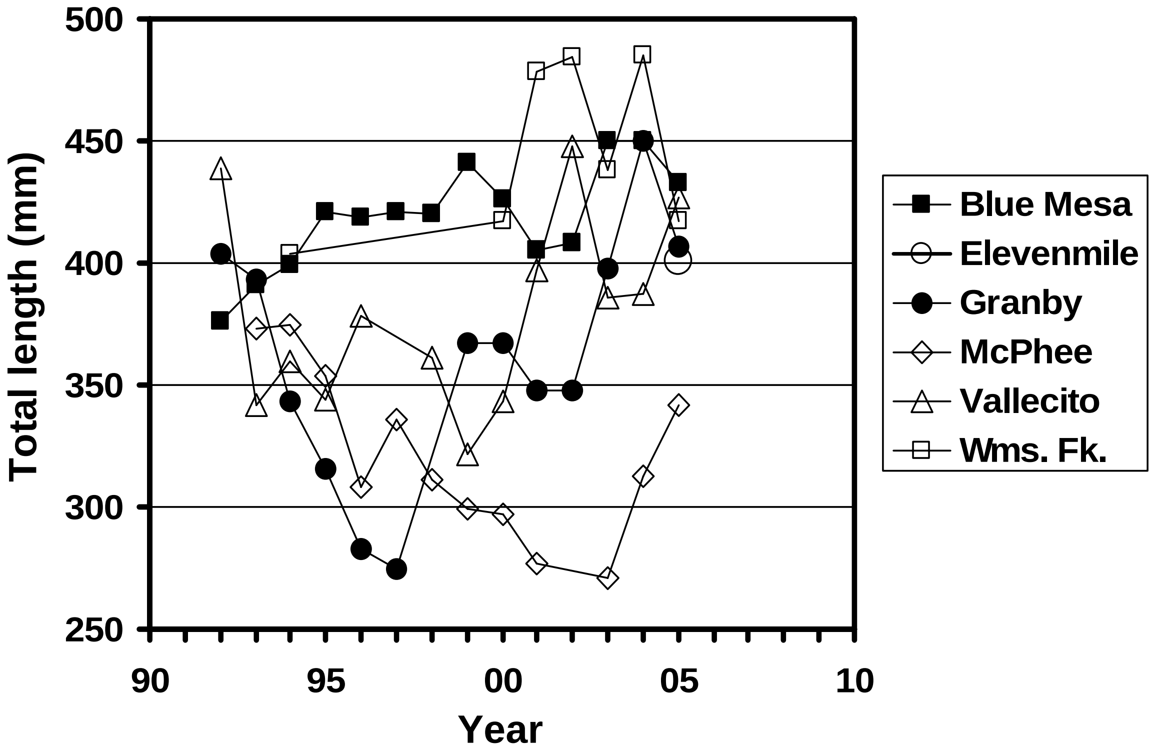

Figure 3. Comparison of mean lengths of mature kokanee in spawn runs of waters supplying kokanee eggs in 2005. Data points interpolated when an annual mean length was unavailable.

Segment Objective 2: Collect and analyze lake trout otoliths and stomach samples from Blue Mesa and Granby Reservoirs, as feasible.

Introduction

This Segment Objective was included to periodically check for change in the growth rates and diet composition of lake trout in key populations if the Aquatic Biologists had specific questions about their waters in response to changes in management strategies or ecological conditions.

Methods and Materials

Lake trout otoliths were not supplied to me from Blue Mesa or Granby reservoirs in 2005. However, lake trout stomachs from Blue Mesa were collected by Dan Brauch, CDOW Aquatic Biologist, on 18 April 2005 to examine predation on kokanee fry newly released from Roaring Judy Hatchery entering the upper portion of the reservoir. Dan captured lake trout, brown trout and yellow perch in gillnets and preserved guts or pumped gut contents from individual fish in muslin bags and fixed these in a bucket of formalin. These samples were transferred to Colorado State University where members of my crew analyzed these samples under the auspices of Dr, Brett Johnson. Greg Policky, Aquatic Biologist in the upper Arkansas River basin, supplied me with a sample of lake trout otoliths from Twin Lakes and Turquoise Reservoir for sectioning and aging.

Results and Discussion

Table 15 shows the results of the diet analysis from Blue Mesa Reservoir in April 2006. The recently stocked, young-of-year kokanee (YOY), weighed about 1-g each and were the principle size of kokanee found among the stomach contents. In this sample of fish, brown trout, the most abundant fish captured with 29 specimens, contained 80% YOY kokanee by biomass. The five lake trout had only 19% YOY kokanee by biomass, but contained 78% yellow perch by biomass ranging in length from about 43-128 mmTL. The stomach contents of the four yellow perch captured contained 96% YOY kokanee by biomass. The two rainbow trout in the sample contained only invertebrates. Based on this initial observation, both brown trout and yellow perch may be the species most likely to prey heavily and selectively in the shallow portion of the reservoir nearest the Gunnison river inlet during the time of the annual release of kokanee fry in April. Additional data will be helpful in formulating management actions if this pattern of predation on YOY kokanee persists. Illicitly introduced yellow perch are already under a no-bag regulation. Based on this initial data, brown trout should not be stocked or managed with restrictive regulations in the reservoir as either scenario could enhance their numbers and predation on YOY kokanee.

Figure 4 shows the ages of lake trout from Twin Lakes and Turquoise Reservoir determined from otoliths in 2005. These data show that lake trout in these populations grow slowly, reaching 500 mmTL (20 in.) at about age 8. In contrast, lake trout in Blue Mesa Reservoir reach about 700 mmTL (28 in.) at about age 8 (Appendix A).

Table 15. Summary of prey identified in stomachs of fishes captured in Blue Mesa Reservoir 18 April 2005.

Predator length and weight		Prey														
		Kokanee			Salmonid			Yellow perch			Sucker			Invertebrate		
TLmm	Grams	No.	Wt. (g)	Size (TL, mm)	No.	Wt.(g)	Size (TLmm)	No.	Wt. (g)	Size (TLmm)	No.	Wt. (g)	Size (TLmm)	No.	Wt. (g)	Size (g)
Brown trout																
387	520	5	5.55	43.7-58.7	8	7.31	46.2-57.4									
372	540				1	2.05	63.7-63.7							5	3.89	<0.01-2.63
377	460	3	3.32	34.9-58.7												
1175	1100				4	3.10	56.2-59.9									
362	420	4	4.29	49.9-53.7												
362	480	4	4.50	43.7-58.7												
412	580	26	27.68	42.4-57.4												
288	200	10	12.02	42.4-62.4												
314	240													11	1.20	<0.01-0.77
299	220				3	2.19	42.4-48.7									
433	840	25	22.74	41.2-58.7												
426	800	24	26.46	38.7-62.4												
380	520	31	33.62	43.7-58.7												
307	260	8	10.86	42.4-67.4	1	1.70	59.9-59.9									
424	700				6	7.88	39.9-58.7	2	5.45	58.7-67.6	1	10.62	102.0-102.0			
357	340				2	1.21	53.7-53.7							15	0.02	<0.01-0.02
351	400							1	4.09	72.0-72.0						
348	300	4	5.13	44.9-62.4												
410	660	12	14.58	44.9-63.7												
329	340				2	1.17	37.4-46.2							8	0.06	0.01-0.02
305	240	5	5.11	47.4-52.4												
326	300				1	1.05	51.2-51.2									
307	240													14	0.69	<0.01-0.42
402	540	17	21.02	44.9-64.9	5	1.30	54.9-54.9	1	4.09	72.0-72.0						
392	520	10	9.99	41.2-56.2												
377	480	8	9.81	43.7-68.7										1	1.31	1.36-1.36
351	380	19	21.55	39.9-57.4				1	1.95	57.2-57.2	1	0.34	32.4-32.4			
319	280													7	0.05	0.01-0.03
382	500	8	12.14	47.4-66.2												
Subtotal		**223**	**252.86 = 80%**		**33**	**26.77 = 9%**		**5**	**15.58 = 5%**		**2**	**10.96 = 4%**		**61**	**7.22 = 2%**	

Table 15. Continued. Summary of prey identified in stomachs of fishes captured in Blue Mesa Reservoir 18 April 2005.

Predator length and weight		Prey														
		Kokanee			Salmonid			Yellow perch			Sucker			Invertebrate		
TLmm	Grams	No.	Wt.(g)	Size (TL, mm)	No.	Wt.(g)	Size (TL, mm)	No.	Wt.(g)	Size (TL, mm)	No.	Wt.(g)	Size (TL, mm)	No.	Wt.(g)	Size (g)
Lake trout																
530	1560							6	51.98	52.8-128.2						
437	700	10	10.92	46.2-58.7	2	1.13	52.4-52.4									
450	800	3	2.24	43.7-47.4				4	8.62	43.9-67.6						
521	1380				2	1.67	46.2-48.7									
434	780	3	3.74	52.4-56.2				3	8.48	61.6-67.6						
Subtotal		**16**	**16.90 = 19%**		**4**	**2.80 = 3%**		**13**	**69.08 = 78%**							
Yellow perch																
146	.	1	0.77	46.2-46.2												
143	.													11	0.03	<0.01-0.0
142	.													2	0.04	0.02-0.03
267	180	1	0.83	47.4-47.4												
Subtotal		**2**	**1.60 = 96%**											**13**	**0.07 = 4%**	
Rainbow trout																
350	460													7	0.04	<0.01-0.10
287	220													13	0.63	<0.01-0.42
Subtotal														**20**	**0.67 = 100%**	
TOTAL		**18**	**271.36 = 67%**		**4**	**29.57 = 7%**		**13**	**84.66 = 21%**			**10.96 = 3%**		**33**	**7.96 = 2%**	

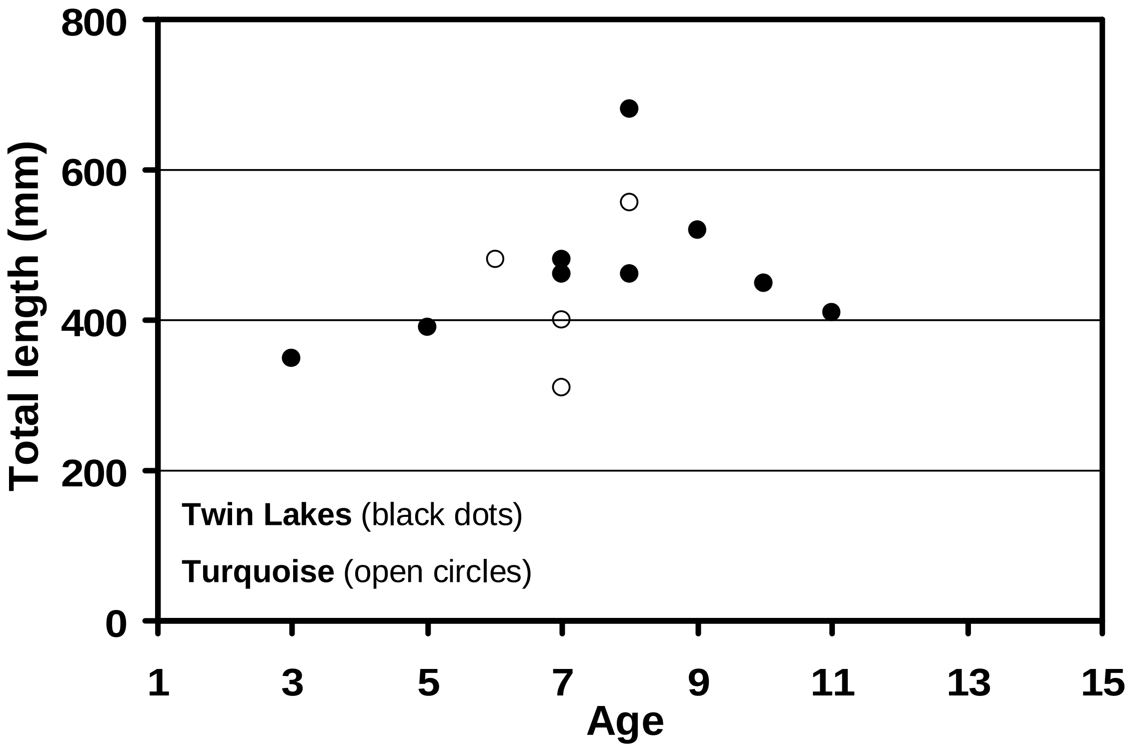

Figure 4. **Growth of lake trout in Twin Lakes and Turquoise reservoirs determined from otoliths collected in 2005.**

<u>OBJECTIVE 3:</u> ZOOPLANKTON COMPOSITION AND DENSITY AND *MYSIS* DENSITY IN SELECTED WATERS

Estimate zooplankton composition and density in established and proposed kokanee brood sources, and Mysis *density in reservoirs where they are an important food-web component (Dillon, Granby, Taylor Park) and in other waters where* Mysis *have been introduced as resources allow.*

Segment Objective 1: Collect and analyze crustacean zooplankton from Blue Mesa, Elevenmile, Granby, McPhee, Ridgeway, Taylor Park, Vallecito and Williams Fork Reservoirs.

Introduction

Crustacean zooplankton monitoring provides data for tracking trends in reservoir food webs. Annual collection of zooplankton data has proven valuable for forecasting management for sport fisheries and kokanee egg production, particularly in reservoirs containing *Mysis relicta*.

Methods and Materials

Crustacean zooplankton was sampled in 15 coldwater reservoirs in 2006. Blue Mesa was sampled on 23 June and 4 August, Dillon on 8 August, Elevenmile on 29 July, Granby on 30 June and 27 July, Jefferson on 8 August, McPhee on 22 July, Ridgeway on 22 June and 20 July, Taylor Park on 3 August, Vallecito on 21 July and William Fork on 28 July. Shadow Mountain Reservoir was added to the schedule upon request from Sherman Hebein, CDOW Senior Aquatic Biologist, in anticipation of a drawdown to control aquatic vegetation in the reservoir. To begin to build a dataset to examine potential fishery impacts Shadow Mountain was sampled on three dates: 1 July, 27 July and 6 September. Green Mountain was added to the schedule late in the season upon request from Billy Atkinson, CDOW Aquatic Biologist, due to a demand by some anglers for special protective regulations for lake trout. Green Mountain was sampled on 7 September. Samples collected in Horsetooth Reservoir on one date deteriorated and could not be analyzed. Samples were also collected in Avery Reservoir and Grand Lake on one date each, but this additional effort was secondary and processing of these samples was not completed during this Segment.

Zooplankton was sampled by oblique tows in the 0-10 stratum with a Clarke-Bumpus metered sampler (153 μm net). Samples were placed in 4 oz. Whirl-Pac bags and preserved in 70% ethanol. Processing of samples, zooplankter measurements and estimates of density were performed as described by Martinez (1992). Temperature and dissolved oxygen profiles were also measured on the dates of zooplankton sampling with a YSI Model-57 meter. Secchi depths were measured to the nearest centimeter.

Results and Discussion

Crustacean zooplankton densities and size structures from samples collected in coldwater reservoirs in 2006 are presented in Tables 16-39. Temperature, dissolved oxygen profiles and Secchi depths measured on the dates of zooplankton sampling are provided in Appendix B. Blue Mesa had very high *Daphnia* densities, > 20/l (Table 16), dominated by large (≥ 1.5 mm) *D. pulex* in August (Table 17). Dillon had a very low *Daphnia* density, < 1.0/l, and was dominated by small zooplankton species (Table 19), in part due to the effects of *Mysis* (Martinez & Bergersen 1991). Elevenmile had a high *Daphnia* density > 10/l (Table 20), dominated by large (≥ 1.5 mm) *D. pulex* (Table 21).

Granby had a very low *Daphnia* density on 30 June (Table 22), which coincided with cool epilimnetic water temperatures (Appendix B-5). A month later on July 27, the epilimnion had warmed sufficiently to exclude *Mysis* (Martinez and Wiltzius 1995) and Daphnia pulex, the preferred food of kokanee, was the dominant cladoceran (>10/l) with some large individuals exceeding 2.0 mm in length (Table 23). Similarly, Green Mountain, potentially containing *Mysis* (Martinez and Bergersen 1991) had a high *Daphnia* density (>15/l) dominated by *Daphnia pulex* (Table 24), but the size structure was smaller than in Granby (Table 25). Another water historically receiving *Mysis,* Jefferson (Martinez and Bergersen 1989), contained a modest *Daphnia* density (>5/l), dominated by *Daphnia galeata mendotae* (Table 26), which had a smaller size structure (Table 27) than seen in reservoirs dominated by *D. pulex*.

McPhee had a high *Daphnia* density (>10/l) dominated by *Daphnia pulex* (Table 28), but this species did not have as large a size structure (Table 29) as that in Blue Mesa, Elevenmile or Granby. Ridgeway had modest *Daphnia* densities dominated by *Daphnia galeata mendotate* (Table 30). The size structure of this species was small, averaging about 1.0 mm in length (Table 31). Shadow Mountain, also potentially containing *Mysis* (Martinez and Bergersen 1989), had low (<5/l) to very high (>30/l) *Daphnia* densities dominated by *Daphnia galeata mendotae* (Table 32). The *Daphnia* in Shadow Mountain were mostly small, around 1.0 mm in length (Table 33).

Taylor Park's *Daphnia* population appears to be strongly dependent on reservoir operations which greatly influence water temperature and stratification. *Mysis* tend to overexploit *Daphnia* when the reservoir is low and cool. Conversely, *Daphnia* flourish when the reservoir is maintained closer to capacity in early summer, facilitating warming and hastening the onset of stratification (Martinez 2002). Despite stratification having developed by August, epilimnetic temperatures remained cool, suggesting a delayed onset of stratification. This probably contributed to the low *Daphnia* density of <5/l (Table 34), but excluded *Mysis* sufficiently to allow some *Daphnia pulex* to reach larger sizes >1.5 mm in length (Table 35).

Vallecito had a high *Daphnia* density > 20/l dominated by *Daphnia galeata mendotae* (Table 36), but few *Daphnia* exceeded 1.5 mm in length (Table 37). Williams Fork had a low *Daphnia* density <5/l dominated by large *Daphnia pulex* (Table 38), with some approaching 3-mm in length.

Table 16. **Crustacean zooplankton, excluding nauplii, densities (number per liter) estimated from duplicate samples collected on two dates at three stations in Blue Mesa Reservoir, 2005.**

Zooplankton Species	Cebolla (0-10m)			Iola (0-10m)			Sapinero (0-10m)			Mean No./L
	a	b	mean	a	b	mean	a	b	mean	
Blue Mesa - 23 June 2005 - Mean *Daphnia* density = 23.1										
Bosmina longirostris	7.0	5.8	6.4	6.8	8.0	7.4	1.9	3.8	2.9	5.5
unknown *Daphnia spp.*	2.4	5.2	3.8	0.0	4.6	2.3	2.5	3.3	2.9	3.0
Daphnia mendotae	5.8	8.8	7.3	11.9	13.8	12.8	6.3	4.9	5.6	8.6
Daphnia pulex	11.6	21.2	16.4	4.8	10.7	7.8	11.0	9.8	10.4	11.5
Diacyclops b. thomasi	15.3	20.6	17.9	10.4	15.9	13.1	20.4	21.4	20.9	17.3
Leptodiaptomus nudus	1.2	0.0	0.6	0.3	0.3	0.3	0.6	0.3	0.4	0.4
Mean total no./L	52.5			43.7			43.0			46.4
Zooplankton Species	Cebolla (0-10m)			Iola (0-10m)			Sapinero (0-10m)			Mean No./L
	a	b	mean	a	b	mean	a	b	mean	
Blue Mesa - 04 August 2005 - Mean *Daphnia* density = 25.1										
Bosmina longirostris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	>0.1
unknown *Daphnia spp.*	1.7	0.0	0.9	0.0	0.9	0.4	1.1	0.8	1.0	0.8
Daphnia mendotae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.3	0.1
Daphnia pulex	24.4	21.6	23.0	26.0	15.8	20.9	25.4	32.2	28.8	24.2
Diacyclops b. thomasi	7.2	7.6	7.4	18.0	10.4	14.2	9.3	6.8	8.1	9.9
Leptodiaptomus nudus	2.9	5.2	4.0	5.9	6.0	5.9	5.4	10.2	7.8	5.9
Mean total no./L	35.3			41.1			46.0			40.8

Table 17. Length frequency of crustacean zooplankton (measured to nearest 0.01 mm) collected in Blue Mesa Reservoir, 2005. Bl = *Bosmina longirostris*, Dp spp. = unidentified *Daphnia*, Dbt = *Diacyclops bicuspidatus thomasi*, Dgm = *Daphnia galeata mendotae*, Dp = *Daphnia pulex* and Ln=*Leptodiaptomus nudus.*

Length class in mm	Blue Mesa - 23 June 2005						Length class in mm	Blue Mesa - 04 August 2005					
	Bl	**Dp spp.**	**Dbt**	**Dgm**	**Dp**	**Ln**		***Bl***	***Dp spp.***	***Dbt***	***Dgm***	***Dp***	***Ln***
0.2	1						0.2						
0.3	12		1				0.3	1		1			
0.4	15		4				0.4			6			1
0.5	4		7			1	0.5			32		1	6
0.6			23	3	2	2	0.6			42			7
0.7		11	31	8	1		0.7		1	47			4
0.8		6	20	40	6		0.8		1	17		2	7
0.9		15	14	33	26		0.9		3	14	1	6	4
1.0		6	7	12	23		1.0		4	1		8	1
1.1		9	2	12	32		1.1		1	3		3	
1.2		6		13	24		1.2		3	2		18	2
1.3		6		4	7		1.3		1			8	2
1.4				4	8		1.4		1			22	
1.5		2		3	1		1.5		1		1	19	1
1.6				2	6		1.6					13	
1.7					3		1.7					18	
1.8					3		1.8					4	1
1.9				1	2		1.9			1		7	
2.0							2.0					8	
2.1							2.1					2	
2.2							2.2					4	
2.3							2.3					5	
2.4							2.4					1	
Totals	32	61	109	135	144	3	**Totals**	1	166	2	149	16	36
Mean length	0.4	1.0	0.7	1.0	1.1	0.6	**Mean length**	0.3	1.1	0.7	1.2	1.5	0.8

Table 18. **Crustacean zooplankton, excluding nauplii, densities (number per liter) estimated from duplicate samples collected on one date at five stations in Dillon Reservoir, 2005.**

Zooplankton Species	Station 1 (0-10)			Station 2 (0-10m)			Station 3 (0-10m)			Station 4 (0-10m)			Station 4 (0-10m)			Mean No./L
	a	b	mean	a	b	mean	a	b	mean	a	b	mean	a	b	mean	
Dillon - 8 August 2005 - Mean *Daphnia* density = 0.7/L																
Bosmina longirostris	12.0	7.4	9.7	7.8	9.6	8.7	7.4	9.2	8.3	3.9	4.8	4.3	7.2	13.0	10.1	8.2
Daphnia mendotae	0.2	0.1	0.2	0.0	0.0	0.0	0.0	0.2	0.1	0.2	0.1	0.2	2.2	1.6	1.9	0.5
Daphnia pulex	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.1	>0.01
Diacyclops b. thomasi	22.2	14.2	18.2	17.1	27.9	22.5	35.2	23.1	29.2	8.5	11.3	9.9	34.3	55.0	44.7	24.9
Mean total no./L	28.2			31.2			37.5			14.4			56.8			33.6

Table 19. **Length frequency of crustacean zooplankton (measured to nearest 0.01 mm) collected in Blue Mesa Reservoir, 2005. Bl = *Bosmina longirostris*, Dgm = *Daphnia galeata mendotae*, Dp = *Daphnia pulex* and Dbt = *Diacyclops bicuspidatus thomasi.***

Length class in mm	Dillon - 8 August 2005			
	Bl	Dgm	Dp	Dbt
0.2	2			
0.3	74			2
0.4	52			13
0.5	7	2		31
0.6		1		90
0.7		5		116
0.8		3	1	73
0.9		3		53
1.0		4	1	17
1.1		1		1
1.2		3		
Totals	135	22	2	396
Mean length	0.3	0.9	0.9	0.7

Table 20. Crustacean zooplankton, excluding nauplii, densities (number per liter) estimated from duplicate samples collected on one date at five stations in Elevenmile Reservoir, 2005.

Zooplankton Species	Station 1 (0-10)			Station 2 (0-10m)			Station 3 (0-10m)			Station 4 (0-10m)			Station 5 (0-10m)			Mean No./L
	a	b	mean	a	b	mean	a	b	mean	a	b	mean	a	b	mean	
Elevenmile - 29 July 2005 - Mean *Daphnia* density = 10.6/L																
Bosmina longirostris	1.0	1.7	1.3	0.2	0.0	0.1	0.5	0.3	0.4	0.6	0.0	0.3	0.8	0.6	0.7	0.6
unidentified *Daphnia spp.*	0.2	0.3	0.3	0.5	1.1	0.8	0.8	0.7	0.8	0.9	0.5	0.7	0.4	1.0	0.7	0.6
Alona guttata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.0	0.0	0.0	>0.01
Daphnia mendotae	1.4	1.7	1.5	1.0	1.1	1.1	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Daphnia pulex	7.0	7.3	7.1	13.1	9.2	11.2	16.1	15.9	16.0	9.4	7.7	8.5	5.9	8.0	6.9	10.0
Daphnia rosea	0.0	0.0	0.0	0.0	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	>0.01
Diacyclops b. thomasi	12.4	11.4	11.9	7.3	9.5	8.4	13.7	14.9	14.3	16.8	12.8	14.8	14.5	15.1	14.8	12.8
Leptodiaptomus nudus	2.9	3.3	3.1	1.6	4.0	2.8	3.3	6.2	4.8	4.7	0.0	2.4	0.8	3.2	2.0	3.0
Mean total no./L	25.2			24.5			36.6			26.9			25.1			27.6

Table 21. Length frequency of crustacean zooplankton (measured to nearest 0.01mm) collected in Elevenmile Reservoir, 2005. Ag = *Alona guttata*, Bl = *Bosmina longirostris*, Dp spp. = unidentified *Daphnia*, Dgm = *Daphnia galeata mendotae*, Dp = *Daphnia pulex*, Dr = *Daphnia rosea*, Dbt = *Diacyclops bicuspidatus thomasi* and Ln=*Leptodiaptomus nudus*.

Length class in mm	Elevenmile - 29 July 2005							
	Ag	Bl	Dp spp.	Dgm	Dp	Dr	Dbt	Ln
0.3		4					1	
0.4		5					1	2
0.5							18	4
0.6			1				30	2
0.7	1		1	2			28	3
0.8			2	6	3		31	1
0.9			2	6	15		19	3
1.0			1	2	19		6	1
1.1			4	1	17		10	1
1.2			3		21		5	3
1.3				3	9			1
1.4				1	16		2	3
1.5					11	1		
1.6				4	16			
1.7				1	13			
1.8			4	1	10			
1.9			3	1	17		1	
2.0					23			
2.1			1		12			
2.2					13			
2.3					11			
2.4					3			
2.5			1		3			
2.6					6			
2.7					1			
Totals	1	9	23	28	239	1	152	24
Mean length	0.7	0.4	1.4	1.1	1.6	1.5	0.8	0.9

Table 22. Crustacean zooplankton, excluding nauplii, densities (number per liter) estimated from duplicate samples collected on two dates at five stations in Granby Reservoir, 2005.

Zooplankton Species	Station 1 (0-10)			Station 2 (0-10m)			Station 3 (0-10m)			Station 4 (0-10m)			Station 5 (0-10m)			Mean No./L
	a	b	mean	a	b	mean	a	b	mean	a	b	mean	a	b	mean	
Granby - 30 June 2005 - Mean *Daphnia* density = 0.2/L																
Bosmina longirostris	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.3	0.1
Daphnia galeata mendotae	0.2	0.3	0.3	0.3	0.0	0.1	0.0	0.0	0.0	0.4	0.0	0.2	0.3	0.0	0.2	0.1
Daphnia pulex	0.2	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Diacyclops b. thomasi	44.0	43.5	43.7	43.9	44.0	43.9	71.8	86.4	79.1	80.6	79.7	80.2	63.9	58.9	61.4	61.7
Leptodiaptomus nudus	0.0	0.5	0.3	0.6	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Mean total no./L	44.6			44.4			79.1			80.3			61.9			62.1
Granby - 27 July 2005 - Mean *Daphnia* density = 16.6/L																
Bosmina longirostris	0.0	0.0	0.0	3.0	5.0	4.0	0.0	1.0	0.5	0.4	0.4	0.4	0.5	0.0	0.2	1.0
unidentified *Daphnia spp.*	0.0	2.0	1.0	2.2	0.8	1.5	1.0	3.5	2.3	1.8	2.0	1.9	0.9	2.6	1.7	1.7
Daphnia galeata mendotae	3.9	2.0	3.0	3.9	3.8	3.8	5.6	7.5	6.6	4.4	3.6	4.0	7.4	4.3	5.8	4.6
Dapnia pulex	6.1	19.8	13.0	5.6	5.4	5.5	4.6	11.4	8.0	10.5	9.1	9.8	24.5	6.0	15.3	10.3
Diacyclops b. thomasi	40.4	34.1	37.2	39.8	40.8	40.3	38.5	55.7	47.1	21.9	24.2	23.1	52.8	27.6	40.2	37.6
Leptodiaptomus nudus	0.0	3.6	1.8	2.2	5.0	3.6	8.2	7.0	7.6	6.1	6.3	6.2	5.1	6.3	5.7	5.0
Mean total no./L	56.0			58.8			72.0			45.4			69.0			60.2

Table 23. **Length frequency of crustacean zooplankton (measured to nearest 0.01 mm) collected in Granby Reservoir, 2005. Bl = *Bosmina longirostris*, Dp spp. = unidentified *Daphnia*, Dgm = *Daphnia galeata mendotae*, Dp = *Daphnia pulex*, Dbt = *Diacyclops bicuspidatus thomasi* and Ln=*Leptodiaptomus nudus.***

Length class in mm	Granby - 30 June 2005					Length class in mm	Granby - 27 July 2005					
	Bl	Dgm	Dp	Dbt	Ln		Bl	Dp spp.	Dgm	Dp	Dbt	Ln
0.2						0.2	1					
0.3	1			1		0.3	5				1	
0.4				27		0.4					28	12
0.5		2		77		0.5			2		52	12
0.6				136	1	0.6		2	6	1	52	5
0.7		1		141		0.7		7	12		82	3
0.8			1	93		0.8		13	26	12	45	2
0.9				60		0.9		3	33	20	23	1
1.0		1		18		1.0		3	7	32	8	
1.1				5		1.1		3	4	36	5	2
1.2				6	1	1.2		1	8	37	2	1
1.3				1		1.3		1		8		1
1.4			1			1.4		2	3	6	1	
1.5						1.5		3	2	5		
1.6						1.6		1	2	3		1
1.7		1				1.7		1	1	6		
1.8						1.8		1		3		
1.9						1.9			1	5		
2.0						2.0			1	4		
2.1						2.1				3		
2.2						2.2				4		
2.3						2.3				1		
2.4						2.4				2		
2.5						2.5				1		
Totals	1	5	2	565	2	**Totals**	6	41	108	218	299	40
Mean length	0.3	0.9	1.1	0.7	0.9	**Mean length**	0.3	1.0	0.9	1.2	0.7	0.6

Table 24. Crustacean zooplankton, excluding nauplii, densities (number per liter) estimated from duplicate samples collected on one date at five stations in Green Mountain Reservoir, 2005.

Zooplankton Species	Station 1 (0-10)			Station 2 (0-10m)			Station 3 (0-10m)			Station 4 (0-10m)			Station 5 (0-10m)			Mean No./L
	a	b	mean	a	b	mean	a	b	mean	a	b	mean	a	b	mean	
Green Mountain - 07 September 2005 - Mean *Daphnia* density = 15.1/L																
Bosmina longiristris	0.0	0.7	0.4	0.0	0.0	0.0	0.0	3.1	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Daphnia mendotae	0.0	1.1	0.6	0.2	1.3	0.8	0.9	1.5	1.2	1.0	0.4	0.7	0.8	0.5	0.7	0.8
Daphnia pulex	12.1	7.8	9.9	12.3	10.9	11.6	11.8	9.2	10.5	10.3	18.1	14.2	12.5	15.4	13.9	12.0
Daphnia spp.	0.3	0.0	0.2	2.6	4.0	3.3	3.9	2.5	3.2	1.0	1.8	1.4	3.5	3.1	3.3	2.3
Diacyclops b. thomasi	3.4	1.9	2.6	1.3	2.9	2.1	1.3	0.8	1.1	3.2	2.0	2.6	2.9	2.1	2.5	2.2
Leptodiaptomus nudus	13.8	0.0	6.9	9.0	8.5	8.8	8.3	7.1	7.7	6.9	11.0	8.9	7.7	3.1	5.4	7.5
Mean total no./L	20.6			26.6			25.3			27.9			25.9			25.2

Table 25. Length frequency of crustacean zooplankton (measured to nearest 0.01 mm) collected in Green Mountain Reservoir, 2005. Bl = *Bosmina longirostris*, Dgm = *Daphnia galeata mendotae*, Dp = *Daphnia pulex*, Dp spp. = unidentified *Daphnia*, Dbt = *Diacyclops bicuspidatus thomasi* and Ln=*Leptodiaptomus nudus.*

Length class in mm	Green Mountain - 07 August 2005					
	Bl	Dgm	Dp	Dp spp.	Dbt	Ln
0.4	2				1	3
0.5		2	4		7	10
0.6		7	6	4	17	9
0.7		10	7	5	28	16
0.8		13	1	7	43	17
0.9		12	2	11	30	8
1.0		10	3	11	14	15
1.1		8	2	9	1	7
1.2		14	2	18	2	10
1.3		12	2	5		6
1.4		6	3	6		
1.5		3	1	8		
1.6		2		4		
1.7		1		1		
Totals	2	100	33	89	143	101
Mean length	0.4	1.0	0.9	1.1	0.8	0.9

Table 26. **Crustacean zooplankton, excluding nauplii, densities (number per liter) estimated from duplicate samples collected on one date at three stations in Jefferson Lake, 2005.**

Zooplankton Species	Station 1 (0-10)			Station 2 (0-10m)			Station 3 (0-10m)			Mean No./L
	a	b	mean	a	b	mean	a	b	mean	
Jefferson Lake - 08 August 2005 - Mean *Daphnia* density = 6.5/L										
Bosmina logirostris	5.3	6.4	5.8	14.1	8.4	11.2	3.4	3.5	3.5	6.8
Daphnia pulex	0.0	0.5	0.3	0.9	0.2	0.5	0.4	0.0	0.2	0.3
Daphnia galeata mendotae	4.8	5.1	4.9	7.2	4.7	5.9	4.3	5.0	4.6	5.2
Daphnia spp.	1.5	1.0	1.3	0.0	1.6	0.8	1.1	1.0	1.0	1.0
Diacyclops b. thomasi	8.3	9.7	9.0	17.0	14.9	15.9	13.3	11.9	12.6	12.5
Mean total no./L	21.3			34.5			22.0			25.9

Table 27. **Length frequency of crustacean zooplankton (measured to nearest 0.01mm) collected in Jefferson Lake, 2005. Bl = *Bosmina longirostris*, Dp spp. = unidentified *Daphnia*, Dbt = *Diacyclops bicuspidatus thomasi*, Dgm = *Daphnia galeata mendotae* and Dp = *Daphnia pulex.***

Length class in mm	Jefferson Lake 08 August 2005				
	Bl	**Dp spp.**	**Dbt**	**Dgm**	**Dp**
0.3	21				
0.4	22		2	1	
0.5	9	1	9	1	
0.6		2	11	5	1
0.7		3	21	8	
0.8		4	27	10	1
0.9		3	18	18	
1.0		3	7	22	1
1.1				10	
1.2		2		18	4
1.3		1		6	
1.4				7	1
1.5		3		8	
1.6		2		3	
1.7		2		7	
Totals	52	26	95	124	8
Mean length	0.4	1.1	0.8	1.1	1.1

Table 28. Crustacean zooplankton, excluding nauplii, densities (number per liter) estimated from duplicate samples collected on one date at five stations in McPhee Reservoir, 2005.

Zooplankton Species	Station 1 (0-10)			Station 2 (0-10m)			Station 3 (0-10m)			Station 4 (0-10m)			Station 5 (0-10m)			Mean No./L
	a	b	mean	a	b	mean	a	b	mean	a	b	mean	a	b	mean	
McPhee - 22 July 2005 - Mean Daphnia density = 13.5/L																
Bosmina longirostris	4.9	2.0	3.4	2.0	0.6	1.3	0.7	0.6	0.6	0.7	0.7	0.7	0.0	0.0	0.0	1.2
Ceriodaphnia megalops	0.0	1.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Diaphanosoma birgei	0.3	0.6	0.4	0.0	0.3	0.1	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2
unidentified *Daphnia spp.*	2.6	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Daphnia galeata mendotae	7.5	3.9	5.7	1.7	1.2	1.4	1.0	1.6	1.3	0.0	0.0	0.0	2.2	2.5	2.4	2.2
Daphnia pulex	8.5	8.1	8.3	13.4	13.0	13.2	11.4	10.9	11.2	12.1	11.5	11.8	6.4	12.0	9.2	10.7
Daphnia rosea	1.3	0.0	0.7	0.8	0.3	0.6	0.0	0.0	0.0	0.0	0.4	0.2	0.0	0.0	0.0	0.3
Daphnia schoedleri	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<0.1
Diacyclops b. thomasi	9.8	7.0	8.4	7.8	10.9	9.4	13.8	17.8	15.8	14.5	18.5	16.5	12.2	8.4	10.3	12.1
Leptodiatomus nudus	14.4	11.2	12.8	4.2	13.0	8.6	6.0	5.9	6.0	5.7	6.7	6.2	17.5	8.7	13.1	9.3
Mean total no./L	41.9			34.6			35.0			35.3			35.0			36.4

Table 29. Length frequency of crustacean zooplankton (measured to nearest 0.01mm) collected in McPhee Reservoir, 2005. Bl = *Bosmina longirostris*, Cdm = *Ceriodaphnia megalops*, Db = *Diaphanosoma birgei*, Dp spp. = unidentified *Daphnia*, Dgm = *Daphnia galeata mendotae*, Dp = *Daphnia pulex* Dr = *Daphnia rosea,* Ds = *Daphnia schoedleri,* Dbt = *Diacyclops bicuspidatus thomasi*, and Ln = *Daphnia galeata mendotate.*

Length class in mm	McPhee - 22 July 2005									
	Bl	*Cdm*	*Db*	*Dp spp.*	*Dgm*	*Dp*	*Dr*	*Ds*	*Dbt*	*Ln*
0.2	2									
0.3	6					1				
0.4	6	1			1	1			2	2
0.5	1		1			1			3	18
0.6		2	1		2	3			10	17
0.7					4	3	1		20	12
0.8		1		2	14	10	2		31	12
0.9				1	19	41	2		31	6
1.0			1		8	30			7	9
1.1			1	1	8	24			8	7
1.2			1	1	6	34	1			4
1.3				2	4	19				
1.4					3	17	1			
1.5				1	1	23	2	1		1
1.6						16		1		
1.7						15				
1.8						8				
1.9						2				
Totals	15	4	5	8	70	248	9	2	112	88
Mean length	0.3	0.6	0.9	1.1	1.0	1.2	1.1	1.6	0.8	0.8

Table 30. Crustacean zooplankton, excluding nauplii, densities (number per liter) estimated from duplicate samples collected on two dates at five stations in Ridgeway Reservoir, 2005.

Zooplankton Species	Station 1 (0-10)			Station 2 (0-10m)			Station 3 (0-10m)			Station 4 (0-10m)			Station 5 (0-10m)			Mean No./L
	a	b	mean	a	b	mean	a	b	mean	a	b	mean	a	b	mean	
Ridgeway - 22 June 2005 - Mean *Daphnia* density = 3.9/L																
Bosmina longirostris	37.1	47.7	42.4	114.2	53.0	83.6	73.4	100.5	86.9	14.0	27.2	20.6	23.5	25.8	24.6	51.6
Daphnia galeata mendotae	7.0	6.4	6.7	0.0	2.0	1.0	4.5	2.9	3.7	2.0	5.1	3.5	0.7	3.8	2.2	3.4
Daphnia pulex	0.0	0.0	0.0	0.8	0.0	0.4	0.0	0.5	0.2	0.3	0.0	0.1	0.0	0.0	0.0	0.2
Daphnia spp.	0.9	0.4	0.7	0.4	0.4	0.4	0.0	0.0	0.0	0.6	0.3	0.5	0.0	0.0	0.0	0.3
Diacyclops bicuspidatus thomasi	32.9	27.7	30.3	88.2	36.1	62.2	86.5	93.8	90.1	24.8	33.0	28.9	35.4	30.7	33.0	48.9
Mean total no./L	80.1			147.6			181.0			53.6			59.9			104.4
Ridgeway - 20 July 2005 - Mean *Daphnia* density = 11.9 /L																
Bosmina longirostris	2.2	1.9	2.0	0.8	1.4	1.1	0.0	0.0	0.0	1.8	1.6	1.7	2.7	2.5	2.6	1.5
Ceriodaphnia megalops	0.0	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.3	0.1
Daphnia galeata mendotae	8.5	8.5	8.5	10.2	9.8	10.0	11.1	13.2	12.2	12.2	10.5	11.3	6.9	9.4	8.2	10.0
Daphnia pulex	0.3	0.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.4	0.6	1.1	0.4	0.7	0.4
Daphnia spp.	0.0	1.3	0.6	1.1	2.5	1.8	3.3	0.5	1.9	2.3	1.2	1.7	0.5	2.5	1.5	1.5
Diacyclops bicuspidatus thomasi	6.9	6.3	6.6	9.8	9.4	9.6	2.9	3.4	3.2	5.0	8.5	6.7	7.5	12.3	9.9	7.2
Mean total no./L	18.6			22.6			17.2			22.1			23.2			20.7

Table 31. **Length frequency of crustacean zooplankton (measured to nearest 0.01 mm) collected in Ridgeway Reservoir, 2005. Bl = *Bosmina longirostris*, Dgm = *Daphnia galeata mendotae*, Dp = *Daphnia pulex*, Dp spp. = unidentified *Daphnia* and Dbt = *Diacyclops bicuspidatus thomasi*.**

Length class in mm	Ridgeway - 22 June 2005					Ridgeway – 20 July 2005					
	Bl	Dgm	Dp	Dp spp.	Dbt	Bl	Cdm	Dgm	Dp	Dp spp.	Dbt
0.2	3										
0.3	77					7		2			
0.4	104				6	23	1	1			5
0.5	8	12		2	16	1	3	1		1	4
0.6		9		1	54			16		3	33
0.7		11		1	73			39	3	10	73
0.8		7	1	1	58			49	1	4	53
0.9		12		1	30			28	1	7	14
1.0		16	1	1	3			19	2	4	1
1.1		7		1	2			19	4	4	
1.2		6	1					38		6	
1.3		1						19		2	
1.4								12			
1.5		1	1					6		1	
1.6								1			
Totals	192	82	4	8	242	31	4	250	11	42	183
Mean length	0.4	0.8	1.1	0.8	0.7	0.4	0.5	1.0	0.9	0.9	0.7

Table 32. **Crustacean zooplankton, excluding nauplii, densities (number per liter) estimated from duplicate samples collected on three dates at three stations in Shadow Mountain Reservoir, 2005.**

Zooplankton Species	Station 1 (0-10)			Station 2 (0-10m)			Station 3 (0-10m)			Mean No./L
	a	b	mean	a	b	mean	a	b	mean	
Shadow Mountain - 01 July 2005 - Mean *Daphnia* density = 0.2/L										
Bosmina longirostris	2.0	0.8	1.4	0.7	1.1	0.9	4.3	2.3	3.3	1.9
Daphnia mendotae	0.1	0.0	<0.1	0.0	0.0	0.0	0.3	0.6	0.5	0.2
Diacyclops b. thomasi	9.4	4.8	7.1	3.8	7.0	5.4	6.6	10.9	8.7	7.1
Mean total no./L	8.5			6.3			12.5			9.1
Shadow Mountain - 27 July 2005 - Mean *Daphnia* density = 38.3/L										
Bosmina longirostris	37.8	41.4	39.6	22.7	21.2	21.9	30.0	47.4	38.7	33.4
unidentified *Daphnia spp.*	0.0	0.6	0.3	0.5	3.0	1.7	3.7	0.0	1.8	1.3
Daphnia galeata mendotae	44.7	43.3	44.0	28.1	26.1	27.1	41.1	37.5	39.3	36.8
Daphnia pulex	0.0	0.0	0.0	0.5	0.4	0.4	0.6	0.0	0.3	0.2
Diacyclops bicuspidatus thomasi	33.7	34.6	34.2	15.0	16.7	15.8	27.0	28.7	27.8	25.9
Leptodiaptomus nudus	0.0	0.6	0.3	0.0	0.0	0.0	0.0	0.6	0.3	0.2
Mean total no./L	118.4			67.0			108.3			97.9
Shadow Mountain - 06 September 2005 - Mean *Daphnia* density = 10.0/L										
Bosmina longirostris	0.0	0.0	0.0	0.0	0.7	0.3	0.0	0.0	0.0	0.1
unidentified *Daphnia spp.*	0.0	0.8	0.4	0.5	1.0	0.8	0.0	0.0	0.0	0.4
Daphnia galeata mendotae	4.1	3.6	3.9	14.3	11.8	13.0	7.6	6.8	7.2	8.0
Daphnia pulex	0.1	0.6	0.4	0.8	0.7	0.7	1.0	0.6	0.8	0.6
Diacyclops b. thomasi	4.5	4.4	4.4	6.5	4.7	5.6	9.0	9.6	9.3	6.4
Leptodiaptomus nudus	0.2	0.1	0.2	0.0	0.3	0.2	1.1	0.3	0.7	0.4
Mean total no./L	9.2			20.6			18.0			15.9

Table 33. **Length frequency of crustacean zooplankton (measured to nearest 0.01mm) collected in Ridgeway Reservoir, 2005. Bl = *Bosmina longirostris*, Dgm = *Daphnia galeata mendotae*, Dp = *Daphnia pulex*, D.spp. = unidentified *Daphnia*, Dbt = *Diacyclops bicuspidatus thomasi* and Ln = *Leptodiaptomus nudus*.**

Length class in mm	01 July 2005			Length class in mm	27 July 2005					Length class in mm	06 September 2005					
	Bl	Dgm	Dbt		Bl	D. spp.	Dgm	Dp	Dbt		Bl	D.spp.	Dgm	Dp	Dbt	Ln
0.2	2		1	0.2	2					0.2						
0.3	35		5	0.3	77				3	0.3	1					
0.4	15	2	5	0.4	54		2		5	0.4			1			
0.5	2	1	23	0.5	7	3	12		13	0.5		3	7		1	
0.6	1	2	21	0.6	2	5	30		21	0.6	1	4	27		11	
0.7	1	4	30	0.7		2	27		17	0.7		2	18	1	16	
0.8	1		34	0.8		2	16	1	15	0.8			11		27	
0.9		1	35	0.9		1	15	1	9	0.9			6	3	24	
1.0		1	21	1.0			8		3	1.0		2	10	1	8	
1.1			12	1.1		1	13		2	1.1			3	3	2	
1.2			21	1.2		1	9	1	1	1.2			6	2	2	3
1.3			8	1.3			7		2	1.3			3	2		1
1.4		1	2	1.4		1	8			1.4			10	1		1
1.5			2	1.5			2			1.5			11	1		
1.6				1.6						1.6			14	3		
1.7			1	1.7						1.7			6	1		
1.8				1.8						1.8			9			
1.9				1.9						1.9			3	1		
2.0				2.0						2.0			2			
2.1				2.1						2.1			3			
2.2				2.2						2.2				1		
Totals	142	91	16	**Totals**	142	16	149	3	91	**Totals**	2	11	150	20	91	5
Mean length	0.4	0.7	0.8	**Mean length**	0.4	0.8	0.8	1.0	0.7	**Mean length**	0.5	0.7	1.1	1.3	0.8	1.3

Table 34. Crustacean zooplankton, excluding nauplii, densities (number per liter) estimated from duplicate samples collected on one date at five stations in Taylor Park Reservoir, 2005.

Zooplankton Species	Station 1 (0-10)			Station 2 (0-10m)			Station 3 (0-10m)			Station 4 (0-10m)			Station 5 (0-10m)			Mean No./L
	a	b	mean	a	b	mean	a	b	mean	a	b	mean	a	b	mean	
Taylor Park - 03 August 2005 - Mean *Daphnia* density = 2.2/L																
unidentified *Daphnia spp.*	0.0	0.4	0.2	0.4	0.0	0.2	0.5	0.5	0.5	0.5	0.9	0.7	1.0	1.0	1.0	0.5
Daphnia mendotae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	<0.1
Daphnia pulex	0.4	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	2.0	4.1	3.1	4.4	4.5	4.5	1.6
Diacyclops b. thomasi	120.3	98.0	109.2	110.3	85.2	97.7	79.9	85.6	82.8	72.7	62.6	67.6	58.1	59.5	58.8	83.2
Leptodiaptomus nudus	0.4	0.8	0.6	0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.0	0.0	0.3	0.3	0.3	0.2
Mean total no./L	47.5			35.0			39.3			38.2			35.5			39.1

Table 35. **Length frequency of crustacean zooplankton (measured to nearest 0.01 mm) collected in Taylor Park Reservoir, 2005. D.spp. = unidentified *Daphnia*, Dgm = *Daphnia galeata mendotae*, Dp = *Daphnia pulex*, Dbt = *Diacyclops bicuspidatus thomasi* and Ln = *Leptodiaptomus nudus*.**

Length class in mm	Taylor Park - 03 August 2005				
	D.spp.	Dgm	Dp	Dbt	Ln
0.4				2	
0.5				39	
0.6	2			126	
0.7	5	2	3	132	
0.8	2			39	1
0.9	1		2	20	
1.0			8	2	
1.1	1		1		
1.2			1		
1.3			1		1
1.4	1		2		
1.5			2		
1.6			5		3
1.7			4		1
1.8			2		
1.9			1		
2.0	1		4		
2.1			1		
Totals	13	2	37	360	6
Mean length	0.9	0.7	1.4	0.7	1.4

Table 36. **Crustacean zooplankton, excluding nauplii, densities (number per liter) estimated from duplicate samples collected on one date at three stations in Vallecito Reservoir, 2005.**

Zooplankton Species	**Station 1 (0-10)**			**Station 2 (0-10m)**			**Station 3 (0-10m)**			**Mean No./L**
	a	b	mean	a	b	mean	a	b	mean	
Vallecito - 21July 2005- Mean *Daphnia* density = 21.0/L										
unidentified *Daphnia spp.*	3.9	1.3	2.6	0.5	3.6	2.0	0.0	0.4	0.2	1.6
Daphnia mendotae	7.5	15.0	11.2	23.9	10.3	17.1	8.4	12.9	10.7	13.0
Daphnia pulex	9.2	12.1	10.6	3.3	6.2	4.7	4.6	3.0	3.8	6.4
Daphnia rosea	0.9	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	>0.1
Diacyclops b. thomasi	16.2	22.1	19.2	10.8	12.8	11.8	5.5	23.9	14.7	15.2
Leptodiaptomus nudus	0.0	0.0	0.0	0.5	0.0	0.2	0.0	0.4	0.2	>0.1
Mean total no./L	44.1			35.9			29.5			35.9

Table 37. **Length frequency of crustacean zooplankton (measured to nearest 0.01 mm) collected in Vallecito Reservoir, 2005. D.spp. = unidentified *Daphnia*, Dgm = *Daphnia galeata mendotae*, Dp = *Daphnia pulex*, Dr = *Daphnia rosea*, Dbt = *Diacyclops bicuspidatus thomasi*.**

Length class in mm	Vallecito - 21 July 2005				
	Dp spp.	Dgm	Dp	Dr	Dbt
0.3					1
0.4					7
0.5					3
0.6	1	2			15
0.7	5	17	1		23
0.8	4	24	2		25
0.9	2	39	8		20
1.0	2	16	12		2
1.1	2	10	17		1
1.2	2	5	10		3
1.3	1		3		
1.4		2	7		
1.5		4	4		
1.6		3	3	2	
1.7	1	2	1		
1.8			2		
1.9			2		
2.0	1		7		
2.1			1		
Totals	21	124	80	2	100
Mean length	1.0	0.9	1.3	1.6	0.7

Table 38. **Crustacean zooplankton, excluding nauplii, densities (number per liter) estimated from duplicate samples collected on one date at three stations in Williams Fork Reservoir, 2005.**

Zooplankton Species	Station 1 (0-10)			Station 2 (0-10m)			Station 3 (0-10m)			Station 4 (0-10m)			Station 5 (0-10m)			Mean No./L
	a	b	mean	a	b	mean	a	b	mean	a	b	mean	a	b	mean	
William's Fork - 28 July 2005 - Mean *Daphnia* density = 2.4/L																
unidentified *Daphnia spp.*	0.0	0.0	0.0	0.0	0.6	0.3	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	<0.1
Daphnia mendotae	0.0	0.0	0.0	0.0	0.3	0.2	0.0	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	<0.1
Daphnia pulex	1.2	2.1	1.6	1.6	3.0	2.3	2.1	2.5	2.3	1.8	3.4	2.6	2.6	2.4	2.5	2.3
Diacyclops b. thomasi	47.6	43.5	45.5	33.1	30.9	32.0	29.7	42.1	35.9	37.4	31.6	34.5	30.2	25.8	28.0	35.2
Leptodiaptomus nudus	0.3	0.3	0.3	0.5	0.0	0.3	1.3	0.6	0.9	1.2	0.7	0.9	4.3	5.8	5.0	1.5
Mean total no./L	47.5			35.0			39.3			38.2			35.5			39.1

Table 39. Length frequency of crustacean zooplankton (measured to nearest 0.01 mm) collected in Williams Fork Reservoir, 2005. D.spp. = unidentified *Daphnia*, Dgm = *Daphnia galeata mendotae*, Dp = *Daphnia pulex*, Dbt = *Diacyclops bicuspidatus thomasi* and Ln = *Leptodiaptomus nudus*.

Length class in mm	Williams Fork - 28 July 2005				
	Dp spp.	*Dgm*	*Dp*	*Dbt*	*Ln*
0.2				1	
0.3				12	
0.4				52	
0.5				114	
0.6				109	2
0.7				58	
0.8				31	1
0.9	1	2	1	17	2
1.0	1		4	14	1
1.1			5	2	
1.2			7	2	1
1.3			3		1
1.4			4		1
1.5			10		2
1.6			6		2
1.7			3		1
1.8			2		
1.9			4		
2.0	1		8		
2.1			3		
2.2			5		
2.3			7		
2.4			4		
2.5			2		
2.6			2		
2.7					
2.8			2		
2.9					
3.0			1		
3.1			1		
Totals	3	2	84	412	14
Mean length	1.3	0.9	1.8	0.6	1.2

Segment Objective 2: Sample *Mysis* in Granby Reservoir and in Dillon, Taylor Park and Jefferson reservoirs as feasible.

Introduction

Mysis predation on *Daphnia* can be a complicating factor in the fishery management of several reservoirs in Colorado. However, having periodic, preferably annual, data on *Mysis* abundance can help fishery managers account for and predict the success of these fisheries, allowing for adjustments in fish stocking as warranted. Examples of these management adjustments include: 1) introducing Arctic char into Dillon Reservoir whose *Daphnia* continues to be suppressed by *Mysis*; 2) increasing the number of kokanee fry into Granby Reservoir during cycles of abundant *Daphnia* and low *Mysis* density; and stocking rainbow trout through the ice at Taylor Park Reservoir when *Mysis* numbers are high to facilitate overwinter survival and growth of these fish to enhance ice-out and spring fishing opportunity.

Methods and Materials

Quantitative sampling for *Mysis* was performed on six reservoirs in 2005. Sampling was performed in Dillon on 10 August, in Granby on 9 August, in Horsetooth on 27 September, in Jefferson on 8 August, in Shadow Mountain on 6 September and in Taylor Park on 3 August. Sampling was done at night, near the date of the new moon. Samples were collected using a 1-m diameter x 3-m long conical net with 500 μm mesh lowered to the reservoir bottom at standardized stations located by GPS and retrieved at 0.37 m/s with an anchor windlass. Duplicate samples collected at each station were placed in 18 oz. Whirl-Pac bags, identified with a rag paper label and preserved in 70% ethanol. In the lab, all samples were enumerated with one sample from each station being randomly chosen for measurement of individual mysids. Mysids were measured to the nearest millimeter from the tip of the rostrum to the tip of the telson, excluding setae.

Results and Discussion

Estimated *Mysis* densities and size structures for waters sampled in 2005 are given in Tables 40-51. Of these waters sampled, Dillon had the highest *Mysis* density at 451/m^2 (Table 40) which was above its long-term average of 305/m^2 (Table 52). The *Mysis* density in Granby, 215/m^2 (Table 42, was half the long-term average of 437/m^2 and very low compared to the historic high density of over 1300/m^2 (Table 52). *Mysis* densities in Dillon and Granby, dropped to $\leq$30/m^2 in 2003 (Table 52) following severe drawdown in both reservoirs in 2002 following a prolonged period of drought in the region. *Mysis* was at an extremely low level, 1.3/m^2, in Horsetooth (Table 44). *Mysis*, introduced into Jefferson in 1972, was not detected in 1976, but was present, but not quantified in 1983 (Nesler 1986). The estimated density of *Mysis* in Jefferson in 2005 was 383.2/m^2, rivaled the long-term density of *Mysis* in Colorado's largest *Mysis* reservoirs (Table 52). The density of *Mysis* in Shadow Mountain, a shallow reservoir, was 10.2/m^2 (Table 48). The density of *Mysis* in Taylor Park in 2005, 447/m^2, was close to this reservoir's long-term mean *Mysis* density of 412/m^2 (Table 52).

Table 40. **Summary of nighttime *Mysis* sampling at ten stations in Dillon Reservoir, August 2005, using a vertical meter net (0.785m^2 bridle opening). Estimates of corrected lakewide mean *Mysis* density derived from duplicate samples at each station expressed as number per square meter.**

Dillon Reservoir - 10 August 2005 - 10 Stations - Mean *Mysis*/m² = 451.0											
Sample number	Sampling stations (water depth in meters)										Data summary
	Stratum I		Stratum II				Stratum III				
	1A - 53.9	1B-53.0	2A-33.7	2B-38.6	2C-35.2	2D-36.5	3A-9.3	3B-11.3	3C-13.5	3D-13.3	
#1	36	82	582	1072	798	153	109	266	128	104	3330
#2	48	84	603	1318	899	121	143	373	84	77	3750
Sum	84	166	1185	2390	1697	274	252	639	212	181	7080
Mean	42	83	592.5	1195	848.5	137	126	319.5	106	90.5	354

Table 41. ***Mysis relicta* length frequency for specimens collected from nighttime vertical meter-net tows in Dillon Reservoir during August 2004. *Mysis* total length in mm (tip of rostrum to tip of telson, excluding setae).**

Dillon Reservoir - 10 August 2005																				
Station & sample #	Juvenile Mysids								Maturing & Adult Mysids											Totals
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1A-1		2	5	32	47	61	82	100	109	57	20	9	5	5	15	21	16	3	1	590
1B-2			7	18	16	24	60	56	80	34	8	11	8	23	25	25	17			412
2A-1			4	8	4	11	27	32	19	9	1									115
2B-2				2	1	4	9	14	14	18	1	1	1	2	1	7	1			76
2C-1	1		2	13	10	13	22	17	13	8	5	2	3	5	15	13	1			143
2D-1			2	2	4	7	15	29	20	25	3	1								108
3A-2				4	2	6	12	14	16	10										64
3B-1					1	2	5	9	6	4										27
3C-1							2	9	7	4	1									23
3D-1					4	5	11	22	30	23	3				1					99
Totals	1	2	20	79	89	133	245	302	314	192	42	24	17	35	57	66	35	3	1	1657
Percent	0.06	0.12	1.21	4.77	5.37	8.03	14.79	18.23	18.95	11.59	2.53	1.45	1.03	2.11	3.44	3.98	2.11	0.18	0.06	100.00

Table 42. **Summary of nighttime *Mysis* sampling at ten stations in Granby Reservoir, August 2005, using a vertical meter net (0.785 m^2 bridle opening). Estimates of corrected lakewide mean *Mysis* density derived from duplicate samples at each station expressed as number per square meter.**

Granby Reservoir- 09 August 2005 - 10 Stations - Mean *Mysis*/m^2 = 215.0											
Sample number	Sampling stations (water depth in meters)										Data summary
	Stratum I		Stratum II				Stratum III				
	A - 49.6	B-48.5	A-28.6	B-25.7	C-31.0	D-22.0	A-15.9	B-11.3	C-15.4	D-18.0	
#1	590	376	115	47	143	108	171	27	23	90	1690
#2	600	412	102	76	158	109	64	29	26	109	1685
Sum	1190	788	217	123	301	217	235	56	49	199	3375
Mean	595.0	394.0	108.5	61.5	150.5	108.5	117.5	28.0	24.5	99.5	168.8

Table 43. ***Mysis relicta* length frequency for specimens collected from nighttime vertical meter-net tows in Granby Reservoir during August 2004. *Mysis* total length in mm (tip of rostrum to tip of telson, excluding setae).**

Granby Reservoir - 09 August 2005																				
Station & sample #	**Juvenile Mysids**								**Maturing & Adult Mysids**											**Totals**
	6	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	
1A-1		2	5	32	47	61	82	100	109	57	20	9	5	5	15	21	16	3	1	590
1B-2			7	18	16	24	60	56	80	34	8	11	8	23	25	25	17			412
2A-1			4	8	4	11	27	32	19	9	1									115
2B-2				2	1	4	9	14	14	18	1	1	1	2	1	7	1			76
2C-1	1		2	13	10	13	22	17	13	8	5	7	3	5	15	13	1			148
2D-1			2	2	4	7	15	29	20	25	3	1								108
3A-2				4	2	6	12	14	16	10										64
3B-1					1	2	5	9	6	4										27
3C-1							2	9	7	4	1									23
3D-1					4	5	11	22	30	23	3									98
Totals	1	2	20	79	89	133	245	302	314	192	42	29	17	35	56	66	35	3	1	1661
Percent	0.06	0.12	1.20	4.76	5.36	8.01	14.75	18.18	18.90	11.56	2.53	1.75	1.02	2.11	3.37	3.97	2.11	0.18	0.06	100.00

Table 44. **Summary of nighttime *Mysis* sampling at ten stations in Horsetooth Reservoir, September 2005, using a vertical meter net (0.785 m^2 bridle opening). Estimates of corrected lakewide mean *Mysis* density derived from duplicate samples at each station expressed as number per square meter.**

Horsetooth Reservoir – 27 September 2005 – 7 Stations – Mean *Mysis*/m^2 = 1.3								
Sample number	**Sampling stations (water depth in meters)**							**Data summary**
	Stratum I							
	HTMY1 (31.7)	HTMY2 (37.0)	HTMY3 (15.2)	HTMY4 (37.9)	HTMY5 (35.5)	HTMY6 (33.5)	HTMY7 (33.3)	
#1	0	0	0	2	0	3	2	7
#2	0	0	0	4	1	3	1	9
Sum	0	0	0	6	1	6	3	16
Mean	0	0	0	3	0.5	3	1.5	1

Table 45. ***Mysis relicta* length frequency for specimens collected from nighttime vertical meter-net tows in Horsetooth Reservoir during September 2004. *Mysis* total length in mm (tip of rostrum to tip of telson, excluding setae).**

Horsetooth Reservoir – 27 September 2005														
Station & sample #	**Juvenile Mysids**			**Maturing & Adult Mysids**										**Totals**
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
HTMY4-1				2											2
HTMY4-2	1									2				1	4
HTMY6-1										1			1	1	3
HTMY6-2							2			1					3
HTMY7-1				1										1	2
HTMY7-2							1								1
Totals	1			3			3			4			1	3	15
Percent	6.67			20.00			20.00			26.67			6.67	20.00	100.00

Table 46. **Summary of nighttime *Mysis* sampling at ten stations in Jefferson Lake, August 2005, using a vertical meter net (0.785 m^2 bridle opening). Estimates of corrected lakewide mean *Mysis* density derived from duplicate samples at each station expressed as number per square meter.**

Jefferson Lake - 08 August 2005 - 6 Stations - Mean *Mysis*/m² = 383.2							
Sample number	**Sampling stations (water depth in meters)**						**Data summary**
	Stratum I						
	JFM1 (7.2)	JFM2 (29.7)	JFM3 (25.5)	JFM4 (40.5)	JFM5 (49.2)	JFM6 (23.4)	
#1	1	475	134	349	329	268	1556
#2	6	596	478	337	312	324	2053
Sum	7	1071	612	686	641	592	3609
Mean	3.5	535.5	306.0	343.0	320.5	296.0	300.8

Table 47. ***Mysis relicta* length frequency for specimens collected from nighttime vertical meter-net tows in Jefferson Lake during September 2004. *Mysis* total length in mm (tip of rostrum to tip of telson, excluding setae).**

Jefferson Lake – 08 August 2005																					
Station & sample #	**Juvenile Mysids**									**Maturing & Adult Mysids**											**Totals**
	5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	
JFM1-2	1		1	1	1	1		1													5
JFM2-1	4	14	48	75	68	56	47	41	27	13	19	22	23	8	6	3					470
JFM3-1		2	7	22	38	42	44	37	17	4	2	5	6	5	1	1	1				234
JFM4-1	6	13	25	45	63	42	20	26	10	26	6	4	25	21	11	4	2				343
JFM5-1	2	21	35	49	15	32	31	17	4	11	26	23	29	7	4	11	5	5		2	327
JFM6-2		7	32	57	71	52	35	29	10	8	4	7	8	2	2						324
Totals	13	57	148	249	256	225	177	151	68	62	57	61	91	43	24	19	8	5	0	2	1703
Percent	0.8	3.3	8.7	14.6	15.0	13.2	10.4	8.9	4.0	3.6	3.3	3.6	5.3	2.5	1.4	1.1	0.5	0.3	0.0	0.1	100.0

Table 48. **Summary of nighttime *Mysis* sampling at ten stations in Shadow Mountain Reservoir, September 2005, using a vertical meter net (0.785 m^2 bridle opening). Estimates of corrected lakewide mean *Mysis* density derived from duplicate samples at each station expressed as number per square meter.**

Shadow Mountain Reservoir- 06 September 2005 - 3 Stations - Mean Mysis/m^2 = 10.2				
Sample number	**Sampling stations (water depth in meters)**			**Data summary**
	Stratum I			
	SM1A-9.0	SMZP2-8.8	SM3A-5.8	
#1	4	12	0	16
#2	1	30	1	32
Sum	5	42	1	48
Mean	2.5	21	0.5	8

Table 49. ***Mysis relicta* length frequency for specimens collected from nighttime vertical meter-net tows in Shadow Mountain Reservoir during September 2004. *Mysis* total length in mm (tip of rostrum to tip of telson, excluding setae).**

Shadow Mountain Reservoir - 06 September 2005								
Station - sample #	**Juvenile Mysids**			**Maturing & Adult Mysids**				**Totals**
	11	**12**	**13**	**14**	**15**	**16**	**17**	
SM1A-1	1			1			2	4
SMZP2-2		6	2	6	9	1	1	25
SM3A-2							1	1
Totals	1	6	2	7	9	1	4	30
Percent	3.3%	20.0%	6.7%	23.3%	30.0%	3.3%	13.3%	100.0%

Table 50. **Summary of nighttime *Mysis* sampling at ten stations in Taylor Park Reservoir, August 2005, using a vertical meter net (0.785 m^2 bridle opening). Estimates of corrected lakewide mean *Mysis* density derived from duplicate samples at each station expressed as number per square meter.**

Taylor Park- 03 August 2005 - 10 Stations - Mean *Mysis*/m² = 447.1											
Sample number	**Sampling stations (water depth in meters)**										**Data summary**
	Stratum I		**Stratum II**				**Stratum III**				
	1A-36.7	1B-39.2	2A-24.4	2B-27.2	2C-16.8	2D-21.9	3A-6.2	3B-7.3	3C-11.1	3D-9.2	
#1	36	53	582	1072	798	153	109	266	128	104	3301
#2	48	53	603	1318	899	121	143	373	84	77	3719
Sum	84	106	1185	2390	1697	274	252	639	212	181	7020
Mean	42.0	53.0	592.5	1195.0	848.5	137.0	126.0	319.5	106.0	90.5	351

Table 51. ***Mysis relicta* length frequency for specimens collected from nighttime vertical meter-net tows in Taylor Park Reservoir during September 2005. *Mysis* total length in mm (tip of rostrum to tip of telson, excluding setae).**

Taylor Reservoir - 03 August 2005																		
Station & sample #	**Juvenile Mysids**									**Maturing & Adult Mysids**								**Totals**
	5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	
1A-1	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	48
1B-2				4	7	8	7	4	1		4	5	5	2		1		82
2A-1				3	14	12	11	17	6	6	4	2	2	3	1		1	580
2B-2		12	10	24	27	83	120	103	49	31	25	15	38	16	8	19		1072
2C-1	2	34	179	228	177	133	118	85	11	9	34	41	16	3	1	1		807
2D-1	2	19	92	151	190	132	76	63	14	4	14	33	13	3			1	131
3A-2		4	17	9	19	16	16	10	4		8	11	10	6	1			110
3B-1				2	10	22	39	26	7	3		1						266
3C-1		5	26	25	43	57	65	34	11									128
3D-1		2	2	7	33	37	40	5	2									77
Totals		1	8	5	11	28	8	12	1	2		1						3301
Percent	4	77	334	458	531	528	500	359	106	55	89	109	84	33	11	21	2	100.0

Table 52. Summary of the estimated densities of *Mysis relicta* in the three largest reservoirs in Colorado containing *Mysis*, Dillon, Granby and Taylor Park, which also have the longest records of sampling for this introduced species during the period from 1991 to 2005.

Year	*Mysis* density (number/m^2)		
	Dillon	Granby	Taylor Park
1991	572	162	437
1992	352	178	456
1993	341	231	165
1994	270	541	170
1995	372	674	93
1996	235	1,365	182
1997	no data	382	no data
1998	246	294	196
1999	236	566	197
2000	223	843	366
2001	no data	378	262
2002	336	460	504
2003	25	30	241
2004	no data	238	399
2005	451	215	447
No. years	12	15	14
Minimum	25	30	93
Maximum	572	1,365	504
Mean no./m^2	305	437	412

OBJECTIVE 4: WATER AND OTOLITH MICROCHEMISTRY AS A FORENSIC TOOL TO TRACE AND PROSECUTE ILLEGAL MOVEMENTS OF FISH

Initiate, facilitate and participate in water and otolith microchemical investigations to identify the utility of this technique as a potential forensic tool for tracing and combating illicit fish stocking by sampling at hatcheries (state, federal and private) and in select large reservoirs and their satellite waters.

Segment Objective 1: Collect water and otolith samples from Blue Mesa, Taylor Park, Crawford and Paonia Reservoirs to evaluate utility of microchemical techniques to identify origins of illicitly stocked fishes in Blue Mesa.

Introduction to Colorado State University Findings

Martinez (2006) discussed the escalating rate of illicit fish introduction in western Colorado, the threat that this activity poses to established sport fisheries, consequences for native fish preservation and endangered fish recovery, strategies to combat this illicit activity and the potential utility of water and otolith microchemistry as a forensic tool to discourage and prosecute illegal movements of fish by the public. This Segment Objective is specific to the illicit movement of yellow perch among reservoirs in the Gunnison River Basin, including Blue Reservoir, a high profile, high value coldwater salmonid sport fishery. Appendix C contains preliminary findings from Colorado State University (CSU) for otolith microchemistry in yellow perch from Blue Mesa and Crawford reservoirs, and muscle stable isotope for northern pike from Crawford and Paonia Reservoirs. Martinez (2006) describes how ongoing work on two of these reservoirs, Crawford and Paonia, will be addressed within a broader investigation to fingerprint reservoirs in western Colorado and northeastern Utah that contain nonnative, nonsalmonid piscivores that may access critical habitat for endangered fishes via escapement from reservoirs. Work on illicit fish introduction into Blue Mesa will be continued under this Coldwater Reservoir Ecology project in conjunction with that broader effort.

Segment Objective 2: Participate in water and otolith collection and analyses from hatcheries and receiving water to facilitate development of this forensic tool for identifying sources of illicitly stocked fishes.

Introduction to Research Sponsored by the CDOW and the Whirling Disease Initiative

Martinez (2005) discussed the impetus to initiate research on potential forensic application of "fingerprinting" water sources and identifying these distinct microchemical compositions in the otoliths of fish to track their illicit transfer among waters by the public and private sectors. Appendix D summarizes research by Dan Gibson-Reinemer, M.S. Candidate at CSU, initially funded in part by the CDOW and then by a grant from the Whirling Disease Initiative, Montana State University.

OBJECTIVE 5: TECHNICAL AND COOPERATIVE SUPPORT IN OTHER RESEARCH INVESTIGATIONS AND IN RESERVOIR MANAGEMENT

Provide technical and cooperative support in other research investigations (e.g. strobes at Vallecito, yellow perch Perca flavescens *in Blue Mesa) and in reservoir management including selecting angling regulations, fish stocking and information dissemination, to help perpetuate fishery productivity and stability.*

Segment Objective 1: Participate in research on fish escapement at Vallecito Reservoir.

Introduction

Martinez (2005) described the background and rationale for conducting a preliminary examination of the utility of strobe lights at the Vallecito Reservoir outlet to reduce and control escapement of kokanee. CDOW Fishery Biologist, Mike Japhet, monitored the timing of kokanee escapement below the dam in 2005. My crew assisted this effort by performing additional hydroacoustics to determine the distribution of kokanee in the reservoir in relation to the outlet.

Methods and Materials

In addition to the standardized annual hydroacoustic survey performed at night in Vallecito in late August 2005 (Figure 2), these same standardized transects were also surveyed during daytime to compare the vertical distribution of kokanee in the reservoir. Kevin Rogers, CDOW Aquatic Researcher, processed these data.

Results and Discussion

Martinez (2005) described the configuration of the penstock at Vallecito Dam through which kokanee become entrained in relation to the fluctuation of the reservoir. At full capacity, the penstock is 25.5 m (83 feet) below the water surface. In 2004, when the preliminary evaluation of kokanee response to a strobe light in Vallecito was performed, the average depth of water above the penstock intake during the months of April through September was 20 m (66 feet). Table 53 compares the numbers of tracked fish, presumed to be almost entirely kokanee (Martinez 1995) in the sonar survey during the day and at night on 29 August 2005 in Vallecito. These data show the difference in fish density as seen by sonar during the day vs. night due to the daytime schooling behavior of kokanee. Of greater interest, however, are the differences in the depth distribution of these pelagic targets between day and night. Note the increase in the proportion of fish below 10 m at night, especially the 376% increase in fish below 20 m from day to night. This diel migration of kokanee places them in greater proximity, depth-wise, to the intake of the penstock at night when they concentrate at depth around 20-m. Thus kokanee are more susceptible to entrainment at night as confirmed by drift nets placed in the tailrace below the dam to track trends in kokanee escapement from the reservoir (Mike Japhet, CDOW Senior Aquatic Biologist, personal communication).

Table 53. Comparison of daytime versus nighttime numbers of fish, primarily kokanee, determined from hydroacoustics along four standardized transects in three strata in Vallecito Reservoir on 29 August 2005.

Water depth (m)	Daytime		Nighttime		From day to night	
	Number	Percent	Number	Percent	Difference	% Change
2-10	2,531	16	1,266	3	1,265	- 50%
10-20	10,285	63	19,538	53	-9,253	+ 90%
>20	3,467	21	16,521	44	-13,054	+ 376%
Total	16,283	100	37,325	100	-21,042	+129.9

Segment Objective 2: Participate in yellow perch investigations at Blue Mesa Reservoir.

Introduction to Colorado State University Findings

Appendix C contains data and information about this Segment Objective. The findings are encouraging in that the diet of yellow perch examined to date do not show overlap with the *Daphnia*-based diet of kokanee in Blue Mesa (Stockwell et al. 1999, Hardiman et al. 2004). This relationship will continue to be monitored periodically in cooperation with Dan Brauch, CDOW Aquatic Biologist, at Blue Mesa. The consumption of kokanee fry by yellow perch, as previously discussed (Table 15) remains a serious concern and will be monitored as well.

Segment Objective 3: Participate in dissemination of information, as needed and feasible.

Introduction

Martinez (2005) reported that presentations were made in meetings in 2004 and 2005 to the public and to CDOW managers, administrators and commissioners to alert them to concerns about the State's kokanee egg supply and the implications for lake trout management in Blue Mesa and Granby reservoirs. Based on this information, liberal regulations for lake trout were maintained at Blue Mesa and the restrictive bag and length limits at Granby were liberalized. These management decisions were intended to maintain the growth, body condition and trophy potential of lake trout in Blue Mesa while preserving the kokanee fishery and the kokanee egg supply. At Granby, the change in lake trout regulations beginning in January 2006 (4 lake trout bag, no length limit) were intended to restore these fishery parameters that had declined or had been lost due to overprotection of lake trout by overly restrictive bag and size limit in the past two decades (Martinez 2005).

Methods and Materials

Given angler concern about the management strategy for Blue Mesa and Granby reservoirs and misinformation circulating among some anglers about the goals of the management actions regarding kokanee and lake trout, I was asked to participate in an Anglers Roundtable meeting on 29 March 2005 in Grand Junction. At that meeting, I reviewed the lake trout management scenario for the western United States (Appendix A), presented data about lake trout predation impacts in Blue Mesa based on lake trout population estimates (Crockett 2004, Crockett et al. 2006) and bioenergetics projections (Johnson and Martinez 2000, Martinez 2005) and discussed the definition and production of trophy lake trout.

Results and Discussion

At the Anglers Roundtable meeting, I presented lake trout consumption estimates for salmonids in Blue Mesa based on the point estimate for the lake trout (5,100) and the upper 95% confidence limit (8,900). This upper limit was used to illustrate the extent of predation demand by lake trout given that recent indices suggest that the size of the lake trout population in Blue Mesa continues to grow (Martinez 2005, D. Brauch, CDOW, personal communication). Further, a Lincoln-Petersen estimate of the lake trout population was about 8,000. Table 54 summarizes the information shared with the public and CDOW managers in attendance at the Angers Roundtable.

The rates of consumption by lake trout shown in Table 54 are alarming to most anglers and managers given that the biomass of salmonids consumed on an annual basis by lake trout can be easily compared to other indices of biomass associated with fish stocking or fishery yield. About half the fish eaten, by biomass. would be kokanee and the other half would be rainbow trout (Martinez 2004, 2005). The projected consumption of kokanee by lake trout at the lower population estimate easily exceeds the average pounds of kokanee (~18,000 lbs) needed for the annual egg-take (Table 54). At the higher population estimate, lake trout consumption of rainbow trout exceed the average pounds of this species stocked into the reservoir annually (~50,000 lbs, Table 54).

Despite these projections of the severe consequences for all sport fishery components when lake trout on a water body overshoot their prey, diminishing not only the rainbow trout and kokanee desired by the bulk of anglers, but also the growth and trophy potential of the lake trout desired by the angling minority, some anglers persist in demanding protective regulations for lake trout. To reiterate these consequences and to help dispel the perceived necessity for protective lake trout regulations, I reviewed the history of the lake trout regulations scenario at Granby Reservoir. Figure 5 shows that the growth of lake trout above 20 inches essentially ceased by 1996 as excessive lake trout numbers and predation functionally eliminated both the reservoir's kokanee fishery and egg-take (Martinez 2005). Figure 5 also shows that lake trout relative weight already averaged less than 100% in the early 1990s under a protected slot limit. This situation was made even worse in 1993 as lake trout body condition began to plummet and the protected slot limit was made more restrictive to protect even larger lake trout.

Table 54. Summary of annual consumption estimates derived from bioenergetics modeling for three size classes of lake trout in Blue Mesa Reservoir feeding on salmonids of hatchery origin.

Length class	Mean length (in.)	Mean weight (lbs)	Pounds eaten per capita per year	Number of lake trout	Pounds of prey eaten per year
5,100 (~0.5/acre) lake trout >17 inch eat **67,000** lbs/year of kokanee & rainbow trout annually					
17-25	22	3.8	8	3,500	28,000
25-32	28	9.5	20	1,200	24,000
32-41	36	24.4	38	400	15,000
Total				5,100	67,000
8,900 (~1.0/acre) lake trout >17 inch eat ~**117,000** lbs/year of kokanee & rainbow trout					
17-25	22	3.8	8	6,100	48,800
25-32	28	9.5	20	2,100	42,000
32-41	36	24.4	38	700	26,600
Total				8,900	117,400

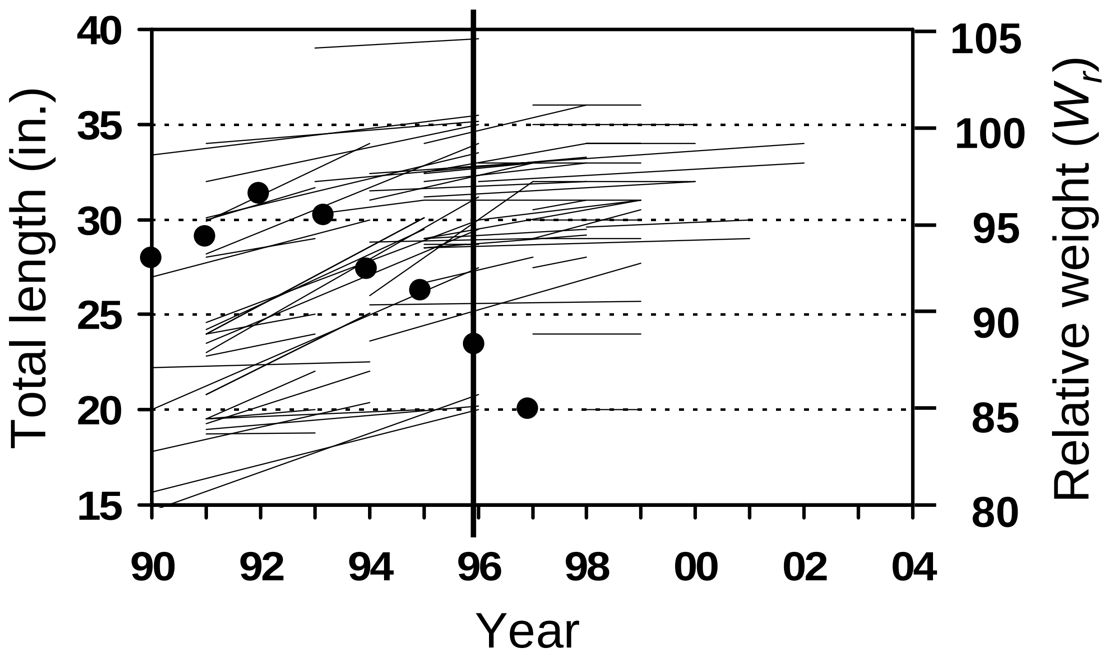

Figure 5. Growth of lake trout in Granby Reservoir, determined by mark and recapture of tagged fish, 1990-2002. Vertical line denotes year, 1996, when lake trout growth functionally ceased. Black dots show trend in lake trout relative weight. Shaded blocks denote length range and duration of protected slot-limits for lake trout.

Given the demand by some anglers for only the largest lake trout, I included a discussion on the definition of trophy lake trout. While there is no single widely accepted definition of trophy fish in general (Wilde and Pope 2004b), the Colorado Master Angler Program defines a trophy lake trout as being $\geq$ 32 inches in length. This trophy size designation was compared to the Length Categorization Systems definitions for its Stock (16 in.), Quality (20 in.), Preferred (24 in.), Memorable (31 in.) and Trophy (39 in.) categories for lake trout (Hubert et al. 1994). The $\geq$ 32 inch definition of a trophy lake trout in Colorado actually falls within the Memorable category under this system. This is consistent with the perception of trophy fish on web-sites advertising or reporting the catching of "trophy" specimens of a variety of fish species. In other words, many outfitters and anglers associate trophy size fish in general, and for lake trout in particular, with the Memorable category of the Length Categorization System. Thus, I deem Colorado to be successfully producing "trophy" lake trout if they equal of exceed 32 inches in length.

Next, I discussed the difference between angler's demand for "trophy" fishing opportunity for lake trout versus the apparent expectations of some anglers that the CDOW must manage for state record class lake trout. Fish of a size that would set or contend for a state-record is one operational definition of trophy fish (Wilde and Pope 2004b), but the largest fish approaching or reaching record -size are at extreme range variation inherent in their species (Wilde and Pope 2004a). Table 55 shows the most recent state records for lake trout produced in prominent destination lake trout fisheries in the western United States. These data reveal that it has been a number of years in some of these waters since a state record lake trout had been confirmed or recorded. Further, the average number of years since these individual waters have produced state records is 15, indicating that production of the largest fish is a rare event. Looking at the production of state record lake trout in a subset of these waters since 1990 shows that the average number of years since a record has been produced is seven. Again, production of state record lake trout is a rare and sporadic event, even when a spectrum of the west's best lake trout waters spanning a large geographic area is taken into account.

It has been suggested that fish reach large size due to a fortuitous combination of genetics and chance, thus the prospects for an individual fish to approach or reach state record size may be better in larger reservoirs (Wilde and Pope 2004b). Genetically, only a small number of fish exhibit the greatest growth and are capable of reaching record weight (Wilde and Pope 2004b). Further, this genetic potential maybe enhanced by a strong year class composed of a larger number of rapidly growing fish that continue to grow well throughout their life (Crawford et al. 2002). Wilde and Pope (2004b) offered several explanations why fish may have a better chance of approaching or achieving record-size in larger reservoirs. Larger reservoirs contain more fish which may favor individuals growing to large size and lessen their chances of capture. Also, larger reservoirs may support an overall greater fish biomass that would better meet the energetic needs of the largest fish.

Table 55. Summary of state record lake trout in nine prominent lake trout fisheries in the western United States known for their production of trophy lake trout.

State	Water	Year	Inches	Lbs-oz	Ave, no. years since state record until 2006	Ave. no. years since 1990 for state record
CA	Tahoe	1974		**37-3**	32	
CO	Blue Mesa	2002	42.6	**46-15**	4	4
CO	Granby	1995	39.5	**38-5**	11	11
ID	Pend Oreille	1995		**43.6**	11	11
ID	Priest	1971	49.0	**57-8**	35	
MT	Flathead	2004	42.5	**42-7**	2	2
UT	Flaming Gorge	1988	45.1	**51-8**	18	
WA	Chelan	2001		**35-7**	5	5
WY	Flaming Gorge	1995	48.0	**50-0**	11	11
WY	Jackson	1983	46.0	**50-0**	23	
Mean			44.7	**42-4**	15	7

Despite the probabilities associated with individual fish possessing favorable genetics or escaping capture for many years, physical and biological factors of individual waters remains a key factor in producing trophy or record size fish (Crawford et al. 2002). As shown in Appendix A, Colorado possesses the smallest waters, Blue Mesa and Granby, known for producing trophy and record-size lake trout in the western United States. Despite their comparative small size, these waters are Colorado's largest reservoirs and they have produced trophy and record lake trout that rival the sizes of this species produced in much larger waters in other states. A number of other waters in Colorado and the west offer fishing opportunity for lake trout, but simply lack the physical or biological characteristics to produce trophy size fish. Thus, it remains advisable to inform anglers of these limitations so they can have realistic expectations and enjoy rewarding fishing experiences in situations where there is no chance of catching a record fish (Casselman et al. 1999). The situation in Granby Reservoir, where lake trout growth ultimately ceased, diminishing or eliminating the kokanee prey base, fishery and egg-take and the trophy potential of lake trout (Johnson and Martinez 2000), was an example of a misplaced, highly protective regulation that resulted in negative biological social and economic consequences (Crawford et al. 2002).

In addition to stressing the need to moderate lake trout numbers, another point made to the public and managers was the importance of maintaining salmonid populations at high levels to support popular fisheries for rainbow trout and kokanee, the vital kokanee egg supply and the numbers of these preferred prey species of lake trout that maintain good growth, body condition and trophy potential for these predators. A review of indices of lake trout body condition was discussed to help the public understand how biologists and researchers utilize length and weight data, in conjunction with other population data, to help guide management decisions. The Standard Weight Equation in pounds for lake trout >11 inches Total Length is: log10 (Ws) = 3.246 x log10 (TLin.) -3.778 (Piccolo et al. 1993). At 32 inches, the length of trophy lake trout in Colorado, the standard weight would be 12.8 pounds. To ensure that lake trout in more productive waters (Johnson and Martinez 2000) retain good growth, it was advised that managers strive for an average relative weight of 115% for larger lake trout. Using the length-weight equation for lake trout 12-35 inches developed at Blue Mesa Reservoir,

$\mathbf{\log_{10} (W_{BMR}) = 3.765 \times \log_{10} (TLmm) - 7.103}$ (Johnson et al. 2005),

a 32 inch lake trout from Blue Mesa would weigh 15.7 lbs, which would be a relative weight of 123%. It is of concern in 2006 that lake trout over 25 inches Total Length in Blue Mesa appear to exhibit a decline in body condition compared to the recent past (Dan Brauch, CDOW, unpublished data). This raises concern that the lake trout population may be poised to exceed the capacity of the prey base to withstand existing or increased lake trout predation. It is recommended that managers encourage and facilitate angler harvest of smaller lake trout to forestall excessive predation that would jeopardize the other valuable fishery components.

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APPENDIX A

ABSTRACT, TABLES AND FIGURES FROM THE DRAFT MANUSCRIPT FOR "WESTERN LAKE TROUT WOES"

Western Lake Trout Woes

by

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Presented at:

2nd Biennial Rocky Mountain Regional Lake and Reservoir Management Conference, Golden, Colorado, February 15-17, 2006
&
Colorado-Wyoming Chapter off the American Fisheries Society, Cheyenne, WY, March 6-9, 2006
&
Bonneville Chapter of the American Fisheries Society Park City, UT, March 20-22, 2006
&
Colorado Division of Wildlife Angler's Roundtable Grand Junction, Colorado, March 29, 2006

ABSTRACT. Colorado's fishery biologists and researchers have received incessant and escalating criticism from anglers who view the production of trophy lake trout *Salvelinus namaycush* as the foremost goal in the management of the state's largest water bodies, Blue Mesa and Granby Reservoirs. The special regulations formerly protecting large lake trout in these waters have been rescinded as the state has witnessed or projected the loss of the kokanee populations and other fishery resources in these reservoirs. Anglers dissatisfied with these management decisions express disbelief that this approach can benefit these fisheries or that such management actions would occur elsewhere. Lake trout are adapted to the deep, cold waters of oligotrophic lakes where their life history is characterized by slow growth, late maturity, low reproductive potential and slow replacement of adults. These characteristics can cause lake trout to be vulnerable to overexploitation and their harvest is often strictly limited to perpetuate or recover native populations. In the western United States, outside of their native range, the ability of lake trout to attain large sizes, over 40 pounds under favorable conditions, fueled their popularity and formerly contributed to the adoption of restrictive harvest regulations to increase their numbers and to produce trophy specimens. However, lake trout have been increasingly identified or implicated as problematic in waters where their piscivory pits them against other popular sport fish upon which they prey, or with native fishes which may face competition, predation or hybridization from nonnative lake trout. As a result of these problems, the recent trend has been to rescind or liberalize low bag and protective length limits for lake trout to reduce their abundance and negative effects. In some waters, more intensive, commercial scale methods of removal are being considered or implemented to reduce lake trout abundance. Colorado's experience with lake trout management is compared with that of other western states facing similar challenges in managing waters containing lake trout and other valued fishery components.

Table A-1. Comparison of past lake trout bag and length limits during the 1980s and 1990s, listing the most protective regulations during that time, with current bag and length limits for lake trout regulations in 15 waters in the western United States.

State	Water	Bag limit		Length limit (inches)	
		Past	Present	Past	Present
CA	Tahoe	2	2	none	none
CO	Blue Mesa	1	8	22-24, slot	none
	Granby	1	4	22-34, slot	none
ID	Pend Oreille	4	none	16, minimum	none
	Priest	3	none	26-32, slot	none
MT	Flathead	5	20	25, minimum	30-36 slot
	Glacier	5	15 to none	none	none
UT	Bear	2	2	none	none
	Flaming Gorge	2	8	26-36, slot	28 minimum
WA	Chelan	5	none	15, minimum	none
WY	Jackson	6	6	24, minimum	24, minimum
	Yellowstone	none	must kill	none	none

Note: Glacier National Park includes four separate waters: Bowman, Kintla, Logging and McDonald.

Table A-2. Record weights of lake trout in key lake trout waters in the western United States.

State	Water	Year	Record lake trout size	
			Inches	Pounds - ounces
California	Tahoe	1974	--	37 - 3
Colorado	Blue Mesa	2002	42.6	46 - 15
	Granby	1995	39.5	38 - 5
Idaho	Pend Oreille	1995	--	43 - 6
	Priest	1971	49.0	57 - 8
Montana	Flathead	2004	42.5	42 - 7
	Glacier	--	--	--
Utah	Bear	--	--	--
	Flaming Gorge	1988	45.1	51 - 8
Washington	Chelan	2001	--	35 - 7
Wyoming	Flaming Gorge	1995	48.0	50 - 0
	Jackson	1995	46.0	50 - 0

Note: Glacier National Park in Montana includes four waters: Bowman, Kintla, Logging and McDonald.

Table A-3. Summary of wildlife species in 15 waters in the western United States impacted by introduced, invasive (underlined) or illicitly introduced (double-underline) lake trout. (Abbreviations in the column heads are the waters listed in Table A-1.)

Species	CA	CO		ID		MT		UT		WA	WY	
	TH	BM	GR	PO	PR	FH	GL	BR	FG	CH	JK	YS
Native cutthroat trout (*Oncorhynchus clarki spp.*)												
Bonneville (*O. c. utah*)								X				
Lahontan (*O. c. henshawi*)	X											
Snake River (*O c. behnkei*)											X	
Westslope (*O. c. lewisi)*				X	X	X	X			X		
Yellowstone (*O. c. bouvieri*)												X
Other native vertebrates												
Bull trout (*Salvelinus confluentus)*				X	X	X	X			X		
Whitefishes (*Prosopium spp.*)						X	X	X		X		
Grizzly bear (*Ursus arctos horriblis*)												X
Bald eagle (*Haliaeetus leucocephalus*)						X	X					
Nonnative sport fish (*Oncorhynchus spp.*)												
Kokanee (*O. nerka*)	X	X	X	X	X	X			X	X		
Rainbow trout (*O. mykiss*)		X	X	X					X	X		

Table A-4. **Summary of control methods or options currently being implemented or considered to reduce or control predation by lake trout in 15 waters in the western United States impacted by introduced, invasive (underlined) or illicitly introduced (double-underlined) lake trout. Numbers in table denote year that lake trout control strategy was implemented. Question marks indicate that a specific control strategy is being considered. (Abbreviations in the column heads are the waters listed in Table A-1.)**

Control strategies	CA	CO		ID		MT		UT		WA	WY	
	TH	BM	GR	PO	PR	FH	GL	BR	FG	CH	JK	YS
Cease lake trout stocking		92	98									
Liberalize lake trout regulations		96	06	03	06	95	00	06		04	06	92
Promote lake trout harvest		00	06	04	04	00	00	06		01		92
Intensive lake trout removal		?		?		?	?					94
Commercial fishing for lake trout				04		?						
Control lake trout movement					05		?					
Stock sterile lake trout								05				
Control of lake trout being considered	?											

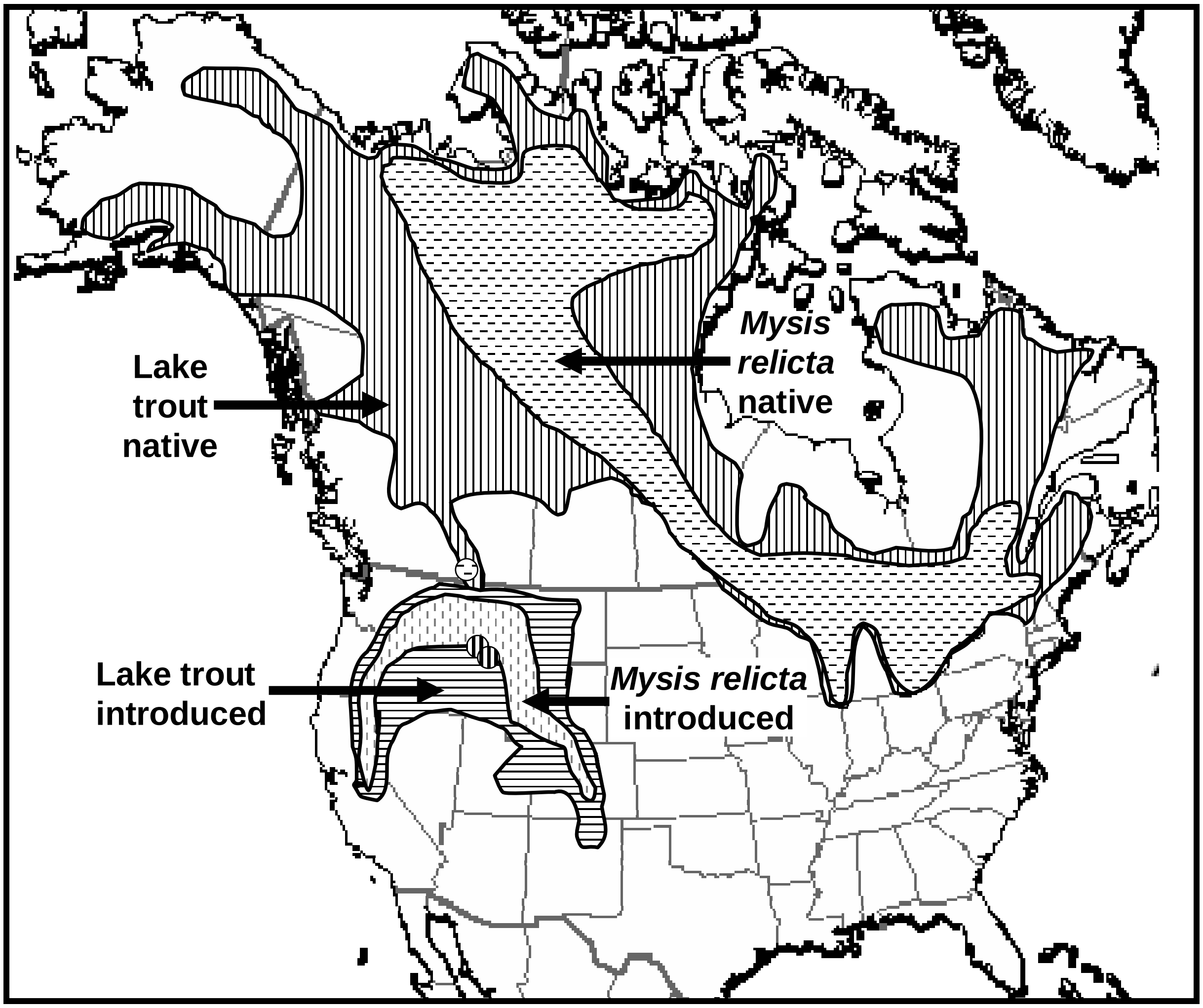

Figure A-1. Map of North America showing native and introduced ranges of lake trout and *Mysis relicta*.

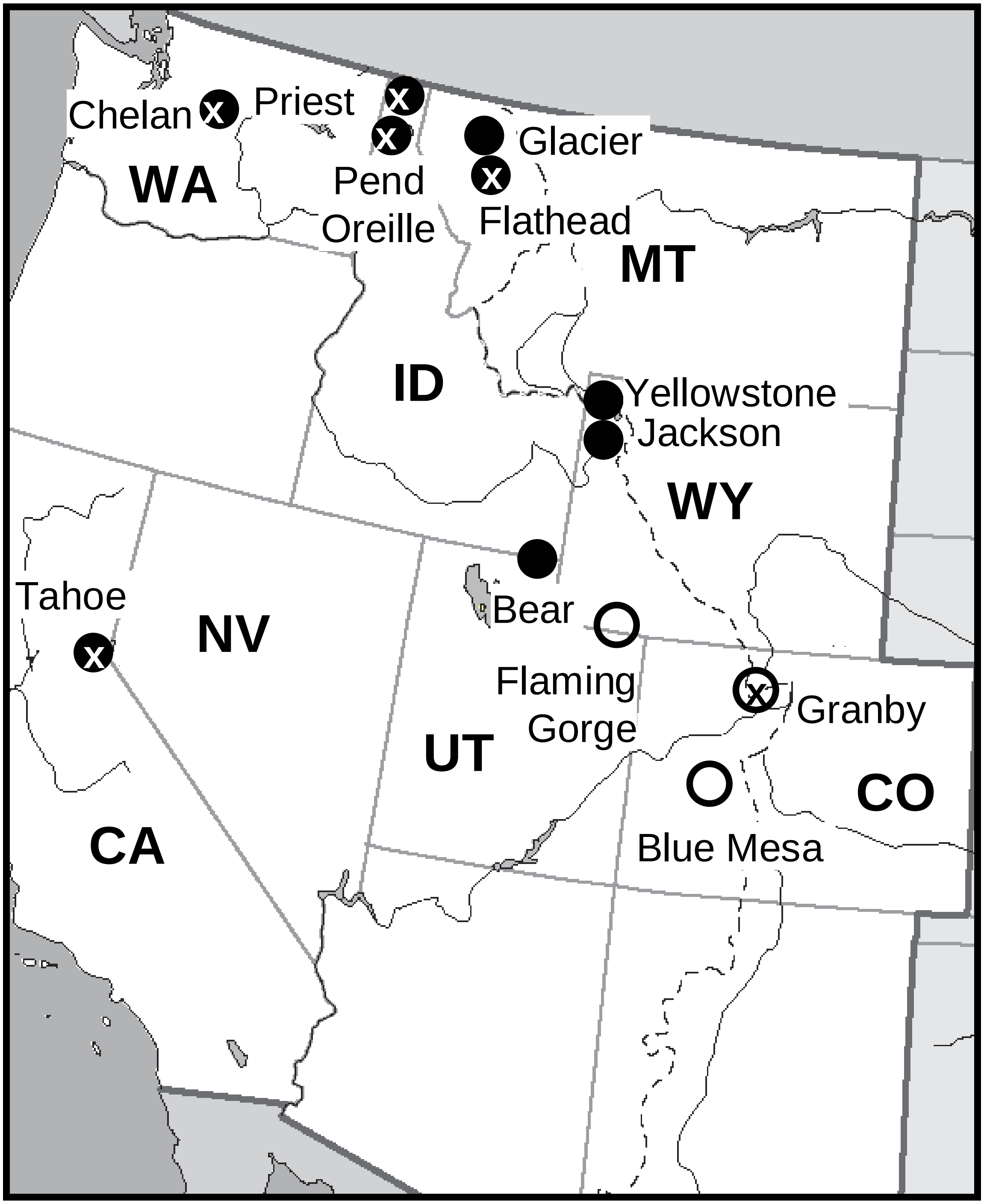

Figure A-2. Lakes (solid dots) and reservoirs (open circles) in the western United States with lake trout management issues or concerns. Waters marked with an "x" denote presence of *Mysis relicta*.

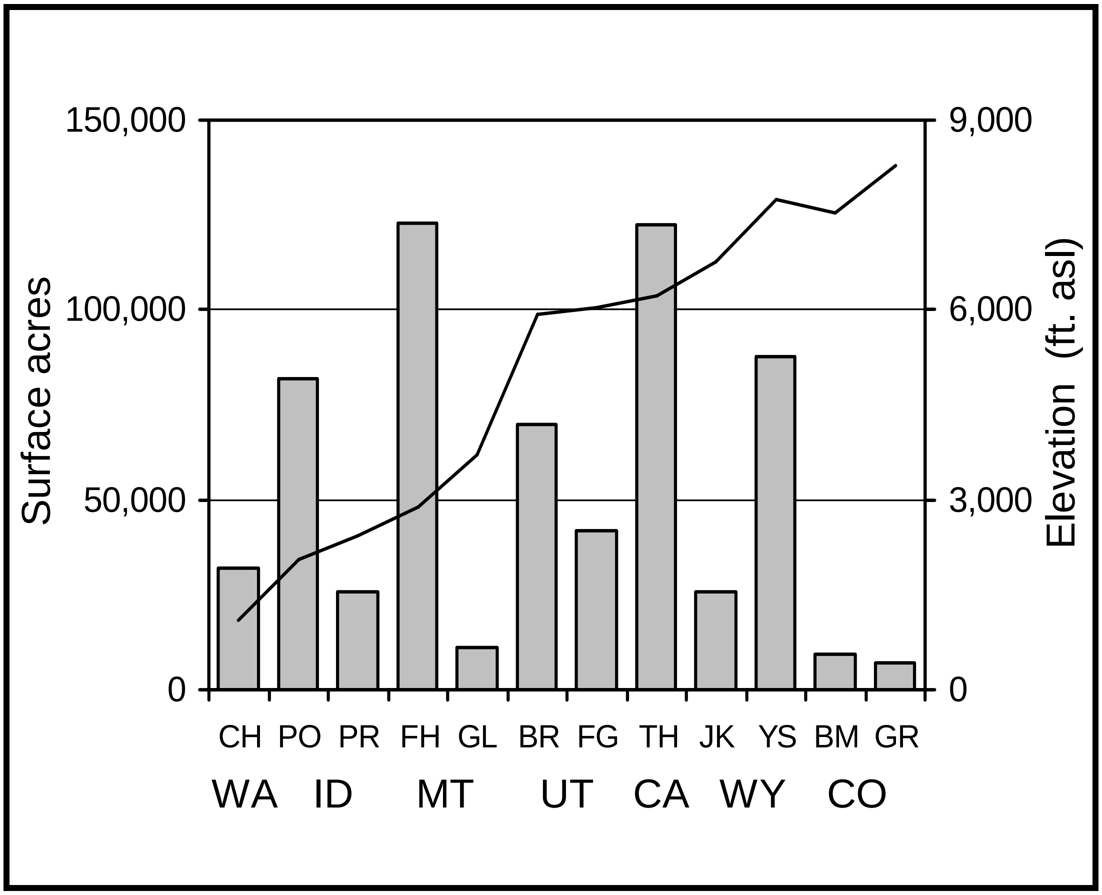

Figure A-3. **Surface area (bars) and elevation (line) of lakes and reservoirs with lake trout management issues or concerns. Waters: CH = Chelan, PO = Pend Oreille, PR = Priest, FH = Flathead, GL = Glacier National Park, BR = Bear, FG = Flaming Gorge, TH = Tahoe, JK = Jackson, YS = Yellowstone, BM = Blue Mesa and GR = Granby.**

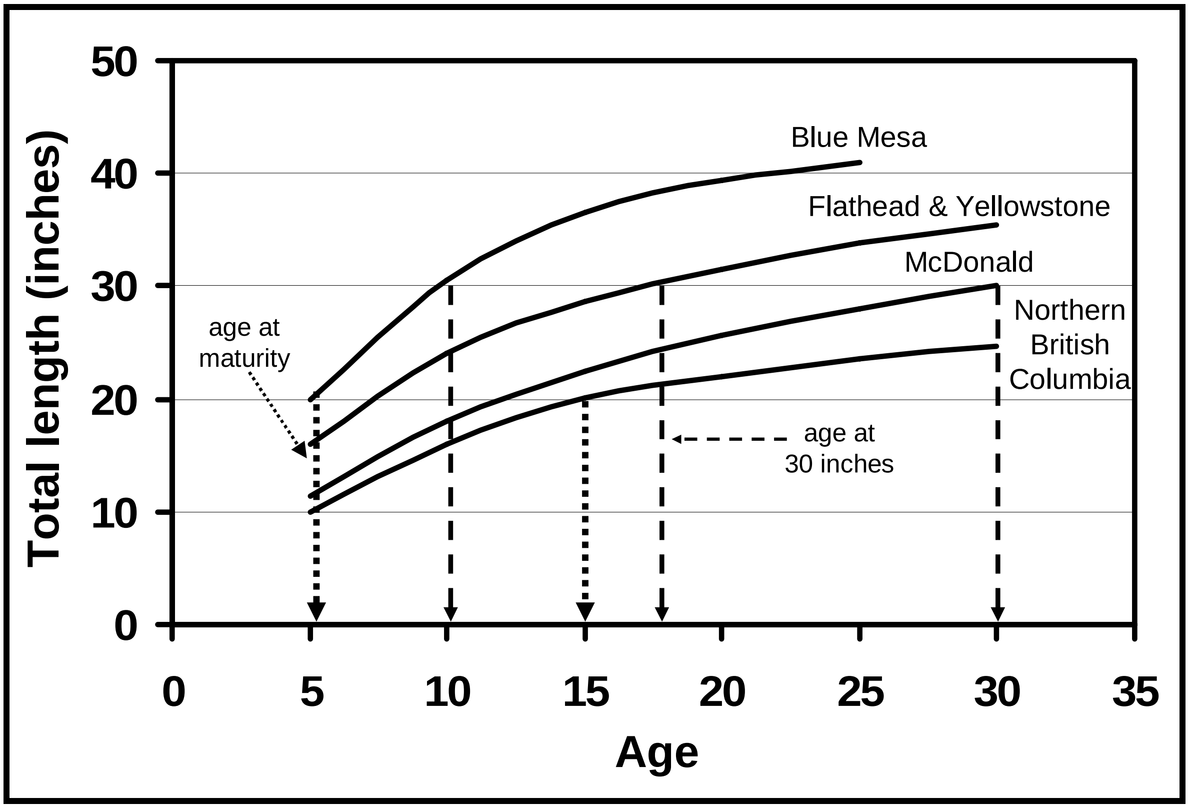

Figure A-4. **Comparison of lake trout growth rates in western North America in Blue Mesa Reservoir, Colorado (Martinez 2004), Flathead Lake, Montana (Beauchamp 1996), Yellowstone Lake, Wyoming (Ruzycki and Beauchamp 1997), Lake McDonald, Montana (Dux 1995) and in lakes in northern British Columbia (deLeeuw 1991) where fork length (FL) converted to total length (TL) by TL=1.023+(1.045 FL) for fish < 68 cm, and TL = 1.488 + (1.032 FL) for fish > 68 cm (Conrad and Gutmann 1996). Finely-dashed arrows compare age at maturity. Coarsely-dashed arrows compare age upon reaching 30 inches in total length.**

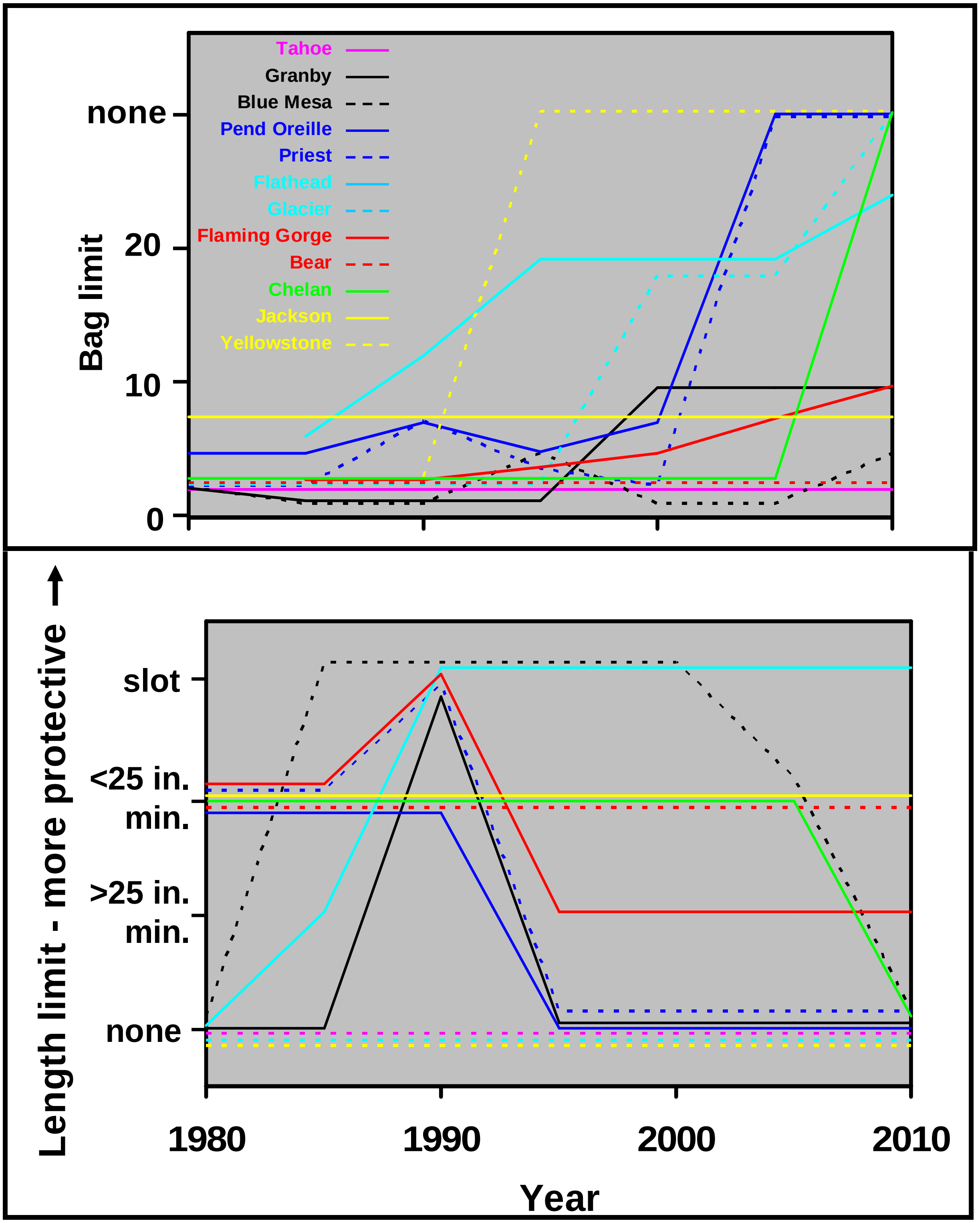

Figure A-5. Lake trout bag and length limits in 15 waters in the western United States showing low bag limits and adoption of protective length limits in the 1980s and the prevailing trend of liberalization of both bag and length limits since 1990. Glacier National Park includes four waters (Bowman, Kintla, Logging and McDonald).

APPENDIX B

TEMPERATURE, DISSOLVED OXYGEN PROFILES AND SECCHI DEPTHS MEASURED IN COLDWATER RESERVOIRS IN 2006

Table B-1. Temperature (°C) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at four one stations in Avery Reservoir, June 2005. Values in parenthesis denote maximum water depth at station.

Water Depth (m)	Avery Reservoir June 21 2005							
	P1 (22.5m)		P2 (15.5m)		P3 (6.3m)		P4 (12.6m)	
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
0	21.6	6.3	20.7	6.9	20.4	6.1	19.2	5.8
1	18.7	5.4	19.1	8.1	17.4	8.5	18.3	8.3
2	16.7	5.1	16.7	7.1	16.4	8.3	16.5	8.3
3	15.4	6.1	15.5	6.6	15.6	6.3	15.8	5.8
4	13.9	6.2	14.4	5.9	13.2	5.5	14.6	5.1
5	12.5	6.1	11.5	5.6	11.3	5.1	12.2	4.8
6	10.9	6.0	10.4	5.2	10.4	4.9	10.7	4.7
7	10.1	5.8	10.0	4.9			10.1	4.4
8	9.7	5.6	9.6	4.7			9.7	4.4
9	9.2	5.0	9.3	4.6			9.5	4.2
10	9.0	4.8	8.7	4.7				
11	8.4	4.3	8.5	4.5				
12	8.3	4.2	8.1	4.3				
13	7.9	4.1	7.6	4.0				
14	7.7	3.8	7.4	3.8				
15	7.6	3.5	7.3	3.6				
16	7.5	3.3						
17	7.4	3.2						
18	7.3	3.1						
19	7.3	3.0						
20	7.2	3.1						
Secchi (m)	2.50		1.90		2.60		2.60	

Table B-2. Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at three stations in Blue Mesa Reservoir in June and August, 2005.

Water Depth (m)	Blue Mesa 23 June 2005						Blue Mesa 4 August 2005					
	Sapinero		Cebolla		Iola		Sapinero		Cebolla		Iola	
	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	16.4	7.6	17.2	7.7	17.3	7.2	19.5	6.7	20.8	6.5	20.7	6.5
1	16.4	7.6	17.2	7.5	17.2	7.2	19.3	6.4	20.5	6.6	20.4	6.7
2	16.3	7.6	17.1	7.6	17.2	7.2	19.2	6.6	20.2	6.7	20.3	6.7
3	16.2	7.6	17.1	7.6	17.1	7.2	19.1	6.6	20.1	6.7	20.2	6.7
4	15.6	7.6	17.1	7.5	19.9	7.2	19.0	6.5	20.0	6.6	20.1	6.7
5	15.1	7.6	17.0	7.5	16.2	7.2	19.0	6.6	20.0	6.7	20.1	6.6
6	14.4	7.5	16.7	7.5	15.5	7.1	18.9	6.4	19.9	6.7	20.0	6.7
7	14.0	7.4	14.6	7.4	15.3	7.0	18.8	6.5	19.9	6.6	20.0	6.7
8	13.3	7.4	14.5	7.4	14.5	6.9	17.7	6.6	19.7	6.5	19.9	6.5
9	13.0	7.1	14.0	7.2	14.1	6.8	17.1	5.6	18.6	5.7	19.7	6.4
10	12.8	7.1	13.5	7.1	14.0	6.7	16.4	5.2	17.7	5.4	19.3	6.1
11	12.7	7.1	13.4	7.0	13.9	6.7	15.5	5.4	17.0	5.1	18.2	5.8
12	12.5	7.1	12.9	6.9	13.7	6.7	15.0	5.3	16.3	4.9	17.6	5.7
13	12.5	7.0	12.8	6.7	13.3	6.7	14.6	5.2	15.4	4.8	16.8	5.7
14	12.2	7.0	12.4	6.6	13.1	6.6	14.3	5.3	15.1	4.7	16.5	5.6
15	11.9	7.0	12.2	6.4	13.0	6.5	14.1	5.3	14.8	4.7	15.2	4.2
16	11.7	6.9	12.2	6.4	12.9	6.5	13.8	5.3	14.7	4.6	15.0	4.0
17	11.5	7.1	12.1	6.3			13.4	5.5	14.1	4.7	14.3	3.5
18	11.1	7.2	11.8	6.2			13.1	5.7	13.7	4.8	13.9	3.1
19	10.9	7.1	11.6	6.2			12.7	5.7	13.3	4.7		
20	10.6	7.1	11.5	6.1			11.8	5.9	12.9	4.8		
25	9.3	7.2	10.3	5.9			10.8	6.2	12.1	4.8		
30	7.7	7.3	8.5	6.0			9.7	5.9	10.8	4.1		
35	6.9	7.3	7.7	7.7			9.7	6.0	9.1	3.4		
40	6.3	7.2	6.6	6.6			7.9	6.0	7.8	3.3		
45	6.0	7.3	6.4	6.4			6.8	6.2	7.1	3.2		
50	5.7	7.3					6.4	6.2				
55							5.8	6.5				
Secchi (m)	3.29		3.50		3.30		5.60		6.10		5.20	

Table B-3. Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at five stations in Dillon Reservoir, August 2005. Values in parenthesis denote maximum water depth at station.

Water Depth (m)	Dillon 10 August 2005									
	P1 (67.4m)		P2 (35.5m)		P3 (19.9m)		P4 (17.7m)		P5 (12.2m)	
	ºC	mg/l	ºC	Mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	16.9	6.6	17.0	6.5	17.1	6.6	16.9	6.4	17.6	6.6
1	16.8	6.7	17.1	6.5	17.2	6.6	16.9	6.4	17.6	6.7
2	16.8	6.6	17.0	6.6	17.2	6.6	16.9	6.4	17.6	6.7
3	16.8	6.6	17.0	6.6	17.0	6.7	16.9	6.4	17.5	6.7
4	16.7	6.6	16.9	6.6	16.9	6.7	16.8	6.4	17.4	6.7
5	16.6	6.6	16.8	6.5	16.9	6.7	16.8	6.5	17.2	6.7
6	14.7	6.6	16.7	6.6	16.8	6.7	16.6	6.5	16.8	6.7
7	13.5	6.6	15.9	6.6	16.8	6.7	16.0	6.4	15.6	6.3
8	13.0	6.5	15.0	6.4	16.7	6.7	14.8	6.4	14.6	5.9
9	12.5	6.5	14.6	6.4	16.6	6.7	14.4	6.4	14.4	5.7
10	12.1	6.4	14.2	6.4	16.6	6.7	11.9	6.3	12.1	5.4
11	11.0	6.5	14.3	6.4	16.6	6.7	10.9	6.3	11.7	3.9
12	10.5	6.5	12.7	6.3	41.2	6.5	10.3	6.3		
13	10.2	6.4	12.1	6.3	13.1	6.2	10.0	6.3		
14	9.3	6.4	10.9	6.1	12.8	6.1	9.5	6.3		
15	8.6	6.4	10.2	6.1	11.9	5.9	9.2	6.2		
16	8.2	6.4	8.7	6.1	11.4	5.7	8.8	6.2		
17	7.9	6.3	8.2	6.2	10.3	5.4				
18	7.5	6.3	7.7	6.2	9.8	5.5				
19	7.3	6.2	7.4	6.2	8.8	5.6				
20	7.1	6.2	6.8	6.1						
25	5.9	6.3	5.7	5.9						
30	5.4	6.1	4.8	5.9						
35	4.8	6.1								
40	4.5	6.1								
45	4.3	6.1								
50	4.1	5.9								
55	4.1	5.8								
Secchi (m)	2.90		3.30		2.90		2.70		2.60	

Table B-4. **Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at five stations in Elevenmile Reservoir, June 2005. Values in parenthesis denote maximum water depth at station.**

Water Depth (m)	Elevenmile 29 June 2005									
	P1 (22m)		P2 (17.4m)		P3 (13.9m)		P4 (14m)		P5 (11.5m)	
	ºC	mg/l	ºC	Mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	18.3	6.6	18.7	6.3	19.3	6.4	19.4	6.4	20.1	6.1
1	18.3	6.7	18.6	6.2	19.3	6.4	19.0	6.5	19.5	6.2
2	18.3	6.6	18.4	6.3	18.9	6.5	18.5	6.3	19.2	6.2
3	18.3	6.6	18.2	6.3	18.8	6.5	18.4	6.3	18.9	6.1
4	18.2	6.6	18.1	6.1	18.7	6.4	18.3	6.2	18.5	6.2
5	18.1	6.4	18.1	6.0	18.5	6.4	18.3	6.1	18.4	6.1
6	18.0	6.3	18.0	6.0	18.3	6.3	18.2	6.1	18.2	6.0
7	17.9	6.1	18.0	6.0	18.0	6.1	18.2	6.2	18.2	5.7
8	17.5	5.9	17.8	6.0	17.7	5.6	18.1	6.0	17.8	5.3
9	17.1	5.6	17.5	5.4	17.1	4.9	17.7	5.3	17.2	4.7
10	16.8	5.4	16.6	4.4	16.4	4.5	17.3	4.9	16.9	4.6
11	16.4	4.9	15.8	3.9	15.8	3.9	16.9	4.2	16.0	3.9
12	15.9	4.5	15.3	3.4	15.4	3.4	14.9	2.7		
13	15.3	4.1	15.0	3.2	14.9	2.9	14.3	2.3		
14	14.8	3.8	14.4	3.0						
15	14.6	3.7	14.3	2.8						
16	14.3	3.5	14.0	2.5						
17	14.0	3.5								
18	13.9	3.4								
19	13.7	3.3								
20	13.4	3.4								
Secchi (m)	7.40		6.80		7.20		6.80		7.60	

Table B-5. Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at five stations in Granby Reservoir in June and July, 2005. Values in parenthesis denote maximum water depth at station.

Water Depth (m)	Granby 30 June 2005										Granby July 27 2005									
	P1 (18m)		P2 (10.2m)		P3 (21.1m)		P4 (48m)		P5 (30.5m)		P1 (20.5m)		P2 (11.7m)		P3 (18m)		P4 (38m)		P5 (31.6m)	
	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	15.5	7.33	16.2	7.05	16.3	7.92	17.1	7.72	16.9	8.32	19.2	6.7	18.9	7.0	19.5	6.6	19.7	6.8	22.1	6.9
1	15.5	7.39	16.0	7.17	15.8	7.69	16.4	7.54	16.4	8.38	19.2	6.6	18.7	6.9	19.0	6.7	19.3	7.0	19.7	7.1
2	15.4	7.34	16.0	7.02	15.5	7.60	15.7	7.51	16.1	8.32	19.2	6.5	18.6	6.9	18.9	6.1	18.8	7.0	19.2	6.8
3	15.4	7.07	16.0	6.95	15.3	7.47	15.6	7.75	16.0	8.15	19.2	6.5	18.5	6.7	18.9	6.8	18.6	7.0	19.1	7.0
4	15.3	6.67	15.9	6.92	15.3	7.53	15.5	7.57	16.0	7.96	19.1	6.5	18.3	6.5	18.7	6.9	18.6	6.9	19.0	7.0
5	14.9	6.99	15.9	6.88	14.9	7.45	15.4	7.45	16.0	7.89	19.1	6.5	17.8	6.3	18.6	6.9	18.5	6.9	19.0	7.1
6	14.5	7.17	15.8	6.83	14.7	7.30	15.2	7.38	15.3	7.81	19.1	6.5	17.6	6.1	18.4	6.8	18.4	6.6	18.8	6.9
7	14.0	7.08	14.4	6.41	14.2	7.15	15.1	7.34	12.6	7.55	16.6	5.1	17.5	5.9	17.4	5.9	18.3	6.7	17.7	6.5
8	13.4	6.60	13.3	6.67	13.4	6.88	13.0	6.82	11.7	7.46	15.6	4.9	17.0	5.5	16.5	5.1	15.9	5.4	15.9	5.7
9	12.5	6.12	12.4	6.21	12.8	6.87	12.4	6.78	11.5	7.37	15.2	4.9	16.2	5.1	15.2	5.0	14.6	5.2	14.0	5.4
10	12.2	6.61	12.2	5.95	11.7	6.82	11.9	6.89	11.0	7.21	14.7	4.8	15.6	4.9	14.1	5.1	14.2	5.1	13.1	5.4
11	12.0	6.31			11.3	6.83	11.5	6.88	10.7	7.41	14.4	4.7	14.9	4.8	12.9	5.2	13.4	5.1	12.3	5.6
12	11.3	6.31			11.1	6.89	11.1	6.62	10.5	7.07	13.8	4.6			12.5	5.2	12.3	5.2	11.6	5.6
13	10.7	5.98			10.7	6.82	10.8	6.68	9.9	7.07	13.2	4.7			11.5	5.3	11.0	5.3	10.9	5.7
14	10.5	5.45			10.2	6.55	10.2	6.70	9.6	6.95	12.5	4.7			11.0	5.4	10.5	5.2	10.5	5.7
15	10.5	5.73			10.1	6.43	9.80	6.64	9.1	6.85	12.0	4.8			10.1	5.5	10.1	5.1	10.3	5.8
16	10.4	5.70			9.8	6.43	9.2	6.31	8.3	6.77	10.8	4.4			9.8	5.5	9.8	5.5	9.8	5.7
17	9.9	5.70			9.6	6.37	8.7	6.10	8.3	6.76	10.3	4.6					9.6	4.9	9.4	5.7
18					8.1	6.00	8.5	6.14	8.1	6.71	9.7	4.4					9.2	5.0	9.1	5.8
19					7.8	6.11	8.4	6.02	7.9	6.67							8.9	4.9	8.7	5.6
20					7.7	6.12	8.2	5.87	7.7	6.66							8.5	4.9	8.4	5.6
25							7.5	6.03	6.8	6.12							8.1	5.0	7.7	5.2
30							7.2	6.01	6.7	5.95							7.7	5.1	7.5	4.7
35							7.0	5.96												
40							6.8	5.97												
45							6.5	6.03												
Secchi (m)	2.63		2.28		1.94		2.45		2.47		4.60		4.60		3.90		4.17		4.80	

Table B-6. **Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at four stations in Grand Lake, June 2005. Values in parenthesis denote maximum water depth at station.**

Water Depth (m)	Grand Lake June 30 2005							
	P1 (54m)		P2 (13.2m)		P3 (72.6m)		P4 (24.3m)	
	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	10.4	7.75	10.7	7.62	10.4	7.31	10.8	7.18
1	10.0	7.57	10.4	7.62	10.4	7.30	10.8	7.19
2	9.8	7.58	9.9	7.47	10.3	7.37	10.8	7.24
3	9.0	7.62	9.4	7.49	10.3	7.36	10.8	7.22
4	8.9	7.50	8.9	7.42	10.2	7.32	10.8	7.16
5	8.8	7.45	8.7	7.37	10.2	7.27	10.8	7.15
6	8.5	7.47	8.7	7.36	10.1	7.30	10.7	7.17
7	8.4	7.45	8.6	7.35	9.8	7.25	10.6	7.20
8	8.4	7.43	8.3	7.31	9.4	7.23	9.1	7.24
9	8.4	7.43	8.1	7.21	9.1	7.29	8.3	7.25
10	8.1	7.41	8.0	7.22	8.3	7.22	8.0	7.19
11	8.0	7.38	7.9	7.14	8.0	7.25	7.9	7.17
12	7.7	7.45	7.7	7.09	7.7	7.20	7.7	7.18
13	7.6	7.38			7.6	7.16	7.4	7.13
14	7.5	7.33			7.3	7.12	7.1	7.11
15	7.4	7.35			7.1	7.07	7.0	7.04
16	7.3	7.16			7.0	7.03	6.8	7.03
17	7.3	7.16			6.9	6.96	6.7	7.01
18	7.1	7.10			6.8	7.01	6.6	6.94
19	6.9	7.07			6.7	7.03	6.6	6.96
20	6.8	6.98			6.6	6.99	6.6	6.96
25	6.0	6.75			5.4	6.64		
30	5.0	6.17			4.9	6.25		
35	4.6	5.83			4.6	5.93		
40	4.3	5.55			4.3	5.50		
45	4.2	5.21			4.2	5.37		
50	4.1	5.12			4.1	5.24		
Secchi (m)	3.30		3.40		2.94		3.10	

Table B-7. **Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at five stations in Green Mountain Reservoir, September 2005. Values in parenthesis denote maximum water depth at station.**

Water Depth (m)	Green Mountain 7 September 2005									
	P1 (19.4m)		P2 (37m)		P3 (34m)		P4 (21m)		P5 (51m)	
	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	17.3	6.6	17.1	6.5	16.7	6.8	17.3	6.8	16.5	6.8
1	17.0	6.7	16.5	6.8	16.8	6.7	16.3	6.9	16.4	6.8
2	16.7	6.8	16.2	6.8	16.2	6.9	15.9	7.0	16.2	6.8
3	16.3	6.9	16.1	6.8	16.0	6.8	15.8	7.0	16.1	6.8
4	16.2	6.9	16.0	6.8	15.9	6.9	15.7	6.9	15.7	6.9
5	16.2	6.8	16.0	6.8	15.7	6.7	15.6	6.8	15.5	6.8
6	16.0	6.8	15.9	6.8	15.5	6.4	15.4	6.5	15.5	6.7
7	15.8	6.5	15.9	6.7	15.3	6.2	15.2	6.3	15.3	6.8
8	15.5	6.5	15.5	6.5	14.9	6.1	15.0	6.3	15.2	6.6
9	14.7	6.2	14.9	6.2	14.6	5.8	14.8	6.3	15.2	6.6
10	14.6	6.2	14.2	5.7	13.8	5.4	14.4	5.9	14.0	5.5
11	13.4	6.3	13.6	5.5	13.4	5.0	13.2	4.8	12.6	4.4
12	12.8	6.4	12.7	5.3	12.4	4.9	12.3	4.3	11.7	4.2
13	12.1	6.0	12.4	5.3	11.9	4.6	11.8	4.3	11.4	4.2
14	11.6	5.6	11.6	5.0	11.6	4.8	11.4	4.3	11.1	4.3
15	11.5	5.2	11.4	4.7	11.1	4.7	10.9	4.4	10.8	4.3
16	11.3	5.2	11.2	4.8	10.8	4.7	10.4	4.4	10.6	4.4
17	11.0	5.0	10.8	4.8	10.6	4.8	10.1	4.6	10.3	4.5
18	10.9	5.1	10.4	4.8	10.3	4.8	10.1	4.6	10.1	4.8
19	10.6	5.1	10.2	4.9	10.0	4.7	9.7	4.7	9.8	4.8
20			10.0	4.8	9.8	4.8	9.5	4.7	9.6	5.0
25			9.3	4.9	9.1	5.0			8.4	5.4
30			8.7	5.0	8.7	5.1			8.6	5.4
35			8.3	5.0					8.3	5.2
40									8.0	5.2
45									7.6	5.3
50									7.7	4.6
Secchi (m)	3.60		3.02		3.0		3.0		3.0	

Table B-8. Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at three stations in Horsetooth Reservoir, September 2005. Values in parenthesis denote maximum water depth at station.

Water Depth (m)	Horsetooth Sept. 21 2005					
	P1 (21.2m)		P2 (23.5m)		P3 (17.8m)	
	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	18.1	7.8	18.2	7.7	18.4	7.6
1	17.9	7.8	18.1	7.7	18.4	7.7
2	17.8	7.7	18.0	7.6	18.0	7.6
3	17.8	7.8	17.9	7.7	17.9	7.4
4	17.8	7.7	17.8	7.7	17.8	7.4
5	17.7	7.6	17.6	7.5	17.8	7.6
6	17.7	7.6	17.6	7.4	17.8	7.5
7	17.6	7.6	17.5	7.4	17.8	7.5
8	17.5	7.4	17.5	7.5	17.7	7.3
9	17.2	7.1	17.5	7.4	17.7	7.1
10	16.9	6.3	17.5	7.3	17.6	6.6
11	16.8	6.4	17.4	7.1	17.6	6.5
12	16.5	6.3	17.3	6.1	16.8	3.6
13	15.7	5.4	16.1	4.1	15.7	2.8
14	15.3	4.6	14.8	3.2	15.2	26
15	14.6	3.9	13.8	3.1	13.7	2.9
16	13.9	3.3	13.2	3.2	12.7	3.0
17	12.2	3.3	12.4	3.5	12.4	2.9
18	10.9	3.8	11.7	3.6		
19	10.5	4.1	10.8	4.0		
20	9.9	4.3	10.2	4.3		
Secchi (m)	2.95		5.09		2.60	

Table B-9. **Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at three stations in Jefferson Lake, August 2005. Values in parenthesis denote maximum water depth at station.**

Water Depth (m)	Jefferson August 8 2005					
	P1 (10m)		P2 (16.2m)		P3 (30.4m)	
	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	14.3	6.8	13.9	6.9	13.0	6.7
1	14.4	6.9	13.9	7.0	14.1	6.8
2	14.3	6.9	13.9	6.9	14.1	6.8
3	14.2	6.9	13.8	6.9	14.1	6.8
4	14.2	6.8	13.8	6.9	14.1	6.8
5	14.1	6.8	13.8	6.9	14.0	6.7
6	14.1	6.8	13.6	6.9	12.6	7.0
7	13.7	7.1	13.0	7.0	11.7	7.7
8	11.7	7.5	11.7	7.4	9.8	8.5
9			10.4	8.0	8.4	8.6
10			9.3	8.3	7.9	8.4
11			8.0	8.2	7.1	8.3
12			7.2	7.9	6.6	7.8
13			6.5	7.7	6.3	7.4
14			6.2	7.5	6.2	7.3
15			6.2	7.0	6.0	6.6
16			6.1	6.8	6.5	6.5
17					6.2	6.2
18					6.1	6.1
19					5.9	5.9
20					5.9	5.9
25					5.9	5.9
30					5.4	5.4
Secchi (m)	6.20		6.60		6.70	

Table B-10. Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at five stations in McPhee Reservoir, June 2005. Values in parenthesis denote maximum water depth at station.

Water Depth (m)	McPhee June 7 2005									
	P1 (18.2m)		P2 (56.7m)		P3 (62.4m)		P4 (22m)		P5 (15.5m)	
	ºC	mg/l	ºC	Mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	20.7	6.5	20.7	6.6	22.6	6.1	20.5	6.2	22.2	6.1
1	20.4	6.5	20.2	6.7	21.7	6.2	19.9	6.3	21.4	6.2
2	20.2	6.4	20.0	6.7	21.2	6.3	19.5	6.3	21.2	6.2
3	20.1	6.4	2.0	6.5	20.3	6.3	19.2	6.3	21.0	6.2
4	20.1	6.4	19.9	6.6	20.0	6.2	19.1	6.3	20.9	6.2
5	20.0	6.4	19.8	6.5	19.4	6.3	18.9	6.1	20.8	6.2
6	19.7	6.3	19.2	6.4	18.8	6.2	18.4	5.9	20.2	6.1
7	19.2	6.2	18.7	5.7	18.5	6.1	18.3	5.8	18.5	5.5
8	17.3	5.6	18.2	5.7	18.3	6.0	18.2	5.7	17.5	5.4
9	16.7	5.5	17.3	5.5	17.3	5.2	17.7	5.3	16.1	5.2
10	15.4	5.4	16.3	5.3	16.8	5.1	17.3	5.0	14.7	5.1
11	15.0	5.5	15.2	5.3	16.1	5.0	15.4	3.9	13.4	5.2
12	14.2	5.6	14.0	5.4	14.5	5.0	14.4	3.6	12.2	5.3
13	12.4	5.4	13.2	5.6	13.1	5.2	13.6	3.9	11.4	5.5
14	12.3	5.4	12.5	5.8	12.6	5.4	13.2	4.0	11.2	5.6
15	11.8	5.4	11.4	6.1	12.1	5.5	1.2	4.2	10.6	5.7
16	11.2	5.4	10.7	6.3	11.6	5.8	12.3	4.4	10.3	5.8
17	10.6	5.6	10.4	6.5	11.1	5.9	11.4	4.3		
18			9.8	6.8	10.5	6.1	11.1	4.5		
19			9.5	6.9	10.1	6.2	10.7	4.6		
20			9.0	7.1	9.7	6.4	10.5	4.7		
25			8.3	7.3	8.9	6.7				
30			7.8	8.1	8.4	7.0				
35			7.5	7.3	7.9	7.0				
40			7.1	7.0	7.8	7.1				
45					7.4	7.2				
50					7.3	7.3				
55					7.2	7.1				
Secchi (m)	2.70		2.10		3.20		3.00		2.20	

Table B-11. Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at five stations in Ridgway Reservoir in June and July, 2005. Values in parenthesis denote maximum water depth at station.

Water Depth (m)	Ridgway June 22 2005										Ridgway July 20 2005									
	P1 (35m)		P2 (17m)		P3 (20m)		P4 (31m)		P5 (19.4m)		P1 (51m)		P2 (12.3m)		P3 (19.5m)		P4 (26.6m)		P5 (19m)	
	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	19.8	7.0	17.9	6.7	18.6	6.5	19.0	6.9	18.8	6.6	21.4	6.8	21.6	6.7	21.6	5.5	22.2	6.1	21.2	6.3
1	18.6	7.1	18.7	6.9	18.5	6.7	18.8	7.0	18.7	6.8	20.7	6.9	20.5	6.9	21.7	6.4	21.0	6.5	21.1	6.4
2	18.3	7.0	18.8	7.0	18.0	6.8	17.8	7.0	18.7	6.8	20.4	7.1	20.2	6.9	20.9	6.4	20.4	6.6	20.3	6.8
3	18.0	7.1	17.7	7.0	17.2	6.9	17.6	6.9	18.3	6.6	19.9	7.1	20.1	7.0	20.6	6.5	20.1	6.6	19.6	6.6
4	17.8	6.9	17.3	7.0	17.0	7.0	15.0	6.9	15.7	6.9	19.6	7.1	19.6	7.0	20.1	6.3	19.9	6.6	19.5	6.7
5	14.4	7.2	15.0	7.1	16.7	6.9	14.7	6.8	13.7	6.8	19.5	7.0	18.7	7.0	19.4	6.3	18.5	6.5	17.3	6.4
6	13.5	7.0	13.6	6.9	15.8	6.9	13.8	6.9	13.5	6.7	16.5	6.8	17.4	6.7	18.6	6.4	16.8	5.9	16.9	6.3
7	12.9	6.8	12.7	7.0	14.3	7.1	13.4	6.9	12.7	6.6	15.3	6.3	16.4	6.5	17.1	6.3	15.8	5.9	15.5	5.9
8	12.4	6.8	12.3	7.0	14.0	7.1	12.9	6.9	12.3	6.5	14.5	6.3	15.5	6.3	15.8	6.6	15.5	5.9	14.7	5.7
9	12.1	6.8	12.1	7.1	13.6	7.2	12.7	7.0	11.8	6.5	14.1	6.2	14.9	6.1	15.2	6.6	15.4	5.9	14.2	5.6
10	11.7	6.8	12.0	7.1	13.2	7.2	11.4	7.1	11.4	6.6	13.7	6.2	14.6	6.3	14.9	6.6	14.8	5.8	13.9	5.5
11	11.5	6.8	11.8	7.0	12.4	7.3	11.3	7.2	11.0	6.7	13.5	6.2	14.3	6.3	14.4	6.6	14.2	5.8	13.6	5.5
12	11.2	6.8	11.4	7.3	11.8	7.5	11.1	7.1	10.9	6.7	13.4	6.3	13.9	6.3	14.2	6.6	13.7	5.8	13.4	5.5
13	10.9	6.9	11.3	7.3	11.1	7.6	10.9	7.1	10.8	6.8	13.1	6.3			14.0	6.6	13.4	5.8	13.2	5.6
14	10.7	7.0	11.0	7.3	10.9	7.6	10.5	7.1	10.7	6.8	13.0	6.4			13.4	6.5	13.2	5.8	12.7	5.7
15	10.6	6.9	10.8	7.3	10.8	7.6	10.4	7.1	10.5	6.8	12.7	6.4			12.9	6.2	13.1	5.8		
16	10.4	10.4	10.6	7.1	10.6	7.6	10.3	7.1	10.4	6.8	12.6	6.4					12.8	5.7		
17	10.2	10.2			10.5	7.6	10.3	7.0	10.2	6.8	12.5	6.4					12.6	5.9		
18	10.2	10.2			10.2	7.6	10.2	7.1	10.1	6.8	12.4	6.4					12.4	5.7		
19	10.1	10.1			10.0	7.5	10.0	7.1			12.3	6.3					12.2	5.8		
20	10.0	10.0					9.7	7.1			12.1	6.4					11.9	5.9		
25	9.5	9.5					9.2	7.2			11.6	6.7								
30	9.1	9.1					9.0	7.2			11.1	6.8								
35											10.8	6.8								
40											10.5	6.7								
45											9.8	6.5								
50											8.1	6.0								
Secchi (m)	1.6		1.3		1.2		1.2		1.2		2.47		2.09		1.72		2.28		2.27	

Table B-12. Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at three stations in Shadow Mountain Reservoir in July and August, 2005. Values in parenthesis denote maximum water depth at station.

Water Depth (m)	Shadow Mountain July 1 2005						Shadow Mountain July 27 2005						Shadow Mountain Sept. 9 2005					
	P1(5m)		P2(7.8m)		P3(5.3m)		P1(5.9m)		P2(8.7m)		P3(4.9m)		P1(5.6m)		P2(8.8m)		P3(5.3m)	
	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	14.0	6.49	14.0	6.04	14.3	6.23	20.2	6.3	20.3	6.1	19.5	6.0	16.3	7.2	15.9	7.2	16.1	7.1
1	14.0	6.45	14.0	6.28	14.3	6.00	19.0	6.2	20.2	6.1	19.5	5.9	16.1	7.3	15.3	7.0	15.9	7.2
2	14.0	6.29	14.0	6.24	14.2	6.24	18.6	6.1	19.2	6.2	19.3	6.1	15.0	6.9	15.1	7.2	15.0	7.1
3	13.7	6.11	13.9	6.15	14.0	6.16	18.5	6.1	18.8	6.1	18.7	6.0	13.1	5.7	13.6	6.0	13.5	5.7
4	12.8	6.03	12.9	5.75	13.1	5.60	17.8	5.6	17.4	5.0	18.4	5.7	12.1	5.1	12.6	5.3	12.9	5.0
5	11.9	5.28	12.3	5.77	12.0	5.76	16.5	3.4	17.0	4.0			11.6	4.8	11.9	4.4	11.9	4.0
6			11.9	5.65					15.3	2.8					11.6	4.3		
7			11.5	5.37					13.2	1.4					11.4	3.1		
8															11.3	2.8		
Secchi (m)	1.94		2.69		2.22		4.0		3.5		3.1		1.00		1.00		1.00	

Table B-13. Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at five stations in Taylor Park Reservoir, August 2005. Values in parenthesis denote maximum water depth at station.

Water Depth (m)	Taylor Park 3 August 2005									
	P1 (11.3m)		P2 (17m)		P3 (32.6m)		P4 (12.2m)		P5 (11.2m)	
	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	17.7	6.6	17.0	6.7	17.4	6.3	17.6	6.3	17.9	6.1
1	17.7	6.6	17.1	6.5	17.3	6.2	17.7	6.2	17.9	6.2
2	17.5	6.7	16.9	6.5	17.3	6.2	17.6	6.2	17.9	6.1
3	17.4	6.7	16.8	6.5	17.2	6.2	17.6	6.3	17.9	6.1
4	17.4	6.7	16.7	6.5	17.1	6.2	17.4	6.3	17.8	6.1
5	17.3	6.7	16.6	6.4	16.8	6.2	17.1	6.3	17.8	6.1
6	16.7	6.8	14.4	5.3	16.1	6.0	16.9	6.3	17.8	6.2
7	16.6	6.7	13.6	4.8	14.6	5.4	16.4	6.2	17.0	6.1
8	15.7	6.2	13.2	4.5	14.1	5.1	15.8	6.0	16.5	6.1
9	14.8	5.5	12.8	4.3	13.9	4.9	15.1	5.7	14.6	5.3
10	13.8	4.9	12.7	4.4	13.6	4.8	14.8	5.5	13.1	4.4
11			12.3	4.3	13.1	4.5	14.3	5.2	12.4	3.9
12			12.1	4.4	12.8	4.5	13.0	4.4		
13			11.9	4.4	12.3	4.4				
14			11.7	4.4	1.9	4.1				
15			11.5	4.5	11.5	4.2				
16					11.3	4.2				
17					11.0	4.2				
18					10.8	4.2				
19					10.5	4.3				
20					9.9	4.4				
25					9.3	4.5				
30					8.8	4.5				
Secchi (m)	4.10		4.40		3.60		4.30		4.10	

Table B-14. Temperature (ºC) and dissolved oxygen (mg/L) profiles and Secchi depths (m) at three stations in Vallecito Reservoir, July 2005. Values in parenthesis denote maximum water depth at station.

Water Depth (m)	Vallecito July 21 2005					
	P1 (26.2m)		P2 (27m)		P3 (22.2m)	
	ºC	mg/l	ºC	mg/l	ºC	mg/l
0	19.1	6.7	19.8	6.7	20.2	6.5
1	19.0	6.7	19.6	6.7	19.7	6.6
2	19.0	6.7	19.5	6.6	19.4	6.5
3	18.9	6.8	19.5	6.6	19.3	6.5
4	18.9	6.8	19.4	6.6	18.8	6.7
5	18.5	6.8	19.4	6.5	17.4	6.9
6	15.2	6.7	15.6	6.7	16.0	6.9
7	14.8	6.6	14.7	6.7	15.2	6.7
8	14.0	6.5	13.9	6.4	13.7	6.6
9	13.3	6.4	12.9	6.5	13.0	6.5
10	12.9	6.4	12.2	6.2	12.4	6.3
11	12.5	6.5	12.0	6.1	11.8	6.3
12	11.7	6.3	11.9	6.1	11.4	5.9
13	11.2	6.2	11.3	6.0	11.0	5.9
14	10.9	6.1	11.0	6.0	10.9	5.9
15	10.8	6.1	10.9	6.0	10.8	5.9
16	10.6	6.1	10.7	6.0	10.7	5.9
17	10.5	6.0	10.6	5.9	10.7	6.0
18	10.4	6.0	10.6	5.8	10.6	5.9
19	10.4	6.0	10.5	5.9	10.5	5.8
20	10.3	6.0	10.4	5.7	10.4	5.8
25				5.9		
Secchi (m)	9.20		9.10		8.50	

Table B-15. Temperature (°C) and dissolved oxygen (mg/L) profiles and Secchi depths (m) measured at five stations in Williams Fork Reservoir, July 2005. Values in parenthesis denote maximum water depth at station.

Water Depth (m)	Williams Fork 28 July 2005									
	P1 (42.3m)		P2 (44.1m)		P3 (20.4m)		P4 (25m)		P5 (18.1m)	
	°C	mg/l	°C	Mg/l	°C	mg/l	°C	mg/l	°C	mg/l
0	18.4	6.9	19.1	6.4	19.0	6.7	20.7	6.6	20.7	6.7
1	18.4	6.4	18.5	6.3	18.7	6.5	20.0	6.7	19.9	6.8
2	18.3	6.6	18.4	6.4	18.6	6.5	19.5	6.7	19.5	6.9
3	18.2	6.2	18.3	6.4	18.4	6.4	19.4	6.8	19.3	7.0
4	18.2	6.1	18.2	6.2	18.2	6.3	19.1	6.7	18.5	6.4
5	18.2	6.1	18.2	6.2	17.8	5.9	18.8	6.6	17.8	6.1
6	18.1	6.1	18.2	6.3	17.4	5.7	17.8	6.2	16.8	5.7
7	17.7	5.8	17.5	5.6	16.7	5.3	15.9	5.7	16.1	5.6
8	15.7	5.4	15.3	5.3	14.1	5.3	14.9	5.4	15.4	5.5
9	13.9	5.3	13.9	5.3	13.2	5.6	14.4	5.5	14.9	5.5
10	13.6	5.4	13.0	5.4	12.8	5.6	13.8	5.5	13.9	5.6
11	12.8	5.6	12.6	5.6	12.2	5.7	12.7	5.7	12.0	5.8
12	12.0	5.8	11.9	5.7	11.9	5.7	12.3	5.8	11.6	6.1
13	11.4	5.9	11.4	5.8	11.7	5.7	11.7	5.8	10.9	6.2
14	10.9	6.0	11.0	5.7	11.3	5.5	11.1	6.0	10.6	6.2
15	10.7	6.1	10.8	5.9	11.1	5.6	10.9	6.0	10.3	6.2
16	10.5	6.2	10.4	5.9	10.4	5.8	10.7	6.1	10.0	6.6
17	10.3	6.1	10.2	6.0	9.9	5.6	10.1	6.0		
18	10.1	6.2	10.0	6.1	10.3	5.8	10.0	6.1		
19	10.0	6.3	10.0	6.1	9.8	5.7	9.7	6.1		
20	9.9	6.2	9.6	6.1	9.6	5.7	9.3	5.9		
25	9.2	6.3	9.0	6.1			8.3	6.0		
30	8.5	6.1	8.4	6.1						
35	8.2	6.0	8.0	5.8						
40	7.9	5.9	7.9	5.7						
Secchi (m)	4.90		4.80		4.80		4.30		4.30	

APPENDIX C

ANNUAL REPORT FROM COLORADO STATE UNIVERSITY

ISOTOPIC, ELEMENTAL & BIOENERGETICS STUDIES: APPLICATION OF ISOTOPIC AND ELEMENTAL TECHNIQUES TO IDENTIFY PROVENANCE OF FISHES AND TO FACILITATE BIOENERGETICS PROJECTIONS OF FOOD-WEB IMPACTS OF PISCIVORES RESERVOIRS

Prepared for:

Patrick J. Martinez, Aquatic Research Biologist, Colorado Division of Wildlife

**ISOTOPIC, ELEMENTAL & BIOENERGETICS STUDIES:
APPLICATION OF ISOTOPIC AND ELEMENTAL TECHNIQUES TO IDENTIFY PROVENANCE OF FISHES AND TO FACILITATE BIOENERGETICS PROJECTIONS OF FOOD-WEB IMPACTS OF PISCIVORES RESERVOIRS**

Period of Performance: 07/01/04 - 06/30/05

Prepared by:

Dr. Brett M. Johnson, Dr. Greg Whitledge, Mario Sullivan and Dan Gibson-Reinemer

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June 30, 2005

TABLE OF CONTENTS

INTRODUCTION

An understanding of trophic dynamics is fundamental to effective fishery management (Johnson and Martinez 2000). Knowledge of food web interactions is also essential for evaluating the importance of competitive and predatory relationships among fishes. This report summarizes research developing, refining and applying new methodologies for the study of trophic dynamics in reservoirs in Colorado. Results of work developing techniques to trace origins and movement patterns (provenance) of illicitly stocked fishes are also presented.

BIOENERGETICS PROJECTIONS OF CONSUMPTION IN RESERVOIRS

A yellow perch in Blue Mesa Reservoir growing from age-1 to age-5 was predicted to consume 1.96 kg of food of the observed diet (97% chironomids, 3% crayfish). If yellow perch consumed only kokanee then their age-1 to age-5 per capita consumption would be 0.665 kg because of the much higher energy density of kokanee vs. aquatic invertebrates. In order to assess the potential trophic impact of introduced yellow perch on the Blue Mesa Reservoir food web it would be necessary to estimate the lakewide abundance of yellow perch. However, recent diet information suggests that yellow perch do not compete for food with kokanee in Blue Mesa Reservoir (Figure C-1).

In the unfortunate event that exotic zooplankters (e.g., *Daphnia lumholtzi, Bythotrephes cederstroemi*) invade the reservoir then planktonic food availability for fishes will decrease radically, increasing the potential for detrimental effects of yellow perch on kokanee.

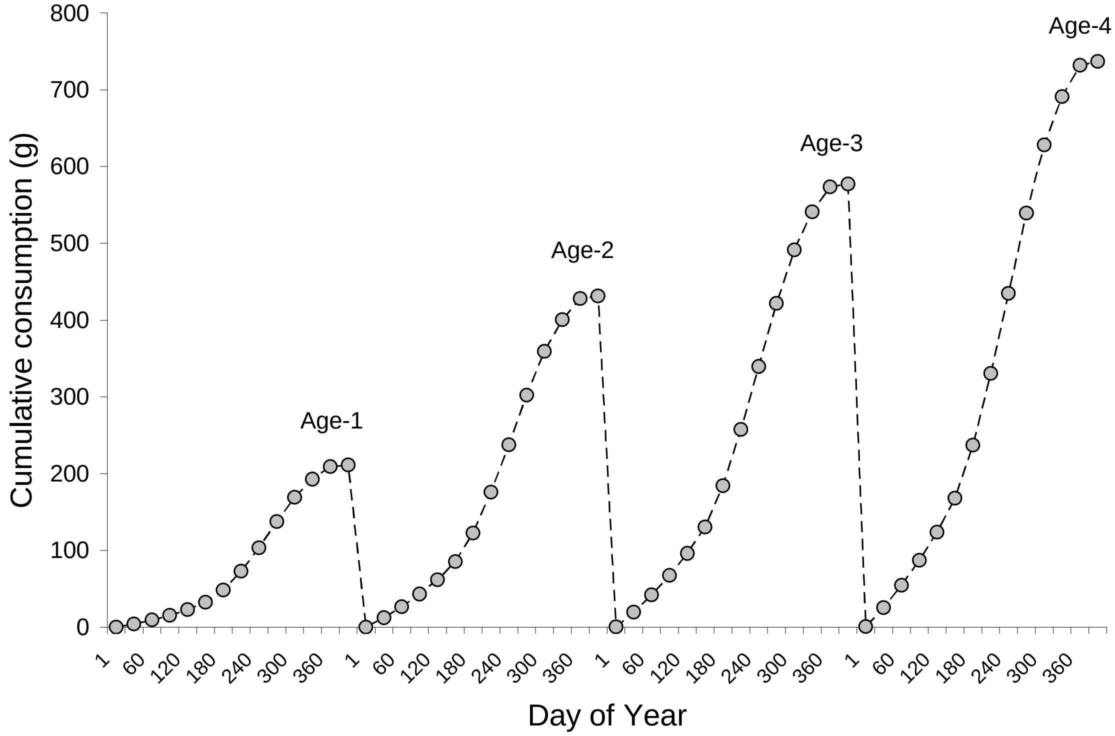

Figure C-1. Per capita consumption (g wet) of all prey by yellow perch using inputs measured at Blue Mesa Reservoir. Diet consisted of 97% chironomids and 3% crayfish.

ISOTOPIC AND ELEMENTAL ANALYSES OF RESERVOIR SAMPLES

Yellow perch

Results from laser ablation analyses of yellow perch otoliths from Crawford and Blue Mesa reservoirs show a distinct separation between individuals from Crawford and those from Blue Mesa based on strontium and barium concentrations for individual fish averaged over the length of transects running from otolith core to edge (Figure C-2).

None of the other elements we analyzed for showed any differences among fish from these two locations. It looks like we'll be able to use Sr and Ba to determine if fish in Blue Mesa may have been transplanted from Crawford (this bodes well for the northern pike study too). We need to examine the Blue Mesa transect data more closely to see if there is any evidence that the fish we've looked at so far may have been translocated from Crawford Reservoir.

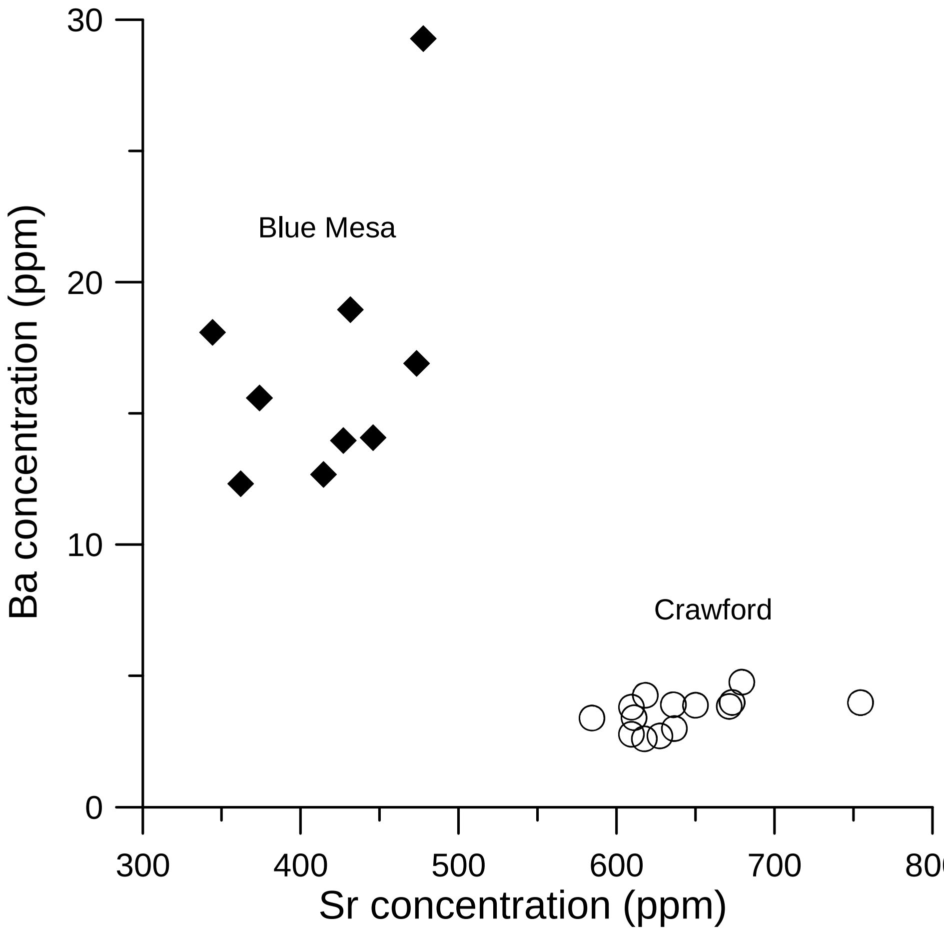

Figure C-2. Mean barium and strontium concentrations in otoliths of yellow perch sampled from Blue Mesa and Crawford reservoirs. Analysis was performed with determined by laser ablation inductively coupled plasma mass spectrometry.

Northern pike

Isotopic analyses of muscle tissue of northern pike sampled from Paonia and Crawford reservoirs showed distinct differences between the two reservoirs in both ^{13}C and ^{15}N signatures. Carbon signatures were higher (Figure C-3) and nitrogen signatures were lower in northern pike from Paonia Reservoir. Several northern pike from Crawford Reservoir exhibited very high ^{15}N signatures (Figure C-4); these were the largest individuals in the sample (>600 mm TL). Stable isotope analysis of northern pike muscle tissue appears to be an effective means of distinguishing suspect source waters if isotopic differences persist over years and the fish are sampled shortly after being introduced to new waters. Isotopic measurements from other waters that may be sources of introduced waters would be useful. It is not known if elemental concentrations in otoliths would differ among waters; this question remains to be addressed in our future research.

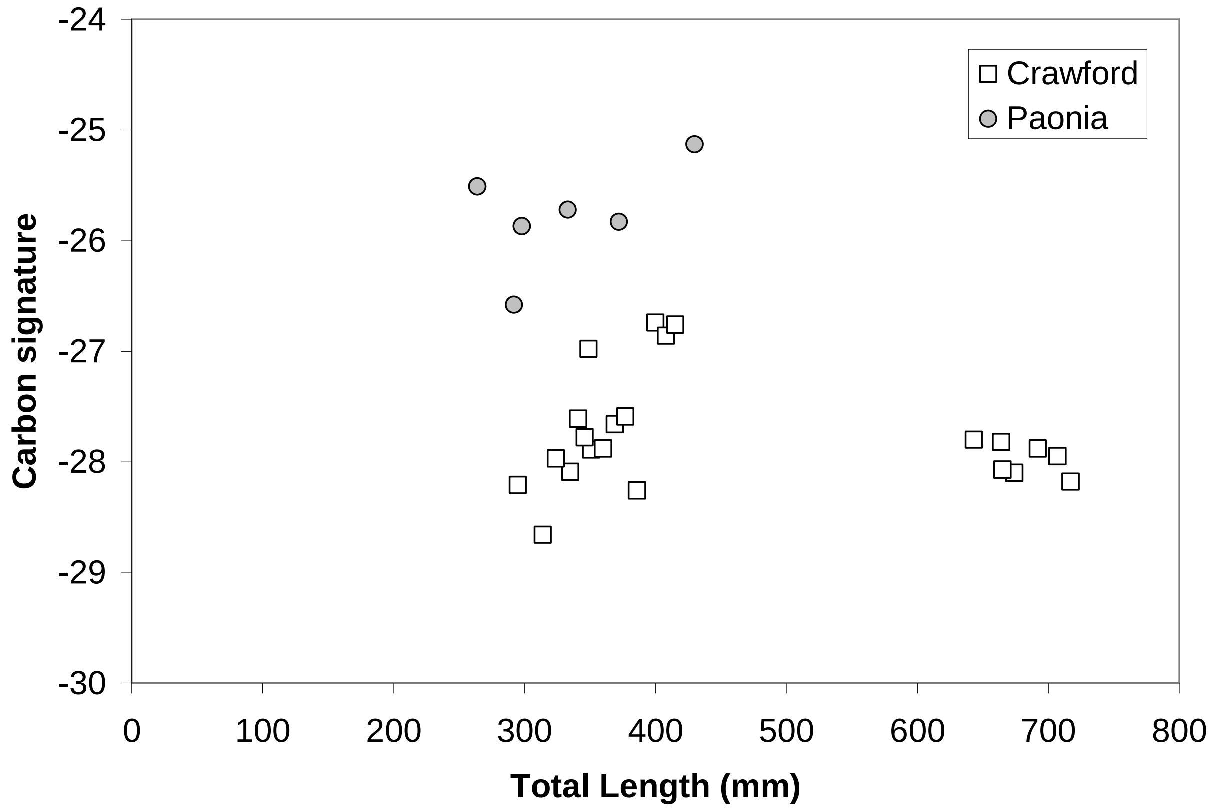

Figure C-3. Carbon signature (^{13}C) of northern pike sampled from Crawford and Paonia reservoirs during September 2003 and June 2004, respectively.

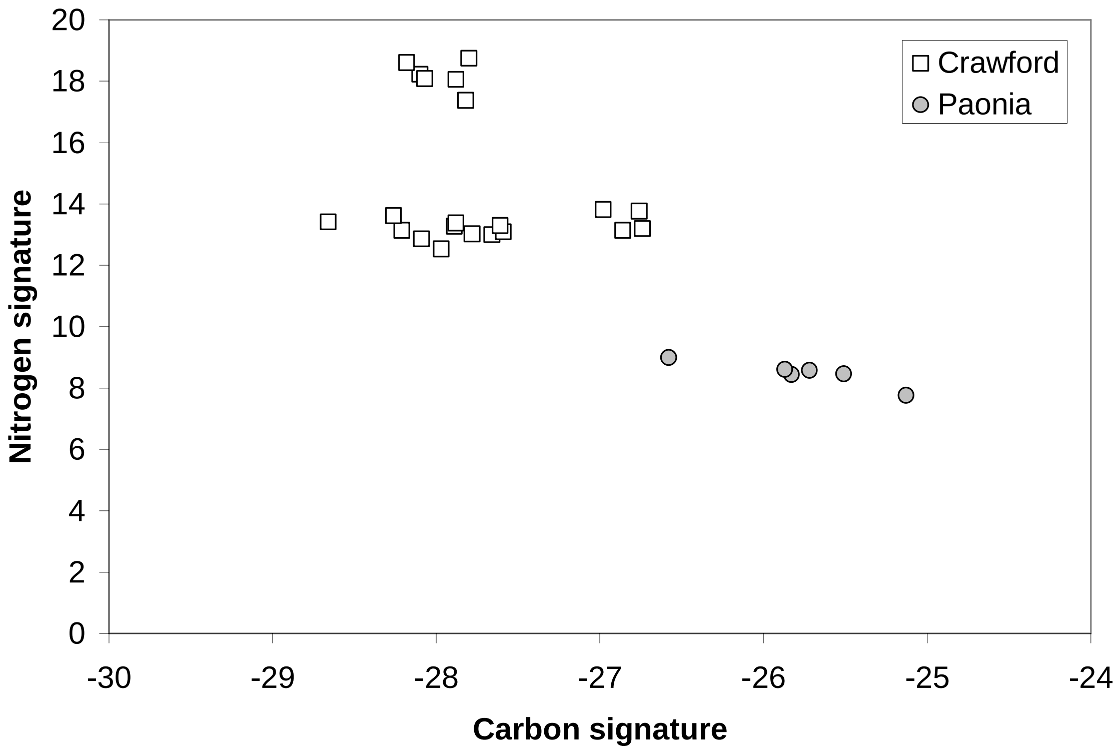

Figure C-4. Carbon (13C) and nitrogen (15N) signature of northern pike sampled from Crawford and Paonia reservoirs during September 2003 and June 2004, respectively.

RECOMMENDATIONS

1. Analysis of northern pike and yellow perch diet composition in Blue Mesa Reservoir should continue to bolster sample sizes and to increase the range of sizes and times of year over which diet inferences are possible.

2. Bioenergetics projections yellow perch consumption in Blue Mesa Reservoir should be refined as new diet data become available.

3. Water, otolith and tissue samples should be collected from illicitly intoroduces species suspected source and recipient waters to refine our ability to trace origins of translocated fish.

4. We should continue to work on manuscripts deriving from this research and submit them to scientific journals.

APPENDIX D

FORENSIC APPLICATIONS OF OTOLITH MICROCHEMISTRY FOR TRACKING SOURCES OF ILLEGALLY STOCKED WHIRLING DISEASE POSITIVE TROUT

FINAL REPORT
DECEMBER 31, 2005

Final Report
December 31, 2005

Forensic Applications of Otolith Microchemistry for Tracking Sources of Illegally Stocked Whirling Disease Positive Trout

Prepared for:

Whirling Disease Initiative
Montana Water Center
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Project Timeline:

August 2004 to December 2005

Non-Technical Project Summary

Maintenance of viable, self-sustaining wild and native trout fisheries is jeopardized by the spread of whirling disease. However, the extent to which the illegal stocking of diseased fishes has contributed to this spread has been difficult to assess because it has been virtually impossible to identify an unmarked fish's location of origin once it is stocked. Thus, managers and law enforcement personnel have been unable to determine the sources of such illegally stocked fish and have been unsuccessful at prosecuting individuals suspected of the violations. This project developed a reliable method for determining origins of stocked trout. The research was conducted collaboratively between Colorado State University (CSU; Drs. Johnson, Winkelman and Whitledge) and Colorado Division of Wildlife Aquatic Research (CDOW; P. Martinez).

Our method applies state-of-the-art technology to determine the chemical composition of fish otoliths ("ear bones"). This technique is emerging as an extremely useful method for tracing origins and movement patterns of many fish species. The basis of this technique is to identify the chemical "fingerprint" of waters the fish has inhabited in its past. We found that hatchery water supplies have distinctive chemical composition imparted by their water sources and geological characteristics of the area surrounding the individual facilities. These signatures are incorporated into the tissues of a fish grown in a particular water source and are permanently recorded in its otoliths as the fish grows, thus laying down a timeline as the fish is moved among waters having different chemical fingerprints. We developed powerful statistical models using a combination of elements to uniquely identify individual hatcheries based on otolith chemistry.

Otoliths from a number of fish we have analyzed thus far showed clear changes in the elemental composition of different regions of the otolith. For example, otolith chemical composition changed at a point corresponding to the transfer of a rainbow trout from one hatchery to a second. Large differences in the abundances of strontium (Sr), barium (Ba) and magnesium (Mg) at the core and edge of otoliths from fish that were transferred from one hatchery as eggs and hatched at another hatchery also supported the idea that otolith microchemistry can be used to track movements of hatchery trout among culture facilities. Continued analysis of the correspondence between chemical changes in the otolith and times of known transfers of fish will be a major thrust of our continuing research. Based on our findings to date, otolith microchemistry has tremendous potential for determining the locations from which stocked fish originate.

Abstract

The extent to which illegal stocking of diseased trout has contributed to the spread of whirling disease has been difficult to assess because it has been virtually impossible to identify an unmarked fish's location of origin once it is stocked. The advent of otolith microchemistry may provide a means to overcome this limitation because the chemical "fingerprint" of water at a particular location is recorded in the fish's tissues. We gathered samples of trout from a variety of CDOW and private hatcheries during 2004 and 2005 and analyzed them with microchemical techniques. Concentrations of trace elements and isotopes we measured in water samples varied by as much as three orders of magnitude among sites in both 2004 and 2005. With the exception of a single location, the elemental abundances of water obtained from a variety of CDOW hatcheries varied little between 2004 and 2005. The correlation among elemental concentrations across hatcheries was generally low and not statistically significant. Heterogeneity and independence of trace element concentrations across locations allowed the development of powerful discriminative models for classifying hatcheries using the chemical composition of their water supplies. Otoliths from a number of fish showed clear discontinuities in the elemental composition measured along longitudinal laser transects suggesting that the chemical composition of the water the fish inhabited changed at some point in its life. Large differences in the abundances of strontium (Sr), barium (Ba) and magnesium (Mg) at the core and edge of otoliths from fish that were transferred from one hatchery as eggs and hatched at another support demonstrated that otolith microchemistry can be used to track movements of hatchery trout among culture facilities. In the otoliths we have examined (n = 68), no single element occurs with within-site variation small enough to correctly identify fish from all locations, necessitating the use of multivariate statistical models. We have analyzed the seven sampling occasions for which we have completed data analysis using multivariate discriminant function analysis and cross-validated classification accuracy of these seven locations has yielded a success rate of 84%. Otoliths from fish taken from some locations had highly distinct chemical signatures which will allow investigators to conclusively pinpoint origins of those fish. Overall, we learned that: there is enormous variation in the chemical makeup of water used in hatcheries across Colorado, trace elements with high variation in the water supplies are readily incorporated into otoliths and can be detected with great precision using the methods we are employing, multivariate classification models using microchemical fingerprints accurately identified origins of fish from a variety of sources, and otolith microchemistry has excellent potential for determining the locations from which stocked fish originate.

Introduction

The maintenance of viable, self-sustaining wild trout fisheries is jeopardized by the spread of whirling disease. Illegal stocking of whirling disease positive (WD+) trout is thought to be an important mode for introducing the disease into uninfected locales. However, it has been virtually impossible to identify an unmarked fish's hatchery of origin once it is stocked. Thus, managers and law enforcement personnel have been unable to determine the sources of such illegally stocked fish and have been unsuccessful at prosecuting individuals suspected of the violations. The development of new technologies that identify hatchery sources would be an invaluable law enforcement tool as well as a potent and effective deterrent to discourage future violations of this nature (Glenn Smith, CDOW Criminal Investigator, personal communication).

Microchemical and stable isotope analysis of otoliths is emerging as an extremely useful method for tracing origins and movement patterns of fishes (Gao and Beamish 1999; Hobson 1999; Kennedy et al. 2000, 2002; Weber et al. 2002; Wells et al. 2003). The basis of this technique is to identify the isotopic signature or microchemical fingerprint of waters the fish has inhabited in its past (Campana and Thorrold 2001). Hatcheries may use water supplies that have distinctive chemical composition imparted by their water sources and geological characteristics of the area surrounding the individual facilities. These signatures are assimilated into the tissues of fish grown in a particular water source and are permanently recorded within the otolith (ear bone) as the fish grows, thus laying down a timeline as a fish is moved among waters having different chemical signatures and fingerprints. Statistical models can be developed using a combination of elements to uniquely identify individual hatcheries.

Otoliths from fish that are suspected to be diseased, or otherwise illicitly stocked, can be analyzed to determine their isotopic or microchemical history. By matching these markers with those of potential sources, it becomes feasible to identify which water body or hatchery they were formerly reared in and the approximate time they were moved from one water body to another by relating changes in chemical signatures across the otolith to the position of annuli that are visible in otolith thin sections.
This project sought to develop reliable methods for determining sources of illegally stocked fishes by microchemical and isotopic analysis of their otoliths. Successful development of the technique will give managers and law enforcement personnel a tool to determine if illegal stocking is responsible for the spread of whirling disease into new locations.

Goals and Objectives

1. Determine variation in microchemical and isotopic signatures of otoliths and water samples obtained from a variety of CDOW hatcheries
2. Assess utility of these signatures for tracing hatchery origins of fish at large.
3. Determine variation in microchemical and isotopic signatures of otoliths obtained from private hatchery fish and assess utility of these signatures for tracing hatchery origins of fish at large.

Methods and Materials

We gathered samples of trout from a variety of CDOW and private hatcheries during 2004 and 2005. The number of private facilities sampled was small because of limited cooperation from private growers. Water samples from the same locations were also collected, using ultra-clean techniques (Shiller 2003). At each hatchery we reconnoitered the site and interviewed the hatchery manager to determine the configuration of the water supplies. The number of samples collected varied at each hatchery depending on the expected distinctiveness of each water source coming into the hatchery. We collected samples from each water source for trace element analysis.
To assess the utility of microchemical signatures for tracing hatchery origins of fish at large, a sample of fish was collected from a variety of locations in Colorado by Kevin Thompson, an aquatic research for the CDOW. Kevin recorded the location from which the fish were collected, but did not provide us with this information. Kevin Thompson also provided us with a sample of fish from the Dolores River, CO, four of which were marked with Visible Implant Fluorescent Elastomer (VIE) tags that identify their origin. Otoliths were extracted with clean techniques and the remains of each fish were retained for possible analysis of other tissues. Otoliths were handled, sectioned and polished according to Whitledge et al. (in prep). Digital images of each otolith section were recorded with ImagePro Plus®. Otolith thin sections were analyzed for elemental concentrations and stable isotope ratios, employing laser ablation inductively coupled mass spectrometry (LA-ICP-MS; Campana 1999; Campana et al. 1994; Thorrold and Shuttleworth 2000). Spectrometric analyses were performed at the USGS Mineral Resources Laboratory, Lakewood, Colorado, under the supervision of Alan Koenig, USGS Research Geologist. We used multivariate discriminant function analysis (Manly 2005; PROC DISCRIM, SAS 9.1) using a suite of elements to discriminate groups of fish from various hatcheries.

Results and Discussion

We collected 24 water samples and 190 fish samples from hatcheries in 2004 and 26 water samples and 200 fish samples in 2005 (Table 1). Only two private hatcheries allowed us to collect samples of fish or water (Mount Massive Lakes and Silver Springs). We obtained an additional 113 fish samples from a variety of locations in Colorado from Kevin Thompson.

There was enormous variation in the chemical makeup of water used in hatcheries around the state; the concentrations of trace elements and isotopes we measured in water samples (Table 2) varied by as much as three orders of magnitude among sites in both 2004 and 2005 (Figure 1, Table 3). Deuterium and oxygen isotopic signatures (Figure 2) also varied to a considerable degree across hatcheries, providing additional variables to be used in classification models. Variation in signatures was vastly greater than instrument precision (Figure 1) indicating that statistical differences in trace element concentrations among water sources can be detected. With the exception of a single location, the elemental abundances of water obtained from a variety of CDOW hatcheries varied little between 2004 and 2005. The correlation among elemental concentrations across hatcheries was generally low and not statistically significant. Heterogeneity and independence of trace element concentrations across locations allowed the development of powerful discriminative models for classifying hatcheries using the chemical composition of their water supplies.

We extracted otoliths from all fish sampled in 2004 and 2005. Otoliths were sectioned and digital images of their microstructure were recorded to allow us to relate chronology to trace element and isotope concentrations within the otoliths. A total of 190 otoliths were analyzed by LA-ICP-MS and by isotope ratio mass spectrometry; 85 of those samples were from fish provided by Kevin Thompson. A total of 24 elements and 32 isotopes were detected in otoliths (Table 2). Detection limits of the LA-ICP-MS instrument varied by element and not all elements were detected in all otoliths. Otoliths from a number of fish showed clear discontinuities in the elemental composition measured along longitudinal laser transects suggesting that the chemical composition of the water the fish inhabited changed at some point in its life. For example, elemental abundances changed at a point corresponding to the transfer of a rainbow trout from one hatchery to a second (Figure 3). Large differences in the abundances of strontium (Sr), barium (Ba) and magnesium (Mg) at the core and edge of otoliths from fish that were transferred from Crystal River hatchery as eggs and hatched at the Durango hatchery (Table 4) also support the hypothesis that otolith microchemistry can be used to track movements of hatchery trout among culture facilities. Continued analysis of the correspondence between chemical changes in the otolith and times of known transfers of fish will be a major thrust of our continuing research.

Comparing elemental composition of otoliths across individual fish is complicated by variation in the crystalline form of the otolith, an issue that must be addressed in continuing research. Hatchery-reared fish may display a characteristic shift in the calcium carbonate structure of their otoliths. Although most salmonid sagittal otoliths are composed of aragonite, some fish display portions of vaterite in their otoliths. Evidence from lake trout (*Salvelinus namaycush*) suggests that more than 80% of hatchery-reared fish may display vaterite portions of otoliths, while vaterite portions were observed in less than half of wild lake trout (Bowen II et al. 1999). A consistently higher proportion of vateritic otoliths among hatchery-reared coho salmon (*Oncorhynchus kisutch*) relative to wild cohorts was also observed by Sweeting et al. (2004). The occurrence of vaterite may serve to help distinguish wild from hatchery fish. However, the switch from aragonite to vaterite may be accompanied by a shift in elemental composition that does not reflect a change in ambient water chemistry (Brown and Severin 1999). In 2006, we hope to evaluate the prevalence of vaterite in hatchery-reared rainbow trout and the effects this may have on otolith microchemistry.

In the otoliths we have examined (n = 68), no single element occurs with within-site variation small enough to correctly identify fish from all locations, necessitating the use of multivariate statistical models. Previous studies of otolith microchemistry in freshwater fishes have also relied upon multivariate analyses to classify fish origin (Brazner et al. 2004, Wells et al. 2003, Thorrold et al. 1998, Bronte et al. 1996). We have analyzed the seven sampling occasions for which we have completed data analysis using multivariate discriminant function analysis (PROC DISCRIM, SAS 9.1). Cross-validated classification accuracy of these seven locations has yielded a success rate of 84% (Figure 4). We expect classification success to improve with the addition of data from more locations. Otoliths from fish taken from some locations had highly distinct chemical signatures which will allow investigators to conclusively pinpoint origins of those fish.

Limited cooperation resulted in a small sample of private hatcheries with which to make comparisons. However, the utility of our technique can be assessed with fish of known origin, whether they be public, private, or federal. Ultimately, geology and geographic location are most influential to the chemical fingerprints of otoliths. We observed consistent seasonal variation in water chemistry from a variety of waters in Colorado in USGS water chemistry databases and that variation was consistent with the seasonal variation observed in our hatchery water samples. These data could be used to develop models to predict chemical fingerprints of fish from any location, regardless of grower cooperation.

Our plans for 2006, supported by additional funding from WDI include: addressing objectives presented in the research proposal that garnered additional funding; presenting our latest findings at the 12th Annual Whirling Disease Symposium, February 9-10, 2006; preparing manuscripts for publication in peer-reviewed scientific journals; and providing a detailed final report in December 2006.

Conclusions

1. There is enormous variation in the chemical makeup of water used in hatcheries across Colorado,

2. trace elements with high variation in the water supplies are readily incorporated into otoliths and can be detected with great precision using the methods we are employing,

3. multivariate classification models using microchemical fingerprints accurately identified origins of fish from a variety of sources and therefore,

4. otolith microchemistry has tremendous potential for determining the locations from which stocked fish originate.


Configuration of trout culture facilities varies greatly from place to place. In some cases fish are hatched and raised to stocking size within a single facility; in others fish are hatched elsewhere and transferred to a second hatchery for rearing. Water supplies may consist of one source or a mix of groundwater and surface water sources.

Need for Further Study

1. The objectives of our research to be conducted in 2006 with additional funding provided by WDI should be accomplished.

2. The implications of aragonite vs. vaterite forms of calcium carbonate within the otolith needs to be explored.

3. A synthetic view of the spread of WD at multiple spatial scales is needed for a more complete understanding of the epidemiology of the disease. While our methods are proving useful for determining origins of fishes based on known water chemistry data, the development of predictive models based upon land use and surface and bedrock geology would allow investigators to examine spatial differences in hydrochemistry at any scale of interest and thereby reconstruct movement patterns of diseased fish within and among watersheds. Such an undertaking is far beyond the scope of the current project, but should be considered for future research if funding becomes available.

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Table D-1. Summary of fish and water samples (n) collected as of December 2005. CDOW is the Colorado Division of Wildlife.

Location/ Hatchery	Ownership	Water samples 2004	Water samples 2005	Fish samples 2004	Fish samples 2005
Bellvue	Public (CDOW)	1	1	10	10
Buena Vista	Public (CDOW)	1	1	10	10
Chalk Cliffs	Public (CDOW)	1	1	10	10
Crystal River	Public (CDOW)	1	2	10	20
Durango	Public (CDOW)	1	1	10	10
Research Hatchery	Public (CDOW)	1	0	10	0
Finger Rock	Public (CDOW)	1	1	10	10
Glenwood Springs	Public (CDOW)	2	2	10	10
Mount Ouray	Public (CDOW)	1	1	10	10
Mount Shavano	Public (CDOW)	1	1	10	10
Monte Vista	Public (CDOW)	1	1	10	10
Pitkin	Public (CDOW)	1	1	10	10
Poudre Rearing Unit	Public (CDOW)	1	1	10	10
Rifle	Public (CDOW)	1	1	10	10
Roaring Judy	Public (CDOW)	2	2	10	10
San Luis	Public (CDOW)	1	1	10	10
Watson Lake	Public (CDOW)	3	3	10	10
Mount Massive Lakes	Private	3	2	10	10
Silver Springs	Private	0	2	0	10
Hotchkiss	Federal (USFWS)	0	1	10	10

Table D-2. The 24 elements (arranged by atomic mass) and 32 isotopes present in otoliths that have been detected in our work with the LA-ICP-MS. Detection limits of the instrument varied by element and not all elements were detected in all otoliths.

Element	Isotope
Boron	^{11}B
Carbon	^{12}C
Sodium	^{23}Na
Magnesium	^{24}Mg, ^{25}Mg
Aluminum	^{27}Al
Phosphorus	^{31}P
Chlorine	^{35}Cl
Calcium	^{42}Ca, ^{43}Ca, ^{44}Ca
Titanium	^{47}Ti
Chromium	^{52}Cr
Iron	^{54}Fe, ^{57}Fe
Manganese	^{55}Mn
Nickel	^{60}Ni, ^{62}Ni
Copper	^{63}Cu
Zinc	^{66}Zn
Arsenic	^{75}As
Krypton	^{83}Kr
Rubidium	^{85}Rb
Strontium	^{86}Sr, ^{87}Sr, ^{88}Sr
Cadmium	^{114}Cd
Barium	^{137}Ba
Cerium	^{140}Ce
Lead	^{208}Pb
Uranium	^{238}U

Table D-3. Mean and variation of 20 trace element concentrations in 24 water samples collected from 18 hatcheries during July, 2004. The element-specific detection limit of the laser ablation inductively coupled plasma mass spectrometer (LA-ICP-MS) is also shown. Measurements below the detection limit will be censored from the data before statistical analysis. C.V. is coefficient of variation.

Element	Units	Mean concentration	Range	C.V.(%)	Limit of detection
Na	µM	232.23	22-756	79	0.05
Mg	µM	401.99	19-1048	65	0.05
Si	µM	244.96	47-1221	106	0.52
S	µM	239.60	29-1185	115	0.34
Ca	µM	1013.23	117-2367	61	0.11
K	µM	37.81	11-105	66	0.03
P	µM	0.12	0.01-0.45	108	0.15
Li	nM	839.40	104-3108	86	17.5
Ce	nM	0.09	0.001-0.823	200	0.01
Pb	nM	0.21	0-1.455	190	0.02
U	nM	13.52	0.46-115	192	0.02
Mn	nM	40.04	0-192.6	152	1.28
Fe	nM	143.43	0-1188.1	194	0.97
Ni	nM	4.87	0.04-76.10	325	0.56
Cu	nM	10.93	0.01-59.77	135	0.17
Zn	nM	76.04	1.02-947.97	277	0.28
Rb	nM	15.93	1.65-74.63	121	0.11
Sr	nM	3061.94	383-12250	110	4.50
Ba	nM	373.55	26-949	75	0.66
Se	nM	4.02	0-19.2	125	2.08

Table D-4. Mean abundance and standard deviation (SD) for strontium (Sr), barium (Ba) and magnesium (Mg) in otoliths collected at the Durango hatchery (CDOW) on July 21, 2004. Fish arrived at Durango from Crystal River (CDOW) as eggs and hatched at Durango. Age at capture was 22 months.

	Core (n=7)		Edge (n=7)		
Element	**Mean**	**SD**	**Mean**	**SD**	**Limit of Detection**
Sr	1004.31	359.78	127.83	13.07	0.0489
Ba	9.86	2.72	1.55	0.42	0.2066
Mg	107.52	39.60	2211.25	264.04	3.091

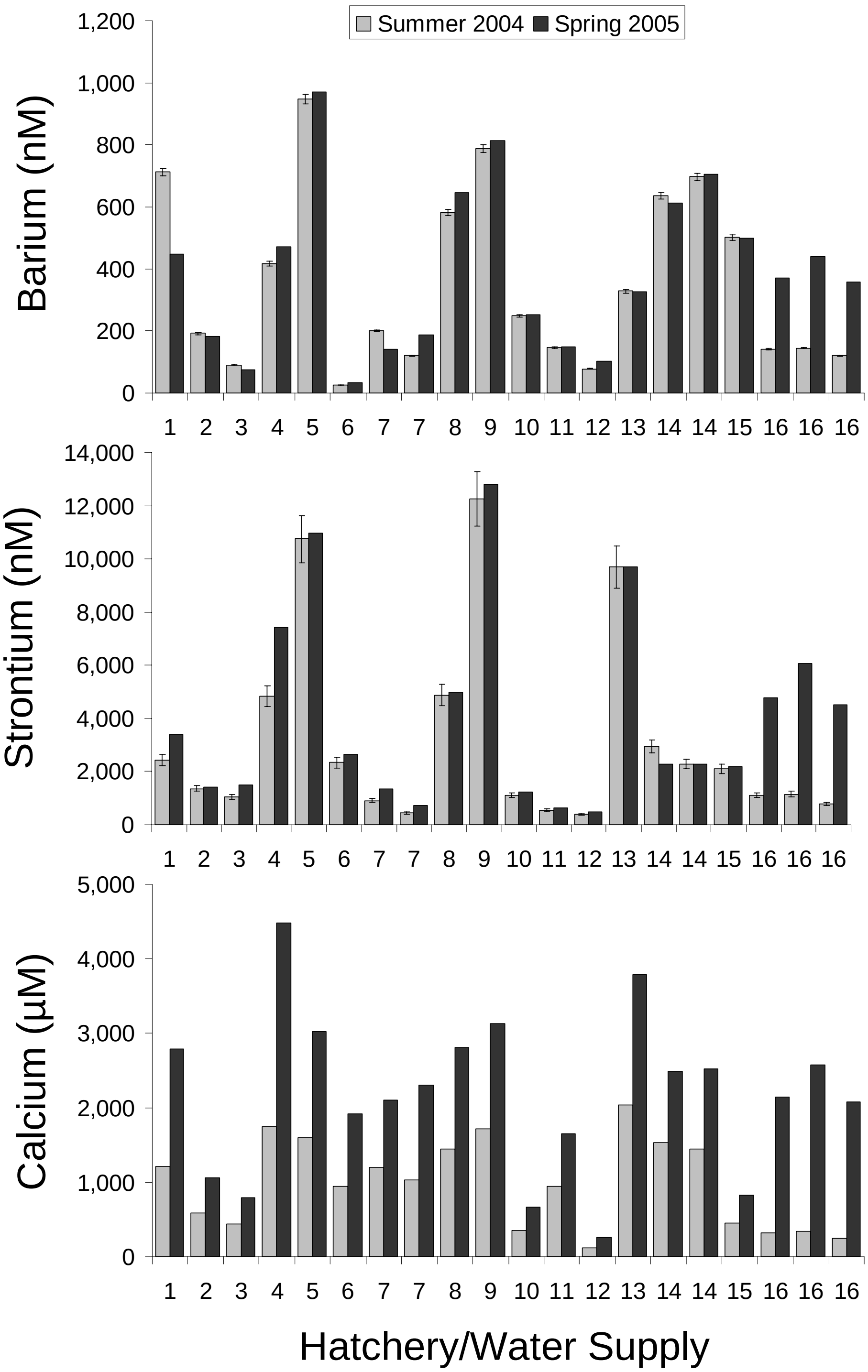

Figure D-1. Concentrations of three trace elements measured in 20 water samples collected from 16 hatcheries in July, 2004 and March, 2005. Error bars represent the measurement error (from standards run on the same day as the samples) of the LA-ICP-MS for each element; error bars for barium are plotted but are almost too small to be seen. Error estimates were not available for the calcium concentration.

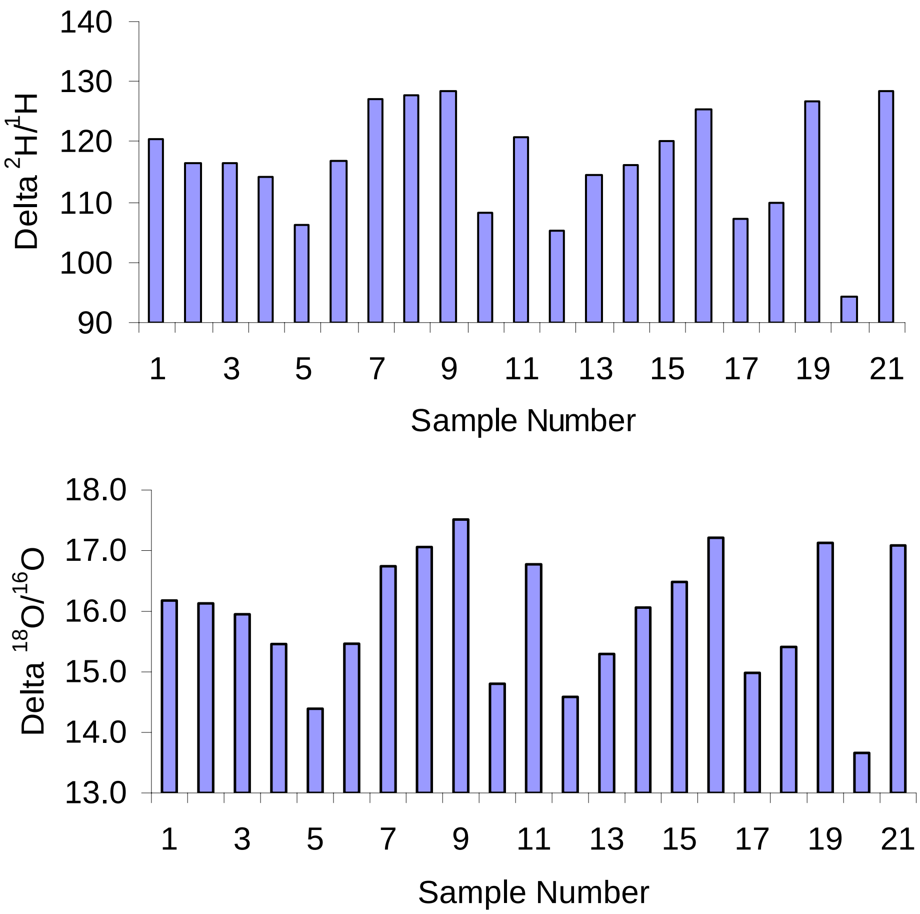

Figure D-2. Stable isotope ratios for $\delta\,^{2}H$(top) and $\delta\,^{18}O$(bottom) of water samples collected from hatcheries in 2004. Data have been transformed to show the absolute value of the ratio.

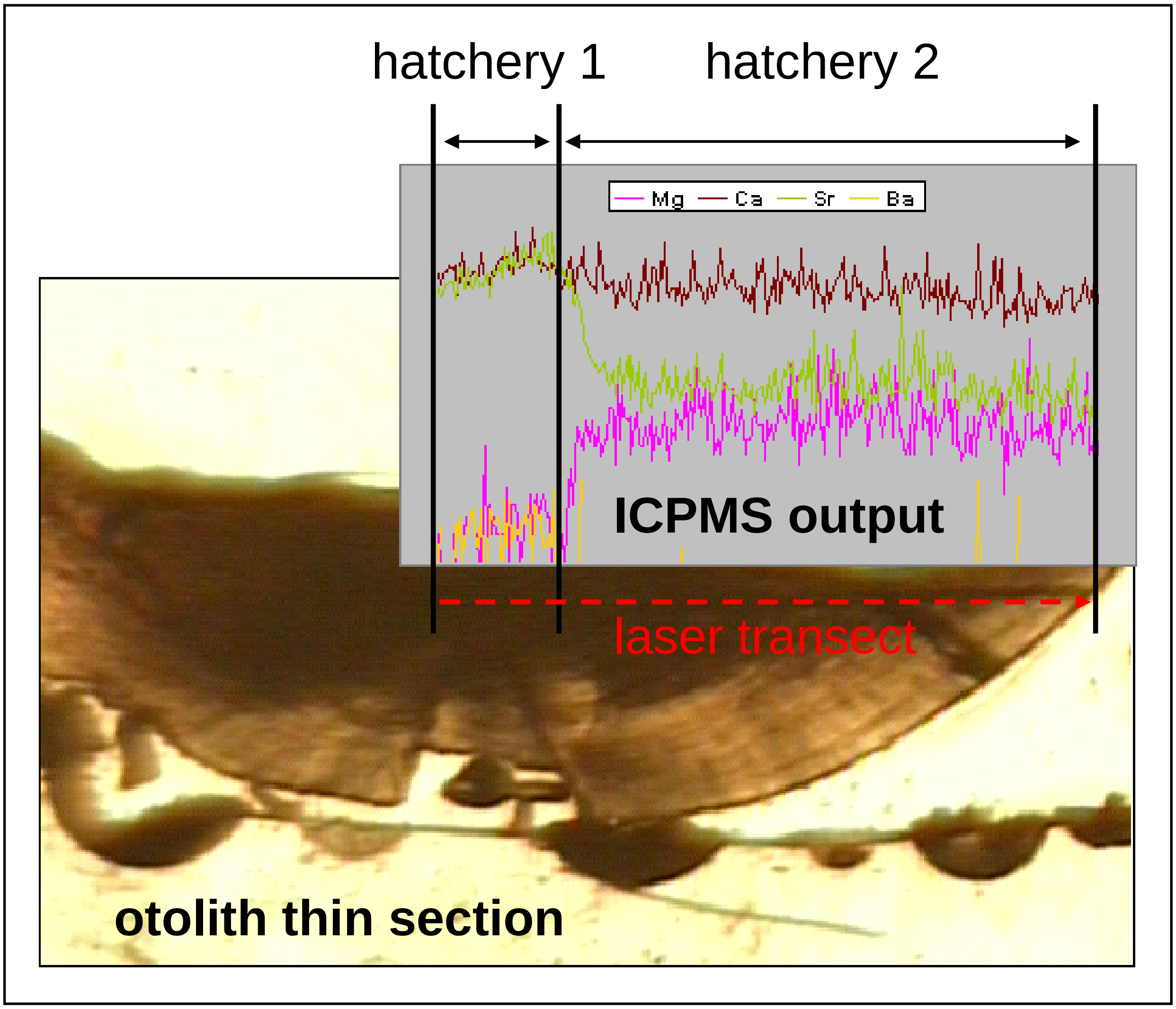

Figure D-3. **Digital micrograph of a thin section of a rainbow trout otolith showing the regions of otolith growth occurring at two hatcheries. The otolith image is overlain with elemental concentrations measured with LA-ICP-MS along a laser transect (can be seen as a dark line just above the dotted red line). Note the change in elemental abundances corresponding to the transfer of the fish to the second hatchery.**

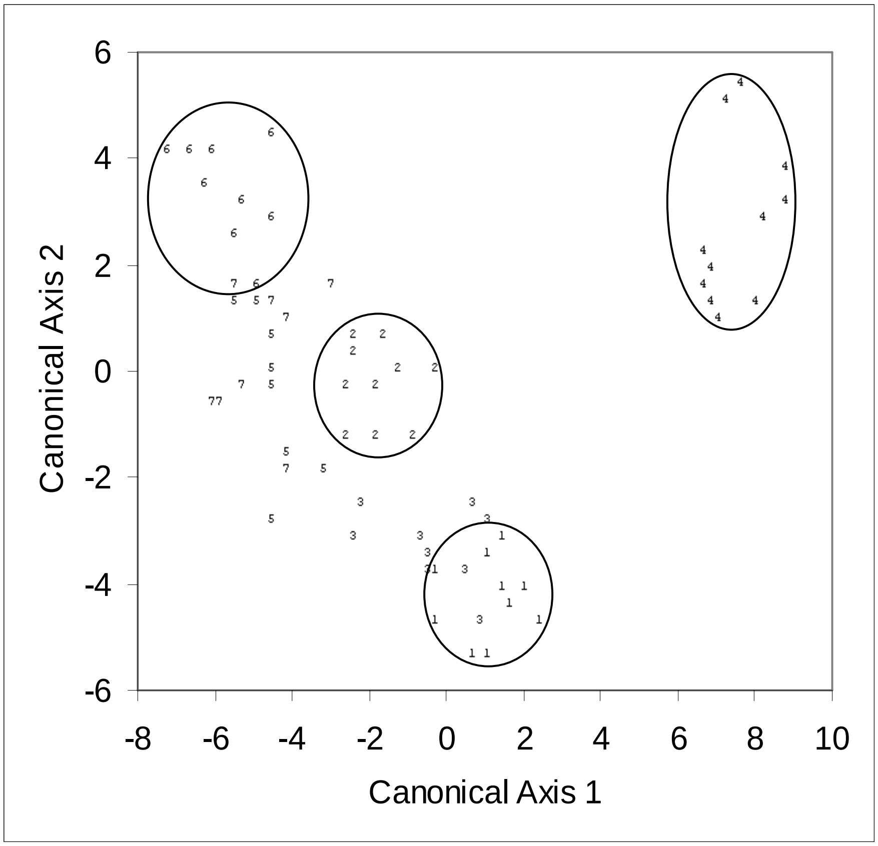

Figure D-4. Plot of canonical correlation factors used in creating a multivariate model to classify fish origins using linear discriminant function analysis. Each number on the plot represents an otolith from that location (n = 68). Ellipses have been drawn around some locations to emphasize the separation of locations, although some otoliths are misclassified. Overall error rate was approximately 16%. Classification accuracy may increase as fish from more hatcheries are included in the development multivariate classification models.