September 1999

WILLAMETTE OXYGEN SUPPLEMENTATION STUDIES

Scale Analyses, Dexter Water Quality Parameters, and Adult Recoveries

Annual Progress Report
September 30, 1998 - September 29, 1999

Annual Report 1998

DOE/BP-92818-7

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views of this report are the author's and do not necessarily represent the views of BPA.

This document should be cited as follows:

R. D. Ewing - Biotech Research and Consulting, Inc., Willamette Oxygen Supplemenation Studies - Scale Analyses, Dexter Water Quality Parameters, and Adult Recoveries, 1999, Annual Progress Report September 30, 1998 - September 29, 1999 to Bonneville Power Administration, Portland, OR, Contract No. DE-BI79-88BP92818, Project No. 1988-160, 142 electronic pages (BPA Report DOE/BP-92818-7)

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ANNUAL PROGRESS REPORT
FISH CULTURE SECTION

Willamette Oxygen Supplementation Studies – Scale Analyses, Dexter Water Quality Parameters, and Adult Recoveries

Project Period:
September 30, 1998 – September 29, 1999

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Project No. 88-160
Contract No. DE-BI79-88BP92818

September 1999

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INTRODUCTION

Hydropower development and operations in the Columbia River basin have caused the loss of 5 million to 11 million salmonids. An interim goal of the Northwest Power Planning Council at the time that this project was initiated was to reestablish these historical numbers by doubling the present runs from 2.5 million adult fish to 5.0 million adult fish. This increase in production was to be accomplished through comprehensive management of both wild and hatchery fish, but artificial propagation was to play a major role in the augmentation process. The current husbandry techniques in existing hatcheries require improvements that may include changes in rearing densities, addition of oxygen, removal of excess nitrogen, and improvement in raceway design. The major emphasis was placed on the ability to increase the number of fish released from hatcheries that survive to return as adults.

Rearing density is one of the most important elements in fish culture. Fish culturists have attempted to rear fish in hatchery ponds at densities that most efficiently use the rearing space available (Ewing and Ewing, 1995). Such efficiency studies require a knowledge of cost of rearing and the return of adults to the fisheries and to the hatchery.

It is widely accepted that the limitations on survival imposed by rearing densities are dependent upon oxygen availability. The models of Westers (1970), Liao (1971), and Banks et al. (1979) are based on the limitations of oxygen availability at various densities, temperature, and sizes of the fish being reared. Oxygen limitations can be overcome by increased flow, but in recent years, addition of oxygen to the raceways has become an acceptable alternative.

In spite of the acceptance of oxygen as the limiting factor in fish culture at the present time, there is little information on the relationship between oxygen availability to cultured salmon and their subsequent survival to adulthood after release. This project will extend that information by examining the effects of oxygen supplementation in a surface water hatchery on the rearing and survival of spring chinook salmon.

The first four years of the project examined the operational aspects of the use of supplemental oxygen, the effects on water quality on oxygen utilization, and overall quality of fish reared at high densities with supplemental oxygen. Raw data and preliminary analyses for four years of juvenile rearing have already been described (Ewing and Sheahan 1990; Ewing and Sheahan 1991; Ewing and Sheahan 1992; Ewing et. al. 1993; Ewing et al. 1994a). The next series of reports provided detailed analyses of water quality and growth parameters during the rearing years and tabulated the recovery of marked adults as they become available. Previous reports analyzed ammonia production (Ewing 1995), growth, mortalities, and feeding (Ewing 1996), and oxygen consumption (Ewing 1997) of fish in the fourteen experimental raceways. Last years report (Ewing 1998) analyzed carbon dioxide production of the experimenatal fish and water chemistry of the water flowing into the hatchery from Salmon Creek. Manuscripts summarizing these analyses are being prepared for publication (Appendix A).

The present report continues the analysis of the 6 million data points collected during the project. In this report, we examine the relationship between scale characteristics of returning adults to determine the fork length at which they entered the ocean. These lengths are then related to the length frequencies of fish in the various experimental groups at the time that they left the hatchery. We also summarize the water quality parameters at Dexter Rearing Ponds and present the complete returns for all experimental groups.

METHODS AND MATERIALS

Hatchery Rearing

Spring chinook salmon (Oncorhynchus tshawytscha) adults were collected and spawned as described in earlier reports (Ewing 1995, 1996, 1997). Juvenile fish were reared in outdoor raceways until the time of tagging (during the month of July) when they were introduced into experimental raceways. Because of the complexity of the experimental design, the letters A through G are used to designate the different test groups (Table 1). Subscripts represent replicates. Ideal experimental conditions and actual experimental conditions at release for each raceway are given in Table 2. Because these conditions were rarely attained due to differences in water temperatures and mortalities, actual rearing densities and loads are also given in Table 2.

Fish were manually fed BioMoist Feed from Bioproducts, Inc., Warrenton, OR. Fish growth was programmed to meet production goals based on historical monthly weight gains. Sample counts to determine fish per pound for the single pass systems were taken at the end of each month by crowding the fish, as described earlier (Ewing 1996). Growth rates for each experimental pond were calculated by regression analysis, as explained in Ewing (1995, 1996).

When required by the experimental design, oxygen was added to the raceways through sealed contact columns (Westers et. al., 1988; Colt et al. 1993). Modifications of the design to fit site-specific requirements were determined before experimental rearing began (Fish Factory, 1990). No packing media or dispersion plates were used in the columns. In raceways with supplemental oxygen, addition of oxygen was adjusted so that the concentration of oxygen in the raceway effluent was approximately equal to

Table 1. Designations and pond number for experimental ponds at Willamette Hatchery.

Designation	Pond	Characteristics
A_1	7	Normal density, no oxygen supplementation
A_2	17	Replicate
B_1	6	Half density, no oxygen supplementation
B_2	16	Replicate
C_1	8	Normal density, oxygen supplementation
C_2	18	Replicate
D_1	9	Triple density, oxygen supplementation
D_2	19	Replicate
E_1	30N	Michigan system, first pass, oxygen added
E_2	30S	Replicate
F_1	20N	Michigan system, second pass, oxygen added
F_2	20S	Replicate
G_1	10S	Michigan system, third pass, oxygen added
G_2	10N	Replicate

Table 2. Ideal and actual characteristics of experimental ponds at Willamette Hatchery.

Date, Group	Number of fish	Final kg	Inflow Lpm	Load kg/Lpm	Pond volume m^3	Density kg/m^3
Ideal Characteristics						
A	36,000	1,633	1895	0.86	104.8	15.58
B	18,000	817	1895	0.43	104.8	7.80
C	36,000	1,633	1895	0.86	104.8	15.58
D	108,000	4,899	1895	2.58	104.8	46.75
E	54,000	2,449	2843	0.86	52.4	46.75
F	54,000	2,449	2843	0.86	52.4	46.75
G	54,000	2,449	2843	0.86	52.4	46.75
Actual Characteristics						
1990-1991						
A1	37,895	1,559	1895	0.82	104.8	14.87
A2	33,300	1,281	1895	0.68	104.8	12.22
B1	19,609	916	1895	0.48	104.8	8.74
B2	18,264	755	1895	0.40	104.8	7.20
C1	37,669	1,589	1895	0.84	104.8	15.17
C2	38,960	1,665	1895	0.88	104.8	15.89
D1	117,889	3,731	1895	1.97	104.8	35.60
D2	100,792	3,775	1895	1.99	104.8	36.02
E1	47,260	1,366	2843	0.48	52.4	26.07
E2	52,509	1,563	2843	0.55	52.4	29.82
F1	50,480	1,672	2843	0.59	52.4	31.90
F2	54,943	1,831	2843	0.64	52.4	34.95
G1	49,341	1,509	2843	0.53	52.4	28.80
G2	47,675	1,528	2843	0.54	52.4	29.16
1991-1992						
A1	38,881	1,717	1895	0.91	104.8	16.39
A2	38,511	1,654	1895	0.87	104.8	15.78
B1	19,345	973	1895	0.51	104.8	9.28
B2	21,546	955	1895	0.50	104.8	9.11
C1	37,420	1,684	1895	0.89	104.8	16.07
C2	37,474	1,518	1895	0.80	104.8	14.49
D1	113,436	4,195	1895	2.21	104.8	40.03
D2	120,854	4,128	1895	2.18	104.8	39.38
E1	58,016	1,682	2843	0.59	52.4	32.09
E2	53,524	1,527	2843	0.54	52.4	29.14
F1	51,952	1,736	2843	0.61	52.4	33.14
F2	55,455	1,923	2843	0.68	52.4	36.70
G1	58,804	2,030	2843	0.71	52.4	38.74
G2	57,627	2,023	2843	0.71	52.4	38.60

Table 2. (cont)

Date, Group	Number of fish	Final kg	Inflow Lpm	Load kg/Lpm	Pond volume m_3	Density kg/m_3
1992-1993						
A1	37,014	1,814	1895	0.96	104.8	17.31
A2	36,480	1,745	1895	0.92	104.8	16.66
B1	19,792	995	1895	0.52	104.8	9.49
B2	19,968	946	1895	0.50	104.8	9.03
C1	38,211	2,065	1895	1.09	104.8	19.71
C2	38,023	1,846	1895	0.97	104.8	17.61
D1	101,943	4,925	1895	2.60	104.8	46.99
D2	105,792	4,990	1895	2.63	104.8	47.62
E1	42,883	1,606	2843	0.57	52.4	30.65
E2	44,016	1,534	2843	0.54	52.4	29.27
F1	50,580	1,923	2843	0.68	52.4	36.70
F2	47,500	1,740	2843	0.61	52.4	33.20
G1	52,786	2,078	2843	0.73	52.4	39.66
G2	49,191	1,714	2843	0.60	52.4	32.71
1993-1994						
A1	38,955	1,116	1895	0.59	104.8	10.65
A2	36,525	1,103	1895	0.58	104.8	10.53
B1	17,550	591	1895	0.31	104.8	5.64
B2	17,550	611	1895	0.32	104.8	5.83
C1	36,704	1,129	1895	0.60	104.8	10.78
C2	33,082	1,081	1895	0.57	104.8	10.32
D1	116,110	3,105	1895	1.64	104.8	29.62
D2	108,378	3,036	1895	1.60	104.8	28.97
E1	44,505	941	2843	0.33	52.4	17.96
E2	41,760	1,093	2843	0.38	52.4	20.86
F1	50,460	1,317	2843	0.46	52.4	25.14
F2	49,077	1,305	2843	0.46	52.4	24.91
G1	53,235	1,431	2843	0.50	52.4	27.31
G2	51,136	1,238	2843	0.44	52.4	23.63

the concentration of oxygen in the inflow. Oxygen flow into the contact column was increased or decreased manually using a Brooks rotometer.

Water flow into the ponds was adjusted by gate valves on the main water supply line to the hatchery. Flow was measured by determining the exact measurements of the pond dimensions and determining the length of time required for a particular flow to increase the depth of the raceway by one inch. An inch of depth represented 920 gallons or 123 ft^3. The time required for a flow of 500 gpm to increase the depth by 1 inch was calculated as (920/500)x60 or 110 seconds.

Length frequencies were obtained from all experimental groups 1-2 weeks before the juvenile salmon were released. These samples represent the best available estimates of length frequencies of the released fish.

Scale Analysis

Scale samples were taken from juvenile fish of various sizes in 1993 and 1994 just before release. These were cleaned and sorted and regenerated scales were discarded. The scale radii were then measured on a microfiche reader and plotted against the fork length recorded for the fish. Regressions of this relationship were obtained for both years.

Adult fish from the experimental groups usually returned to Dexter Rearing Ponds from May to July, where they were sorted and hauled to Willamette or McKenzie Hatchery for holding until mature. Fish judged in excess of the broodstock requirements or those too badly injured to survive until spawning were killed at the Dexter facility and heads were taken from adipose-fin-clipped fish. Lengths and sexes were recorded and enclosed with the snouts in plastic bags. Scale samples were taken and stored in envelopes with the identifying code number and pertinent information.

Spawning at Willamette and McKenzie Hatcheries occurred during September and October. Fish with missing adipose fins were sorted and their heads were removed to plastic bags with identifying numbers, sex, and fork length. Scale samples were also taken at this time. After spawning, all collected snouts were taken to the Clackamas Recovery Center, where coded-wire tags were removed from the snouts and decoded. These were then sorted by tag code and the information was entered into the coded-wire tag database.

Adult scales from adults derived from experimental groups were also sorted and cleaned and non-regenerated scales were mounted on slides. When mounting was complete, the number of millimeters from the focus to advent of seawater growth was determined for up to 12 non-regenerated scales per fish using a microfiche reader. The microfiche reader was calibrated with a hemocytometer. Magnification was 41 x. Size of juveniles when they went to sea was determined by the regression equations for juvenile size vs scale radius. Estimates of size at ocean entrance from scales of adults sorted by brood and experimental raceway were combined and sorted into length frequencies. These length frequency curves (ELF) were superimposed on those measured at the time of release (MLF) to determine which sizes in the juvenile population survived to adulthood.

Dexter Water Quality Measurements

In addition to the fish reared at Willamette Hatchery, about 400,000 juvenile chinook salmon were reared each year at Dexter Rearing Ponds to ensure that mitigation goals for Willamette Hatchery were attained. These fish were also marked with adipose fin clips and coded wire tags. Water quality measurements were taken at intervals for comparison with the measurements of water quality in experimental groups at Willamette Hatchery. These fish were not reared experimentally, except as a comparison between normal rearing techniques and the unusual conditions imposed upon rearing by the experiment with oxygen supplementation at Willamette Hatchery. Methodology for water quality was the same as that described for Willamette Hatchery (Ewing et al. 1993 and 1994).

Adult Return Data

Data from adult returns were collected from the database of coded wire tag recoveries maintained by the Pacific States Fisheries Management Council. Data is available on the internet at http://www.psmfc.org/rmpc/cwt_reports.html. Recoveries of coded wire tags from experimental releases at Willamette Hatchery were summarized by tag code and by age class in this report. The report next year will provide an analysis of the recovery data and a summary of the results of the Willamette Hatchery Oxygen Supplementation experiment.

RESULTS AND DISCUSSION

Scale Analysis of Returning Adults

Introduction

Scale analysis is an important tool for determining life history characteristics of returning adult salmon. These analyses have been used extensively for determining year classes of adult salmon and separating wild from hatchery reared adults. Less work has been done with the scale radius-fork length relationship to determine the size at which juvenile fish enter the sea and survive to return as adults.

In the present report, I describe the results of analysis of scales of returning adults to determine the sizes at which juvenile salmon entered the sea. These lengths were then related to the length frequencies of the same broods of fish just prior to release. Of particular interest was the bimodal character of the length frequencies of some of the faster growing experimental groups (Ewing 1996). In Atlantic salmon, fast growing juveniles often become precocious (Lundqvist 1980; Saunders et al. 1982), do not migrate to the sea (Berglund et al. 1994; Hansen et al. 1989; Fangstam et al. 1993) and thus do not contribute to the adult population. On the other hand, Atlantic salmon reared in hatcheries usually show bimodal length distributions (Thorpe 1977; Thorpe and Morgan 1978). Fish in the upper mode are those that undergo parr-smolt transformation in the spring with subsequent migration to the sea (Thorpe 1977; Bailey et al. 1980).

Pacific salmon in culture also show bimodal distributions of length frequencies, but the implications of the two modes of length frequencies to survival is not clear. I attempted to use scale analysis to determine if the modes of length frequencies were related to their migration tendencies and survival to adulthood.

Length Frequencies of Juvenile Chinook Salmon at Release

Upper and lower modes of length frequency and the percent of the fish measured in each mode were determined by graphic analysis (Figure 1; Table 3). At least one group of fish in each year was unimodal (Figure 2), that is, no evidence of a upper mode was found in graphs of length frequency. In the 1992 release year, five of the groups were found to be unimodal (Table 3). Average lengths of lower modes of combined ponds were significantly smaller than those of the upper modes (Table 4).

Comparisons between average lengths of upper and lower modes could not be made with analysis of variance because of unequal sample sizes. However, t-tests comparing each mode for each year showed that average lengths of lower modes were always significantly smaller in fish reared in Michigan raceways than those reared in conventional raceways (Table 4). Average lengths of upper modes were smaller in fish reared in Michigan raceways (Table 4) but only 2 of the 4 rearing years showed significant differences between fish reared in the two types of raceways.

A discussion of length frequencies in relation to growth can be found in an earlier report (Ewing 1996).

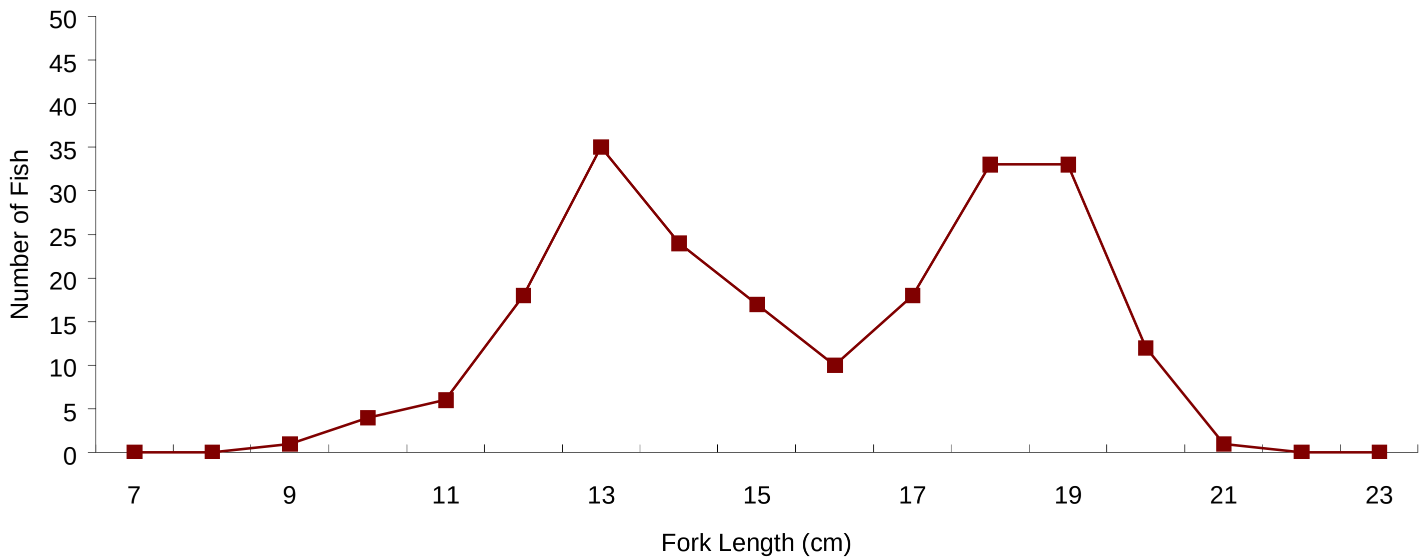

Figure 1. An example of the bimodal length distributions present in hatchery-reared spring chinook salmon at Willamette Hatchery. This example was from group A2 measured on February 28, 1993.

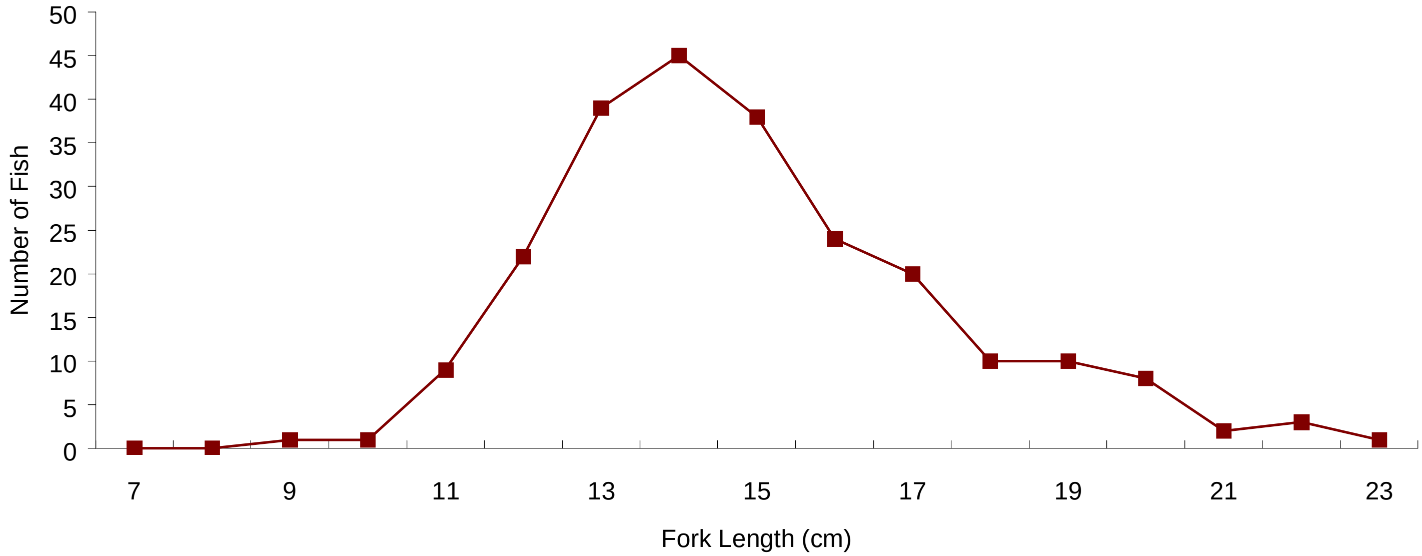

Figure 2. An example of the unimodal length distributions present in hatchery-reared spring chinook salmon at Willamette Hatchery. This example was from group B1 measured on February 20, 1991.

Table 3. Modes of length frequency in cm and the percent of fish measured in each mode. Length frequency measurements were performed during the four rearing years from 1991-1994 at Willamette Hatchery.

Date, group	Lower Mode (cm)	Percent	Upper Mode (cm)	Percent
Feb 20, 1991				
A1	14.5	61.7	18.8	38.3
A2	13.3	64.6	17.2	35.4
B1	13.8	34.3	17.5	66.7
B2	14.2	100.0	--	0.0
C1	14.0	42.2	16.7	57.8
C2	14.2	58.8	18.5	41.7
D1	14.0	100.0	--	0.0
D2	14.0	74.8	18.0	25.6
E1	13.0	100.0	--	0.0
E2	12.8	89.7	16.8	10.3
F1	13.5	66.4	16.3	33.6
F2	13.2	66.9	16.5	33.1
G1	13.5	71.2	16.3	28.8
G2	14.0	65.1	16.5	34.9
Feb 26, 1992				
A1	14.0	49.6	17.5	50.4
A2	13.3	55.0	17.5	45.0
B1	13.0	49.3	18.0	50.7
B2	13.5	74.2	18.3	25.8
C1	14.0	100.0	--	0.0
C2	13.3	66.2	16.5	33.8
D1	14.1	100.0	--	0.0
D2	13.3	100.0	--	0.0
E1	13.0	100.0	--	0.0
E2	13.3	100.0	--	0.0
F1	12.8	69.8	16.8	30.2
F2	13.2	66.4	17.5	33.6
G1	13.4	59.8	16.6	40.2
G2	13.0	82.7	17.2	17.3

Table 3. (cont.)

Date, Group	Lower (cm)	Mode Percent	Upper (cm)	Percent
Feb 23, 1993				
A1	13.4	63.3	19.1	36.7
A2	13.2	51.9	18.8	48.1
B1	13.3	65.6	19.0	34.4
B2	13.0	70.0	18.5	30.0
C1	13.4	64.8	19.2	35.2
C2	13.7	58.4	18.9	41.6
D1	13.0	58.5	18.7	41.5
D2	13.0	56.7	18.2	43.3
E1	12.5	62.8	17.7	37.2
E2	12.5	86.8	17.7	13.2
F1	13.2	52.9	17.5	47.1
F2	12.6	76.8	17.3	23.2
G1	13.4	65.7	18.2	34.3
G2	12.8	100.0	--	0.0
Feb 23, 1994				
A1	13.1	80.1	16.5	19.9
A2	12.7	57.9	14.8	42.1
B1	12.4	61.6	15.3	38.4
B2	13.4	50.0	15.8	50.0
C1	12.8	87.0	16.0	13.0
C2	12.2	84.1	17.0	15.9
D1	12.5	73.8	14.9	26.2
D2	12.0	76.3	15.0	23.7
E1	11.8	90.6	15.0	9.4
E2	11.7	89.3	15.8	10.7
F1	12.0	100.0	--	0.0
F2	12.4	100.0	--	0.0
G1	12.0	87.4	16.1	12.6
G2	11.8	88.9	15.0	11.1

Table 4. Average lengths (cm) of upper and lower modes of length frequency and the average percent of fish measured in each mode. Length frequency measurements were performed during the four rearing years from 1991-1994 at Willamette Hatchery. Asterisks after values indicate significant differences ($P \leq 0.05$) from values in raceways.

Date, group	Lower Mode Length (cm)	Lower Mode Percent	Upper Mode Length (cm)	Upper Mode Percent
Feb 20, 1991				
Raceways	14.00 ± 0.12	67.1 ± 7.9	17.78 ± 0.26	33.0 ± 7.9
Mich Pds	13.33 ± 0.16*	76.6 ± 5.5	16.48 ± 0.07*	23.5 ± 5.5
Combined	13.71 ± 0.13	71.1 ± 5.3	17.19 ± 0.23	28.9 ± 5.3
Feb 26, 1992				
Raceways	13.56 ± 0.14	74.3 ± 7.6	17.56 ± 0.22	25.7 ± 7.6
Mich Pds	13.12 ± 0.08*	79.8 ± 6.5	17.03 ± 0.14	20.2 ± 6.5
Combined	13.37 ± 0.10	76.6 ± 5.2	17.32 ± 0.15	23.4 ± 5.2
Feb 23, 1993				
Raceways	13.25 ± 0.08	61.2 ± 1.9	18.80 ± 0.11	38.9 ± 1.9
Mich Pds	12.83 ± 0.14*	74.2 ± 6.4	17.68 ± 0.12*	25.8 ± 6.4
Combined	13.07 ± 0.09	66.7 ± 3.4	18.37 ± 0.17	33.3 ± 3.4
Feb 26, 1994				
Raceways	12.64 ± 0.15	71.4 ± 4.4	15.66 ± 0.27	28.7 ± 4.4
Mich Pds	11.95 ± 0.09*	92.7 ± 2.1	15.48 ± 0.20	7.3 ± 2.1
Combined	12.34 ± 0.13	80.5 ± 3.9	15.60 ± 0.18	19.5 ± 3.9

Scale Radii vs Fork Lengths for Juvenile Chinook

In 1993, 133 non-regenerated scales were collected at release from 1991 brood juvenile chinook salmon from all 14 experimental ponds. Regressions of scale radii vs fork length for these fish showed a linear relationship (Figure 3) with a slope of 20.937 and a Y-intercept of 2.613. R^2 value was 0.959. In 1994, 239 non-regenerated scales were collected from 1992 brood juvenile chinook salmon from all 14 experimental ponds. Regressions of scale radii vs fork length for these fish also showed a linear relationship (Figure 4) with a slope of 19.769 and a Y-intercept of 2.913. R^2 value was 0.915. When scales from both brood years were combined, 372 non-regenerated scales produced a linear regression with a slope of 20.814, a Y-intercept of 2.463, and an R^2 value of 0.943 (Figure 5). No scales from juveniles in 1989 and 1990 broods were collected for regressions. The regression equation for combined samples was used for analysis of adult scales from 1989 and 1990 brood fish.

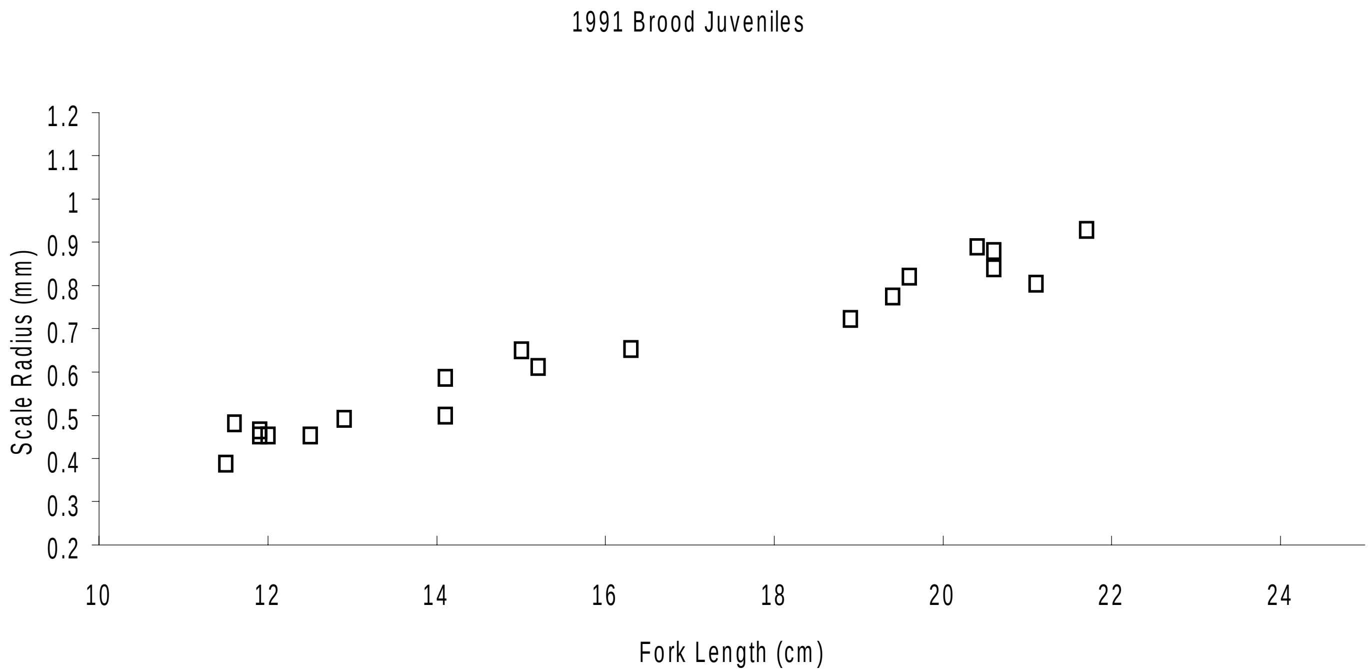

Figure 3. Relationship between fork length of juvenile chinook salmon and scale radius of unregenerated scales, 1991 brood.

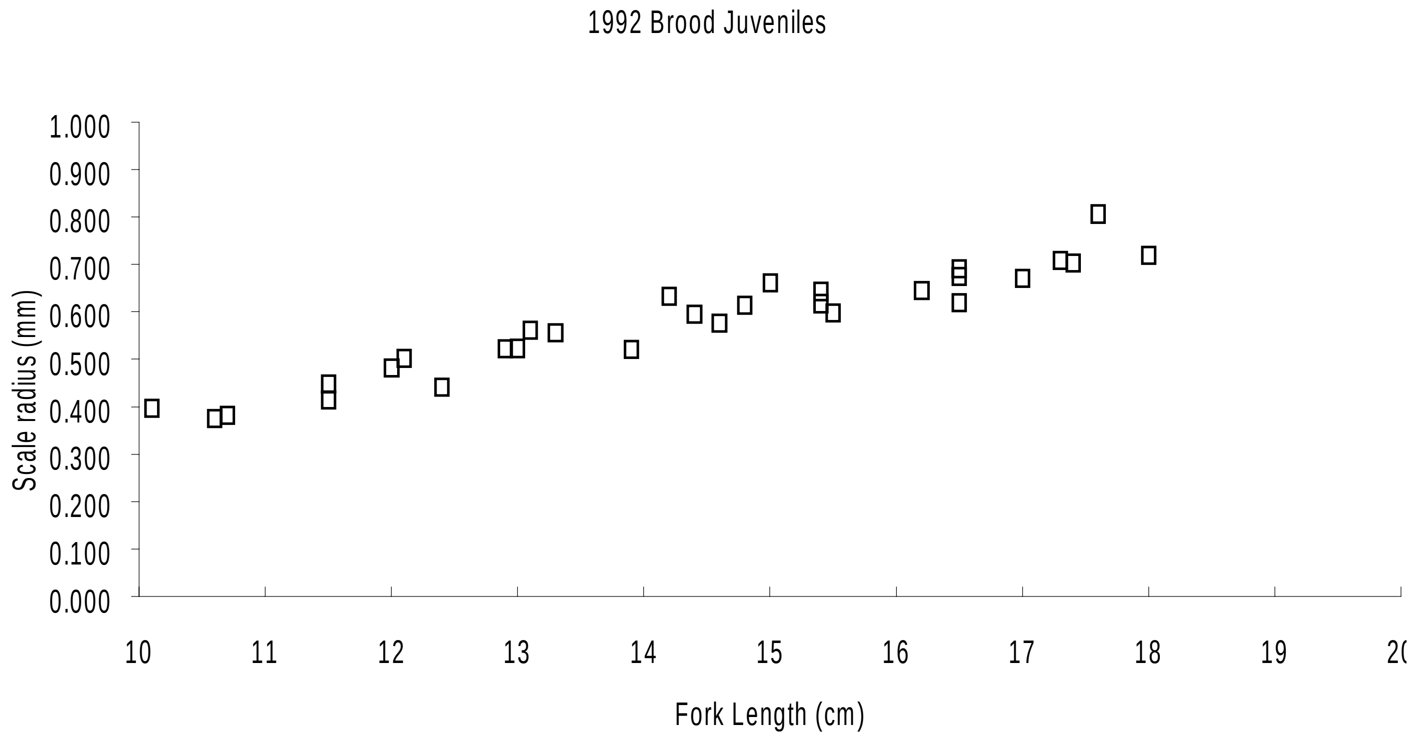

Figure 4. Relationship between fork length of juvenile chinook salmon and scale radius of unregenerated scales, 1992 brood.

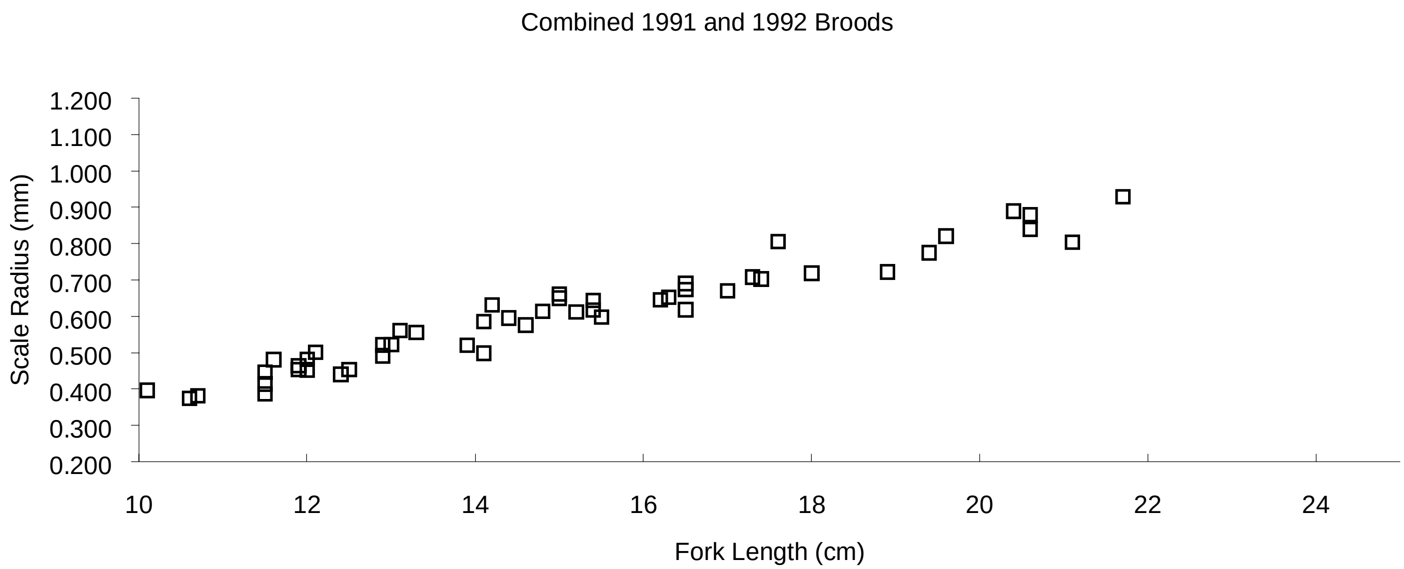

Figure 5. Relationship between fork length of juvenile chinook salmon and scale radius of unregenerated scales from combined 1991 and 1992 broods.

Relationship of Measured Length Frequencies To Those From Scale Estimates

For clarity in discussion, length frequencies of juvenile salmon measured at the time of release from the hatchery will be referred to as measured length frequencies (MLF). Length frequencies derived from estimates of lengths back-calculated from the size of the freshwater portion of scales of returning adults of a particular brood year will be referred to as estimated length frequencies (ELF).

Comparisons of MLF with ELF involved analysis of 56 graphs (14 raceways, 4 brood years). Because much of the information is similar, only the graphics of control raceways (groups A1 and A2) will be shown here. Graphics from comparisons from other experimental raceways are given in Appendix B.

For 1989 brood fish in control raceways, bimodal length frequencies were found in both group A1 (Figure 6) and group A2 (Figure 7). In group A1, length frequencies estimated from scales (ELF) had a maximum similar to that of the length frequencies in February (MLF) (Figure 6). Scales from only a single fish represented lengths from the upper mode of length frequencies. In group A2, the ELF also had a maximum similar to that of the MLF, but no representatives from the upper mode were found (Figure 7). When both groups were combined (Figure 8), ELF was similar to the lower mode of the MLF. Scales from only a single fish represented lengths from the upper mode of MLF. Average lengths at ocean entrance estimated from scales were significantly smaller than those from measured before release (Table 5).

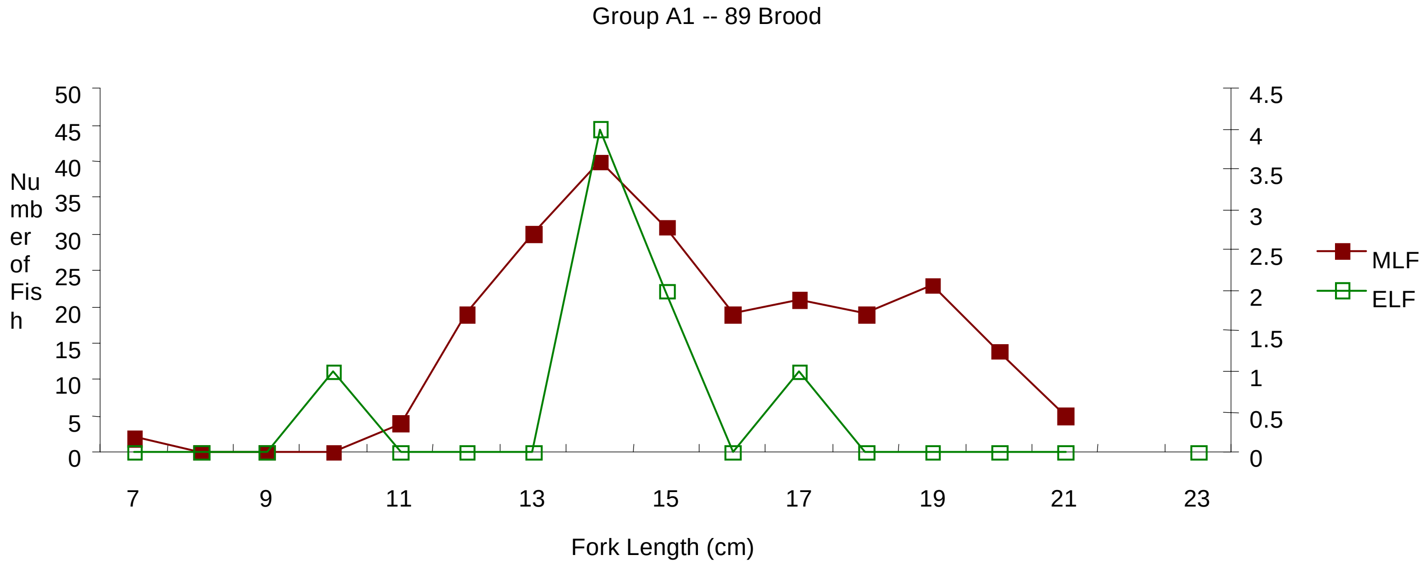

Figure 6. Comparison of fish lengths at ocean entrance, as estimated from scales (ELF), with fish lengths measured on February 20, 1991 just before release from Willamette Hatchery (MLF). Data shown are for group A1, 1989 brood.

■ -- ■, MLF; □ -- □, ELF.

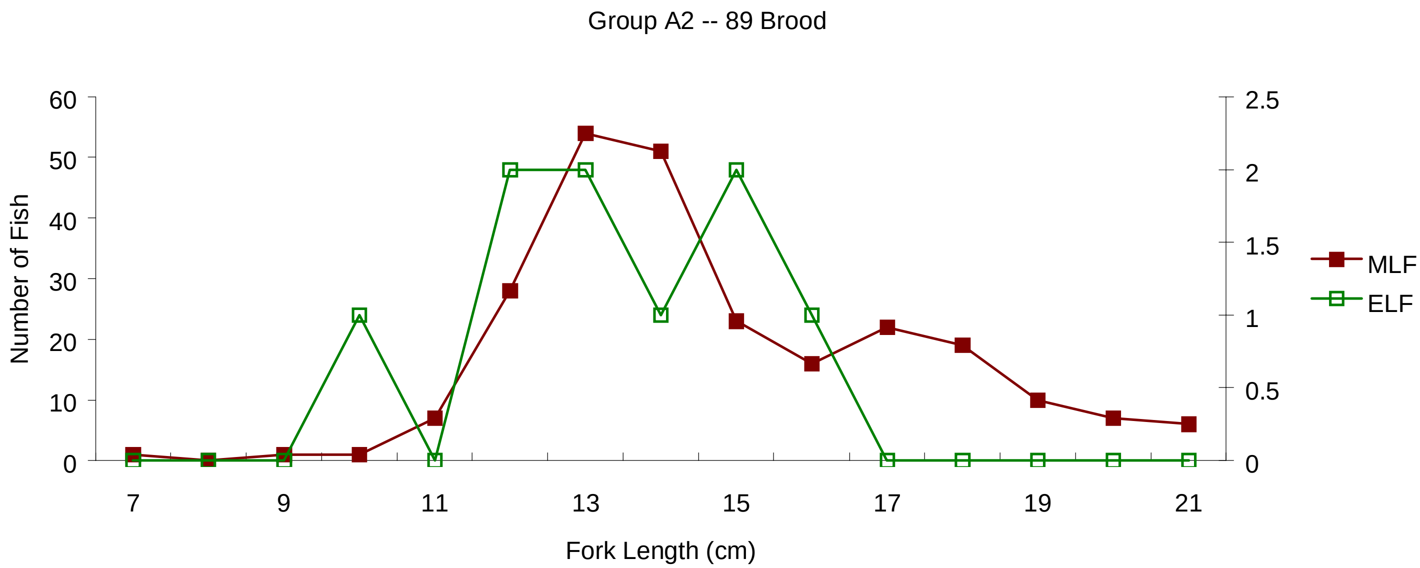

Figure 7. Comparison of fish lengths at ocean entrance, as estimated from scales (ELF), with fish lengths measured on February 20, 1991 just before release from Willamette Hatchery (MLF). Data shown are for group A2, 1989 brood.

■ -- ■, MLF; □ -- □, ELF.

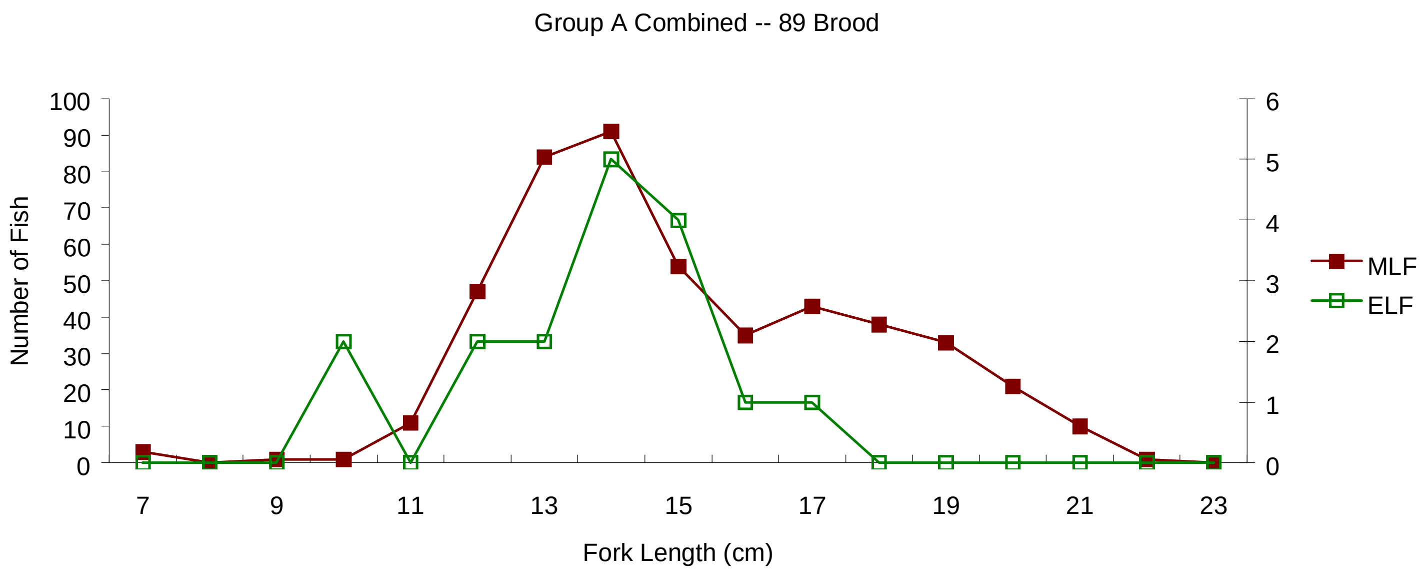

Figure 8. Comparison of fish lengths at ocean entrance, as estimated from scales (ELF), with fish lengths measured on February 20, 1991 just before release from Willamette Hatchery (MLF). Data shown are for combined groups A1 and A2, 1989 brood.

■ -- ■, MLF; □ -- □, ELF.

For 1990 brood fish, only a few scales samples were obtained: four samples for group A1 and 1 sample for group A2. When these were combined and compared to combined measured length frequencies (Figure 9), scale estimates indicated sizes above, below, and between modes of MLF. The single scale sample for A2 was significantly smaller than the average from measured length frequencies, but lengths estimated from scales for group A1 and combined groups A1 and A2 were not significantly different (Table 5).

For 1991 brood fish, bimodal length frequencies were found in both group A1 (Figure 10) and group A2 (Figure 11). In group A1, length frequencies estimated from scales were distributed throughout the range of the MLF (Figure 10). In group A2, length frequencies from scales encompassed the larger end of the lower mode and the smaller end of the upper mode of the MLF (Figure 11). When both groups were combined (Figure 12), the ELF was bimodal, with a lower mode similar to the lower mode of the MLF and an upper mode 2 cm smaller than the upper mode of the MLF. Average length derived from scale analysis was significantly smaller than that from measured length frequencies for group A2 but not for groups A1 or combined groups (Table 5).

Table 5. Average fork lengths (cm) of juvenile chinook salmon from groups A1 and A2 measured before release from Willamette Hatchery and average fork lengths (cm) at ocean entrance, as measured by scale analysis. Averages of scale estimates significantly different from averages of measured fork lengths are marked by asterisks.

Brood Year, Group	Measured Fork Length (cm)	Scale Estimates (cm)
1989		
Group A1	16.10 ± 0.18 (227)	*14.66 ± 0.69 (8)
Group A2	15.38 ± 0.16 (246)	*13.79 ± 0.65 (9)
Combined A	15.73 ± 0.12 (473)	*14.20 ± 0.47 (17)
1990		
Group A1	16.05 ± 0.14 (224)	15.69 ± 2.06 (4)
Group A2	15.74 ± 0.18 (231)	*11.13 (1)
Combined A	15.89 ± 0.11 (455)	14.78 ± 1.84 (5)
1991		
Group A1	15.76 ± 0.30 (218)	15.50 ± 0.51 (38)
Group A2	16.26 ± 0.20 (212)	*15.35 ± 0.35 (35)
Combined A	16.00 ± 0.14 (430)	15.43 ± 0.31 (73)
1992		
Group A1	13.59 ± 0.14 (206)	14.21 ± 0.42 (19)
Group A2	13.98 ± 0.14 (197)	13.94 ± 0.48 (19)
Combined A	13.78 ± 0.10 (403)	14.07 ± 0.31 (38)

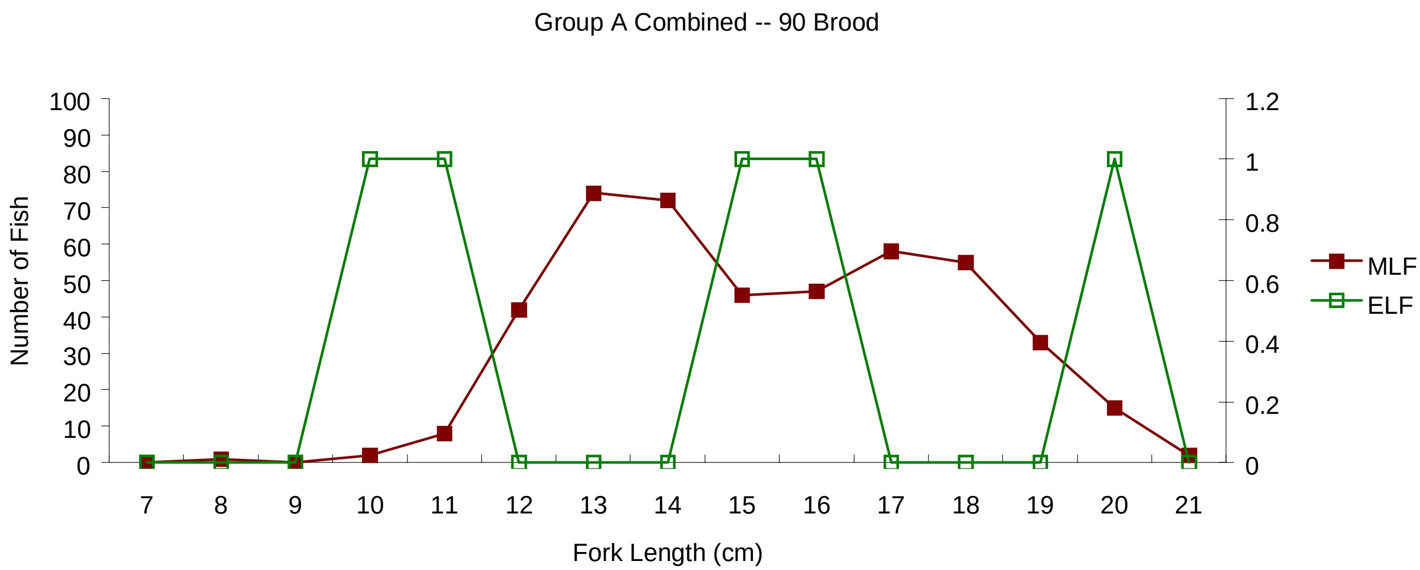

Figure 9. Comparison of fish lengths at ocean entrance, as estimated from scales (ELF), with fish lengths measured on February 26, 1992 just before release from Willamette Hatchery (MLF). Data shown are for combined groups A1 and A2, 1990 brood. ■ -- ■, MLF; □ -- □, ELF.

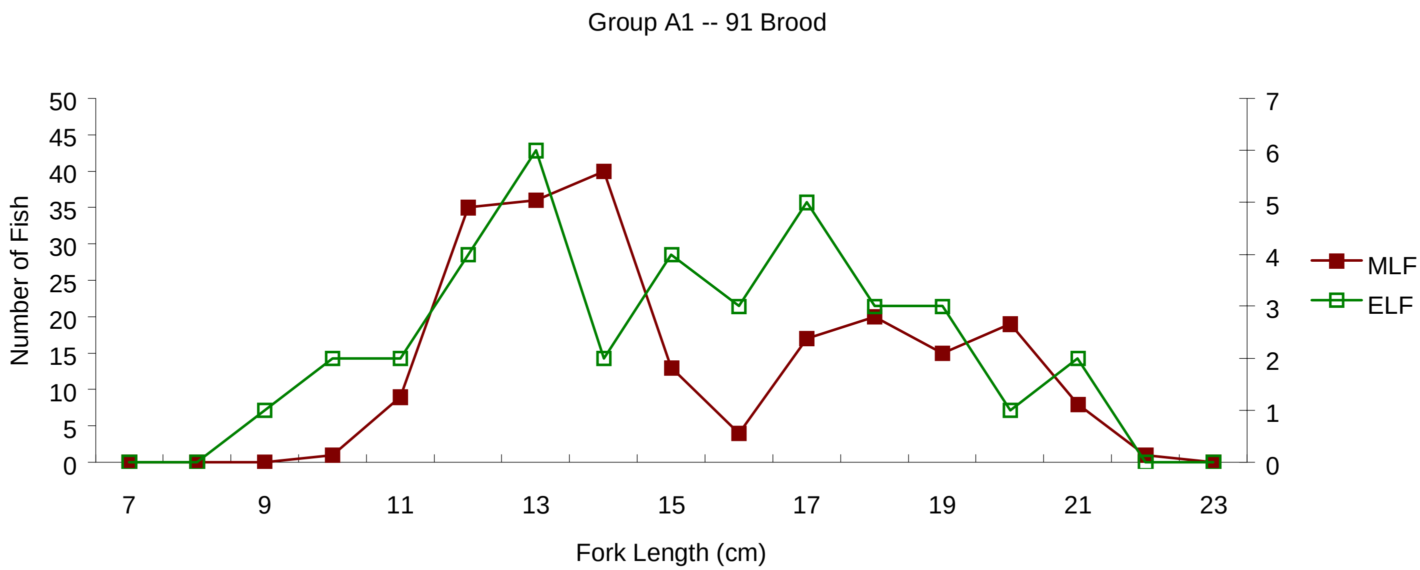

Figure 10. Comparison of fish lengths at ocean entrance, as estimated from scales (ELF), with fish lengths measured on February 23, 1993 just before release from Willamette Hatchery (MLF). Data shown are for group A1, 1991 brood.

■ -- ■, MLF; □ -- □, ELF.

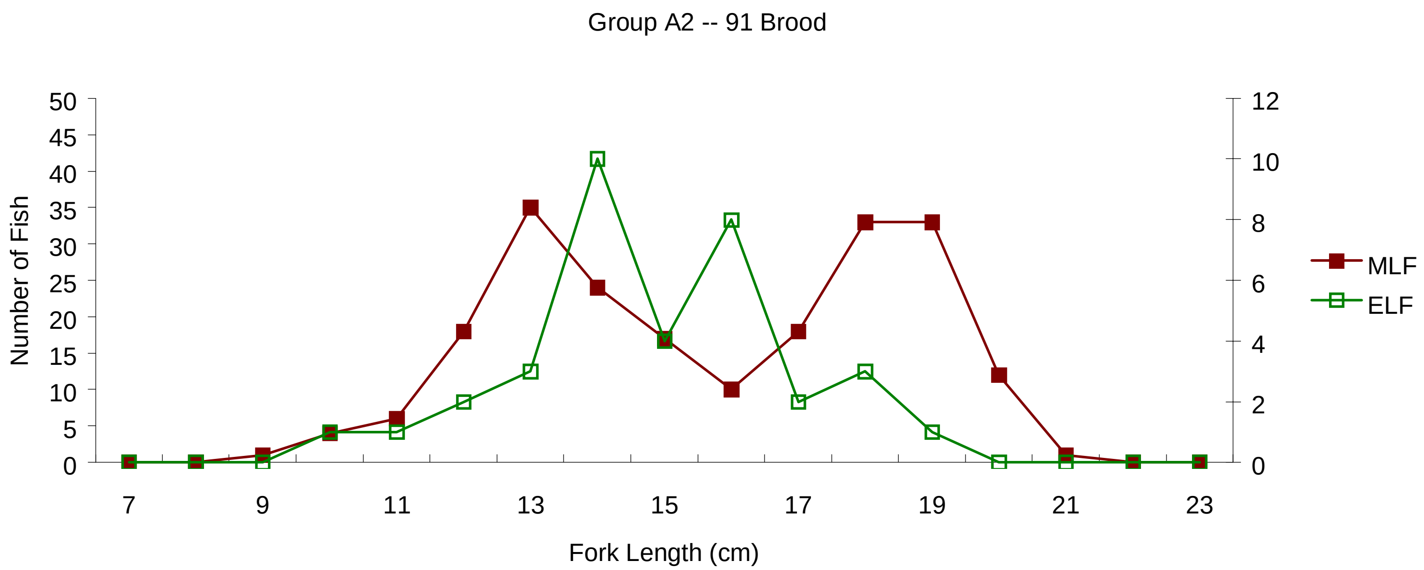

Figure 11. Comparison of fish lengths at ocean entrance, as estimated from scales (ELF), with fish lengths measured on February 23, 1993 just before release from Willamette Hatchery (MLF). Data shown are for group A2, 1991 brood.

■ -- ■, MLF; □ -- □, ELF.

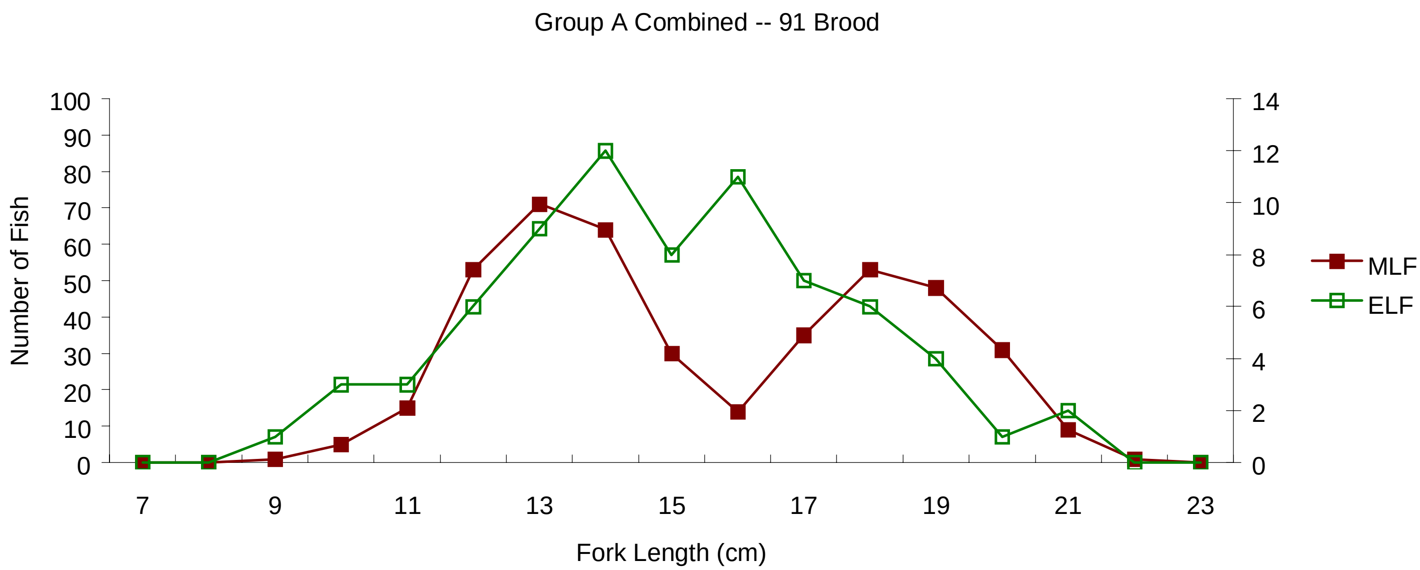

Figure 12. Comparison of fish lengths at ocean entrance, as estimated from scales (ELF), with fish lengths measured on February 23, 1993 just before release from Willamette Hatchery (MLF). Data shown are for combined groups A1 and A2, 1991 brood. ■ -- ■, MLF; □ -- □, ELF.

For 1992 brood fish, bimodal MLF was found in both group A1 (Figure 13) and group A2 (Figure 14). The ELF was also bimodal. The lower mode of the ELF corresponded to that of the MLF, whereas the upper mode of the ELF was smaller than that observed with the MLF. When the groups were combined (Figure 15), both ELF and MLF were similar. Evidence for bimodality was not as distinct in the combined populations.

Average fork lengths derived from scale analysis were not significantly different from those measured before release (Table 5).

These data indicate that, in 1989 and 1990 broods, juveniles from the largest size classes did not survive well and the average lengths measured from scale analysis were significantly smaller than those from the measured lengths before release. In 1991 and 1992 broods, this difference was not evident. Juveniles from the 1992 brood did not grow to the same large size before release as in the other years (Table 4). Survival was similar for 1991 and 1992 broods, but not as great as in the 1989 brood, so that ocean conditions for survival cannot explain the difference between the two results (see later section on returns).

Data from the other experimental raceways from 1989 to 1992 broods is shown in Appendix B. Results from these analyses were similar to that shown for the control group (group A1 and A2) for the four brood years (Tables 6-11).

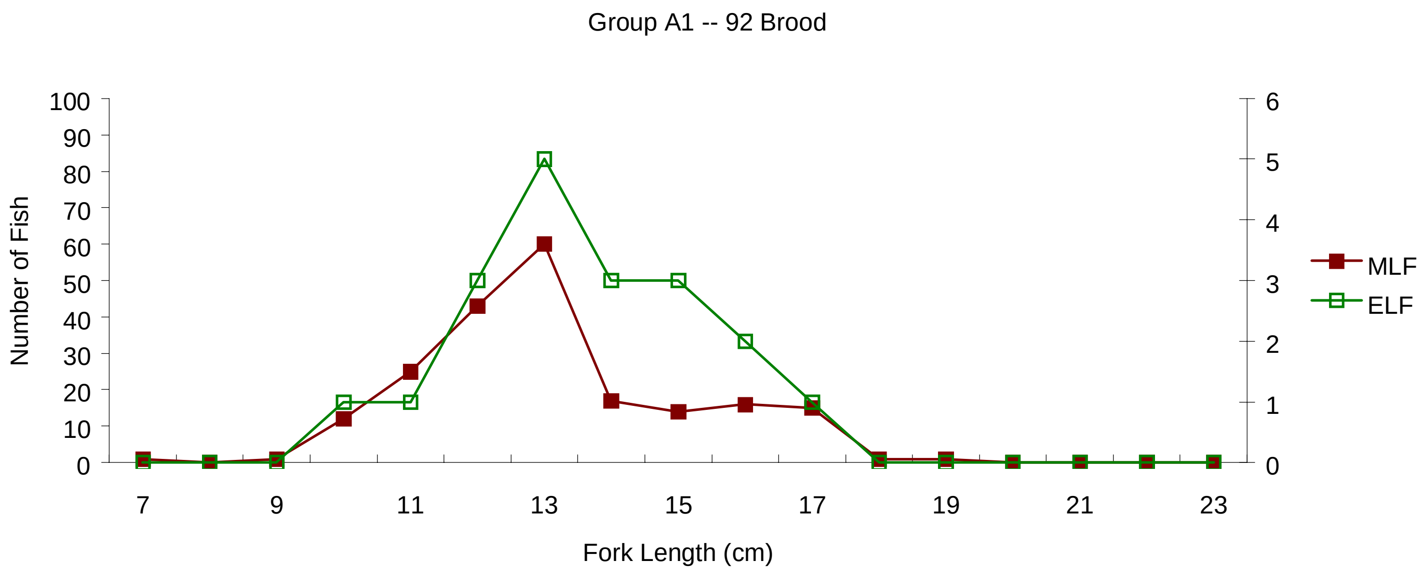

Figure 13. Comparison of fish lengths at ocean entrance, as estimated from scales (ELF), with fish lengths measured on February 23, 1994 just before release from Willamette Hatchery (MLF). Data shown are for group A1, 1992 brood.

■ -- ■, MLF; □ -- □, ELF.

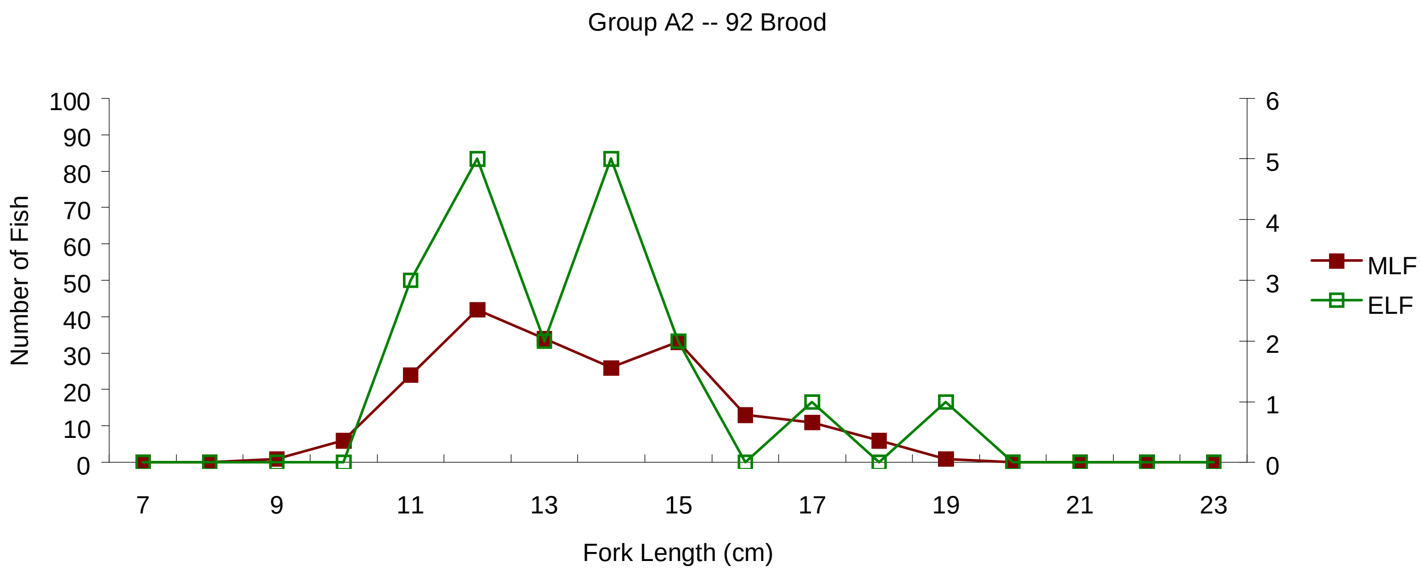

Figure 14. Comparison of fish lengths at ocean entrance, as estimated from scales (ELF), with fish lengths measured on February 23, 1994 just before release from Willamette Hatchery (MLF). Data shown are for group A2, 1992 brood.

■ -- ■, MLF; □ -- □, ELF.

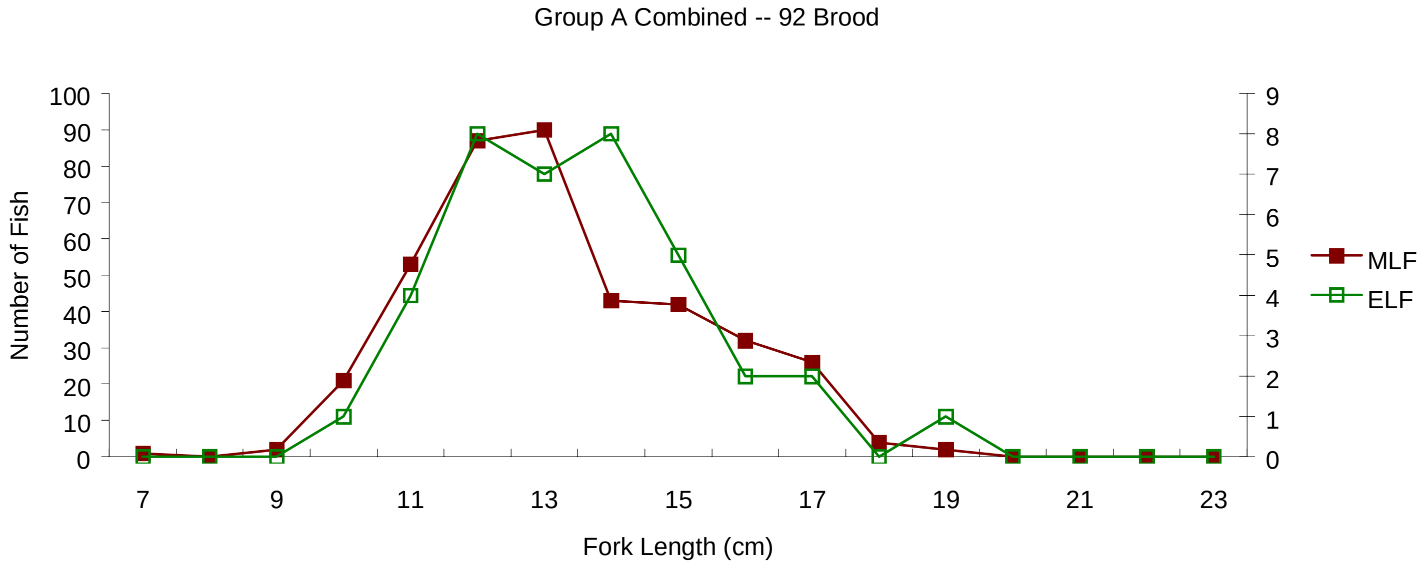

Figure 15. Comparison of fish lengths at ocean entrance, as estimated from scales (ELF), with fish lengths measured on February 23, 1994 just before release from Willamette Hatchery (MLF). Data shown are for combined groups A1 and A2, 1992 brood. ■ -- ■, MLF; □ -- □, ELF.

Table 6. Average fork lengths (cm) of juvenile chinook salmon from groups B1 and B2 measured before release from Willamette Hatchery and average fork lengths (cm) at ocean entrance, as measured by scale analysis. Averages of scale estimates significantly different from averages of measured fork lengths are marked by asterisks.

Brood Year, Group	Measured Fork Length (cm)	Scale Estimates (cm)
1989		
Group B1	16.81 ± 0.20 (209)	14.31 ± 1.34 (6)
Group B2	15.48 ± 0.16 (233)	13.94 ± 1.02 (9)
Combined B	16.11 ± 0.13 (442)	*14.08 ± 0.78 (15)
1990		
Group B1	16.19 ± 0.18 (199)	14.94 ± 1.38 (2)
Group B2	15.22 ± 0.18 (190)	14.83 ± 1.13 (12)
Combined B	15.72 ± 0.13 (389)	14.84 ± 0.97 (14)
1991		
Group B1	16.93 ± 0.19 (199)	16.10 ± 0.53 (30)
Group B2	15.41 ± 0.19 (227)	15.80 ± 0.54 (21)
Combined B	15.68 ± 0.13 (480)	15.98 ± 0.38 (51)
1992		
Group B1	13.88 ± 0.15 (224)	15.36 ± 0.70 (10)
Group B2	14.66 ± 0.14 (210)	14.29 ± 0.61 (15)
Combined B	14.27 ± 0.11 (434)	14.72 ± 0.53 (25)

Table 7. Average fork lengths (cm) of juvenile chinook salmon from groups C1 and C2 measured before release from Willamette Hatchery and average fork lengths (cm) at ocean entrance, as measured by scale analysis. Averages of scale estimates significantly different from averages of measured fork lengths are marked by asterisks.

Brood Year, Group	Measured Fork Length (cm)	Scale Estimates (cm)
1989		
Group C1	16.21 ± 0.18 (206)	*14.07 ± 0.47 (19)
Group C2	16.08 ± 0.18 (212)	*13.47 ± 0.60 (11)
Combined C	16.14 ± 0.13 (418)	*13.85 ± 0.37 (30)
1990		
Group C1	15.75 ± 0.16 (193)	* 8.53 (1)
Group C2	15.50 ± 0.16 (222)	*12.47 ± 1.05 (5)
Combined C	15.62 ± 0.11 (415)	*11.82 ± 1.08 (6)
1991		
Group C1	16.19 ± 0.21 (199)	15.43 ± 0.41 (41)
Group C2	15.81 ± 0.16 (298)	15.24 ± 0.46 (38)
Combined C	15.96 ± 0.13 (497)	15.34 ± 0.30 (79)
1992		
Group C1	13.66 ± 0.12 (215)	14.65 ± 0.51 (20)
Group C2	14.06 ± 0.14 (201)	14.21 ± 0.40 (29)
Combined C	13.85 ± 0.09 (416)	14.39 ± 0.31 (49)

Table 8. Average fork lengths (cm) of juvenile chinook salmon from groups D1 and D2 measured before release from Willamette Hatchery and average fork lengths (cm) at ocean entrance, as measured by scale analysis. Averages of scale estimates significantly different from averages of measured fork lengths are marked by asterisks.

Brood Year, Group	Measured Fork Length (cm)	Scale Estimates (cm)
1989		
Group D1	15.19 ± 0.16 (212)	*13.13 ± 0.75 (5)
Group D2	15.35 ± 0.16 (242)	15.36 ± 1.19 (9)
Combined D	15.27 ± 0.11 (454)	14.56 ± 0.84 (14)
1990		
Group D1	15.23 ± 0.12 (251)	13.03 ± 1.09 (3)
Group D2	14.40 ± 0.13 (204)	14.67 ± 1.27 (3)
Combined D	14.86 ± 0.09 (455)	13.85 ± 0.83 (6)
1991		
Group D1	15.38 ± 0.20 (241)	15.54 ± 0.81 (20)
Group D2	15.39 ± 0.17 (298)	14.54 ± 0.46 (24)
Combined D	15.38 ± 0.13 (539)	14.99 ± 0.45 (44)
1992		
Group D1	13.37 ± 0.13 (257)	12.85 ± 0.32 (14)
Group D2	13.56 ± 0.13 (199)	14.00 ± 0.49 (11)
Combined D	13.45 ± 0.09 (456)	13.35 ± 0.30 (25)

Table 9. Average fork lengths (cm) of juvenile chinook salmon from groups E1 and E2 measured before release from Willamette Hatchery and average fork lengths (cm) at ocean entrance, as measured by scale analysis. Averages of scale estimates significantly different from averages of measured fork lengths are marked by asterisks.

Brood Year, Group	Measured Fork Length (cm)	Scale Estimates (cm)
1989		
Group E1	13.82 ± 0.14 (211)	--
Group E2	13.80 ± 0.11 (282)	--
Combined E	13.81 ± 0.09 (493)	--
1990		
Group E1	13.94 ± 0.12 (220)	--
Group E2	13.76 ± 0.13 (219)	--
Combined E	13.85 ± 0.09 (439)	--
1991		
Group E1	14.87 ± 0.15 (312)	14.61 ± 2.30 (2)
Group E2	13.50 ± 0.13 (303)	--
Combined E	14.20 ± 0.10 (615)	14.61 ± 2.30 (2)
1992		
Group E1	12.56 ± 0.11 (213)	11.71 ± 0.44 (13)
Group E2	13.12 ± 0.11 (214)	12.14 ± 0.40 (6)
Combined E	12.84 ± 0.08 (427)	11.85 ± 0.33 (19)

Table 10. Average fork lengths (cm) of juvenile chinook salmon from groups F1 and F2 measured before release from Willamette Hatchery and average fork lengths (cm) at ocean entrance, as measured by scale analysis. Averages of scale estimates significantly different from averages of measured fork lengths are marked by asterisks.

Brood Year, Group	Measured Fork Length (cm)	Scale Estimates (cm)
1989		
Group F1	14.89 ± 0.16 (232)	--
Group F2	14.94 ± 0.17 (242)	--
Combined F	14.91 ± 0.12 (474)	--
1990		
Group F1	14.14 ± 0.16 (215)	*16.90 (1)
Group F2	14.83 ± 0.14 (256)	--
Combined F	14.52 ± 0.10 (471)	*16.90 (1)
1991		
Group F1	15.65 ± 0.15 (306)	14.21 ± 0.91 (11)
Group F2	14.48 ± 0.16 (237)	*11.35 ± 0.69 (4)
Combined F	15.14 ± 0.11 (543)	*13.44 ± 0.76 (15)
1992		
Group F1	13.24 ± 0.11 (236)	13.99 ± 0.36 (12)
Group F2	13.03 ± 0.11 (220)	11.94 ± 0.35 (15)
Combined F	13.12 ± 0.07 (456)	12.85 ± 0.32 (27)

Table 11. Average fork lengths (cm) of juvenile chinook salmon from groups G1 and G2 measured before release from Willamette Hatchery and average fork lengths (cm) at ocean entrance, as measured by scale analysis. Averages of scale estimates significantly different from averages of measured fork lengths are marked by asterisks.

Brood Year, Group	Measured Fork Length (cm)	Scale Estimates (cm)
1989		
Group G1	14.63 ± 0.15 (219)	--
Group G2	14.98 ± 0.14 (249)	--
Combined G	14.80 ± 0.11 (468)	--
1990		
Group G1	14.85 ± 0.16 (224)	--
Group G2	14.35 ± 0.14 (312)	--
Combined G	14.56 ± 0.10 (536)	--
1991		
Group G1	15.12 ± 0.17 (265)	14.45 ± 1.15 (12)
Group G2	14.73 ± 0.16 (232)	13.66 ± 0.70 (2)
Combined G	14.94 ± 0.12 (497)	14.33 ± 0.99 (14)
1992		
Group G1	13.18 ± 0.12 (214)	13.49 ± 0.38 (20)
Group G2	12.79 ± 0.11 (227)	13.30 ± 0.58 (10)
Combined G	12.96 ± 0.08 (439)	13.43 ± 0.31 (30)

Relationship between Age Class, Adult Size and Juvenile Size at Ocean Entrance

A general understanding in salmon culture is that the age class of the adult fish is determined by the size of the juvenile when it enters the ocean. A search of the literature has not revealed published data to confirm this notion, although it may be confirmed in the gray literature. The present data set with chinook salmon offers some insight into the validity of this relationship.

Scales from adults from experimental groups at Willamette Hatchery were sorted by age class. Estimated lengths at ocean entrance derived from scale analysis were combined for replicate experimenal groups and averaged for each age class. Results indicated that there was a trend for smaller fish at ocean entrance contributing to older age classes (Table 12). This was especially evident between 5 year old and 6 year old fish.

Comparison of size at ocean entrance for each age class of chinook salmon derived from raceways and from Michigan raceways indicated that the sizes of fish from Michigan raceways were usually significantly smaller (Table 12).

Regressions of size at ocean entrance derived from scale analysis against the size of returning adults within a particular age class yielded a surprising result. No significant relationship was found (Table 13), except where only small numbers of scales were obtained. For most groups, R^2 values were less than 0.1 (Table 13). This means that the size reached by the adults in a particular age class was independent of the size of the juveniles that entered the ocean. The lack of a significant relationship was not due to narrow ranges of values, because juveniles ranged from about 10 to 20 cm and adult sizes ranged from about 65 to 100 cm (Figure 16). The relationships were also not due to bias associated with sex. When the major age classes, age 4 and age 5, were sorted by sex, there were still no significant relationships between the size at ocean entry and the size of adults at return (Table 14).

The lack of a relationship was possibly due to the decrease in growth rate for older age fish (Figure 17). The growth of salmon through age 4 was linear, but after age 4, growth slowed considerably. From this relationhip, one could postulate that about 100 cm was the maximum size that this stock of chinook salmon could attain. This decrease in the growth of the salmon after age 4 tends to explain why the relationship between age class of returning adults and size at ocean entry was so weak. It also provides an explanation for the lack of a relationship within an age class between size of returning adults and the size at ocean entry. Apparently, there is a tendency for the smaller fish to produce older age classes, but within an age class, the size attained depends upon random factors of genetics and food supply.

Table 12. Average fork lengths (cm) at ocean entrance, as measured by scale analysis, of different age classes of adult chinook salmon from experimental groups released from Willamette Hatchery. Asterisks mark statistical differences ($P \le 0.05$) from lengths of 5-year-old fish. Ampersands mark statistical differences ($P \le 0.05$) from lengths of combined raceway fish.

Group	Age at Return				
	6	5	4	3	2
A	--	14.81 ± 0.32 (68)	14.95 ± 0.31 (61)	15.11 ± 1.60 (2)	15.00 (1)
B	12.25 ± 0.25* (2)	15.31 ± 0.39 (58)	15.31 ± 0.42 (43)	--	15.95 ± 1.61 (2)
C	13.27 ± 1.12 (4)	14.32 ± 0.27 (86)	15.15 ± 0.31 (69)	11.49 ± 0.52* (2)	17.48 ± 0.20* (3)
D	11.82 ± 1.20* (2)	14.78 ± 0.37 (48)	14.07 ± 0.45 (38)	12.90* (1)	--
E	--	12.66 ± 0.65 (9)	11.70 ± 0.44 (12)	--	--
F	--	13.41 ± 0.58 (18)	12.74 ± 0.41 (22)	15.89 ± 1.55 (3)	13.99 (1)
G	--	13.55 ± 0.52 (23)	13.90 ± 0.56 (21)	--	--
Raceways	12.65 ± 0.62 (8)	14.75 ± 0.17 (260)	14.93 ± 0.18 (211)	13.22 ± 0.97 (5)	16.56 ± 0.61 (6)
Michigan Raceways	--	13.34 ± 0.34@ (50)	12.96 ± 0.30@ (55)	15.89 ± 1.55 (3)	13.99@ (1)

Table 13. Coefficients of regression (R^2) for the relationship between juvenile size at ocean entrance, as estimated from scale analysis, and adult size at return for various experimental groups.

Group	Age at Return				
	6	5	4	3	2
A	--	0.1513 (66)	0.0174 (59)	--	--
B	--	0.0061 (58)	0.0577 (43)	--	--
C	0.8530 (4)	0.0740 (85)	0.0047 (61)	--	0.8305 (3)
D	--	0.0086 (47)	0.0191 (38)	--	--
E	--	0.0040 (9)	0.0295 (12)	--	--
F	--	0.0486 (18)	0.0332 (22)	--	--
G	--	0.0121 (23)	0.2830 (21)	--	--

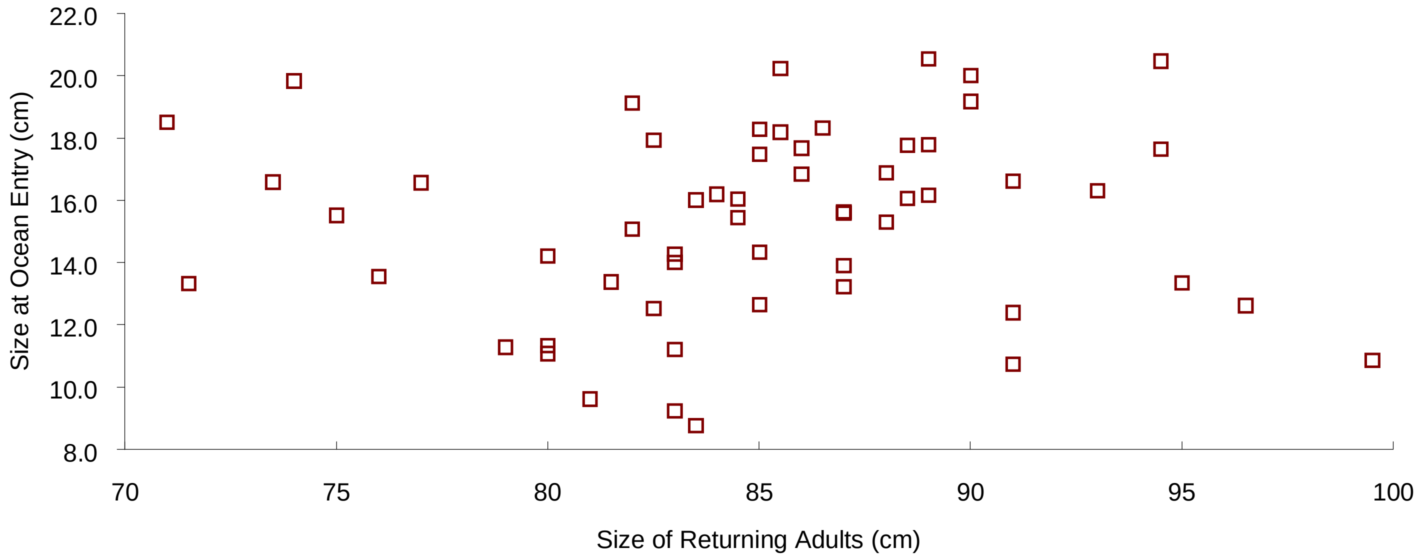

Figure 16. Variability in the relationship between size at ocean entrance of juveniles and size of returning adults. Data shown are from 4-year-old spring chinook salmon from the 1992 brood.

Table 14. Coefficients of regression (R^2) for the relationship between juvenile size at ocean entrance, as estimated from scale analysis, and adult size at return for different sexes in age 4- and 5-year classes.

Group	Age at Return 5		4	
	Male	Female	Male	Female
A	0.0491 (29)	0.2628 (38)	0.0270 (30)	0.0375 (29)
B	0.0002 (32)	0.0626 (26)	0.1253 (25)	0.0029 (18)
C	0.1249 (40)	0.0226 (45)	0.0672 (45)	0.0977 (16)
D	0.0352 (16)	0.0010 (31)	0.0169 (21)	0.0173 (17)
E	0.8430 (4)	0.2001 (5)	0.0159 (10)	--
F	0.1370 (11)	0.0756 (7)	0.1302 (15)	0.5301 (7)
G	0.0555 (8)	0.0037 (15)	0.4066 (15)	0.5371 (6)

Figure 17. Relationship between size of returning adults (cm) and age class in years.

Data are average lengths from 1992 brood fish.

Sources of Error

Fork length of fish entering the sea, as estimated from scale analyses, has several potential sources of error resulting from the assumptions inherent in these analyses. These assumptions are: 1) No size selective mortality occurs during the migration to the sea; 2) No growth occurs during the migration to the sea; 3) Accelerated growth, and its manifestation on the scale, occurs immediately after the fish reach the sea; 4) The freshwater portion of the scale is maintained intact throughout the oceanic life of the salmon, so that the calibration of fork length vs scale radius performed in hatchery juveniles is valid in adult scales.

The assumption that no size selective mortality occurs during migration is probably not very good. Size selective mortality of smolting salmonids is well known (Taylor and McPhail 1985; West and Larkin 1988; Ward and Slaney 1988; Ward et al. 1989). Size is a strong determining factor in the survival to adulthood of chinook salmon (Reisenbichler et al. 1982) and much of this is probably due to size selective predation while the fish are small. Estimates of survival of radiotagged fish released at Pengra (RKM 323) and monitored at Willamette Falls (RKM 43) averaged 33% in 1991 and 66% in 1993 (Schreck et al. 1994). It seems reasonable that the smaller fish had less chance of survival during this journey.

The assumption that little growth took place on their journey to the sea is more reasonable. The water temperature during the first of March is very cold (about 5 C) and very little growth occurred in the hatchery when temperatures that low were encountered (Ewing 1995). In addition, the lack of a readily available food source probably kept growth to a minimum. Fish did feed on the way downstream however (Schreck et al. 1994), but feeding was directly related to flow and migration speed.

Average migration speed of released juveniles was found to be about 3-4 km/hr (Schreck et al. 1994). At that rate, the 280 km from the release site to Willamette Falls would take 3-4 days. Further migration to the Columbia River estuary might take another week. If it were assumed that the released juveniles all made it to the estuary within two weeks of release, one would probably not expect significant growth due to the low water temperature and minimal food available during migration.

Assumptions 3 and 4 could not be checked directly in the present study. However, other studies have used this technique (Koo and Isarankura 1967; Ward et al. 1989) and it is generally assumed that in unregenerated scales the distance from the focus to the area where circuli become spaced more widely represents the region of freshwater growth of the juveniles.

Ward et al. (1989) used scale analyses to show that adult steelhead returning to the Keogh River, British Columbia, had all gone out to sea at a larger size than that estimated from migrating smolts at the mouth of the river. This suggested a size-selective mortality of smolts after entry into seawater. Holtby et al. (1990) showed that large size offered a distinct advantage during years of poor marine survival. Mathews and Ishida (1989) found that, in coho salmon released from Big Creek Hatchery, the lengths at ocean entrance back-calculated from scales of adults were not significantly different from the length of smolts at release.

In all these reported studies, fish at release were either the same size or smaller than the size at ocean entry indicated by scales of returning adults. The present study is the only one I have found that indicates that the smaller members of the hatchery population survived to return as adults.

Summary of Scale Analyses

1. When unregenerated scales only were measured, the relationship between scale radius and fork length in juvenile spring chinook salmon just before release was very strong (R^2 of 0.959 and 0.915 for 1991 and 1992 broods, respectively).

2. Few fish of brood years 1989 and 1990 survived when reared in Michigan ponds, even though the health of these fish seemed no different from those reared in raceways. Consequently, little can be said about the size of the fish at ocean entry that survived to return as adults from these experimental raceways.

3. Adult fish from brood years 1989 and 1990 reared in conventional raceways returned at reasonable rates and scales could be obtained for analysis of size at ocean entrance. Average fork lengths at ocean entrance derived from scale analyses were significantly smaller than average measured fork lengths in 7 of the 16 raceways of salmon. Average fork lengths estimated from scales in six of the remaining raceways were smaller than average measured fork lengths, but the difference was not significant, usually because the number of recovered adults was small.

4. In 1991 and 1992 brood fish, the sizes at which the juvenile fish entered the raceway coincided with the sizes of the fish in raceways prior to release. No significant differences were found between the average size of the juveniles at ocean entry and the average size of the juveniles in experimental ponds before release.

5. Older age classes of fish tended to be derived from smaller fish at ocean entry, but the relationship was not strong except at the oldest age classes.

6. Within an age class, the size of the returning adults were independent of the size of the juveniles entering the ocean.

7. Growth of adults, as measured by changes in average adult size in each age class, was linear from ocean entry to age 4, then growth slowed in age 5 and age 6 fish. This information was derived only from fish from which scales were taken, however. A better relationship can be derived from returns of coded wire tagged fish and will be examined in a future report.

Water Quality Data from Juveniles Reared at Dexter

Water quality data reported so far in this report series has focused exclusively on the experimental raceways at Willamette Hatchery. Information on water quality was also obtained from juvenile chinook salmon reared at the Dexter Rearing Facilities, located at the base of Dexter Dam. These fish were reared as a backup to provide desired numbers of returning adults to the Willamette River in the event that one or more of the experimental conditions at Willamette Hatchery did not produce large numbers of adults. It was fortunate that these fish were reared because:

1) Michigan raceways were very poor at rearing juvenile chinook salmon.

2) They provided a comparison between trucked and non-trucked fish.

3) They provide a check on conclusions obtained from juvenile chinook salmon reared at Willamette Hatchery.

The fish at Dexter Rearing Ponds were reared in a large concrete bottom pond measuring 200 ft x 62 ft and 7 ft deep. The volume of the rearing area was about 54,320 cubic feet and the surface area was 12,400 square feet. Water from Dexter Reservoir was supplied to the pond at the east end at a rate of 23,312 gallons per minute. Turnover for the pond occurred every 33 minutes.

Water quality was followed sporadically during rearing of fish. Parameters independent of fish weight are shown in Table 15. Beginning in 1992, some of the water quality parameters were either dropped or modified. Alkalinity measurements in 1990 and 1991 indicated that there was no substantially change between inflow and outflow, so, for the next two years, only the alkalinity of the inflow was measured. Hardness and dissolved solids were not measured in 1992, 1993, and 1994. Suspended solids were measured with a balance sensitive only to the nearest 10 mg for the 1991-1992 rearing season, so, although the measurements were made, only zeros were obtained. A more sensitive balance was used in 1992-1994.

A comparison of the alkalinities at Dexter with those at Willamette Hatchery indicated that alkalinities at Dexter were generally lower than those at Willamette Hatchery. Because alkalinities are generally attributed to carbonates in the water, the carbonate concentrations at Dexter may have been reduced in some way, either through photosynthetic activity in the Dexter reservoir or by precipitation of insoluble carbonates.

Suspended solids were also lower at Dexter than at Willamette Hatchery. Dexter and Lookout Point reservoirs probably act as large settling ponds for much of the sediment found in the river during freshets.

Parameters dependent upon total fish weight in the rearing pond were also measured once or twice a month (Table 16). Oxygen concentrations usually showed a decrease from the intake to the outlet, suggesting oxygen uptake by the fish. However, changes in pH rarely decreased between the intake and the outlet. Changes in ammonium concentration were also very low and not very different between the intake and outlet.

Table 15. Water quality parameters independent of fish weight measured at the inlet and outlet of Dexter Rearing Ponds.

Brood, date	Alkalinity (mg/L)		Hardness (mg/L)		Dissolved Solids (mg/L)		Suspended Solids (mg/L)	
	In	Out	In	Out	In	Out	In	Out
1990								
11/22/91	27.0	26.5	15.4	15.1	30	30	0.0	0.0
12/06/91	24.4	23.3	15.9	15.4	20	20	0.0	0.0
12/20/91	22.8	22.8	14.0	13.5	20	20	0.0	0.0
01/03/92	23.9	24.4	16.6	16.6	20	20	0.0	0.0
01/17/92	25.4	24.9	17.5	17.5	20	20	0.0	0.0
01/31/92	25.4	25.4	17.9	18.0	20	20	0.0	0.0
02/14/92	26.5	26.5	18.6	18.5	20	20	0.0	0.0
1991								
11/20/92	29.9	--	--	--	--	--	2.5	2.0
12/04/92	27.8	--	--	--	--	--	1.7	1.5
01/08/93	27.6	--	--	--	--	--	1.7	1.8
01/22/93	27.3	--	--	--	--	--	2.0	1.7
02/05/93	26.8	--	--	--	--	--	1.8	2.0
03/05/93	25.7	--	--	--	--	--	1.3	1.7
1992								
10/19/93	27.5	--	--	--	--	--	1.0	1.2
12/10/93	28.1	--	--	--	--	--	1.7	2.2
01/14/94	26.3	--	--	--	--	--	1.7	2.3
01/28/94	--	--	--	--	--	--	0.8	1.3
02/11/94	25.7	--	--	--	--	--	1.6	2.2

Table 16. Water quality parameters dependent on total fish weight measured at the inlet and outlet of Dexter Rearing Ponds.

Brood, date	Oxygen Concentraton (mg/L)		pH		Ammonium Concentration (mg/L)		Temp (C)
	In	Out	In	Out	In	Out	
1989							
12/12/90	11.70	11.55					7.5
01/04/91	10.55	10.32					3.3
1990							
11/22/91	--	--	7.31	7.31	0.05	0.07	11.1
11/27/91	12.38	11.61	--	--	--	--	--
12/06/91	10.86	10.12	7.23	7.25	0.08	0.22	9.0
12/20/91	12.85	12.64	7.24	7.26	0.11	0.15	6.4
01/03/92	13.09	12.77	7.11	7.13	0.08	0.11	5.5
01/17/92	12.42	11.97	7.33	7.31	0.09	0.10	5.6
01/31/92	12.05	10.45	7.31	7.32	0.02	0.07	5.5
02/14/92	11.08	11.08	7.50	7.54	0.03	0.07	7.0
1991							
11/20/92	11.75	11.06	7.27	7.32	0.07	0.12	11.6
12/04/92	13.47	12.88	6.94	6.93	0.07	0.08	8.6
01/08/93	11.83	11.10	6.58	6.51	0.08	0.11	4.9
01/22/93	13.96	13.47	6.60	6.75	0.11	0.11	4.6
02/05/93	13.59	13.11	6.61	6.73	0.09	0.09	5.2
03/05/93	12.50	12.19	7.08	6.95	0.06	0.10	6.1
1992							
10/19/93	9.37	9.16	7.24	7.27	0.04	0.12	11.1
12/10/93	--	--	7.63	7.58	0.10	0.14	
01/14/94	--	--	7.45	7.44	0.16	0.14	
01/28/94	11.74	11.67	7.43	7.44	0.12	0.12	6.0
02/11/94	12.57	11.77	7.31	7.32	0.07	0.12	5.1

Very few growth data for the fish reared in the Dexter pond were available. Length frequencies near the time of release are shown in Figures 18, 19, and 20 for 1990, 1991, and 1992 broods, respectively. All three groups show bimodal length frequency curves. Average lengths for 1990, 1991, and 1992 broods of fish in late February were 17.70 + 0.15 cm (N=231), 16.50 + 0.19 cm (N=203), and 17.10 + 0.16 cm (N=201), respectively. Final numbers released, tag codes, and other information at release are given in Table 17.

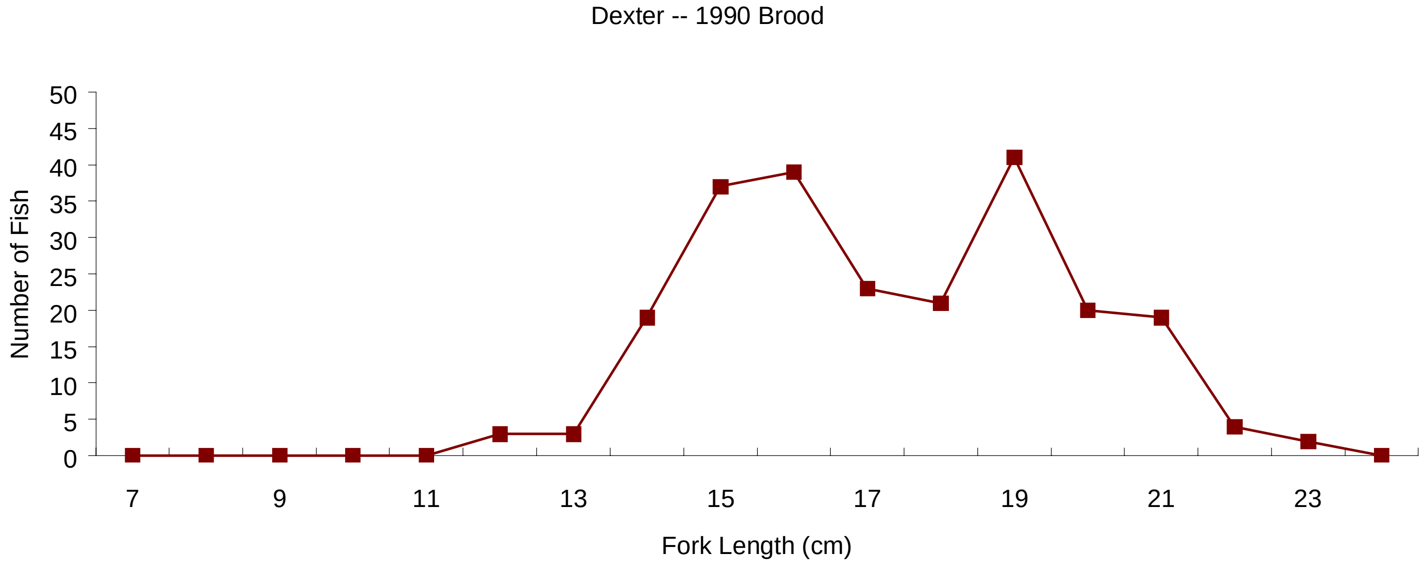

Figure 18. Length frequencies of 1990-brood juvenile spring chinook salmon reared in Dexter Rearing Ponds. Fish were measured on 2/27/92.

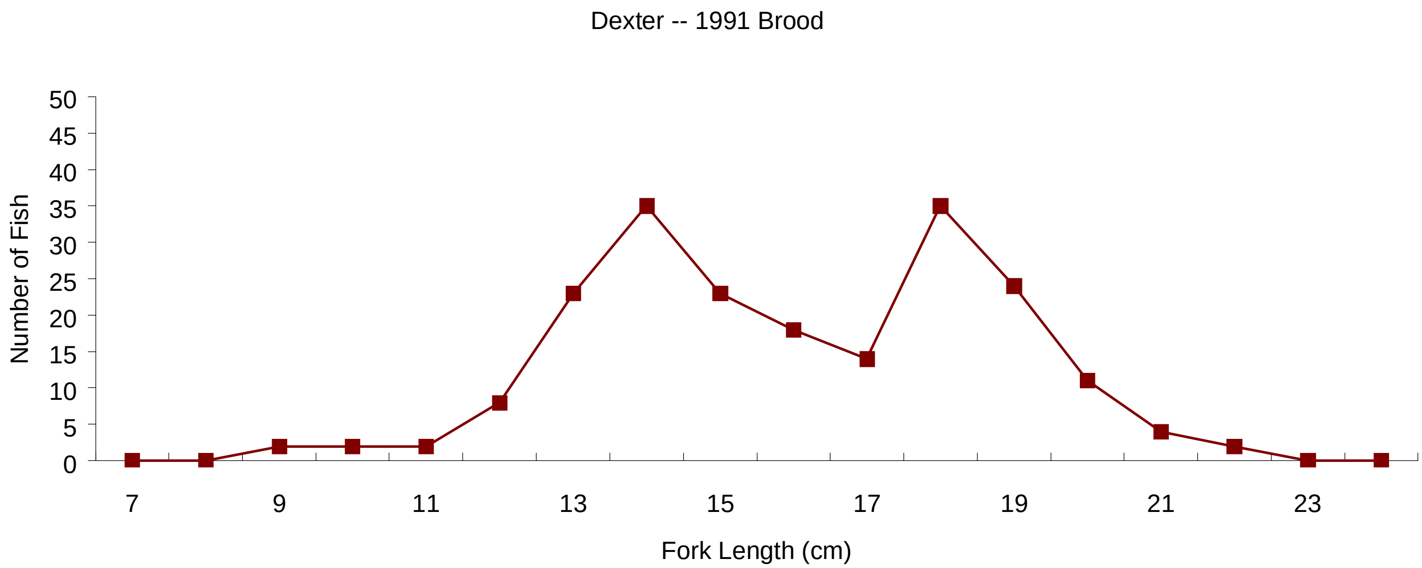

Figure 19. Length frequencies of 1991-brood juvenile spring chinook salmon reared in Dexter Rearing Ponds. Fish were measured on 2/25/93.

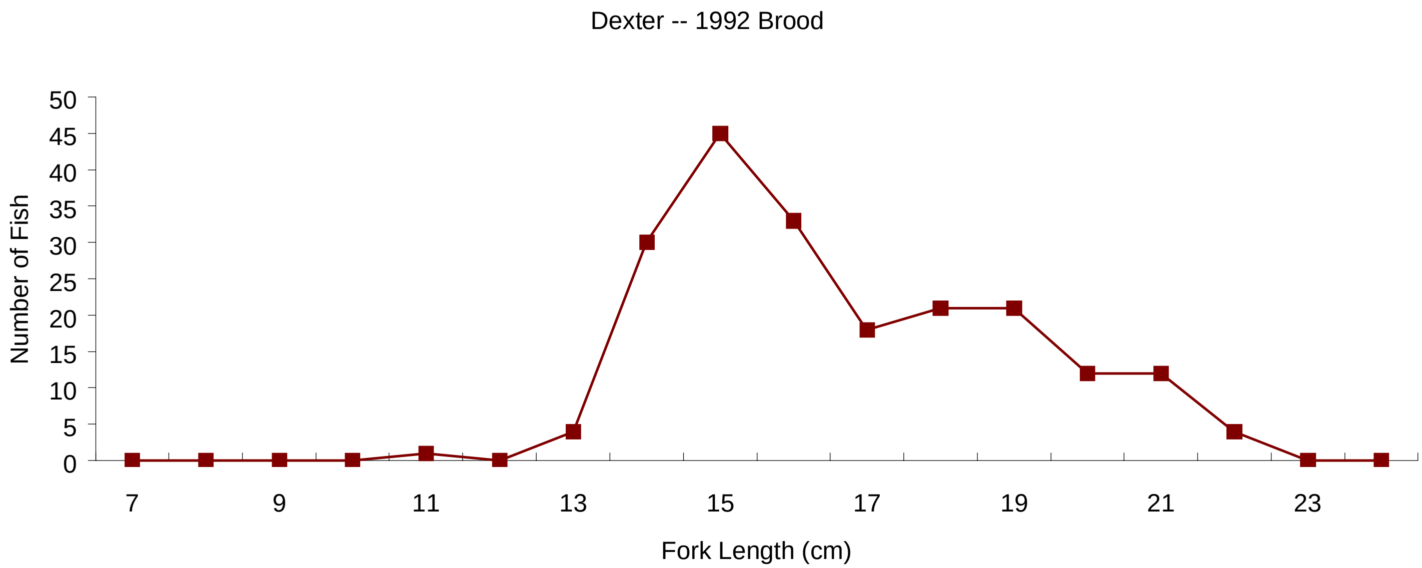

Figure 20. Length frequencies of 1992-brood juvenile spring chinook salmon reared in Dexter Rearing Ponds. Fish were measured on 2/25/94.

Table 17. Data at liberation for four broods of spring chinook salmon released from Dexter Rearing Ponds in February 1991-1994.

Brood	Tag code	Number tagged	Total liberation	Fish/ lb	Tag loss (percent)	Final load lbs/gpm	Final density lbs/ft3
1989	07-55-16	33,277	147,859	9.6	2.76	0.66	0.28
	07-55-15	32,993		9.6	--	--	--
1990	07-56-43	33,082	388,372	8.1	1.0%	2.06	0.88
	07-56-44	33,045		8.1	2.0%	--	--
1991	07-59-33	31,647	382,024	8.5	1.9%	1.93	0.83
	07-59-34	31,505		8.5	1.9%	--	--
1992	07-01-33	32,000	308,728	7.7	9.5%	1.72	0.74
	07-01-34	31,852		7.7	10.9%	--	--

Recoveries of Marked Adults

Information on survival of experimental groups was obtained from coded wire tags collected from adult returns to Dexter Rearing Facility, McKenzie Hatchery, Willamette Hatchery, sport fishing recovery and the ocean fisheries program and compiled by the Pacific States Fisheries Management Council (PSFMC) computer data base. These data on adult returns are shown in Tables 18 and 19.

The highest percent returns from 1989-brood fish were from those reared at Willamette Hatchery until November and then transferred to the Dexter holding pond (Fig. 21). These fish were not part of the experimental design but were tagged for comparison with experimental fish. The number of fish reared each year varied: 147,859 for the 1989 brood, 388,372 for the 1990 brood, 382,024 for the 1991 brood and 308,727 for the 1992 brood.

The second highest percent returns of 1989-brood fish (Fig. 21) were from fish reared at half the normal rearing density (group B), followed by fish reared at normal density with oxygen (group C). Fish reared in Michigan ponds showed very poor recoveries.

Fish from the 1990 brood showed a somewhat different pattern (Fig. 22). Overall, survival of the 1990-brood fish was much less than that of the 1989-brood fish. Fish reared at normal density (group A) and half normal density (group B) showed the best returns of all experimental groups. Fish reared at normal density with oxygen (group C) and at triple density (group D) showed smaller returns. Fish reared at Dexter Rearing Ponds survived best, while fish reared at Willamette Hatchery in Michigan ponds had poorest survival.

Table 18. Percent recovery of adult fish derived from experimental groups released from Willamette Hatchery, 1991-1994. Numbers include data from ocean troll and river sport fisheries as well as returns to various hatcheries.

Group	Tag Code	Number Released[a]	Number Recovered	Percent Recovery
1989 Brood				
A1	07-55-14	32,494	196	0.603
A2	07-55-06	27,950	159	0.569
B1	07-55-17	20,684	168	0.812
B2	07-55-18	20,031	203	1.013
C1	07-54-63	31,531	270	0.856
C2	07-55-03	32,078	257	0.801
D1	07-55-07	33,317	133	0.399
D2	07-55-08	28,975	165	0.569
E1	07-55-09	26,246	11	0.042
E2	07-55-10	29,440	27	0.092
F1	07-55-11	28,087	9	0.032
F2	07-55-12	30,366	34	0.112
G1	07-55-05	27,404	12	0.044
G2	07-55-13	26,596	12	0.045
Dex1	07-55-16	33,277	459	1.379
Dex2	07-55-15	32,993	407	1.234
1990 Brood				
A1	07-56-32	32,678	5	0.015
A2	07-56-31	32,121	68	0.212
B1	07-40-44	19,345	9	0.047
B2	07-40-43	20,091	60	0.299
C1	07-56-34	31,198	14	0.045
C2	07-56-33	31,527	10	0.032
D1	07-56-36	31,653	6	0.019
D2	07-56-35	32,886	19	0.058
E1	07-56-37	32,108	0	0.000
E2	07-56-38	29,778	2	0.007
F1	07-56-39	28,853	2	0.007
F2	07-56-40	30,804	5	0.016
G1	07-56-41	32,747	0	0.000
G2	07-56-42	32,103	16	0.050
Dex1	07-56-43	33,082	107	0.323
Dex2	07-56-44	33,045	127	0.384

[a]Refers to the number of tagged fish released. This is determined by multiplying the number of total fish released (from liberation truck displacements) times the proportion of tagged fish to total fish at the time of tagging.

Table 18. (cont.)

Group	Tag Code	Number Released[a]	Number Recovered	Percent Recovery
1991 Brood				
A1	07-59-21	30,298	83	0.274
A2	07-59-22	29,253	116	0.397
B1	07-59-35	19,792	81	0.409
B2	07-59-36	19,968	92	0.461
C1	07-59-23	31,119	110	0.353
C2	07-59-24	29,993	121	0.403
D1	07-59-25	27,120	48	0.177
D2	07-59-26	27,832	82	0.295
E1	07-59-27	22,807	23	0.101
E2	07-59-28	23,691	6	0.025
F1	07-59-29	27,340	34	0.124
F2	07-59-30	25,649	8	0.031
G1	07-59-31	28,135	35	0.124
G2	07-59-32	26,071	6	0.023
Dex1	07-59-33	31,647	256	0.809
Dex2	07-59-34	31,505	230	0.730
1992 Brood				
A1	07-63-23	31,518	65	0.206
A2	07-63-22	29,866	38	0.127
B1	07-63-37	17,550	32	0.182
B2	07-63-36	17,550	31	0.177
C1	07-63-24	29,691	52	0.175
C2	07-63-25	27,145	63	0.232
D1	07-63-26	31,799	52	0.163
D2	07-63-27	29,694	31	0.104
E1	07-63-28	23,923	27	0.113
E2	07-01-28	22,640	33	0.146
F1	07-01-29	27,357	36	0.132
F2	07-01-30	26,619	33	0.124
G1	07-01-31	28,615	39	0.136
G2	07-01-32	27,493	37	0.135
Dex1	07-01-33	32,000	217	0.678
Dex2	07-01-34	31,892	185	0.580

[a]Refers to the number of tagged fish released. This is determined by multiplying the number of total fish released (from liberation truck displacements) times the proportion of tagged fish to total fish at the time of tagging.

Table 19. Capture of adult fish derived from experimental groups released from Willamette Hatchery, 1991-1994. Numbers include data from ocean troll and river sport fisheries as well as returns to various hatcheries. Data is incomplete and represents only that available as of June 1998.

Group	Tag Code	Age at Capture					Total
		2	3	4	5	6	
1989 Brood							
A1	07-55-14	0	7	89	99	1	196
A2	07-55-06	0	3	72	82	2	159
B1	07-55-17	0	1	110	56	1	168
B2	07-55-18	1	3	98	99	2	203
C1	07-54-63	0	8	148	111	3	270
C2	07-55-03	0	1	160	95	1	257
D1	07-55-07	0	2	85	45	1	133
D2	07-55-08	0	5	82	77	1	165
E1	07-55-09	0	0	2	9	0	11
E2	07-55-10	0	1	16	5	5	27
F1	07-55-11	0	0	9	0	0	9
F2	07-55-12	0	11	14	9	0	34
G1	07-55-05	0	0	2	10	0	12
G2	07-55-13	0	0	5	7	0	12
Dex1	07-55-16	0	29	275	154	1	459
Dex2	07-55-15	0	14	238	140	15	407
1990 Brood							
A1	07-56-32	0	0	1	4	0	5
A2	07-56-31	1	1	29	37	0	68
B1	07-40-44	0	0	4	4	1	9
B2	07-40-43	0	1	20	39	0	60
C1	07-56-34	0	2	10	2	0	14
C2	07-56-33	0	0	5	5	0	10
D1	07-56-36	0	0	3	3	0	6
D2	07-56-35	0	0	15	3	1	19
E1	07-56-37	0	0	0	0	0	0
E2	07-56-38	0	0	1	1	0	2
F1	07-56-39	0	0	1	1	0	2
F2	07-56-40	0	0	5	0	0	5
G1	07-56-41	0	0	0	0	0	0
G2	07-56-42	0	5	6	5	0	16
Dex1	07-56-43	0	9	51	46	1	107
Dex2	07-56-44	7	6	49	64	1	127

Table 19 (cont.)

Group	Tag Code	Age at Capture 2	3	4	5	6	Total
1991 Brood							
A1	07-59-21	3	1	47	32	0	83
A2	07-59-22	0	2	87	27	0	116
B1	07-59-35	0	0	56	24	1	81
B2	07-59-36	0	1	69	17	5	92
C1	07-59-23	0	3	62	42	3	110
C2	07-59-24	0	7	82	32	0	121
D1	07-59-25	0	0	25	23	0	48
D2	07-59-26	0	0	67	15	0	82
E1	07-59-27	0	2	10	11	0	23
E2	07-59-28	0	0	5	1	0	6
F1	07-59-29	0	1	21	12	0	34
F2	07-59-30	0	0	4	4	0	8
G1	07-59-31	0	1	20	11	3	35
G2	07-59-32	0	0	3	3	0	6
Dex1	07-59-33	0	11	161	84	0	256
Dex2	07-59-34	0	5	142	83	0	230
1992 Brood							
A1	07-63-23	1	1	45	18	0	65
A2	07-63-22	1	2	15	20	0	38
B1	07-63-37	3	0	18	11	0	32
B2	07-63-36	2	0	17	12	0	31
C1	07-63-24	4	1	20	27	0	52
C2	07-63-25	0	0	37	26	0	63
D1	07-63-26	0	1	27	24	0	52
D2	07-63-27	1	0	12	18	0	31
E1	07-63-28	1	0	13	13	0	27
E2	07-01-28	0	8	13	12	0	33
F1	07-01-29	0	7	17	12	0	36
F2	07-01-30	1	1	12	19	0	33
G1	07-01-31	0	1	18	20	0	39
G2	07-01-32	0	7	19	11	0	37
Dex1	07-01-33	20	5	121	71	0	217
Dex2	07-01-34	17	16	92	60	0	185

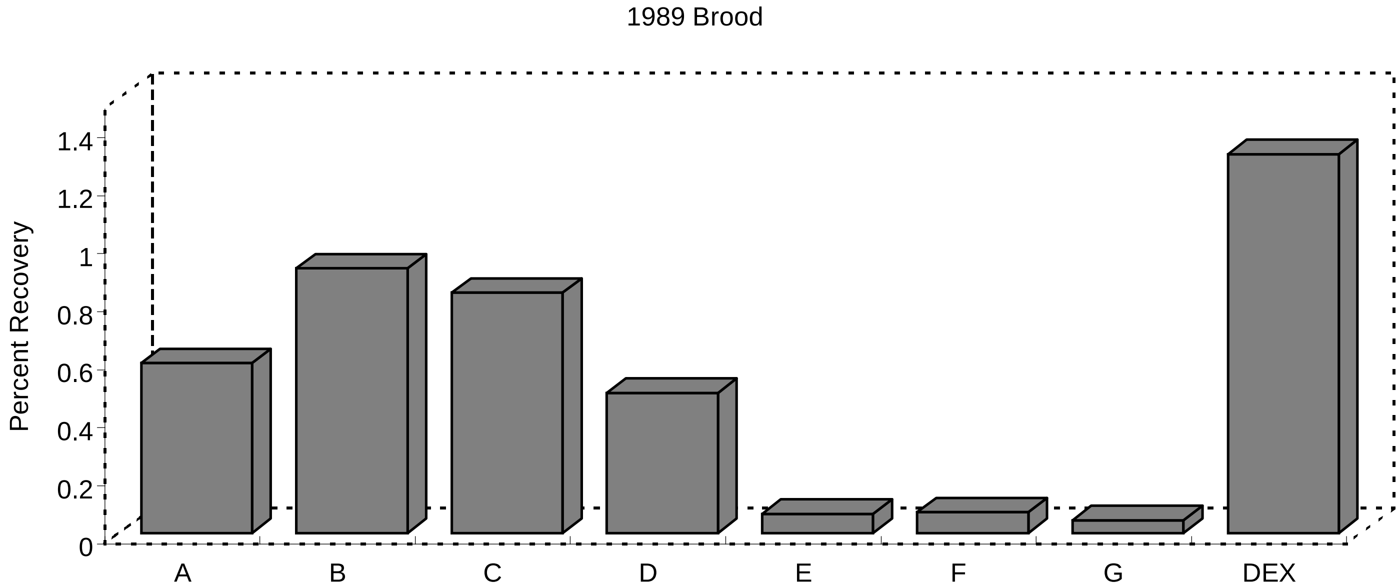

Figure 21. Percent recoveries of 1989-brood chinook salmon reared in experimental raceways at Willamette Hatchery. Values are averages of recoveries from the two replicate raceways.

Figure 22. Percent recoveries of 1990-brood chinook salmon reared in experimental raceways at Willamette Hatchery. Values are averages of recoveries from the two replicate raceways.

Fish from the 1991 brood showed moderate survival (Figure 23). The relationship between groups was about the same as that found for the 1989 brood. Highest survival occurred in the group of fish reared from November to February at Dexter Rearing Ponds. Second highest survival occurred in the group reared at the lowest rearing density. Order of recoveries was: Dexter > B > C > A > D > F > G > E. As in other years, fish reared in Michigan ponds did not survive well.

Fish from the 1992 brood had low and more uniform survival (Figure 24). The order of recoveries was: Dexter > C > B > A > G > D > E > F. Groups of fish reared at the highest rearing density (Group D, E, F, G) had similar survivals.

Average survival for the four brood years (Figure 25) showed the same order of survival as the 1989 brood: Dexter > B > C > A > D > F > G > E. These averages are not weighed for average percent survival, however. The higher survivals in 1989 brood fish would bias the simple averages toward the pattern shown for that brood year. Weighed averages will be presented in the report on analysis of adult returns.

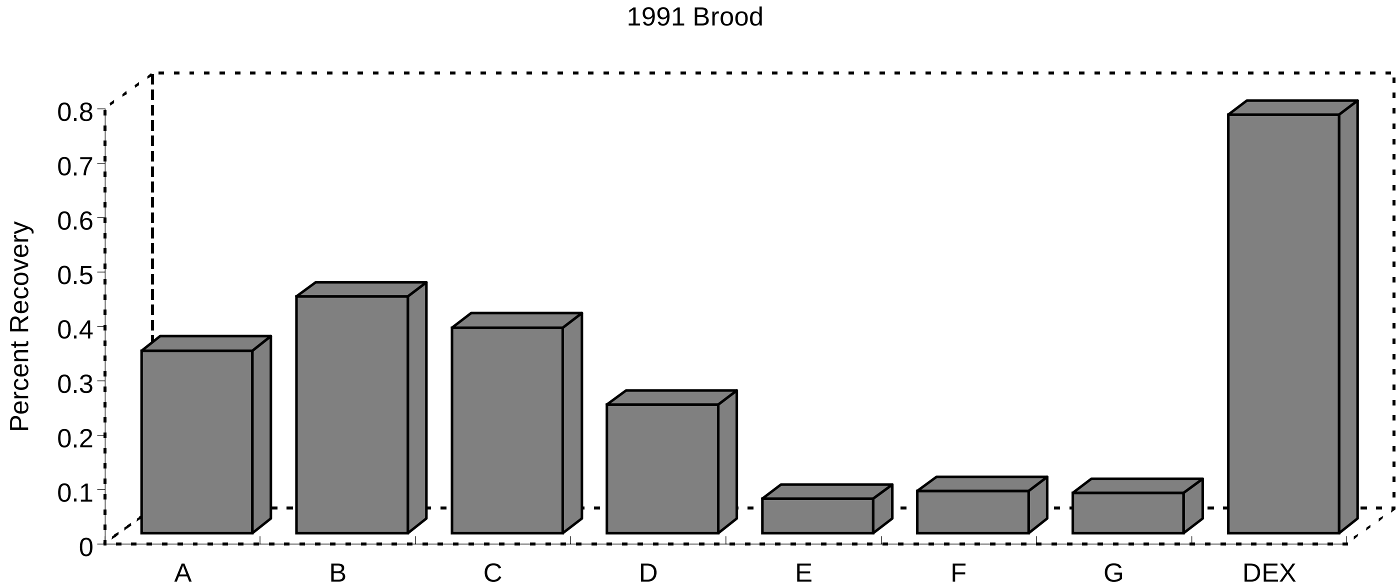

Figure 23. Percent recoveries of 1991-brood chinook salmon reared in experimental raceways at Willamette Hatchery. Values are averages of recoveries from the two replicate raceways.

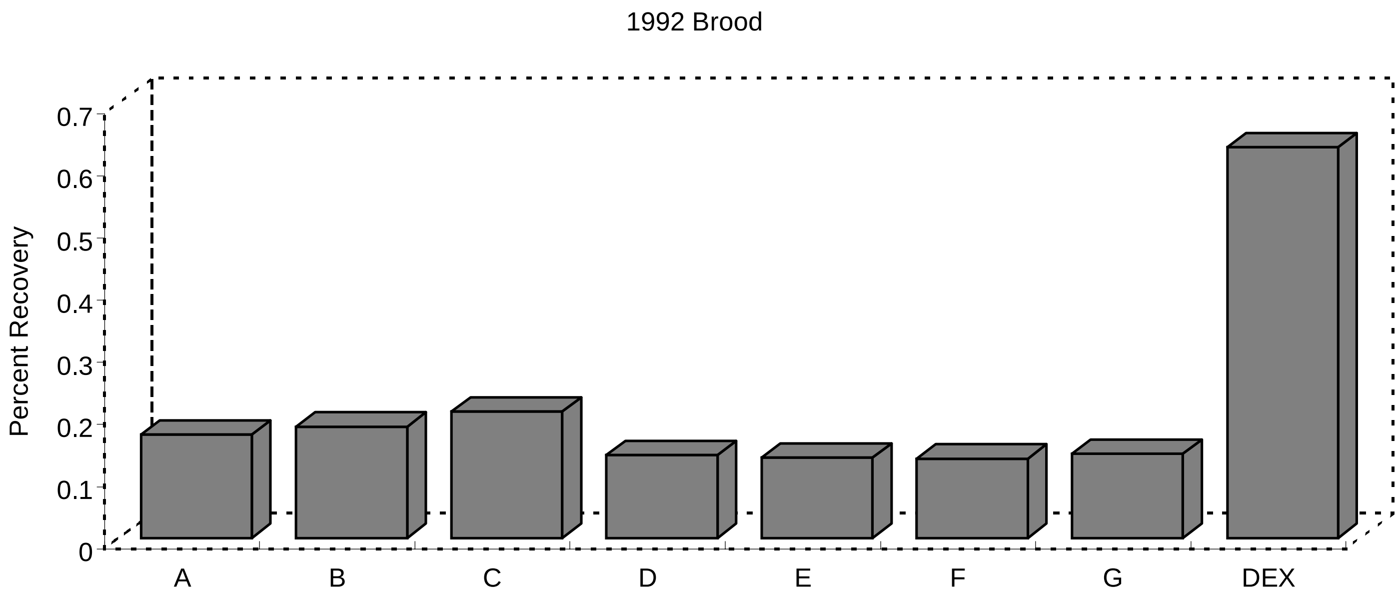

Figure 24. Percent recoveries of 1992-brood chinook salmon reared in experimental raceways at Willamette Hatchery. Values are averages of recoveries from the two replicate raceways.

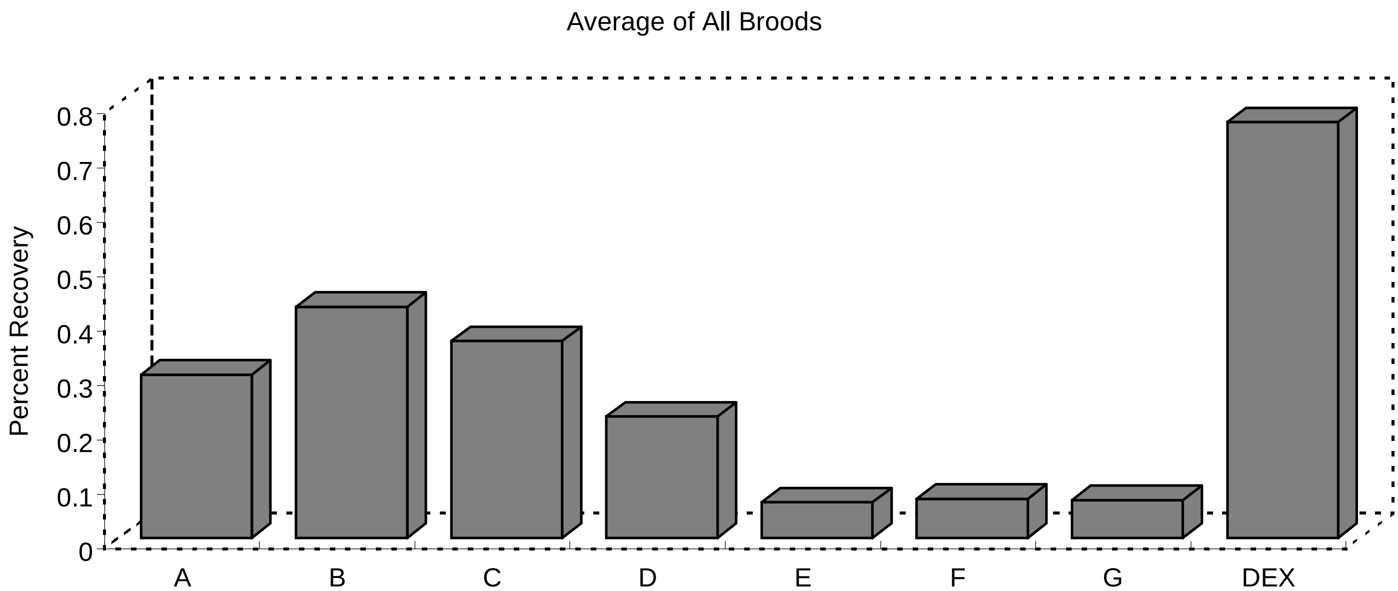

Figure 25. Average percent recoveries for the four brood years of chinook salmon reared in experimental raceways at Willamette Hatchery. Values are averages of the duplicate raceways for each of the brood years.

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APPENDICES

Appendix A

List of Publications To Date From This Project

Colt, J., J. E. Sheahan, and G. R. Bouck. 1993. Evaluation of the "Michigan" type pure oxygen columns for oxygen addition and nitrogen removal. Aquacultural Engineering 12:141-154.

Ewing, R. D., T. R. Walters, M. A. Lewis, and J. E. Sheahan. 1994. Evaluation of inventory procedures for hatchery fish. I. Estimating weights of fish in raceways and transport trucks. Prog. Fish-Cult. 56:153-159.

Ewing, R. D. and S. K. Ewing. 1995 Review of the effects of rearing density on survival to adulthood for Pacific salmon. Prog. Fish Cult.57:1-25..

Ewing, R. D. and J. E. Sheahan. 1996. Airlift debris removal system for water intake structures. Prog. Fish-Cult. 58:284-285.

Ewing, R. D., M. A. Lewis, J. E. Sheahan, and S. K. Ewing. 1998. Evaluation of inventory procedures for hatchery fish. III. Nonrandom distributions of chinook salmon in raceways. Prog. Fish-Cult, 60:159-166.

Ewing, R. D., J. E. Sheahan, M. A. Lewis, and A. N. Palmisano. 1998 Effects of rearing density and raceway conformation on growth, food conversion and survival of juvenile spring chinook salmon. Prog. Fish-Cult. 60:167-178.

Ewing, R. D. and G. S. Ewing. 1998. Accuracy and variance associated with estimations of oxygen consumption rates using Liao's equations. Submitted to Prog. Fish-Cult,

Ewing, R. D. (in preparation) Bimodal length distributions of cultured chinook salmon and their relationship to optimum size at release. To Aquaculture.

Ewing, R. D., J. E. Sheahan, and S. K. Ewing. (in preparation). Ammonia excretion in relation to rearing density in juvenile chinook salmon. To Prog. Fish-Cult.

Ewing, R. D., J. E. Sheahan, and S. K. Ewing. (in preparation). Ammonia excretion of juvenile chinook salmon reared in raceways and Michigan ponds. To Prog. Fish-Cult.

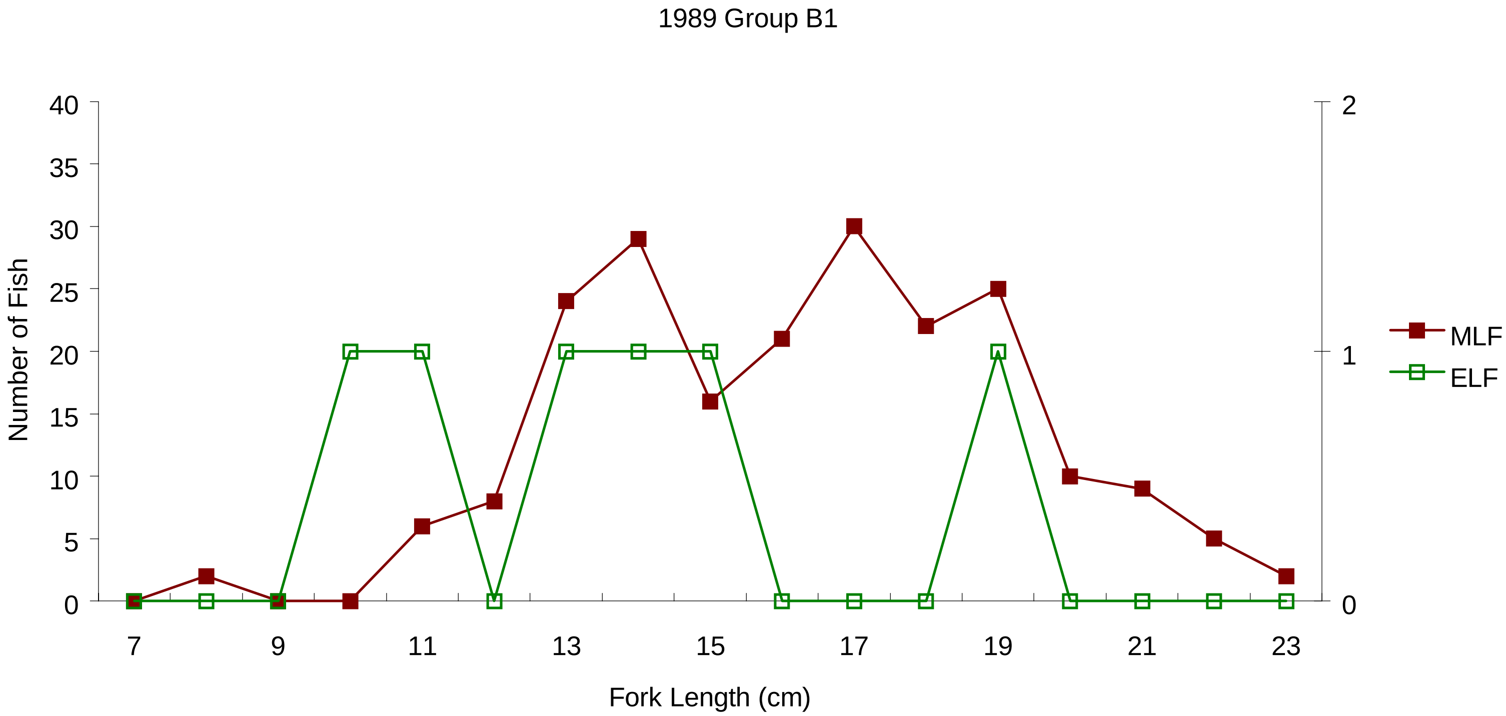
Appendix B

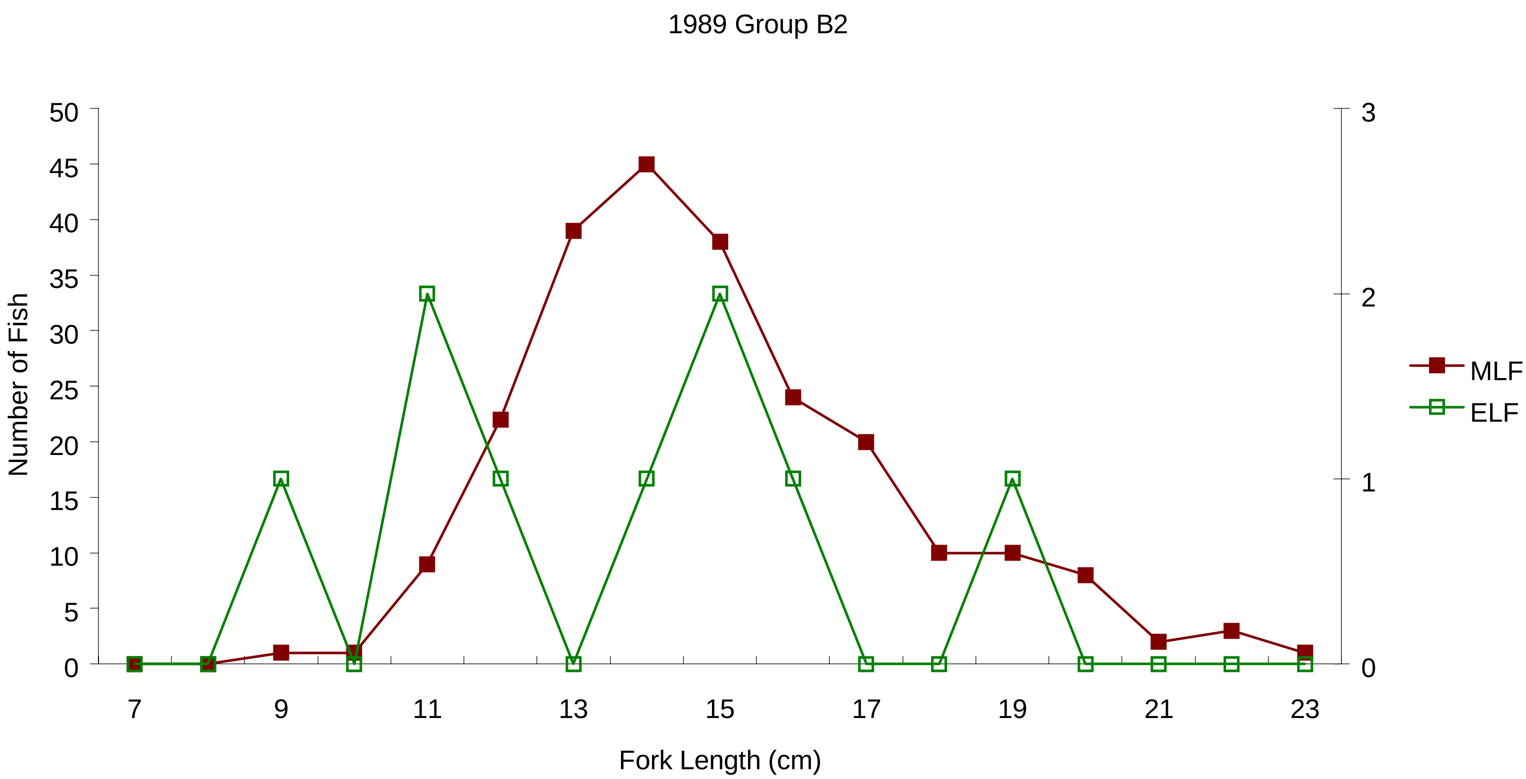
Graphic Comparisons Between Measured Length Frequencies (MLF) at Release from Willamette Hatchery and Estimated Length Frequencies (ELF) Calculated from Scale Analysis.

Page

Appendix B (cont.)

Appendix B (cont.)


1989 Group B1
Number of Fish
40
35
30
25
20
15
10
5
0
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF


1989 Group B2
Number of Fish
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45
40
35
30
25
20
15
10
5
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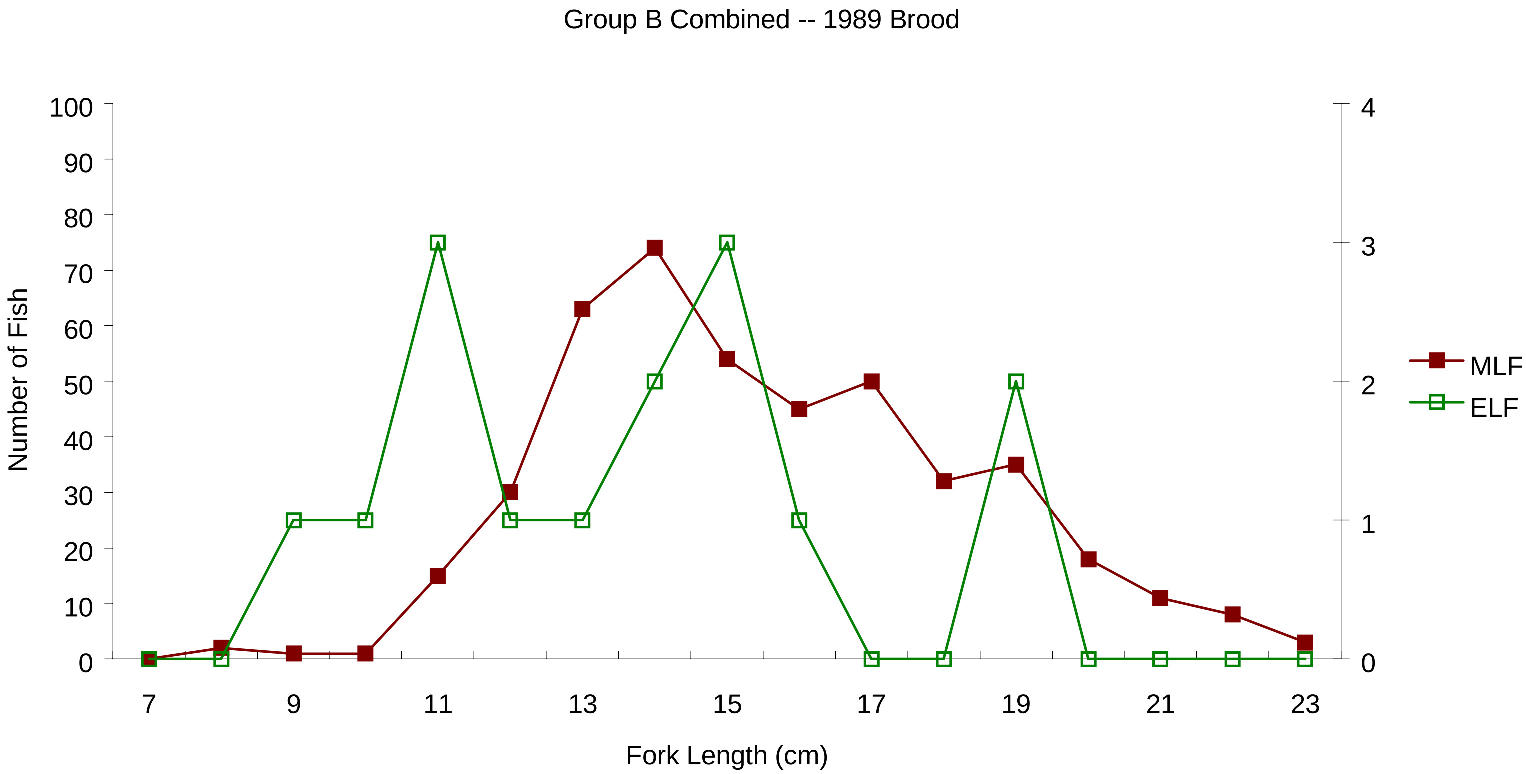
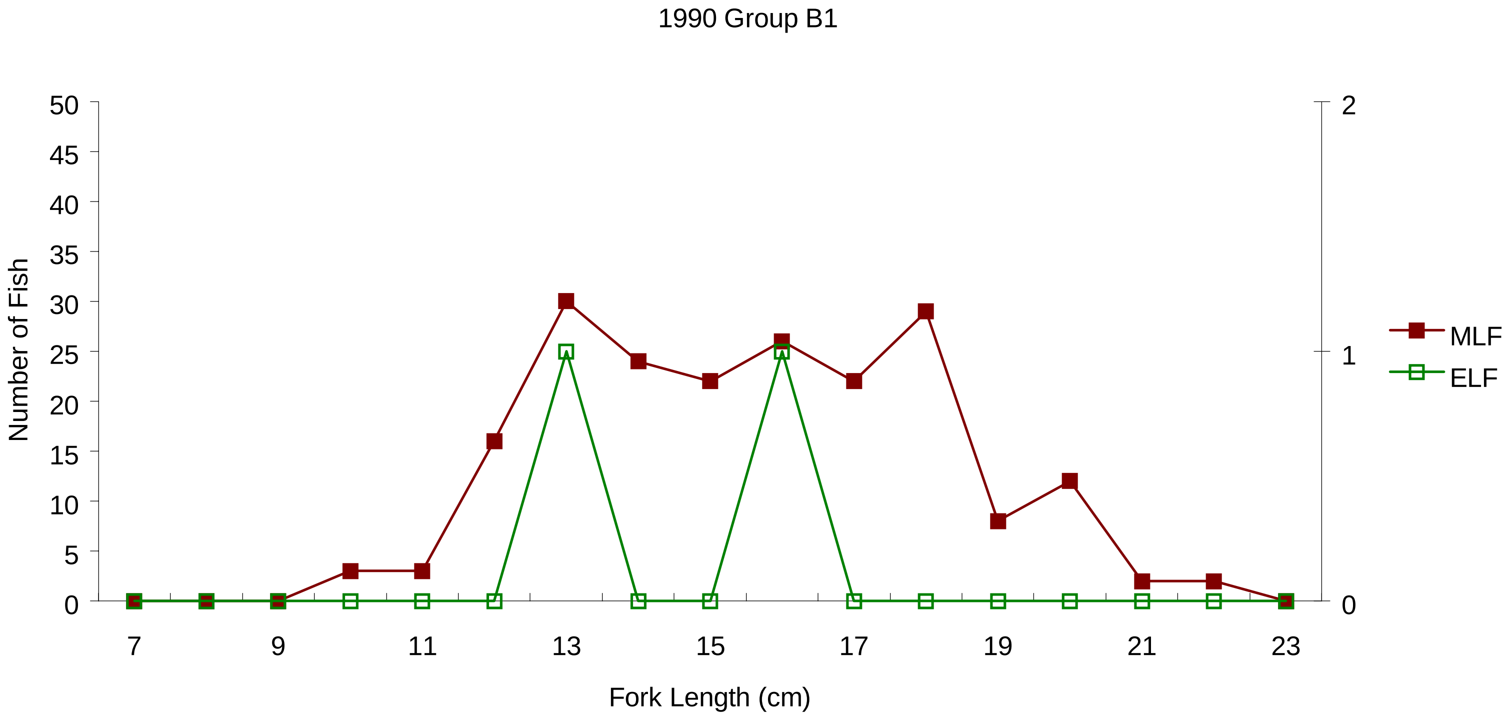
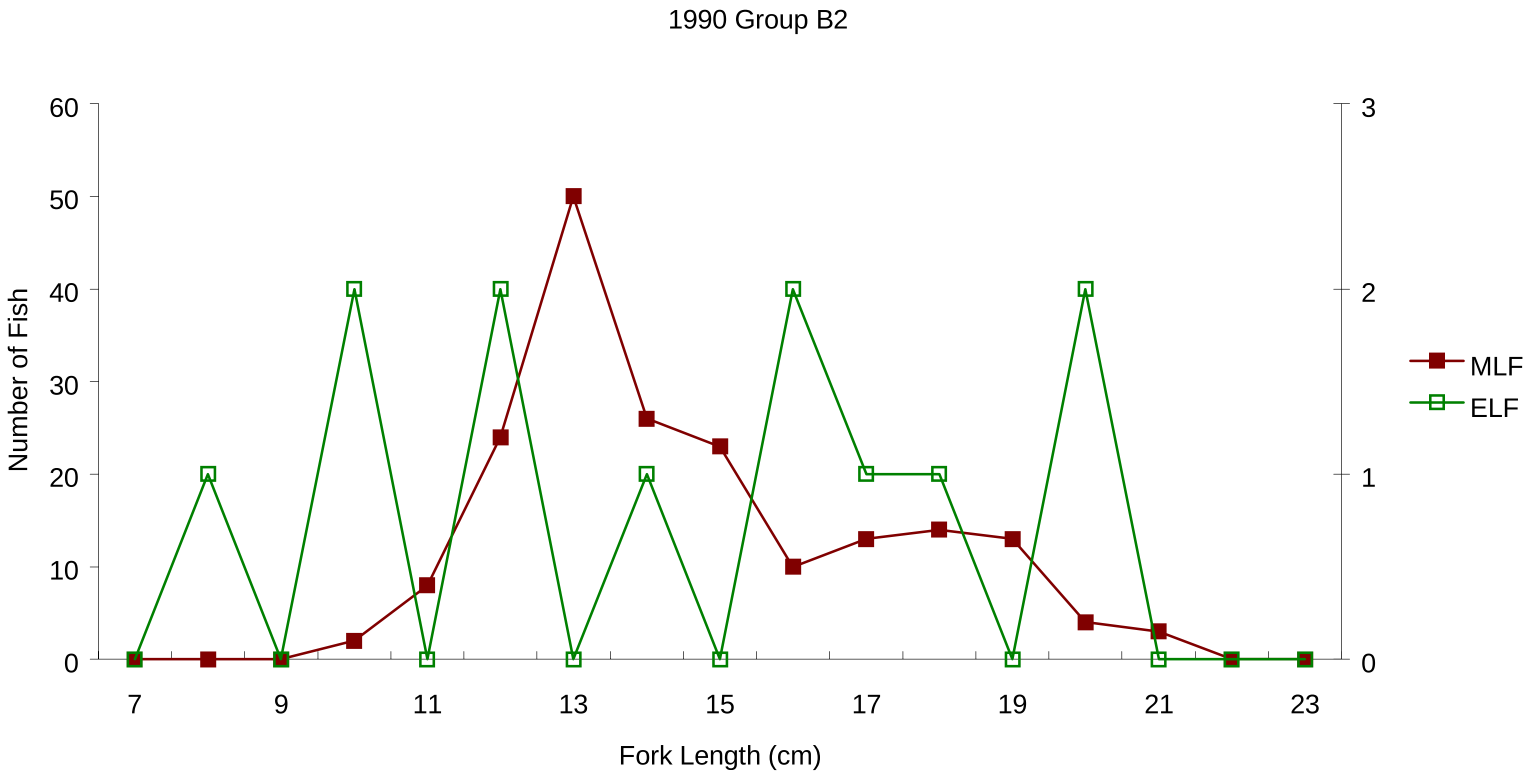
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

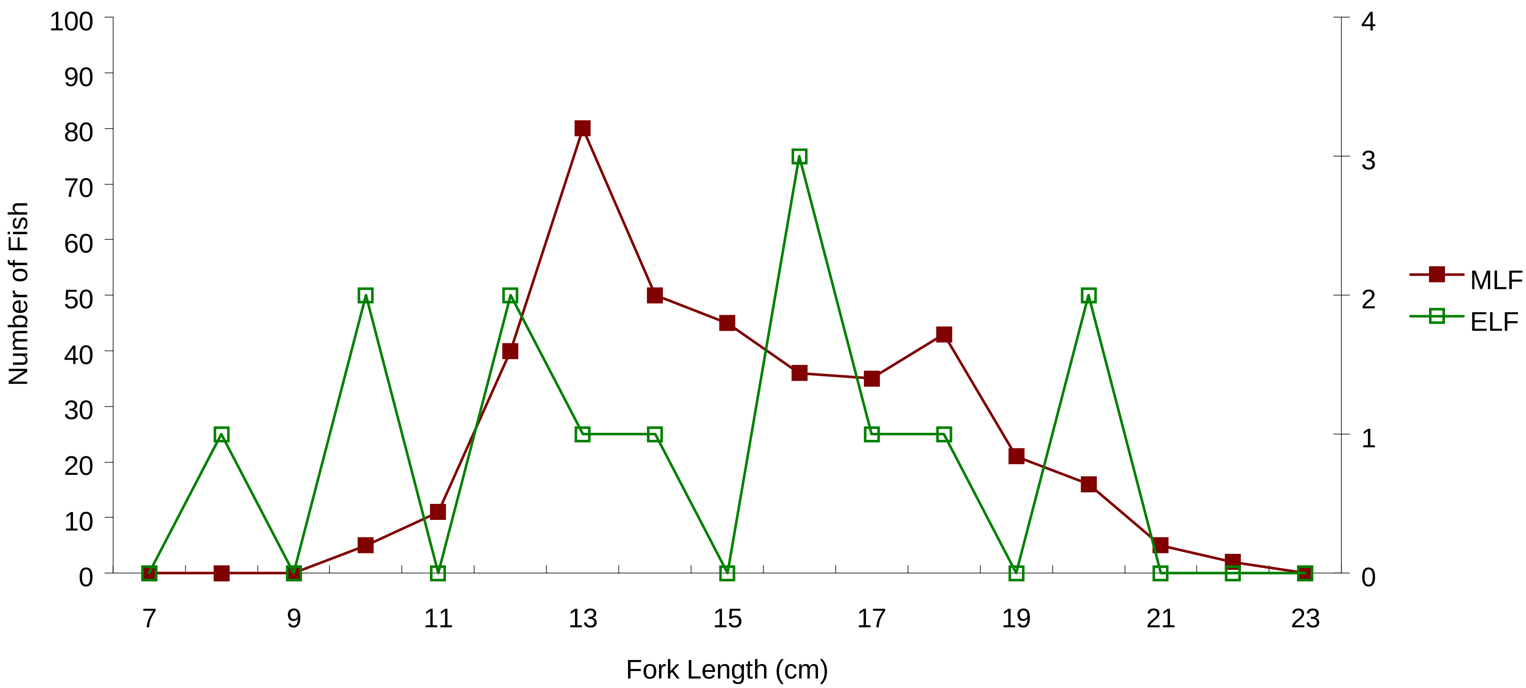

Group B Combined -- 1989 Brood
Number of Fish
100
90
80
70
60
50
40
30
20
10
0
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

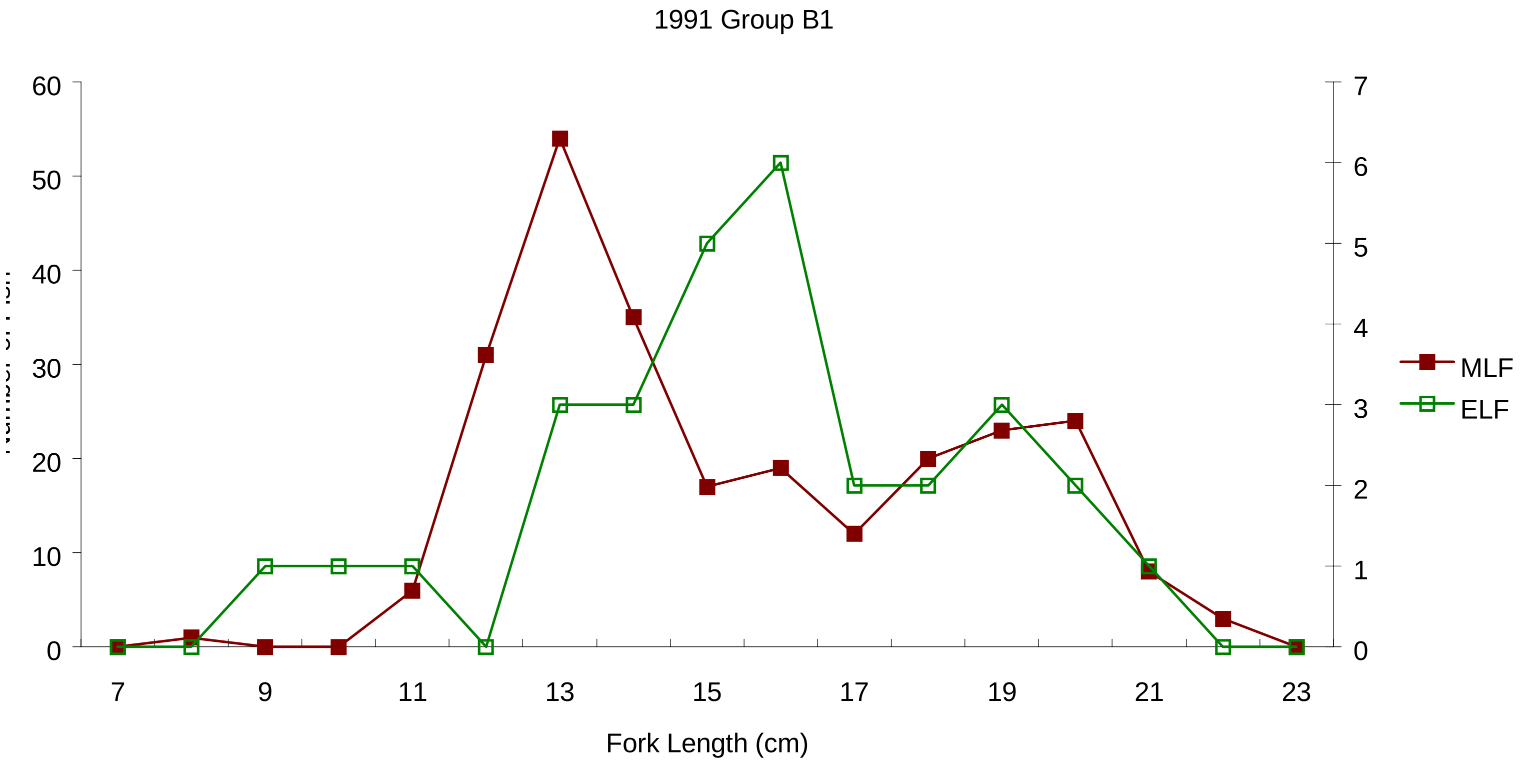

1990 Group B1
Number of Fish
50
45
40
35
30
25
20
15
10
5
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
2
1
0
MLF
ELF



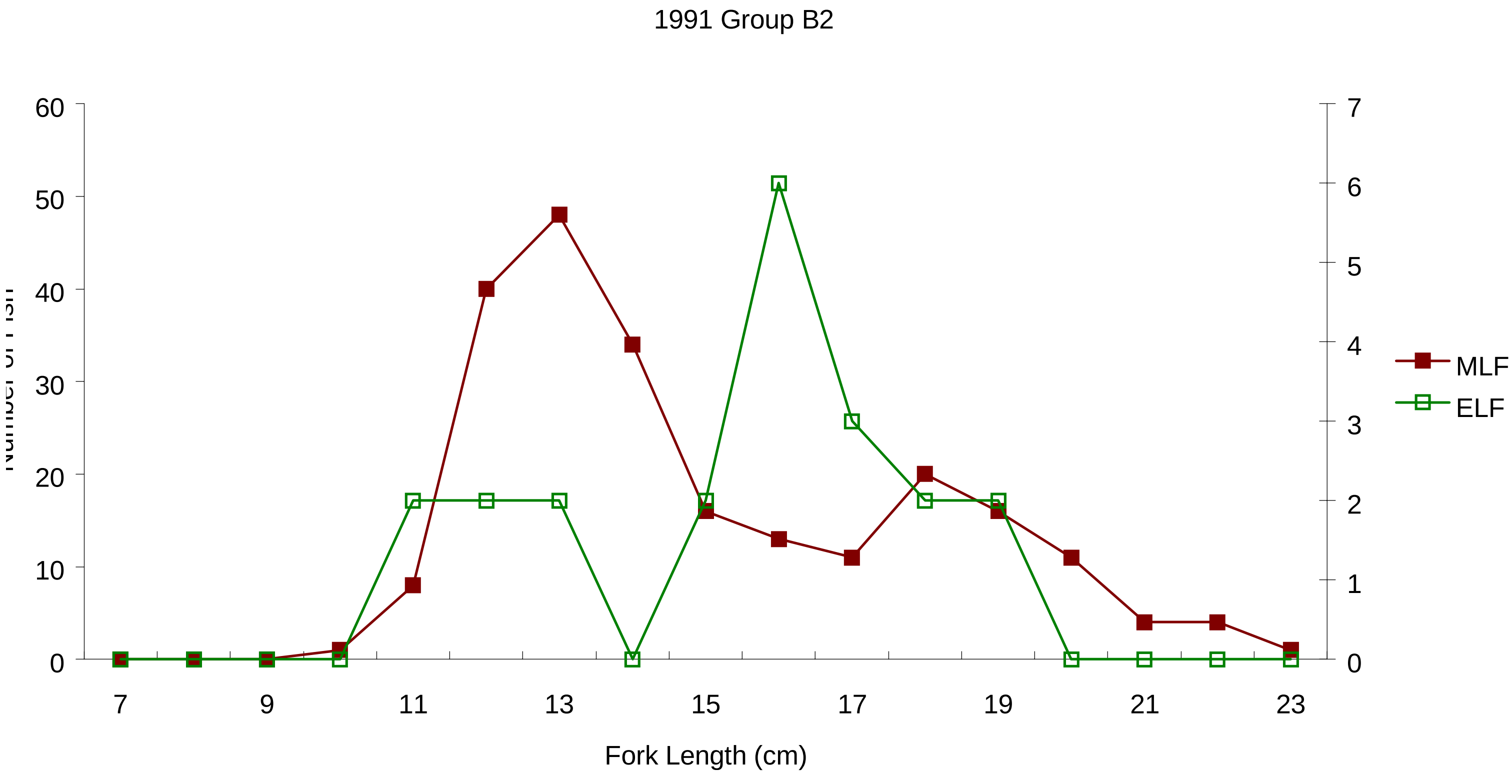
1990 Group B2
Number of Fish
60
50
40
30
20
10
0
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

1990 Group B Combined





1991 Group B1
60
50
40
30
20
10
0
7
6
5
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF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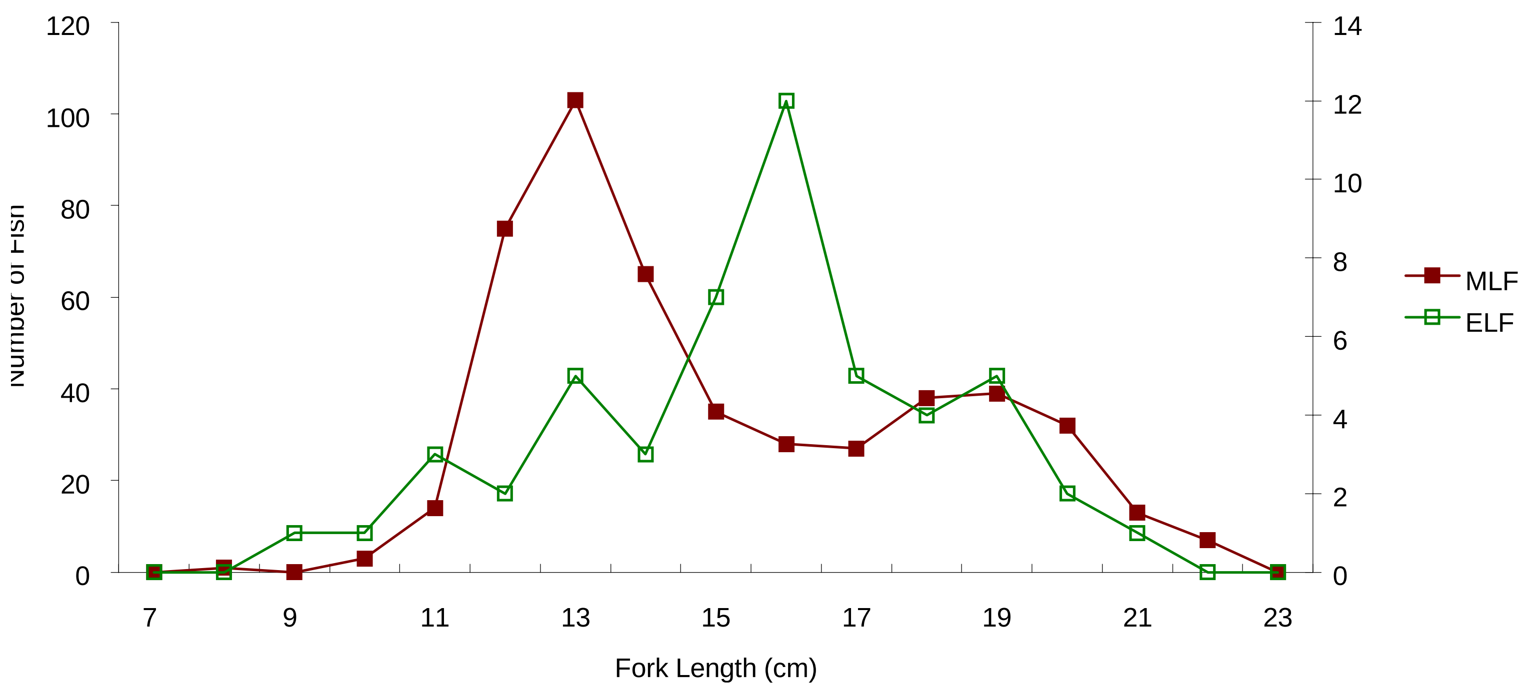
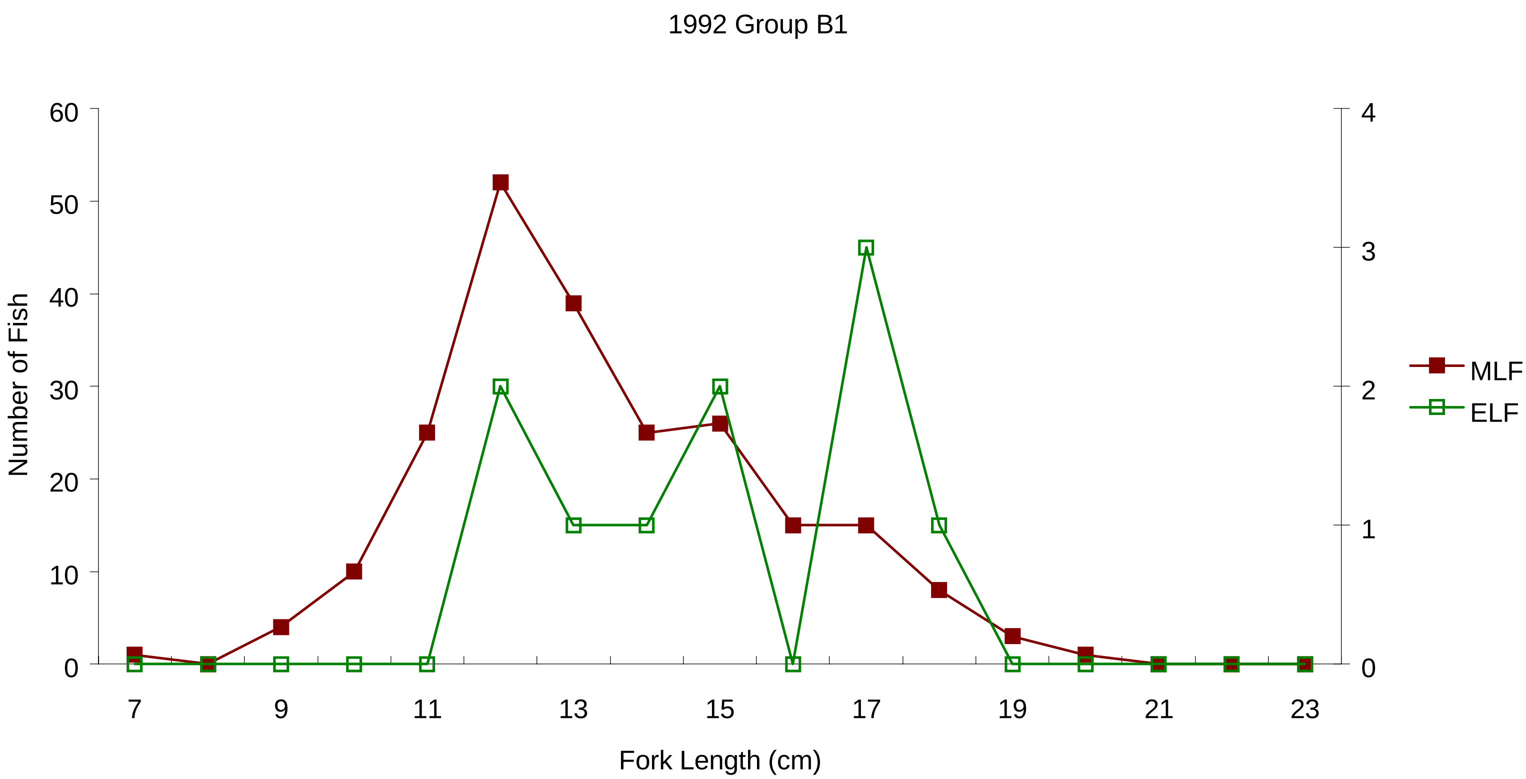
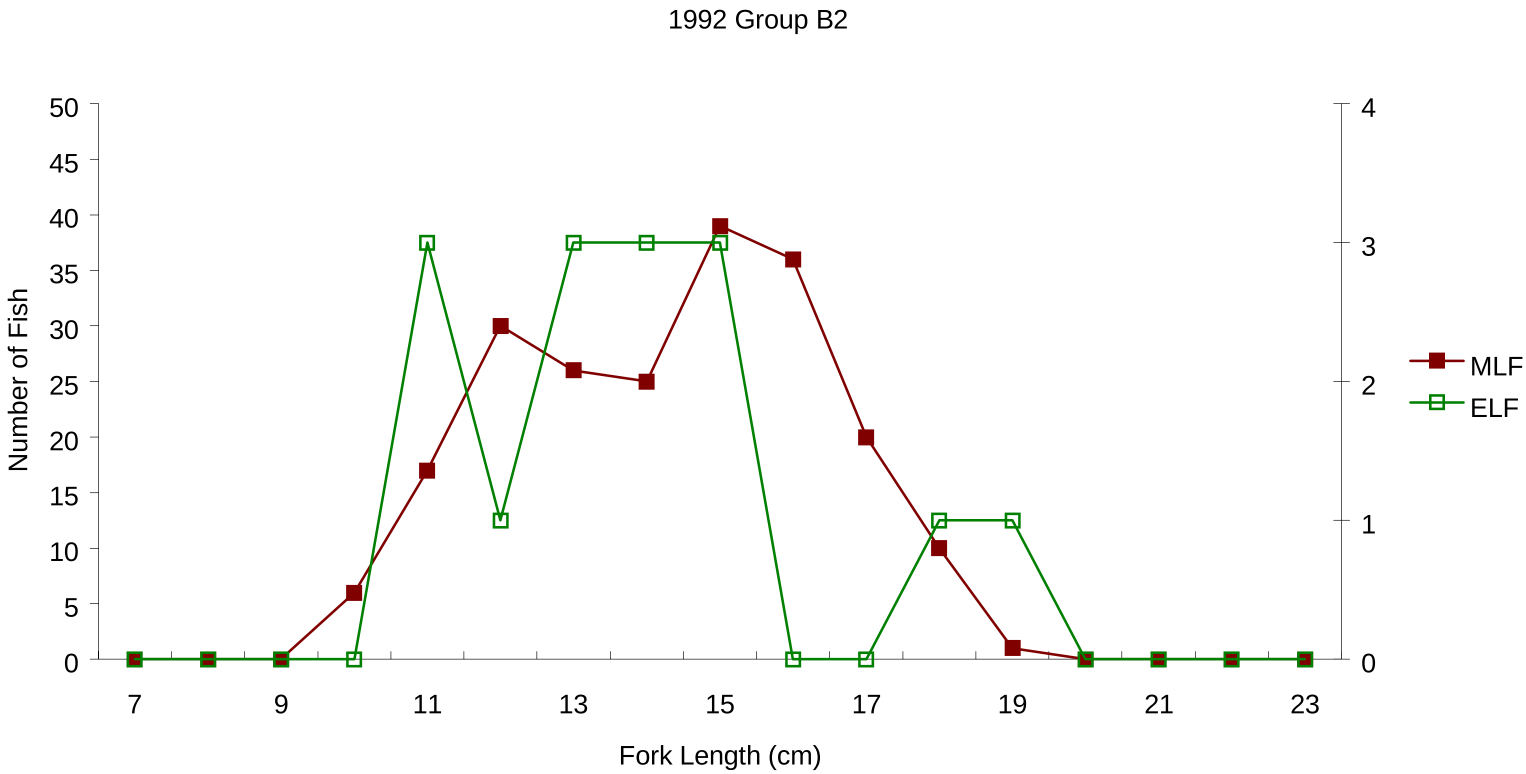
30
20
10
0
7
6
5
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

1991 Group B Combined




1992 Group B1
Number of Fish
60
50
40
30
20
10
0
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF


1992 Group B2
Number of Fish
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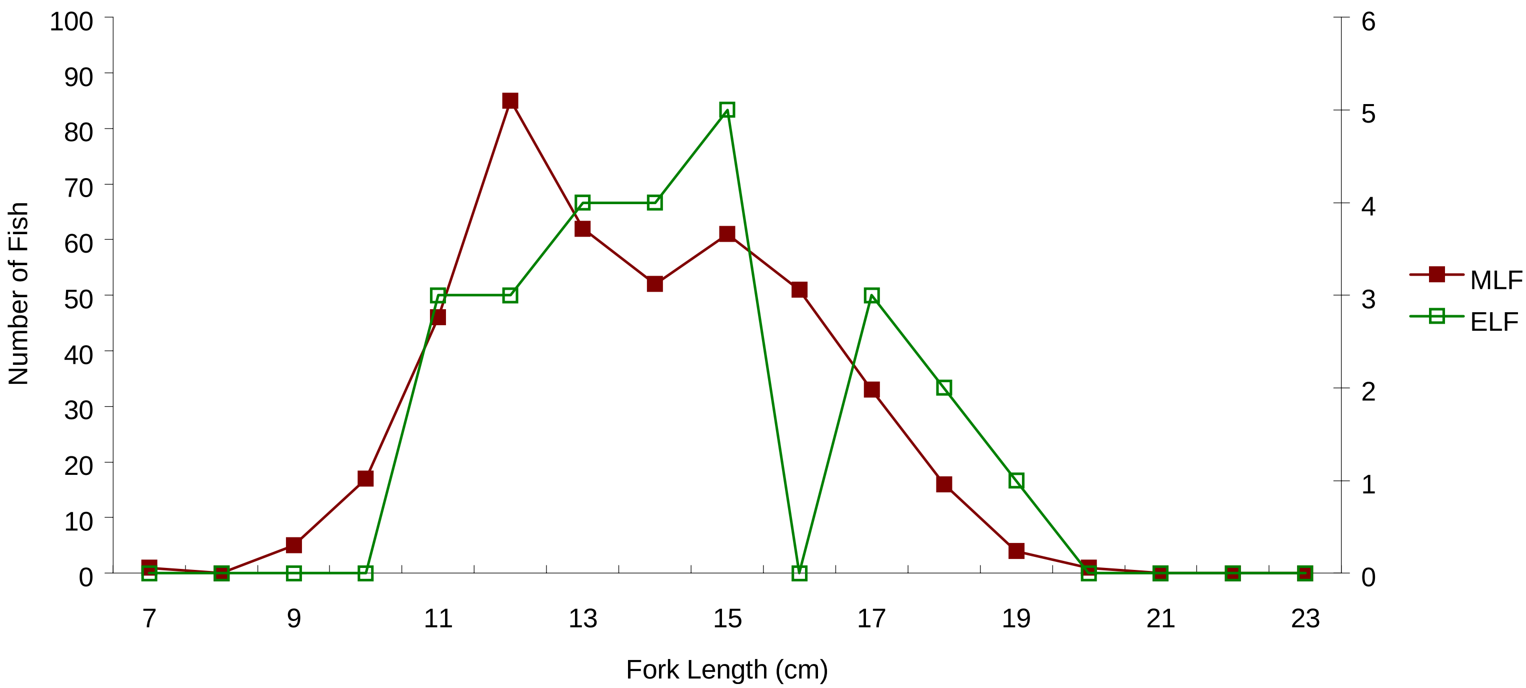
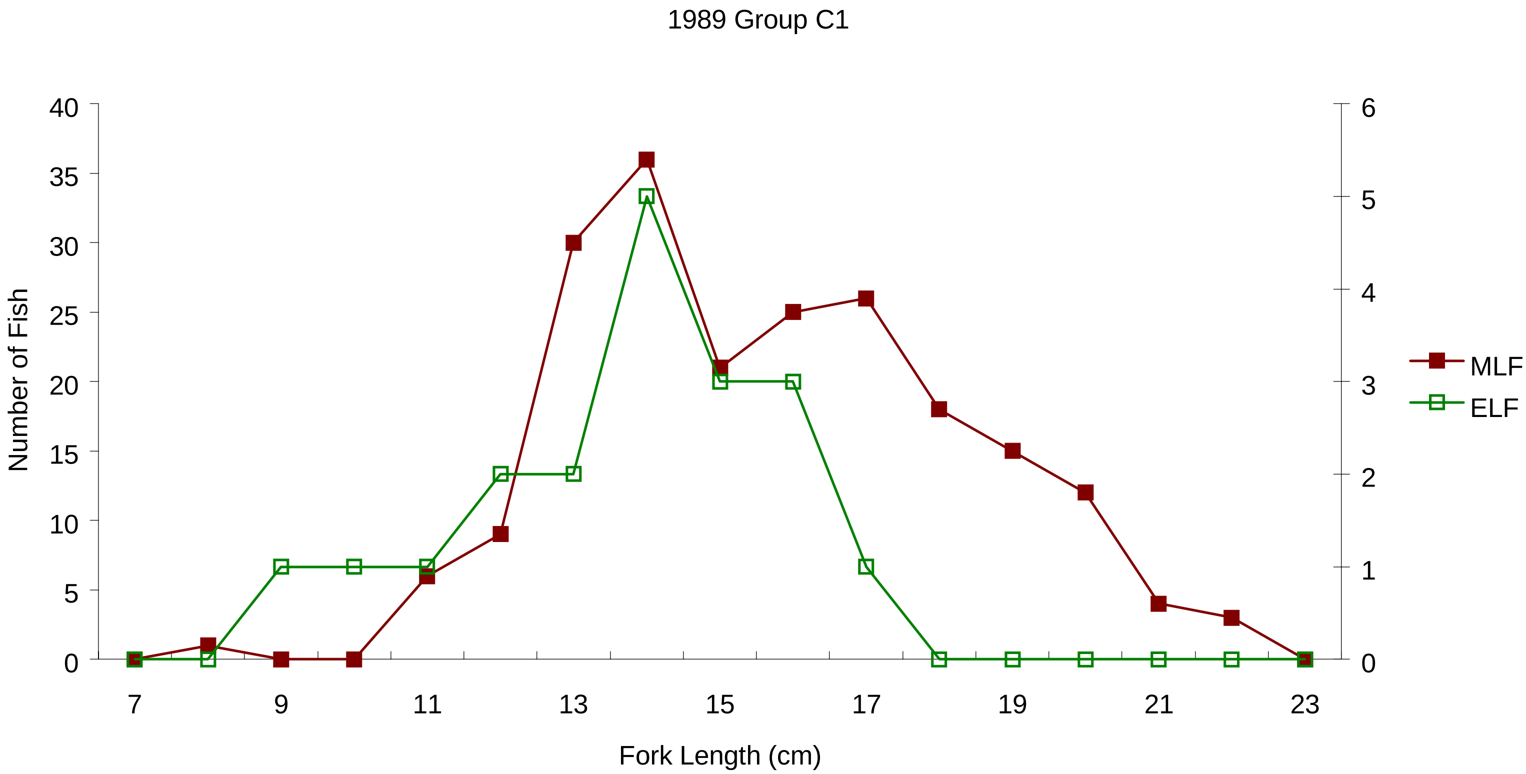
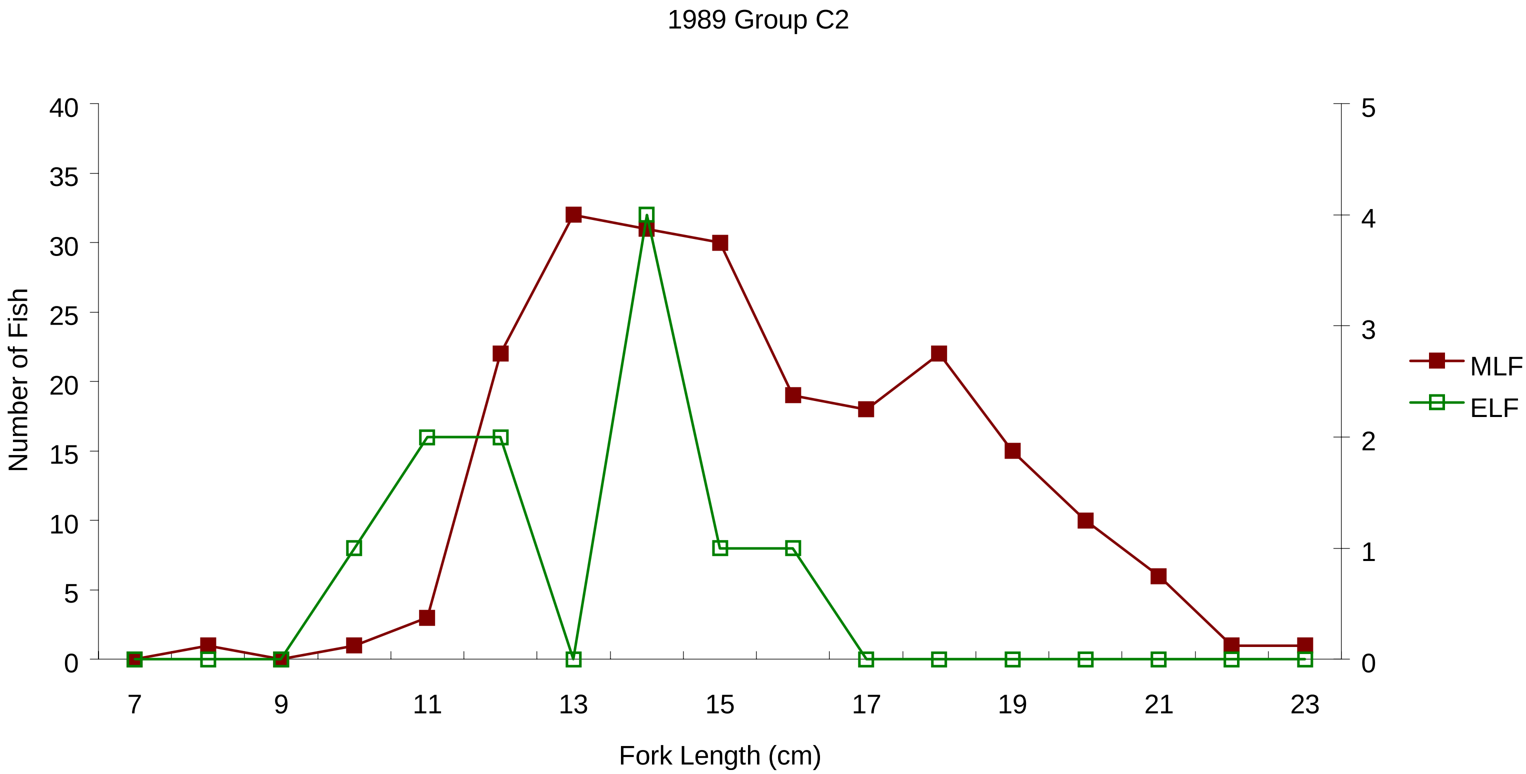
45
40
35
30
25
20
15
10
5
0
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

1992 Group B Combined

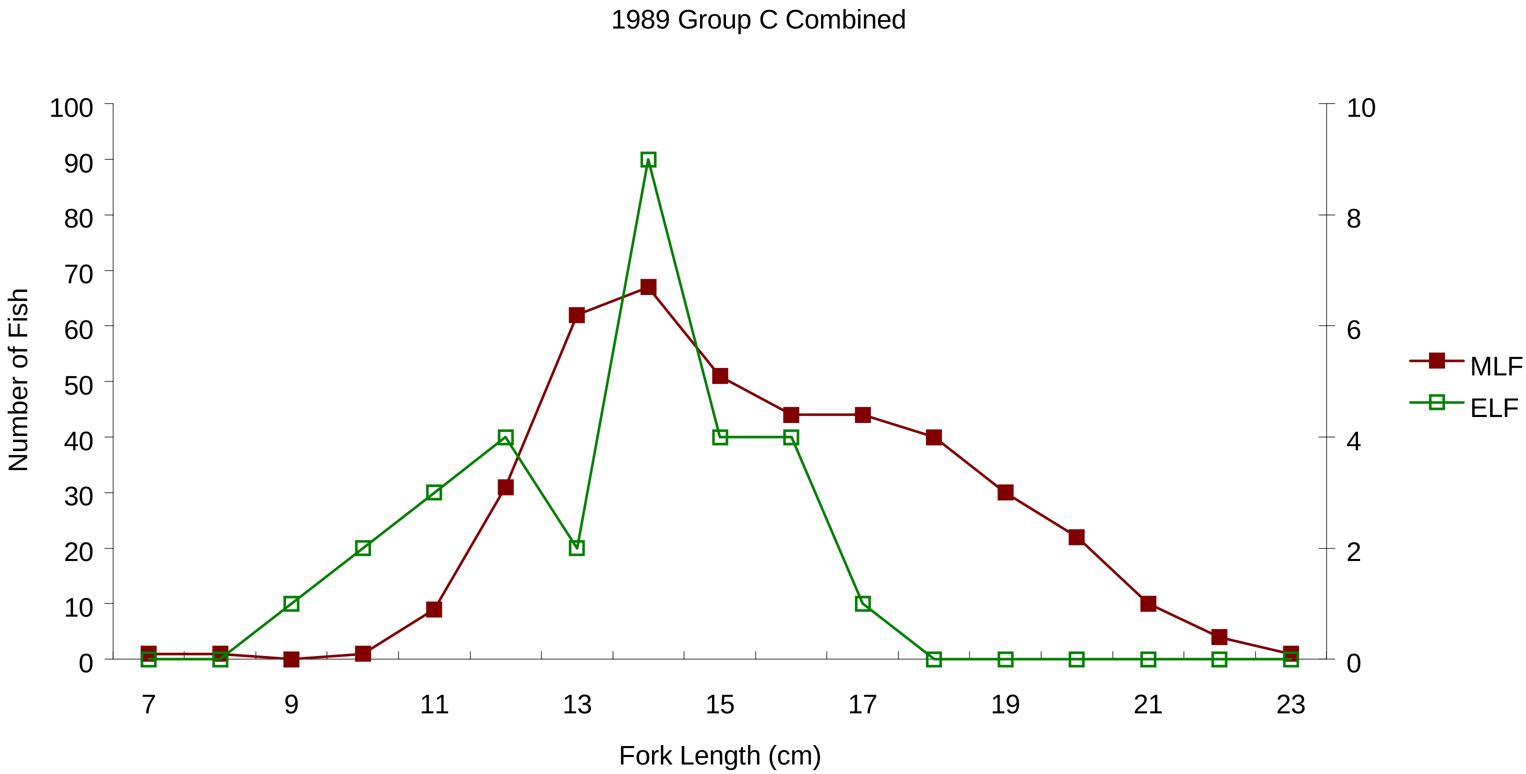


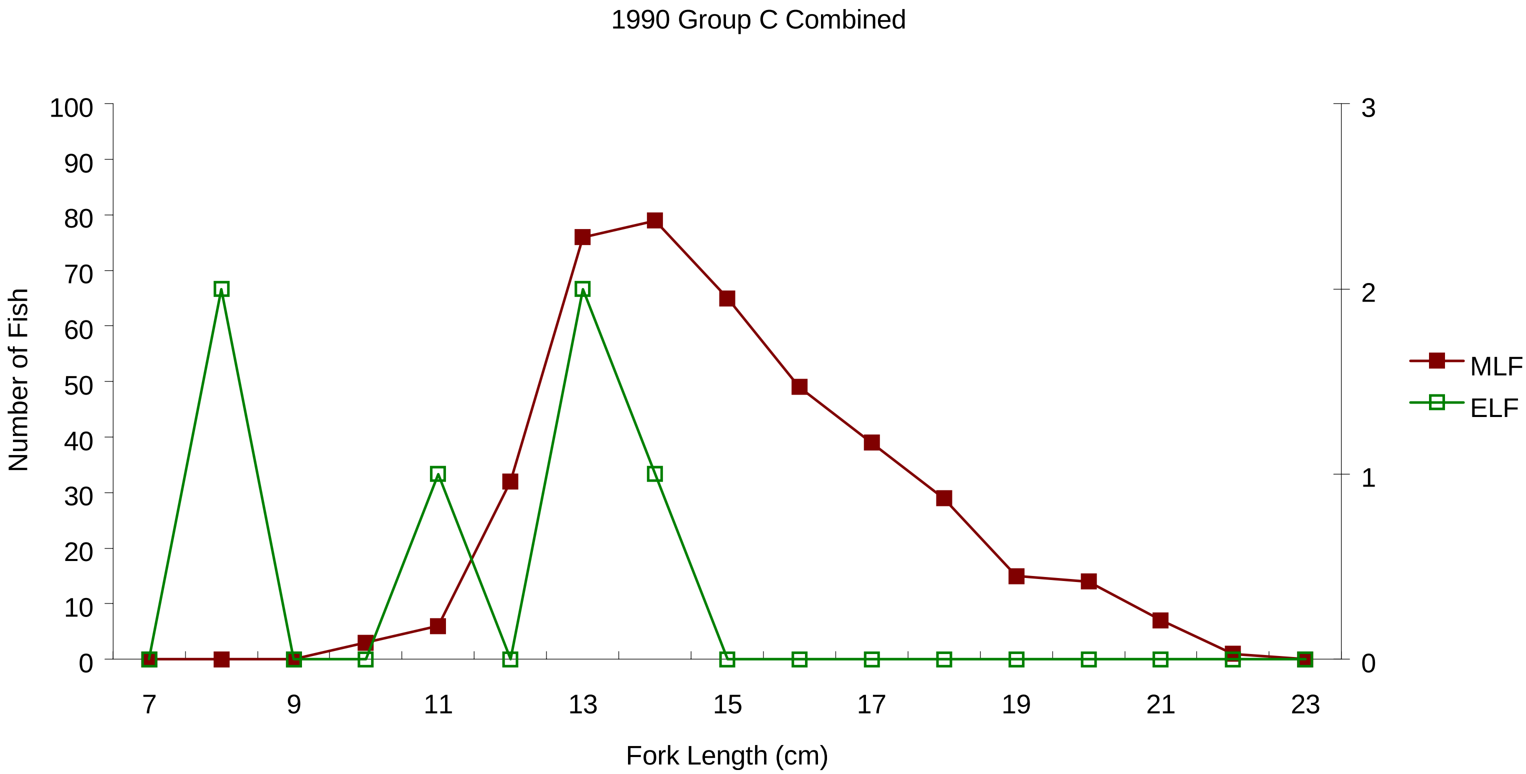


1989 Group C1
Number of Fish
40
35
30
25
20
15
10
5
0
6
5
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

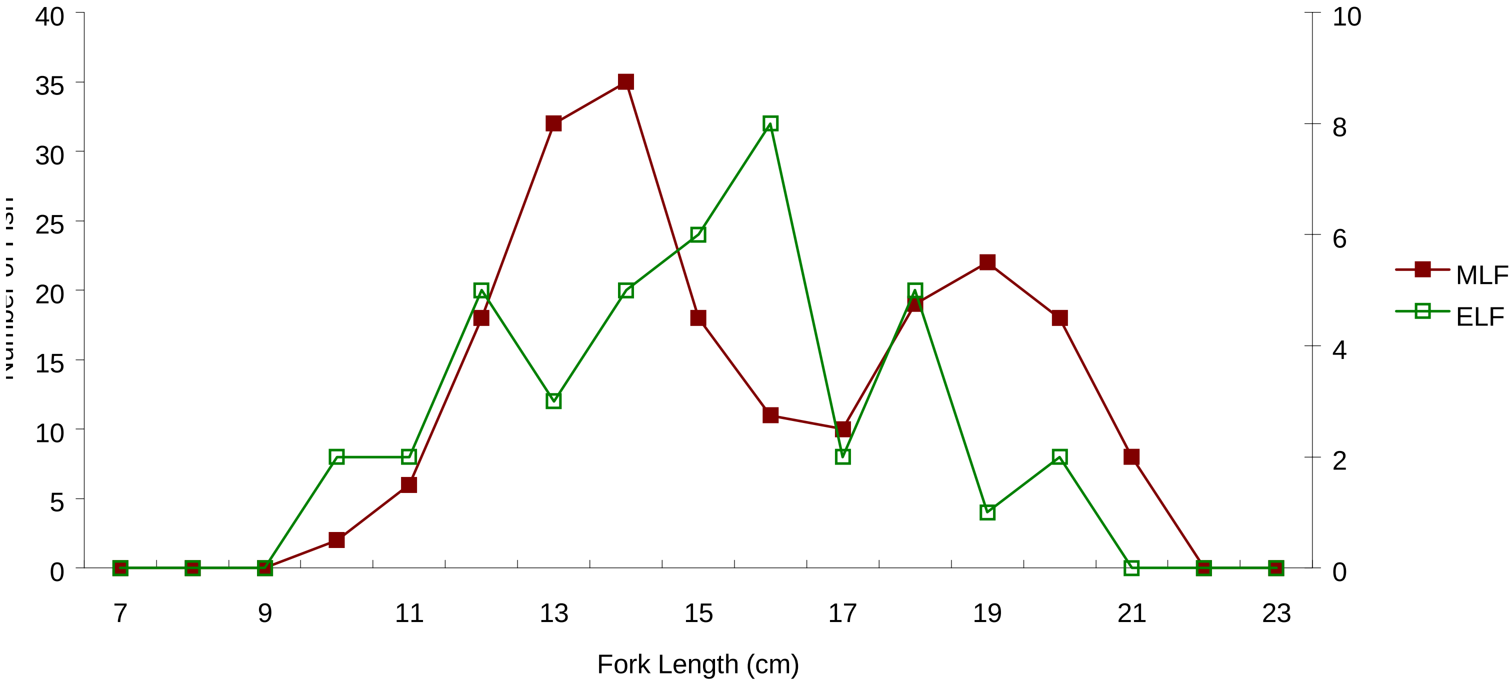


1989 Group C2
Number of Fish
40
35
30
25
20
15
10
5
0
5
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

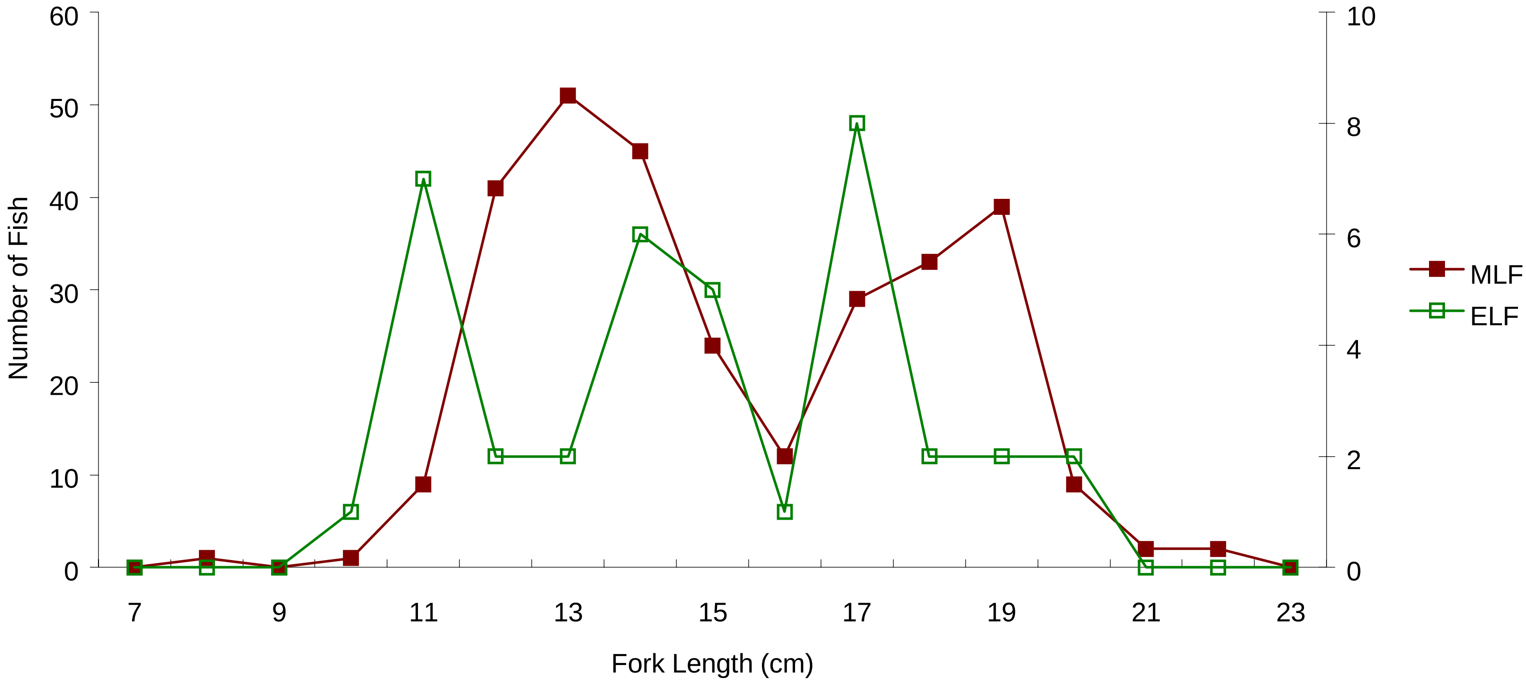

1989 Group C Combined
Number of Fish
100
90
80
70
60
50
40
30
20
10
0
10
8
6
4
2
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

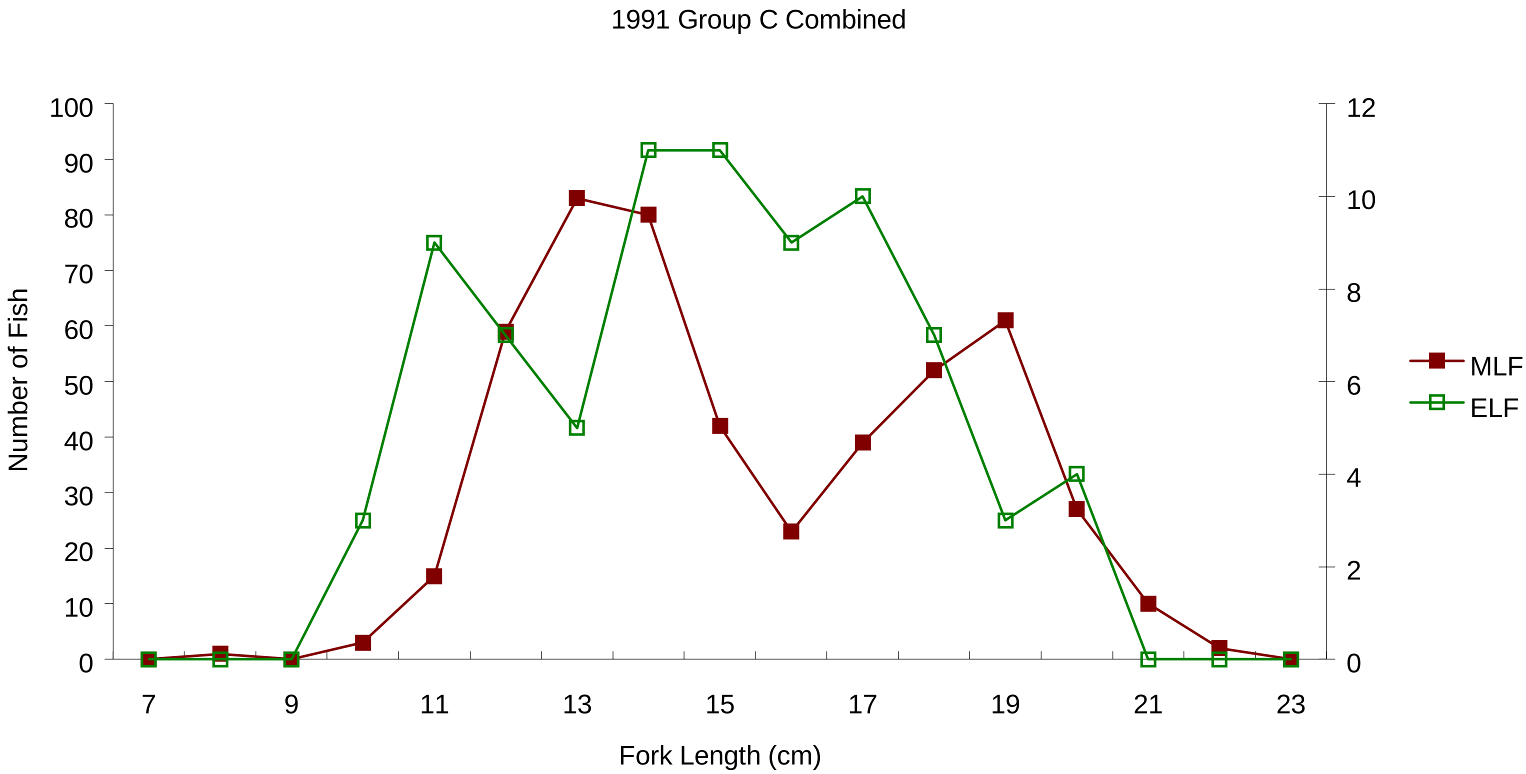

1990 Group C Combined
Number of Fish
100
90
80
70
60
50
40
30
20
10
0
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

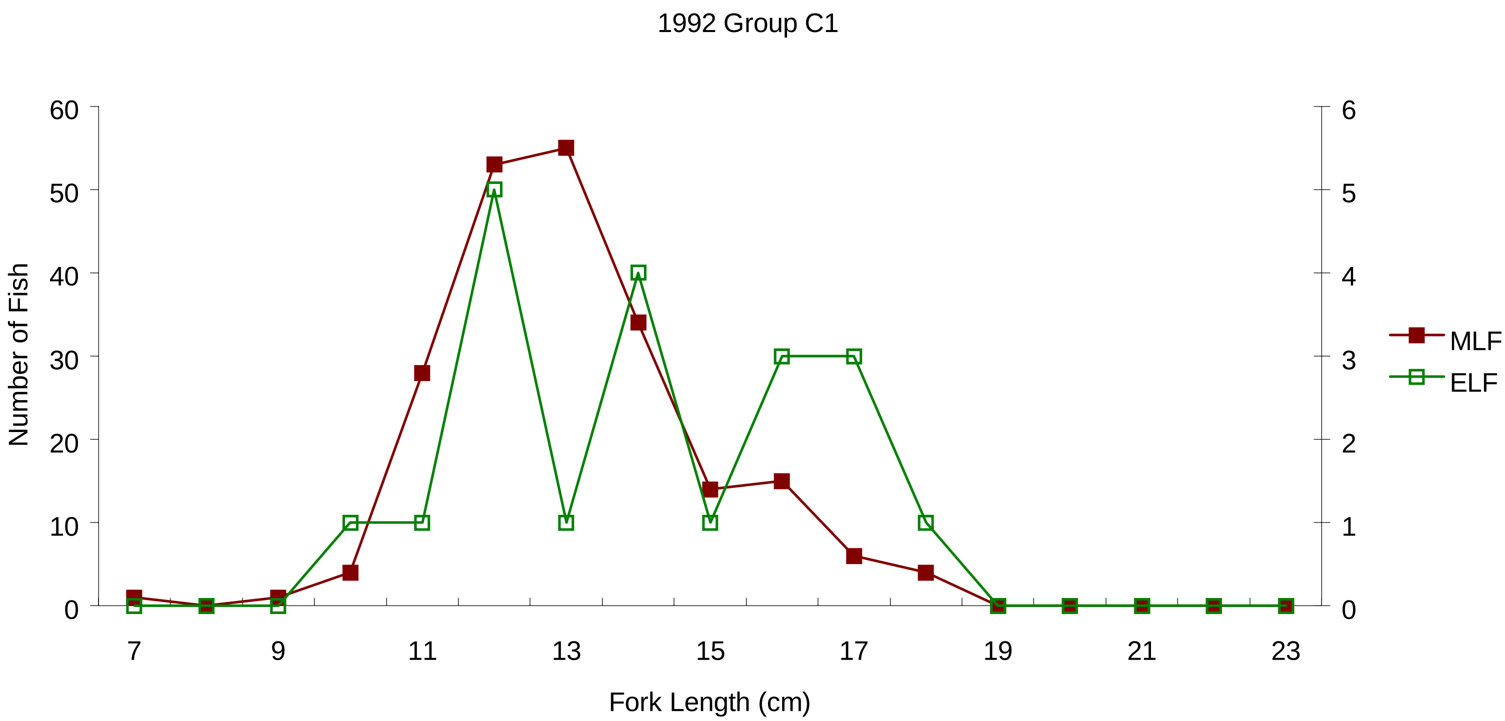
1991 Group C1



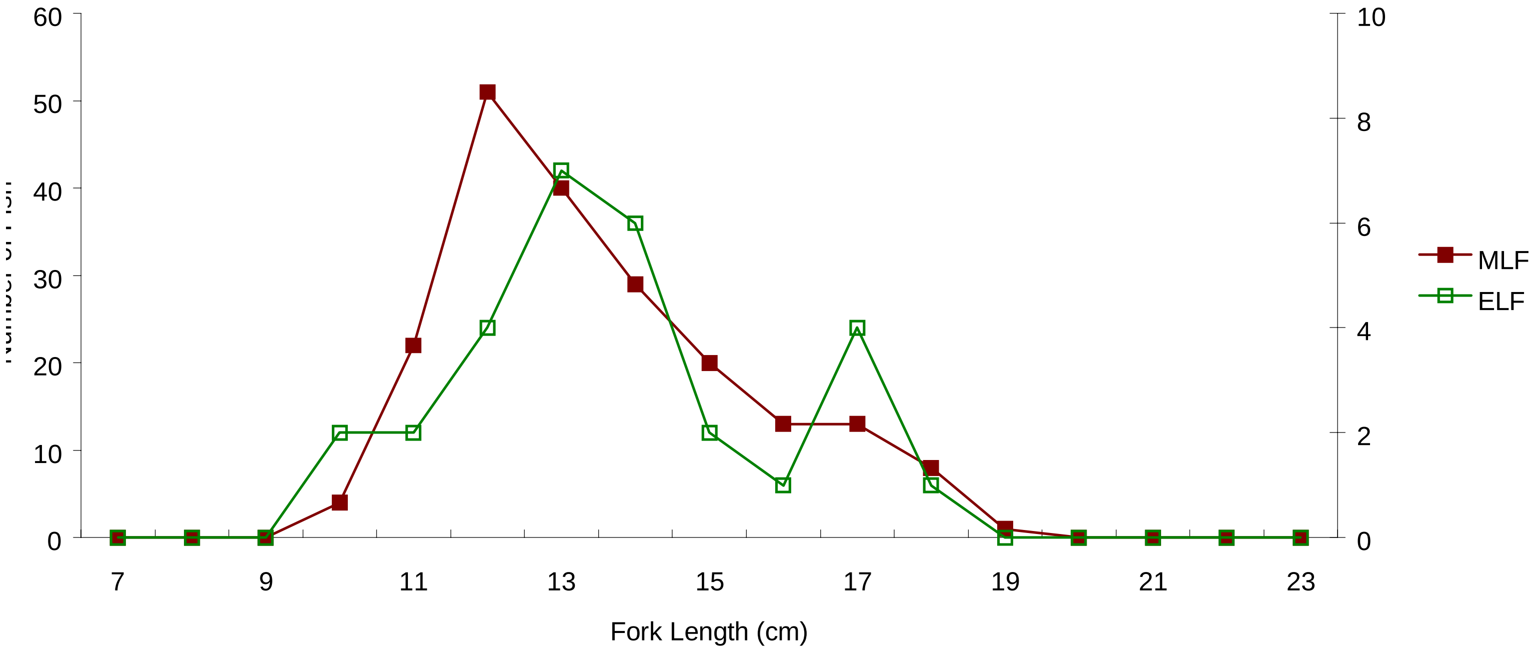
1991 Group C2

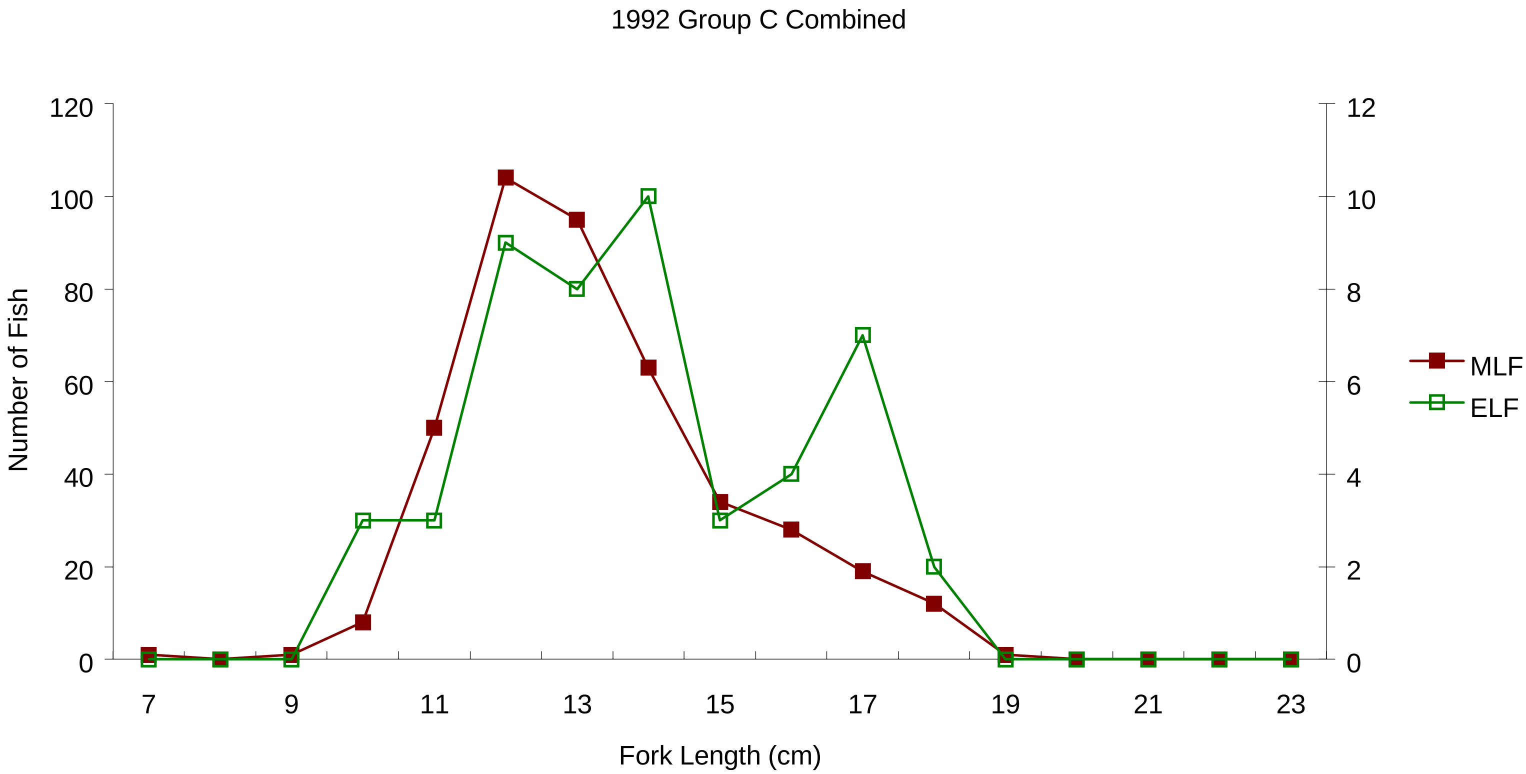


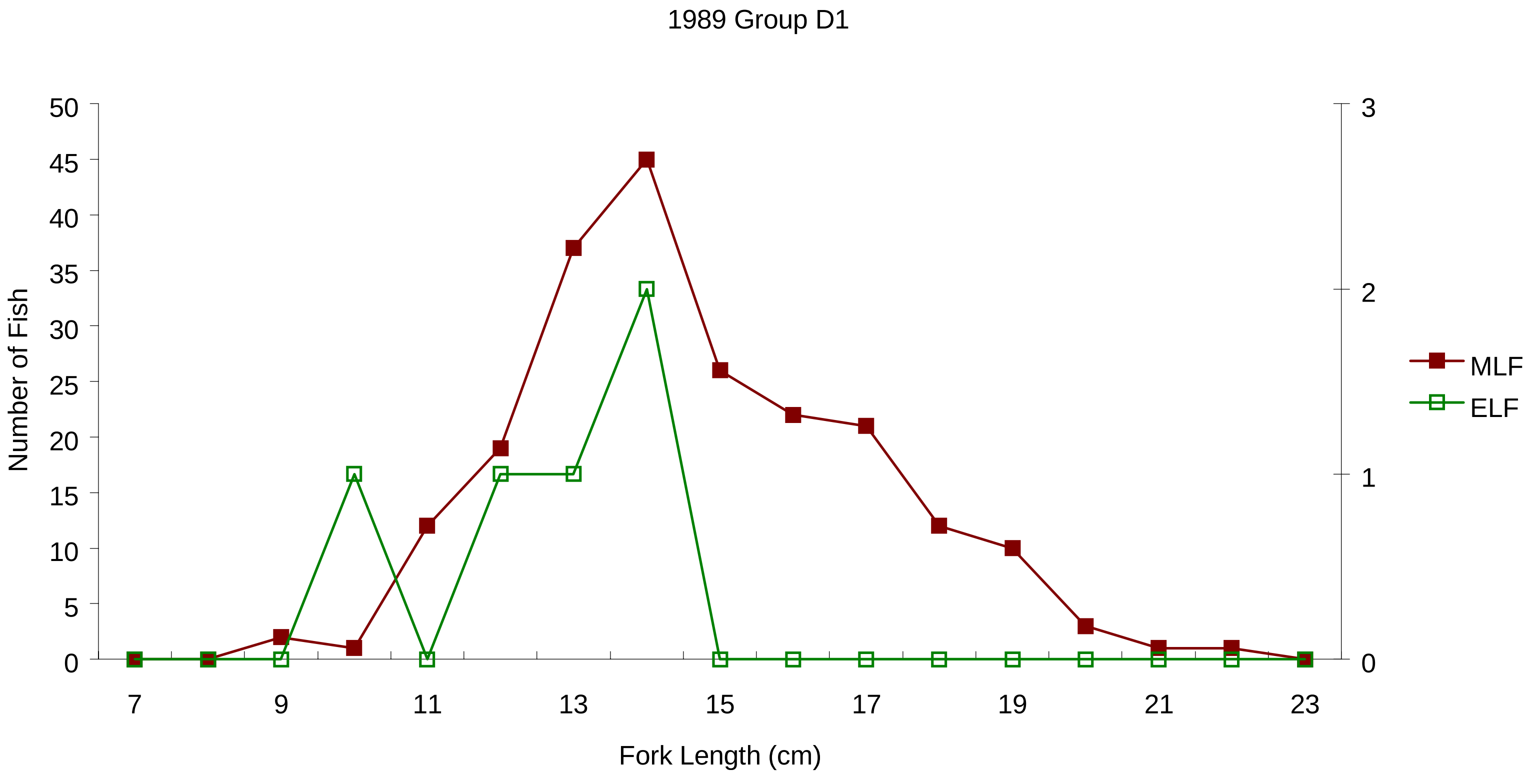

1991 Group C Combined
Number of Fish
100
90
80
70
60
50
40
30
20
10
0
12
10
8
6
4
2
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

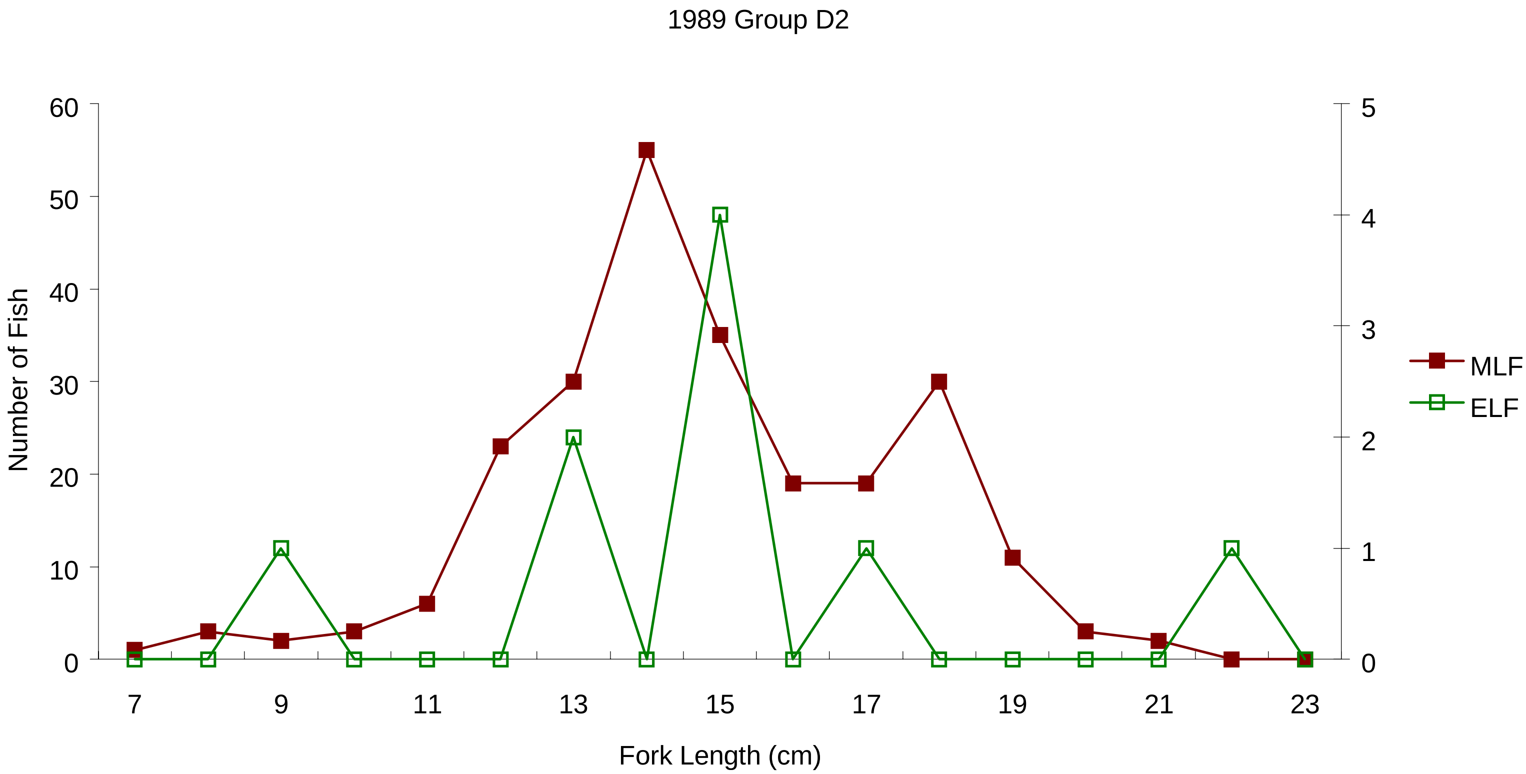

1992 Group C1
Number of Fish
60
50
40
30
20
10
0
6
5
4
3
2
1
0
MLF
ELF
7
9
11
13
15
17
19
21
23
Fork Length (cm)

1992 Group C2




1992 Group C Combined
Number of Fish
120
100
80
60
40
20
0
12
10
8
6
4
2
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF


1989 Group D1
Number of Fish
Fork Length (cm)
MLF
ELF
50
45
40
35
30
25
20
15
10
5
0
3
2
1
0
7
9
11
13
15
17
19
21
23


1989 Group D2
Number of Fish
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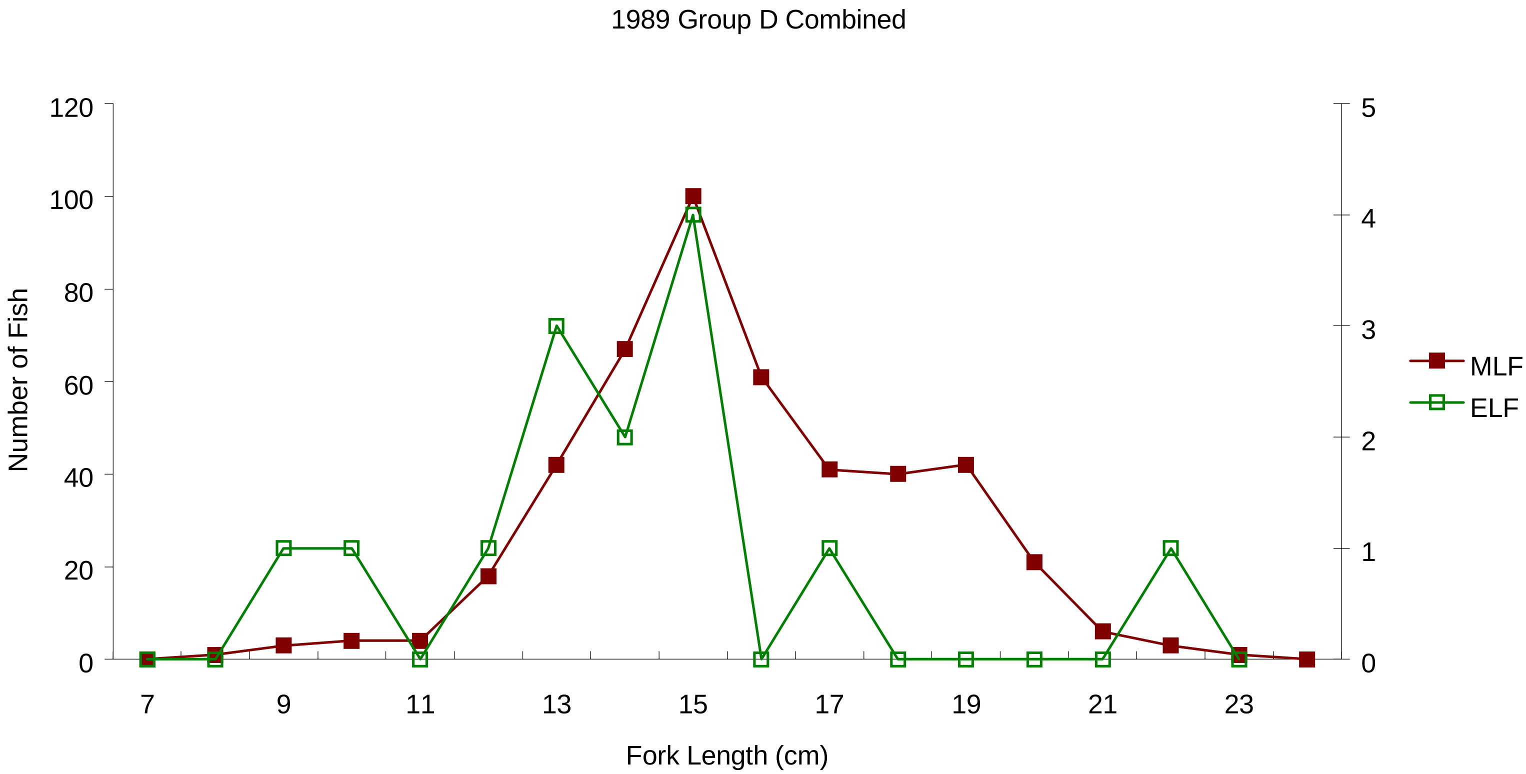
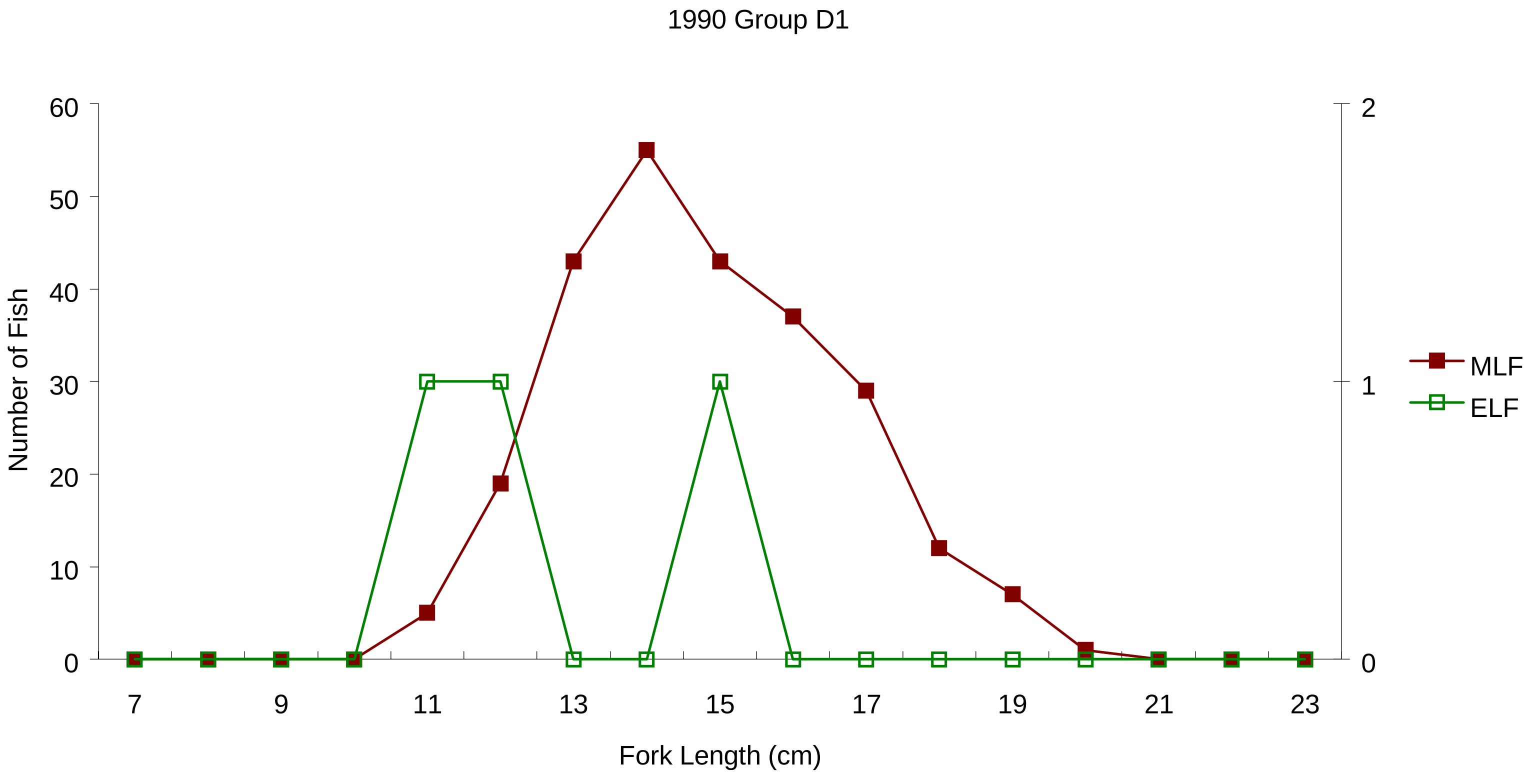
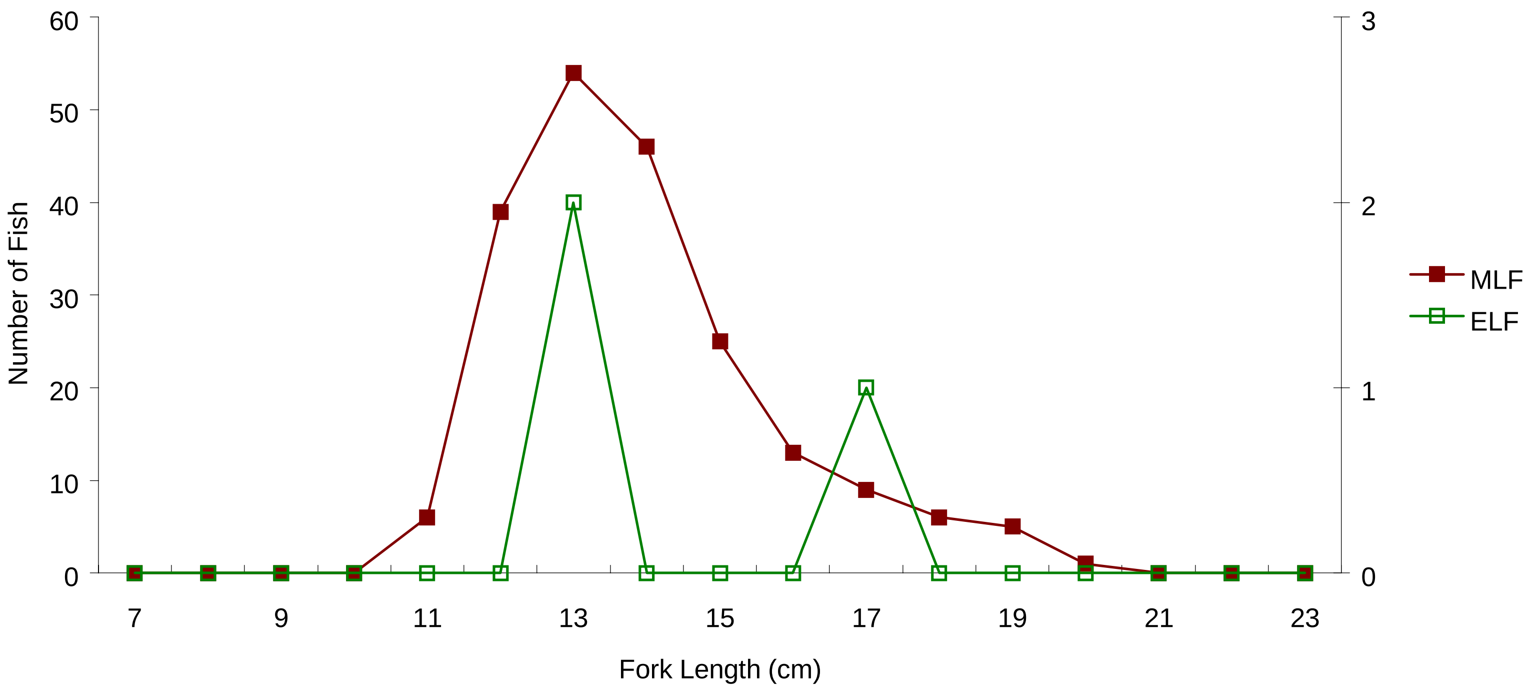
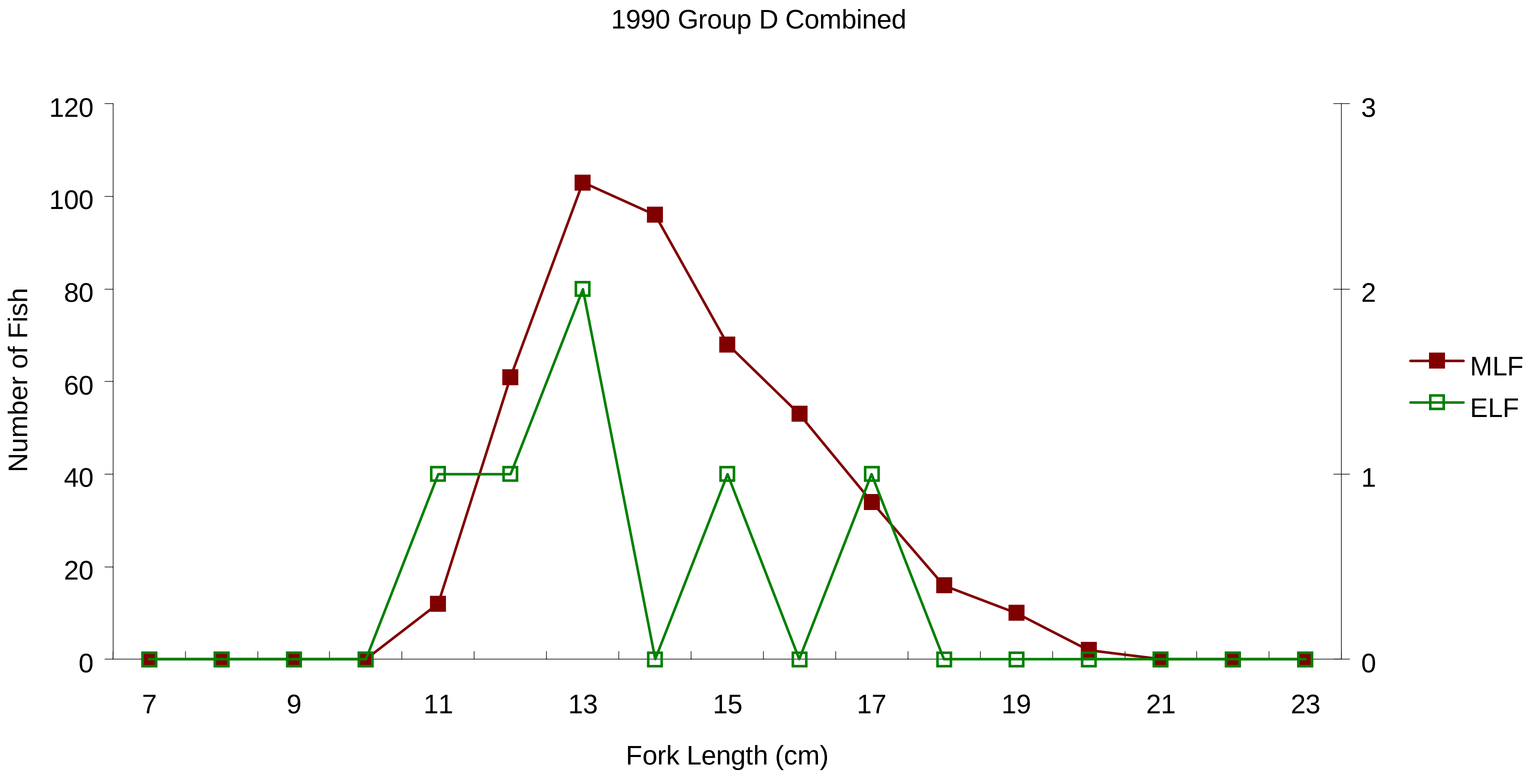
50
40
30
20
10
0
5
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF


1989 Group D Combined
Number of Fish
120
100
80
60
40
20
0
5
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

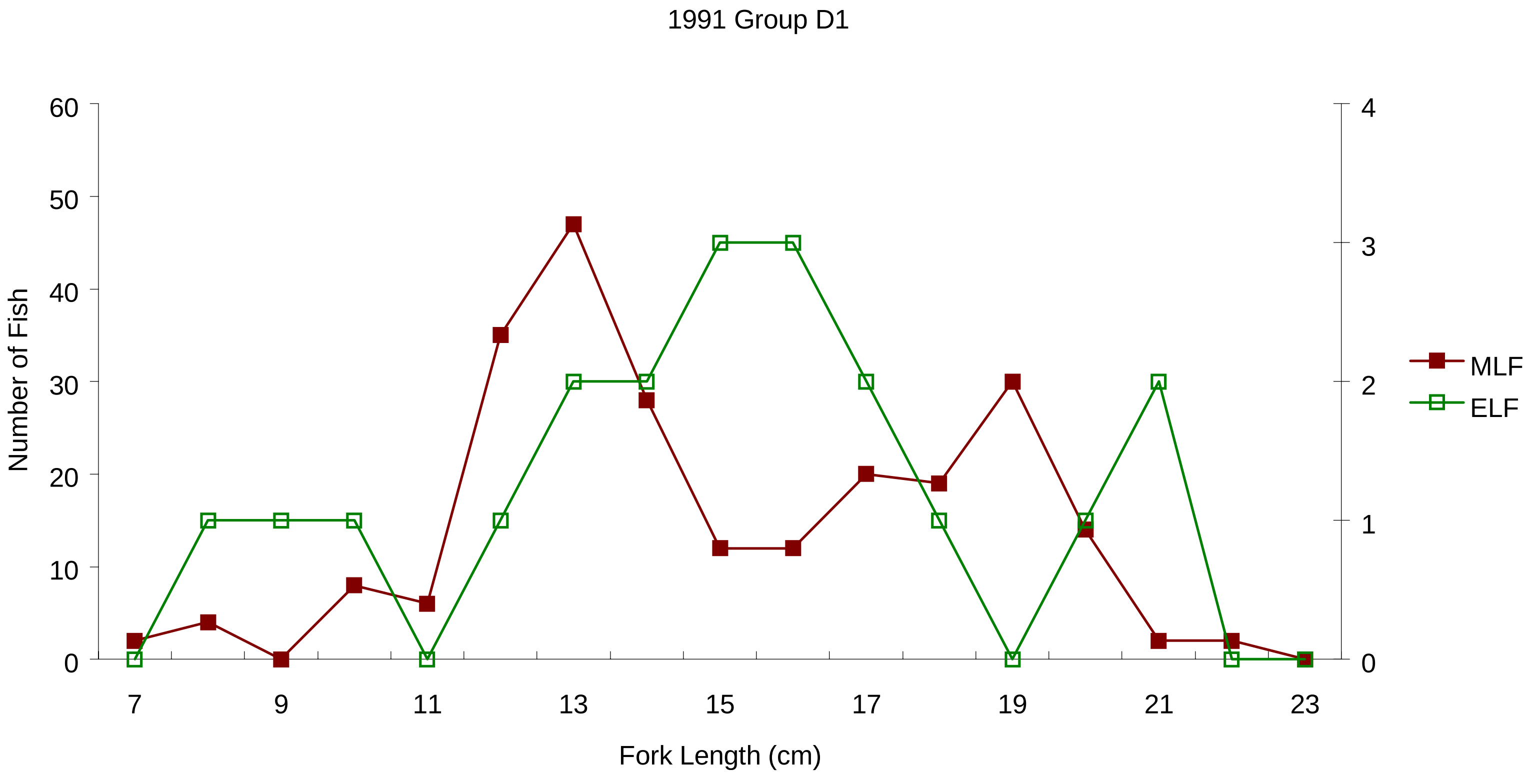

1990 Group D1
60
50
40
30
20
10
0
Number of Fish
2
1
0
MLF
ELF
7
9
11
13
15
17
19
21
23
Fork Length (cm)

1990 Group D2





1990 Group D Combined
Number of Fish
120
100
80
60
40
20
0
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF


1991 Group D1
60
50
40
30
20
10
0
Number of Fish
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2
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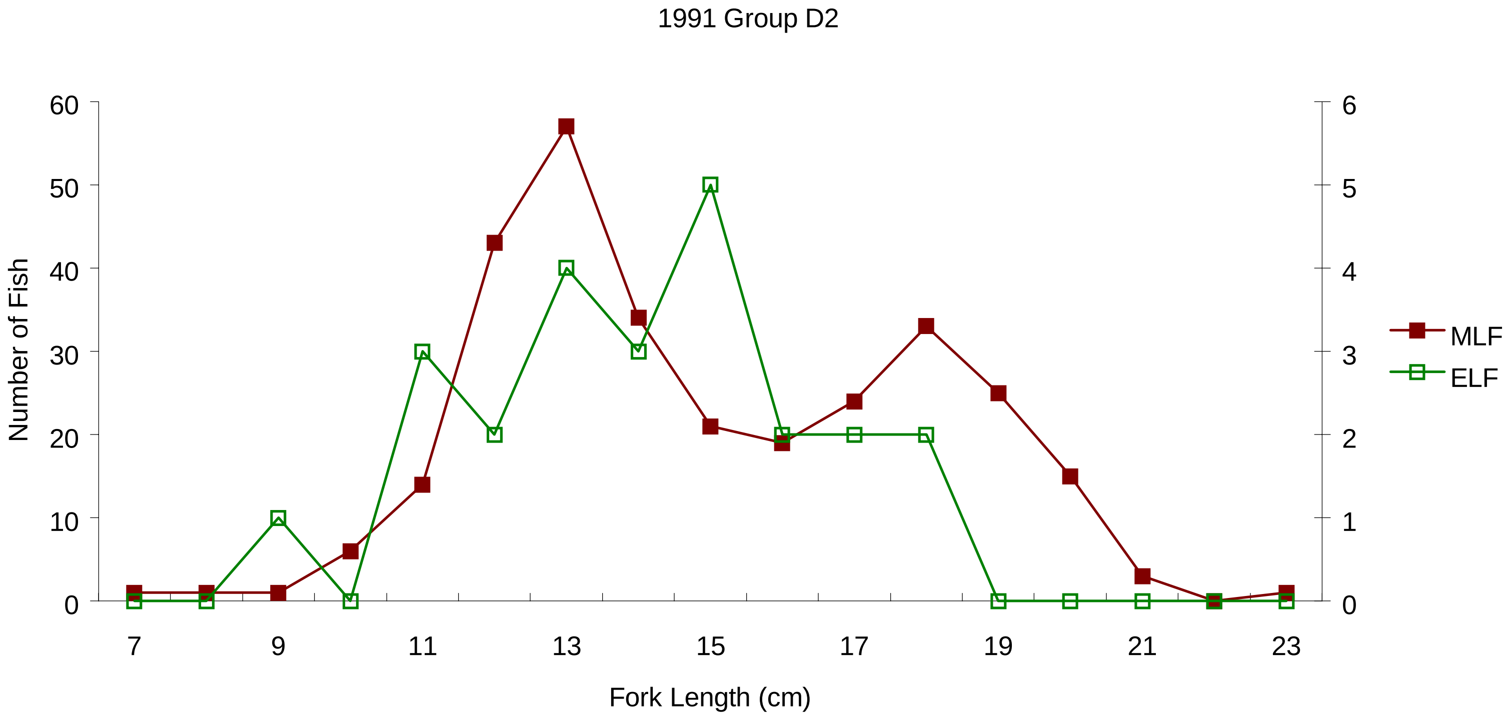
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF


1991 Group D2
Number of Fish
Fork Length (cm)
MLF
ELF
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10
20
30
40
50
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2
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4
5
6
7
9
11
13
15
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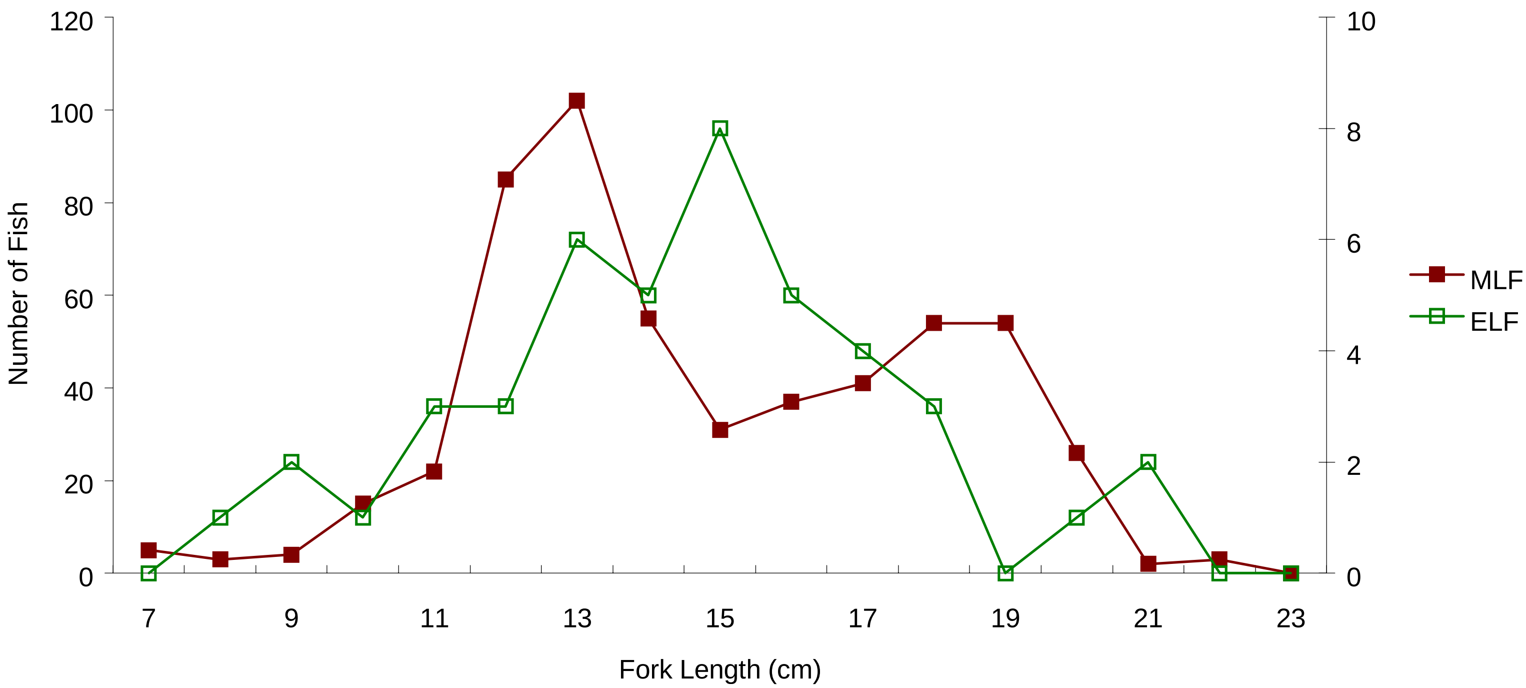
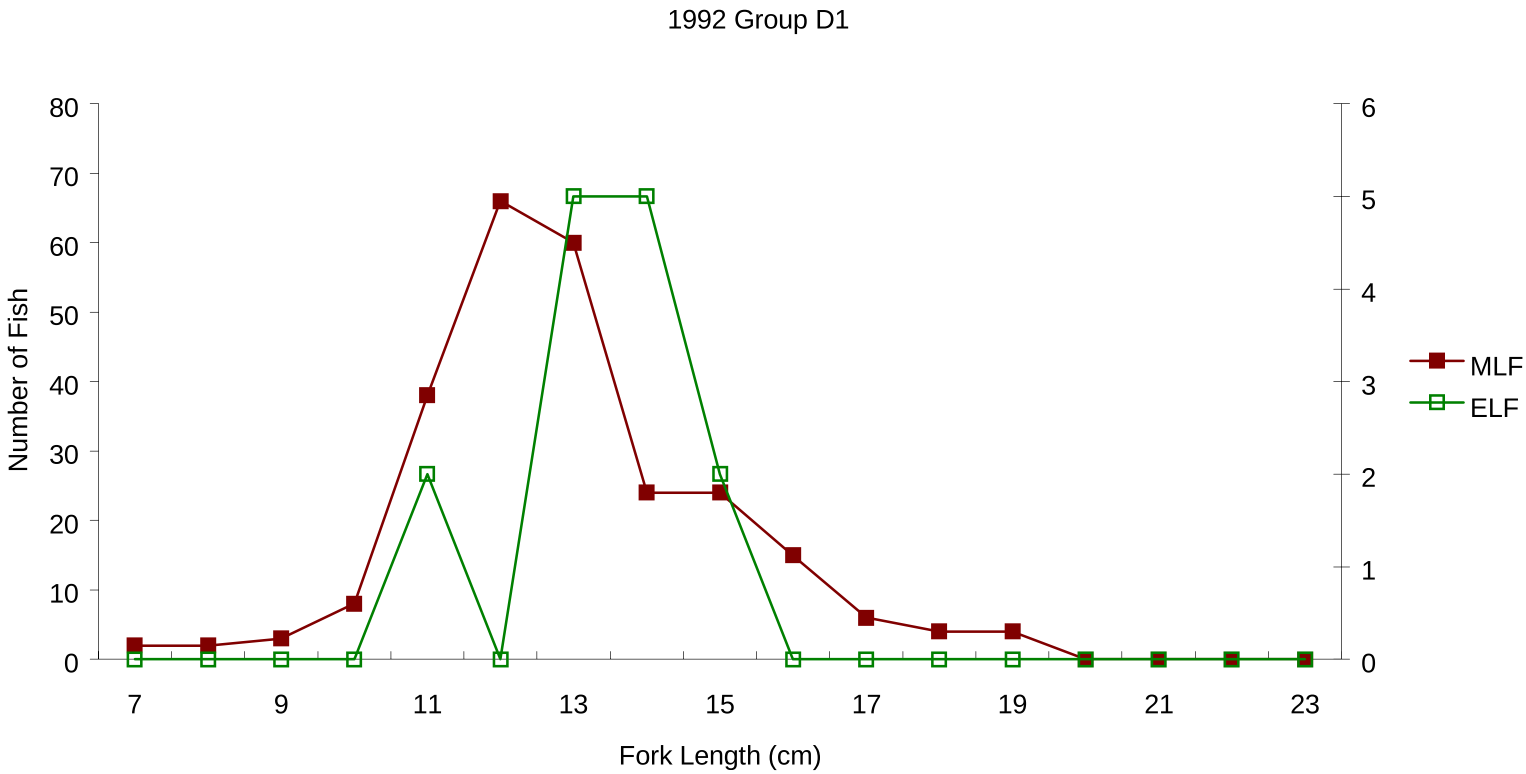
19
21
23

1991 Group D Combined





1992 Group D1
Number of Fish
80
70
60
50
40
30
20
10
0
6
5
4
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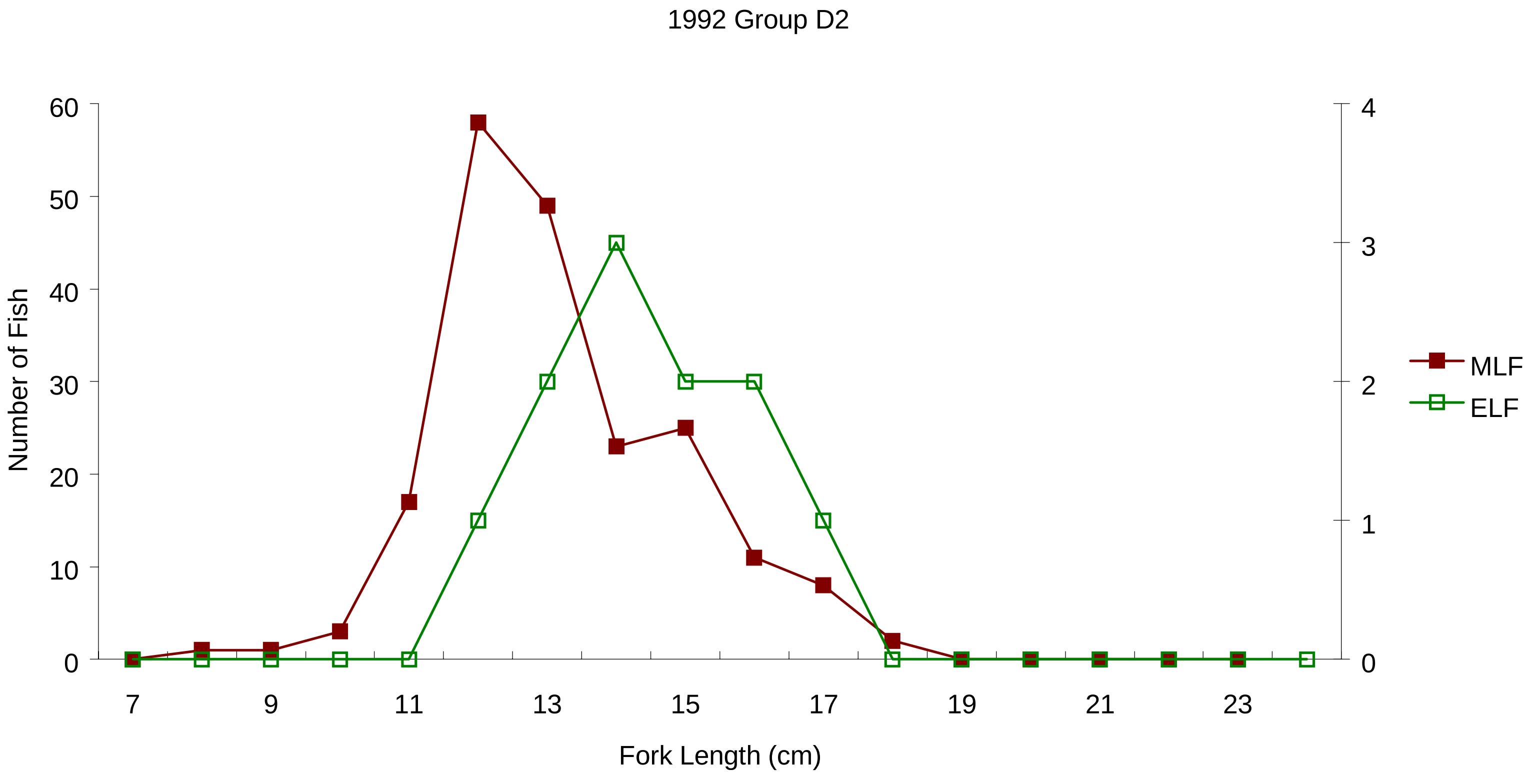
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF


1992 Group D2
Number of Fish
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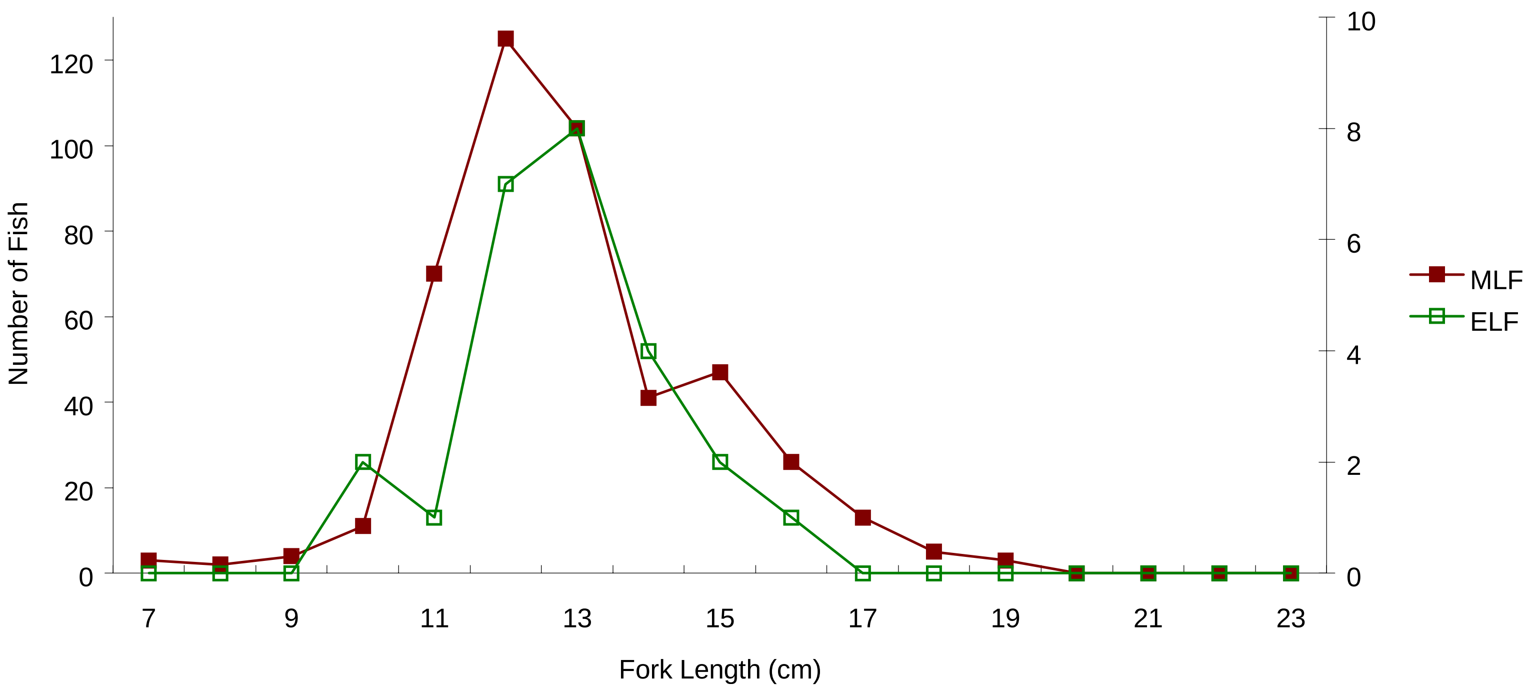
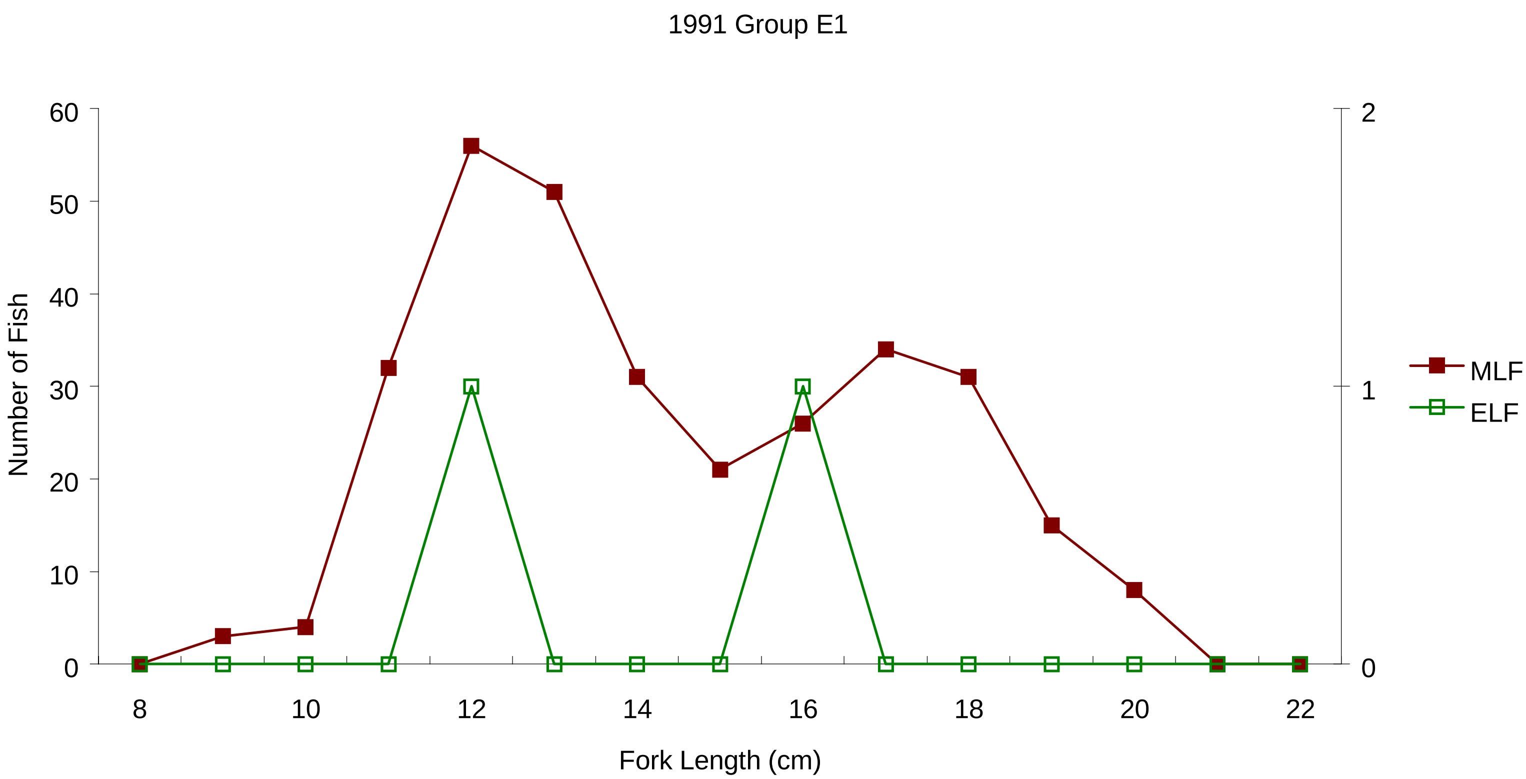
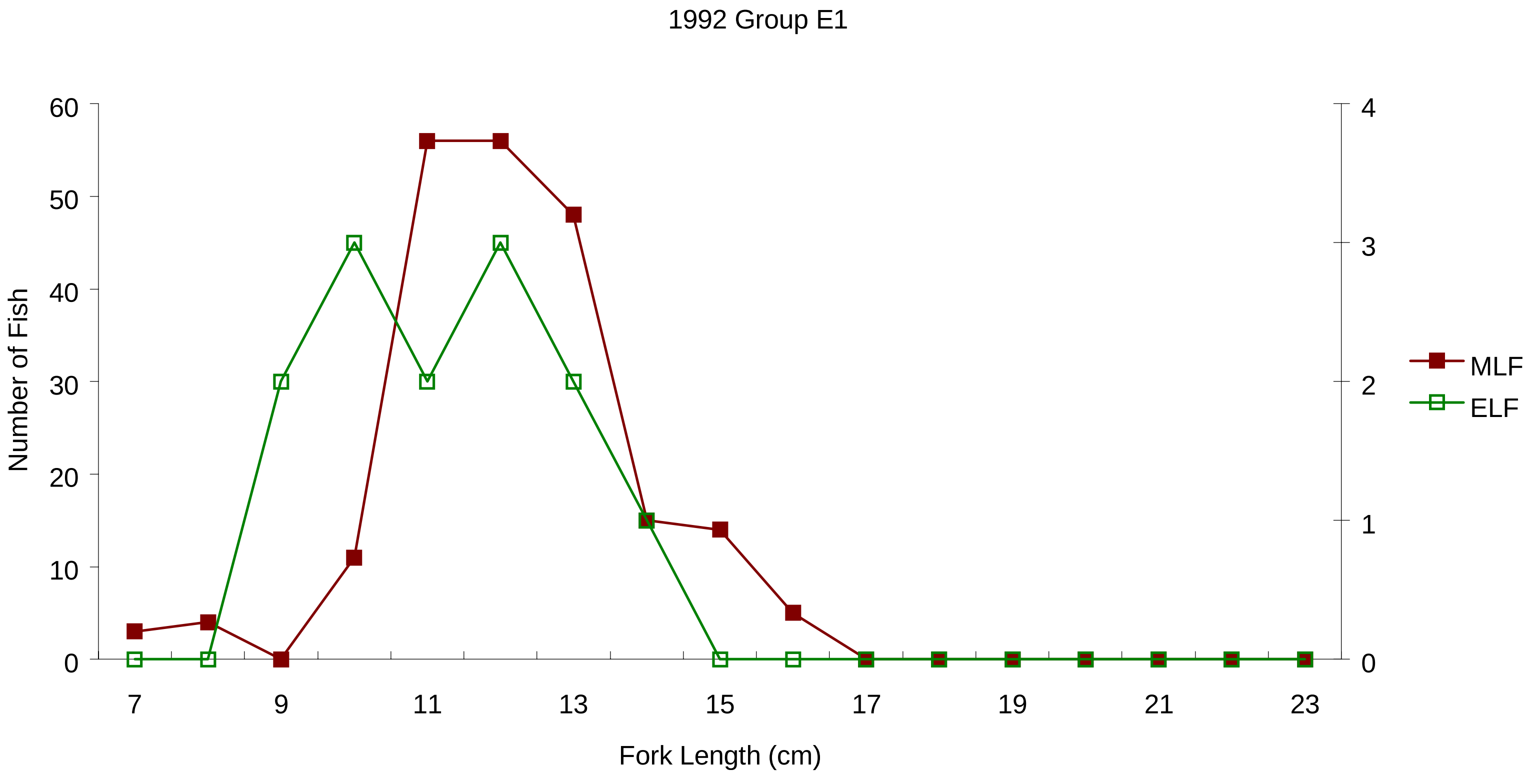
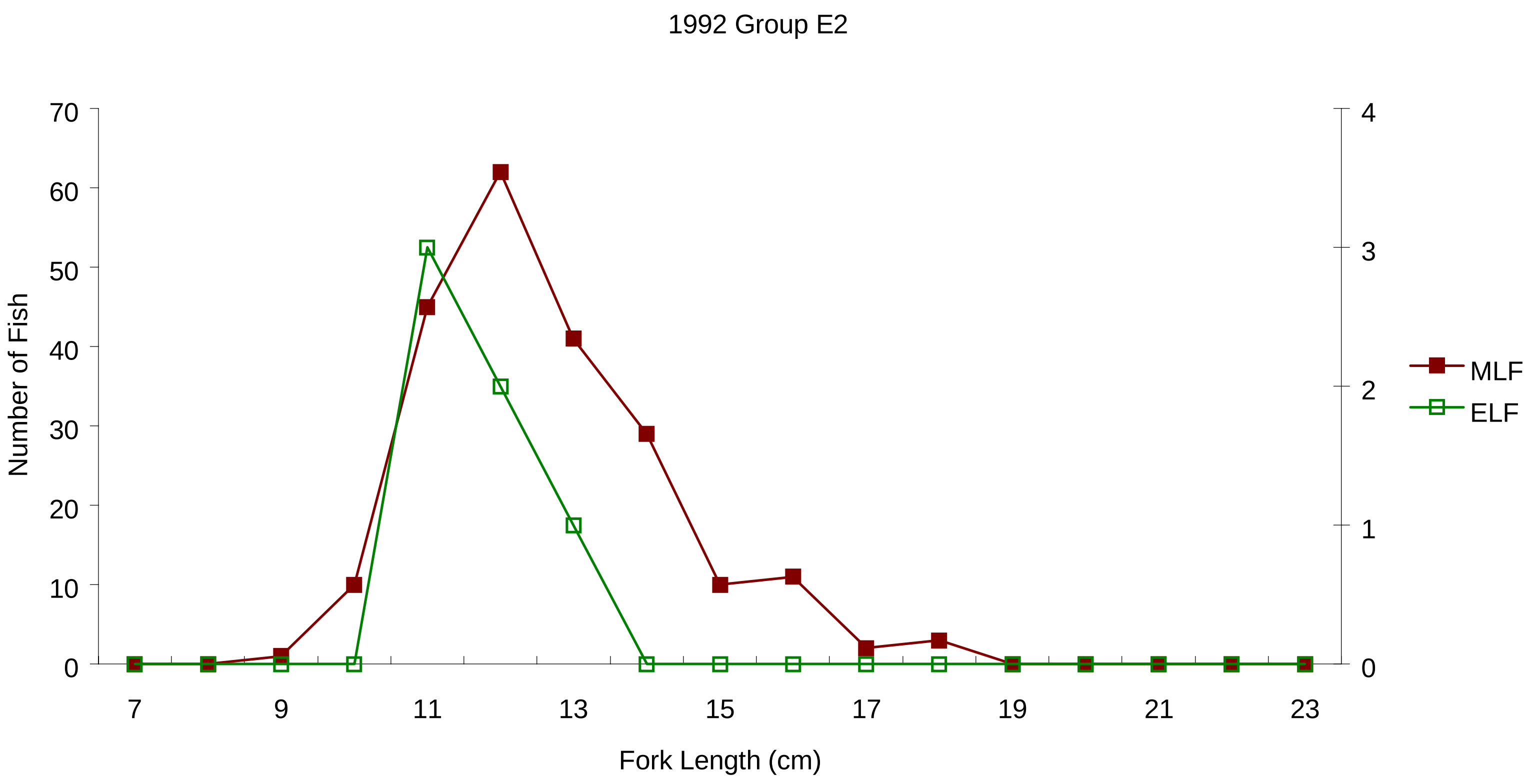
40
30
20
10
0
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

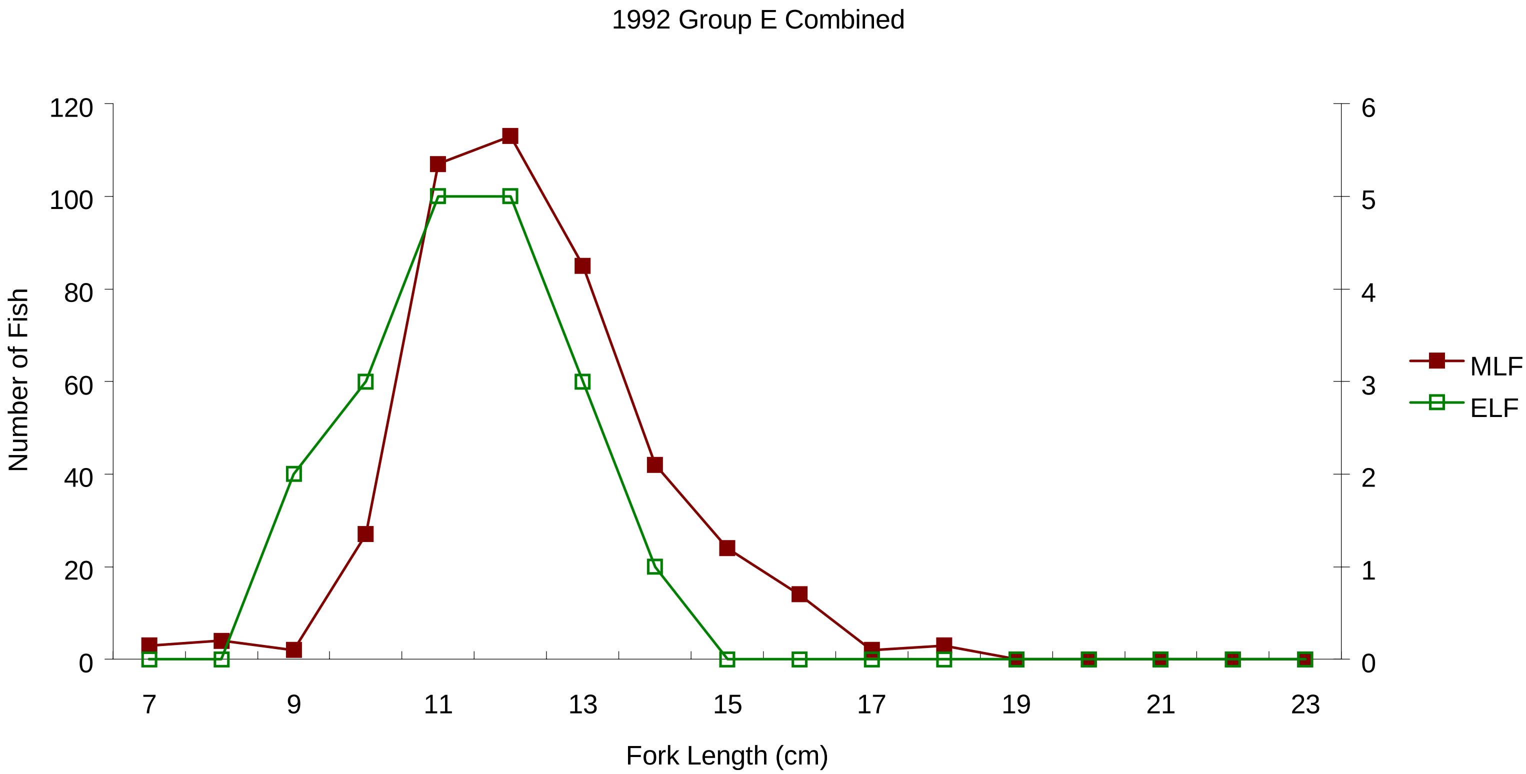
1992 Group D Combined

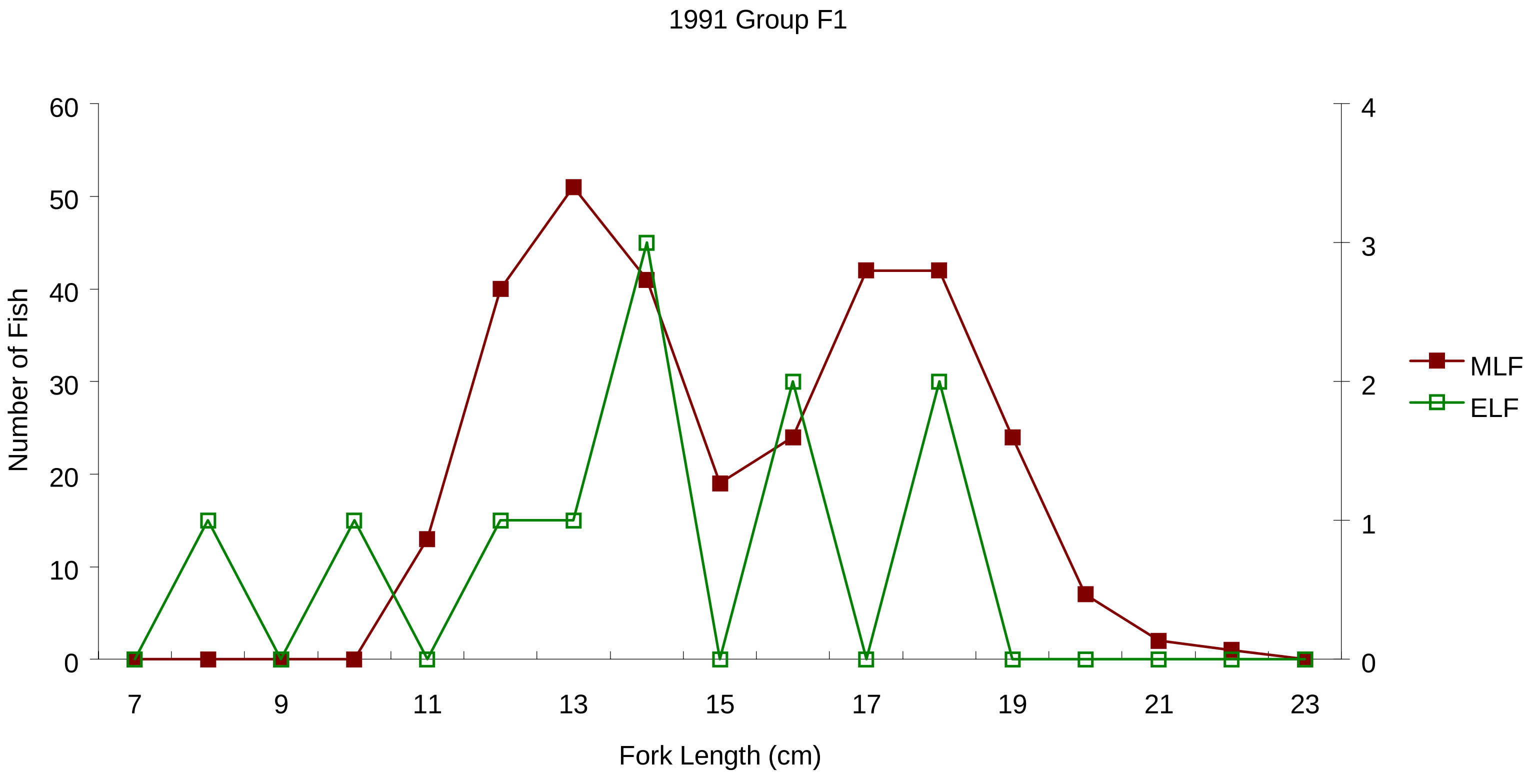



1991 Group E1
Number of Fish
60
50
40
30
20
10
0
2
1
0
8
10
12
14
16
18
20
22
Fork Length (cm)
MLF
ELF

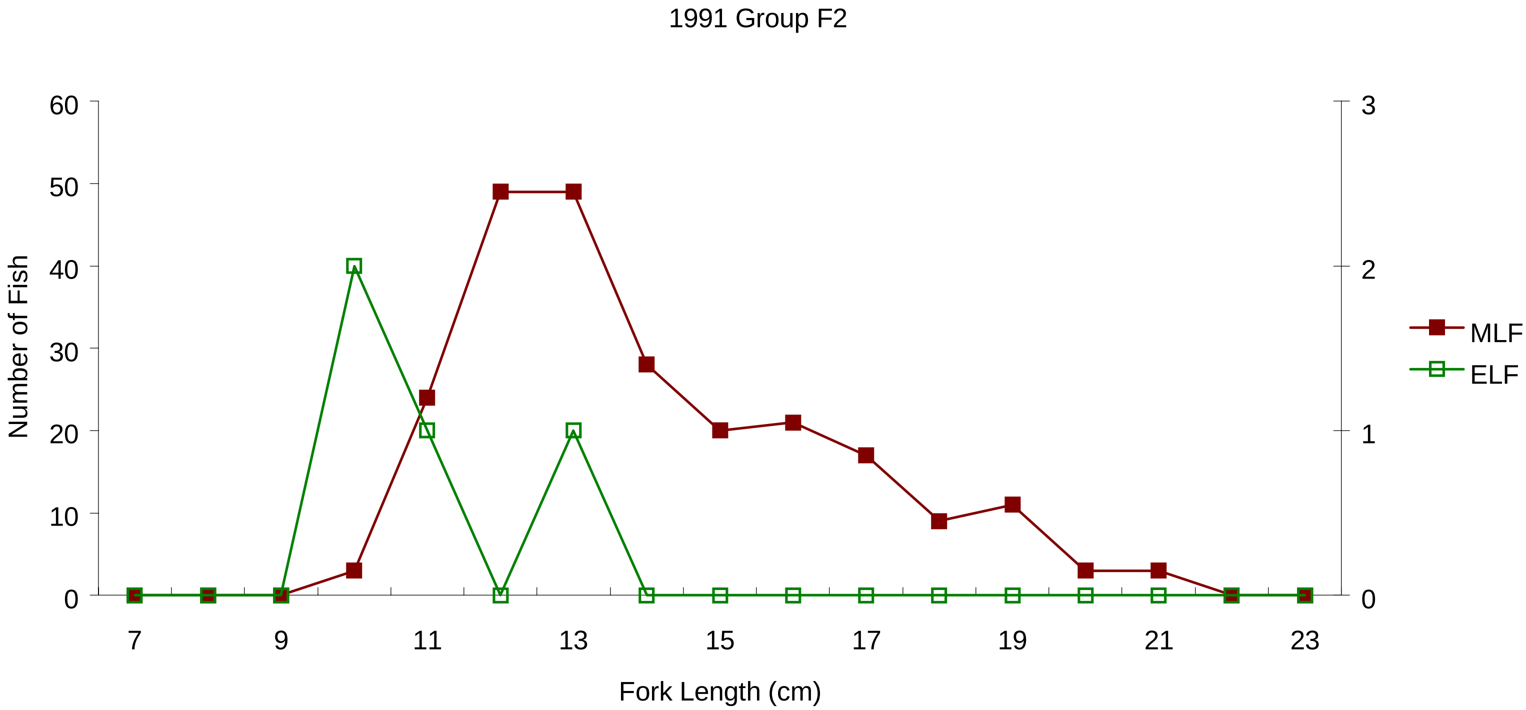

1992 Group E1
Number of Fish
60
50
40
30
20
10
0
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

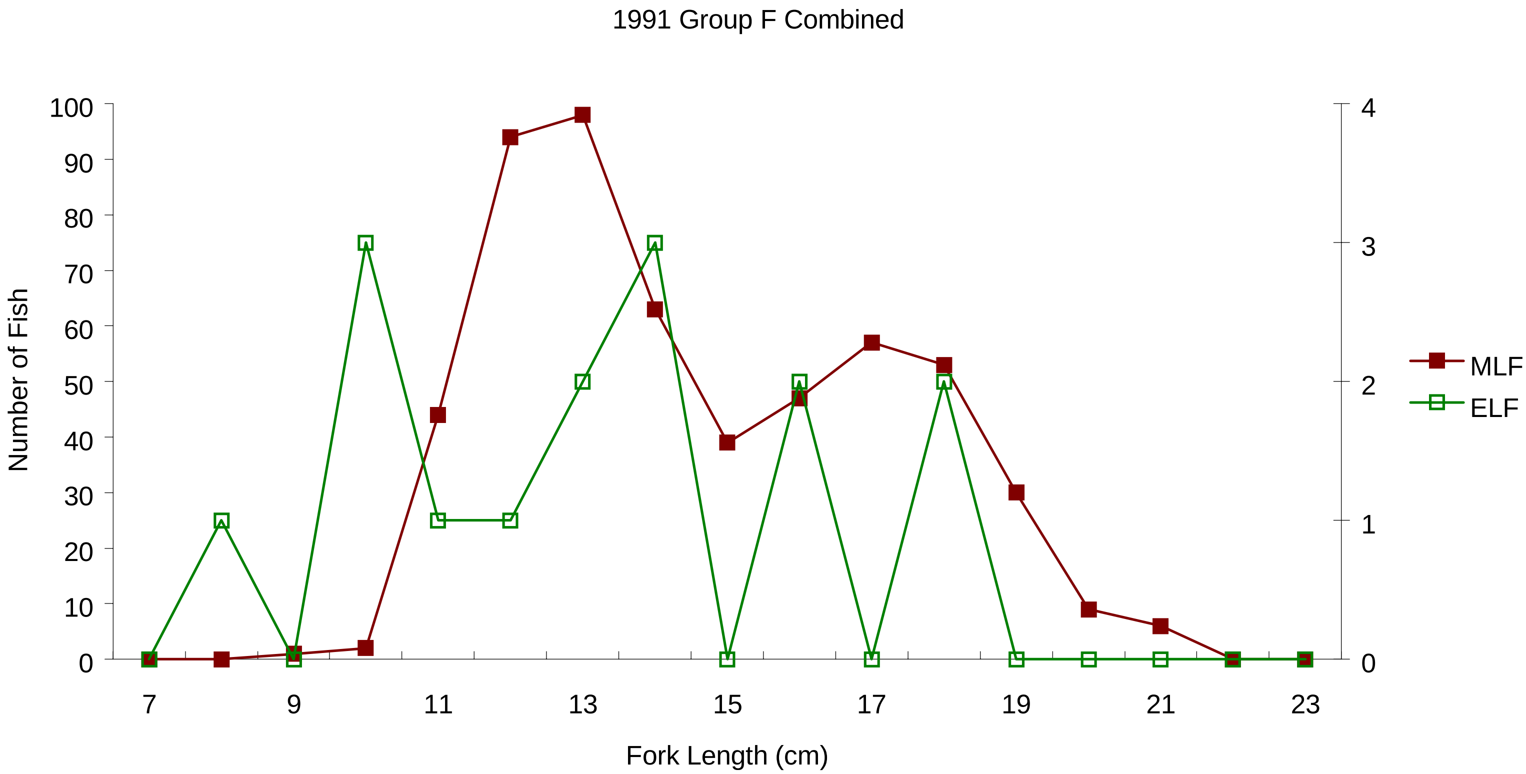

1992 Group E2
70
60
50
40
30
20
10
0
Number of Fish
4
3
2
1
0
MLF
ELF
7
9
11
13
15
17
19
21
23
Fork Length (cm)

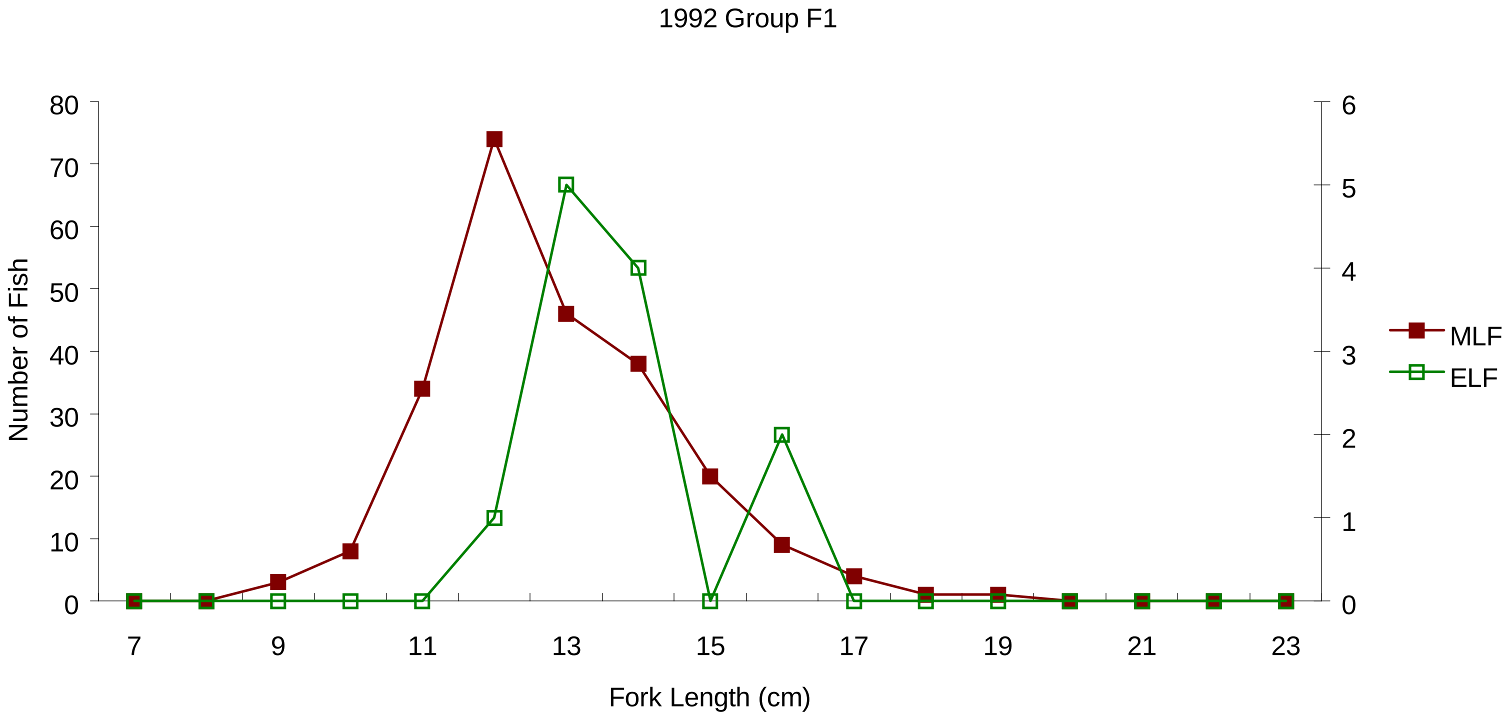

1992 Group E Combined
Number of Fish
120
100
80
60
40
20
0
6
5
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

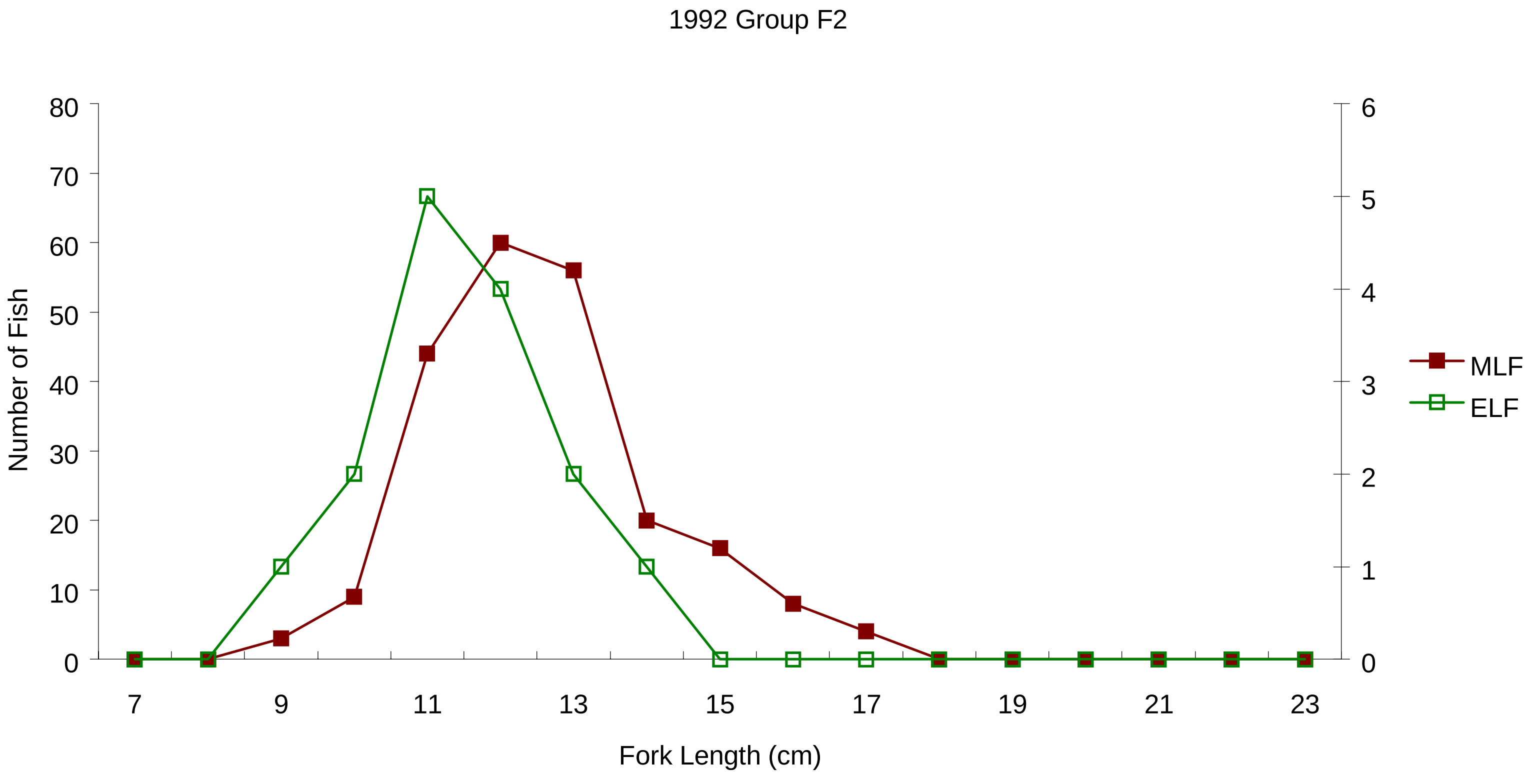


1991 Group F1
Number of Fish
60
50
40
30
20
10
0
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

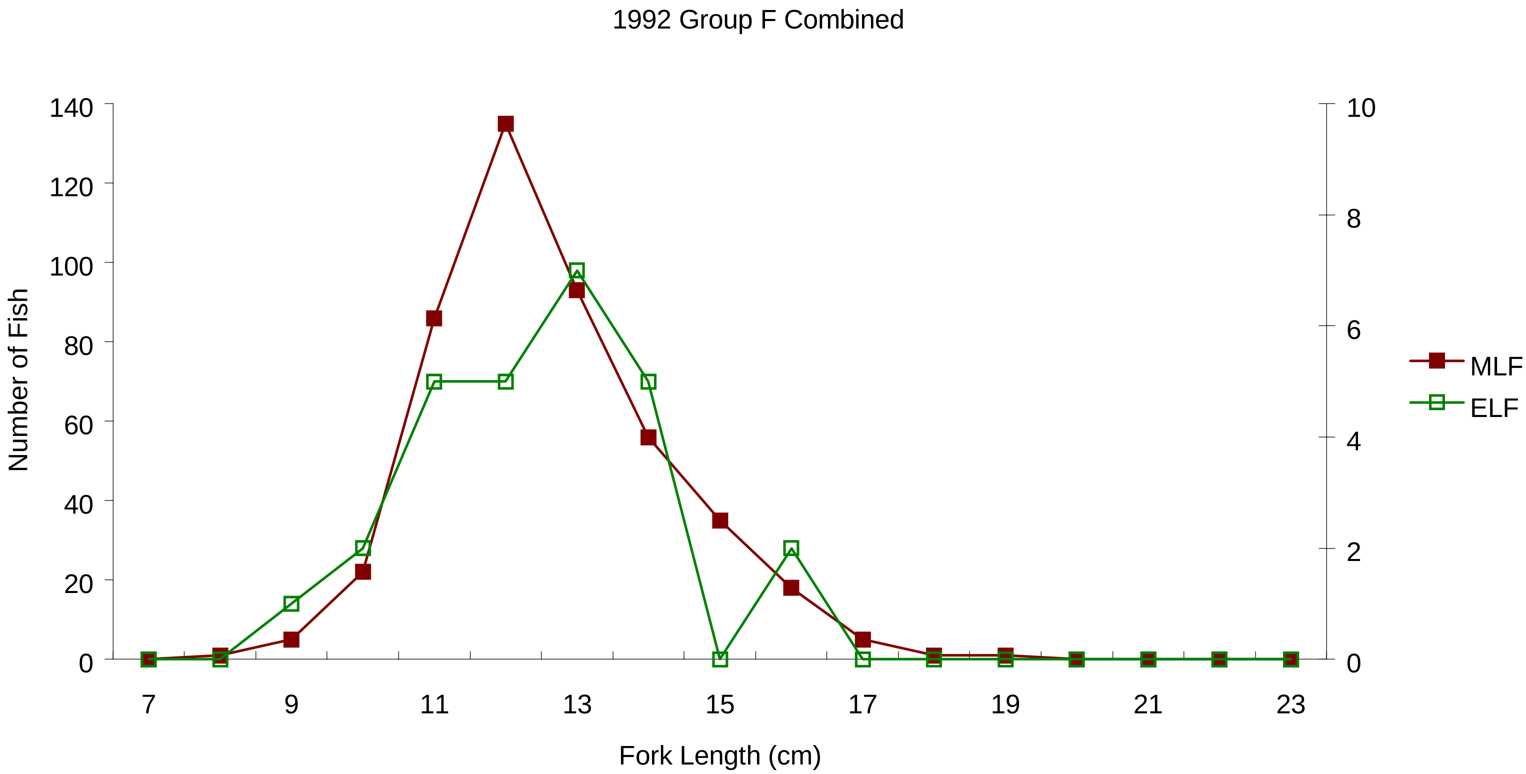

1991 Group F2
60
50
40
30
20
10
0
3
2
1
0
Number of Fish
MLF
ELF
7
9
11
13
15
17
19
21
23
Fork Length (cm)


1991 Group F Combined
Number of Fish
100
90
80
70
60
50
40
30
20
10
0
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

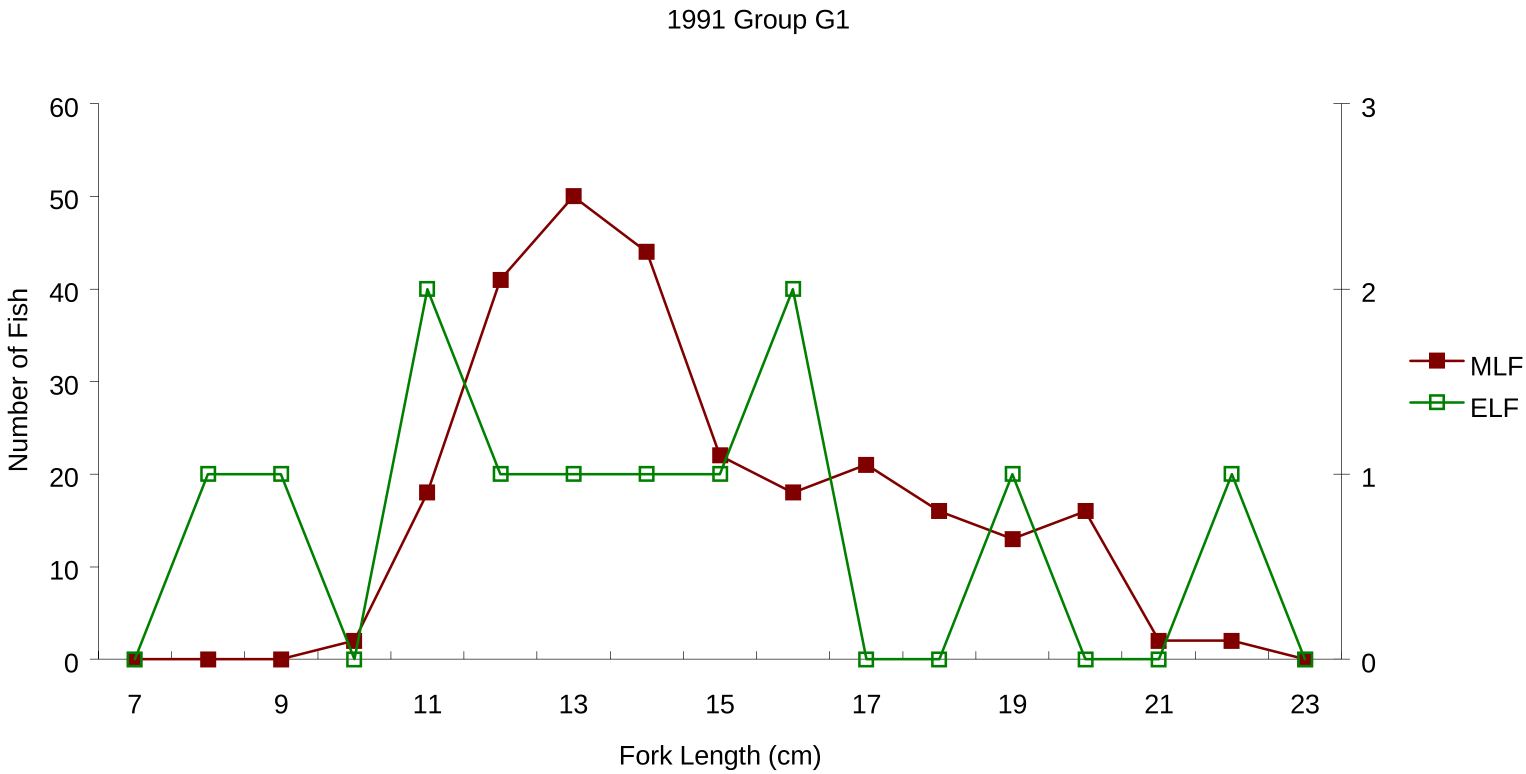

1992 Group F1
Number of Fish
80
70
60
50
40
30
20
10
0
6
5
4
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

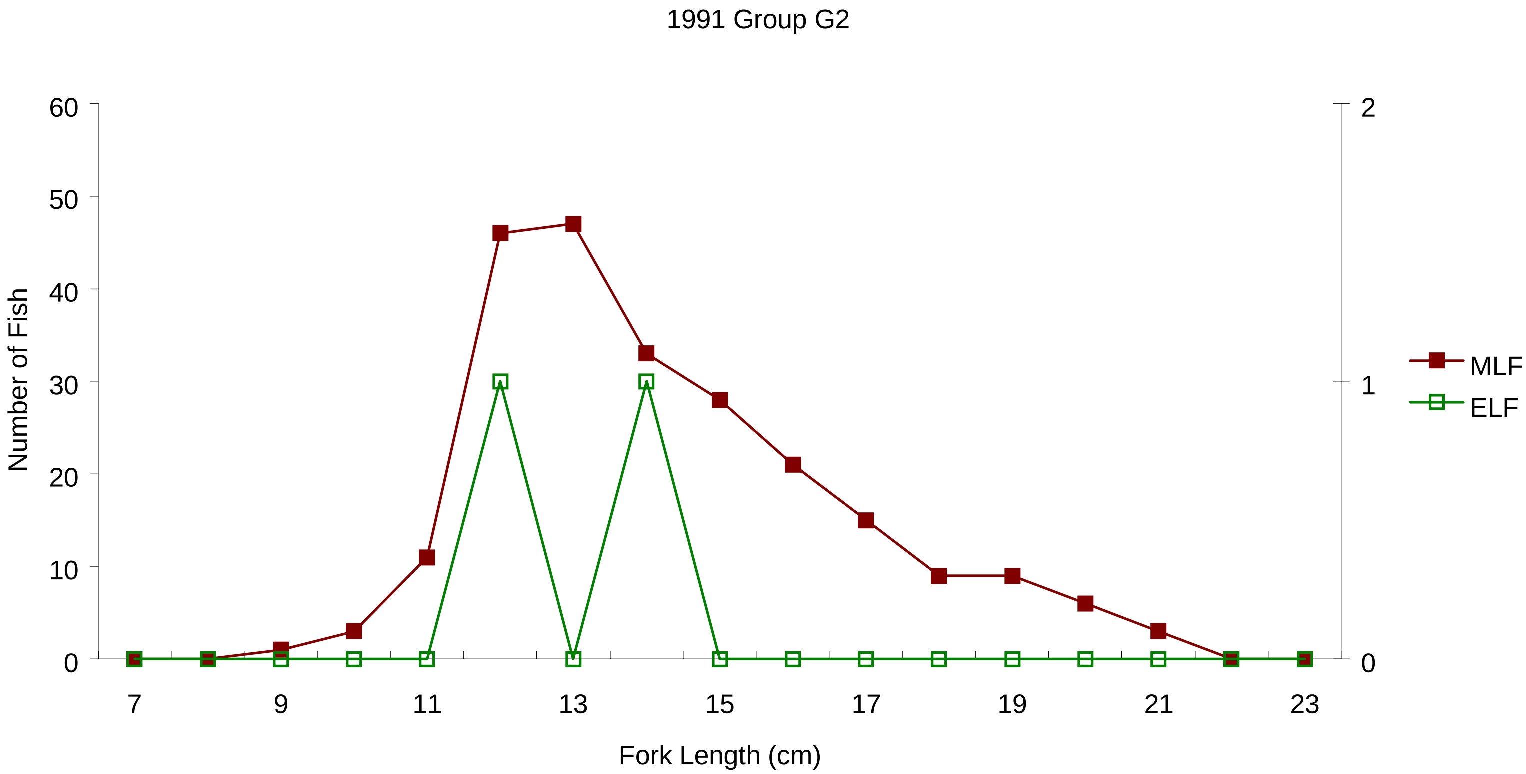


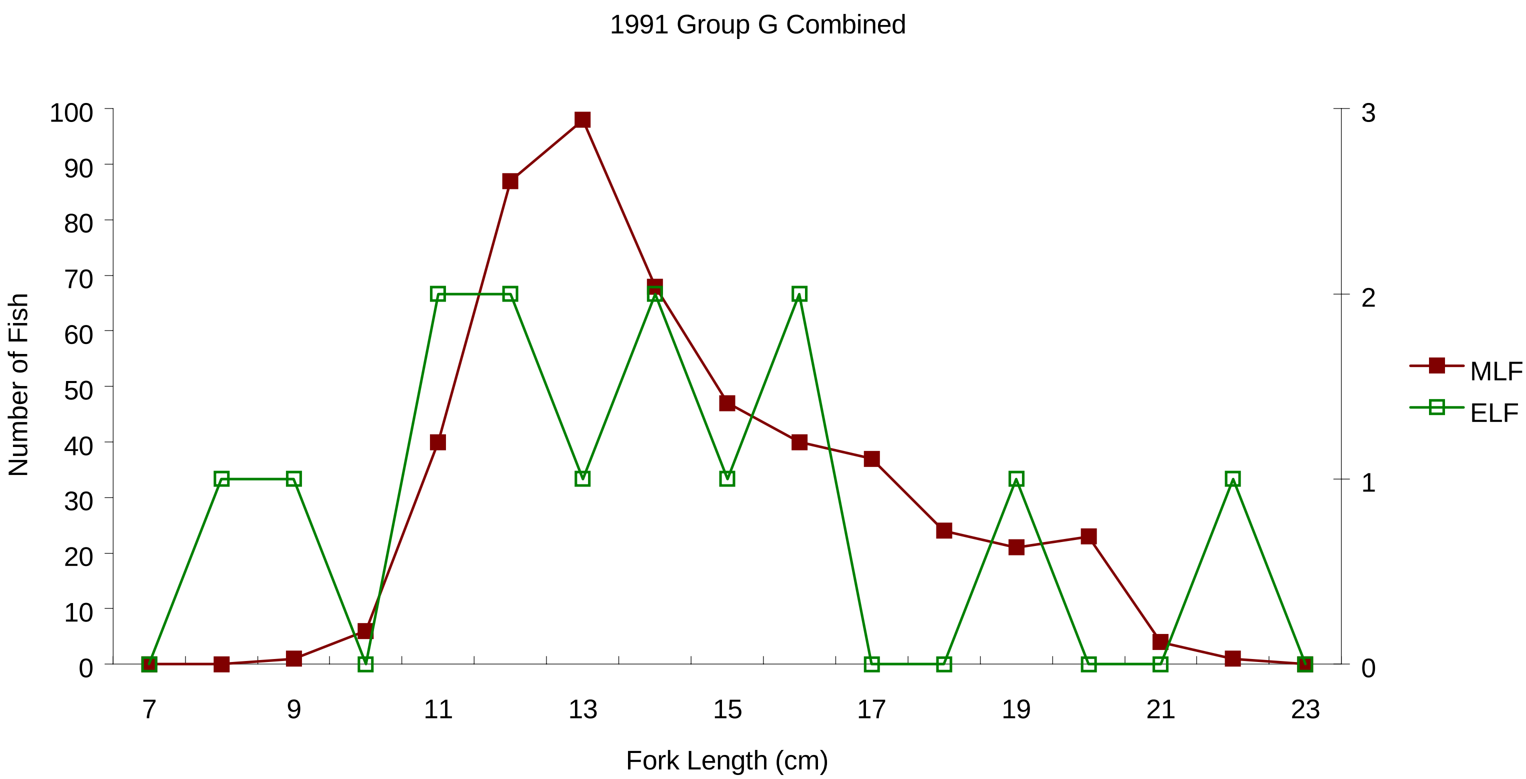
1992 Group F2
Number of Fish
80
70
60
50
40
30
20
10
0
6
5
4
3
2
1
0
MLF
ELF
7
9
11
13
15
17
19
21
23
Fork Length (cm)

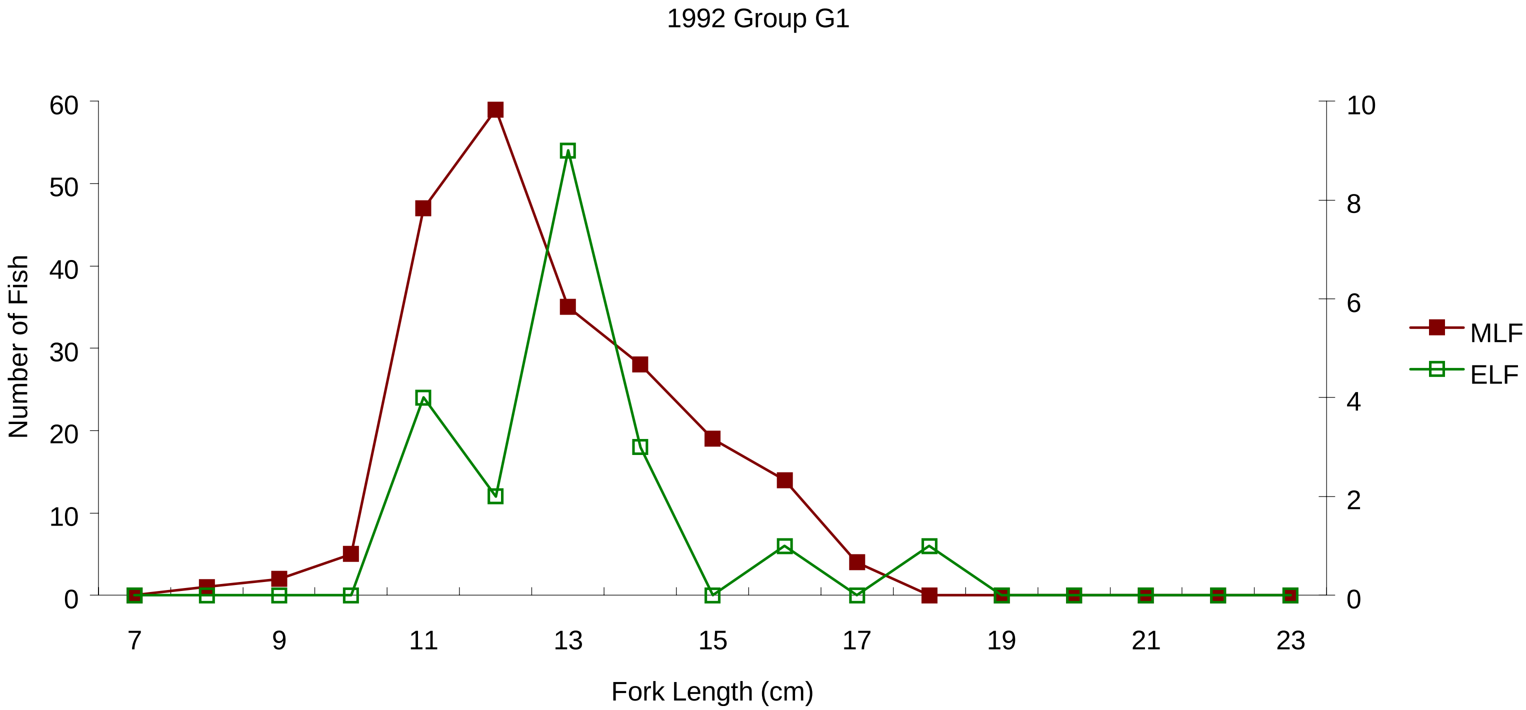


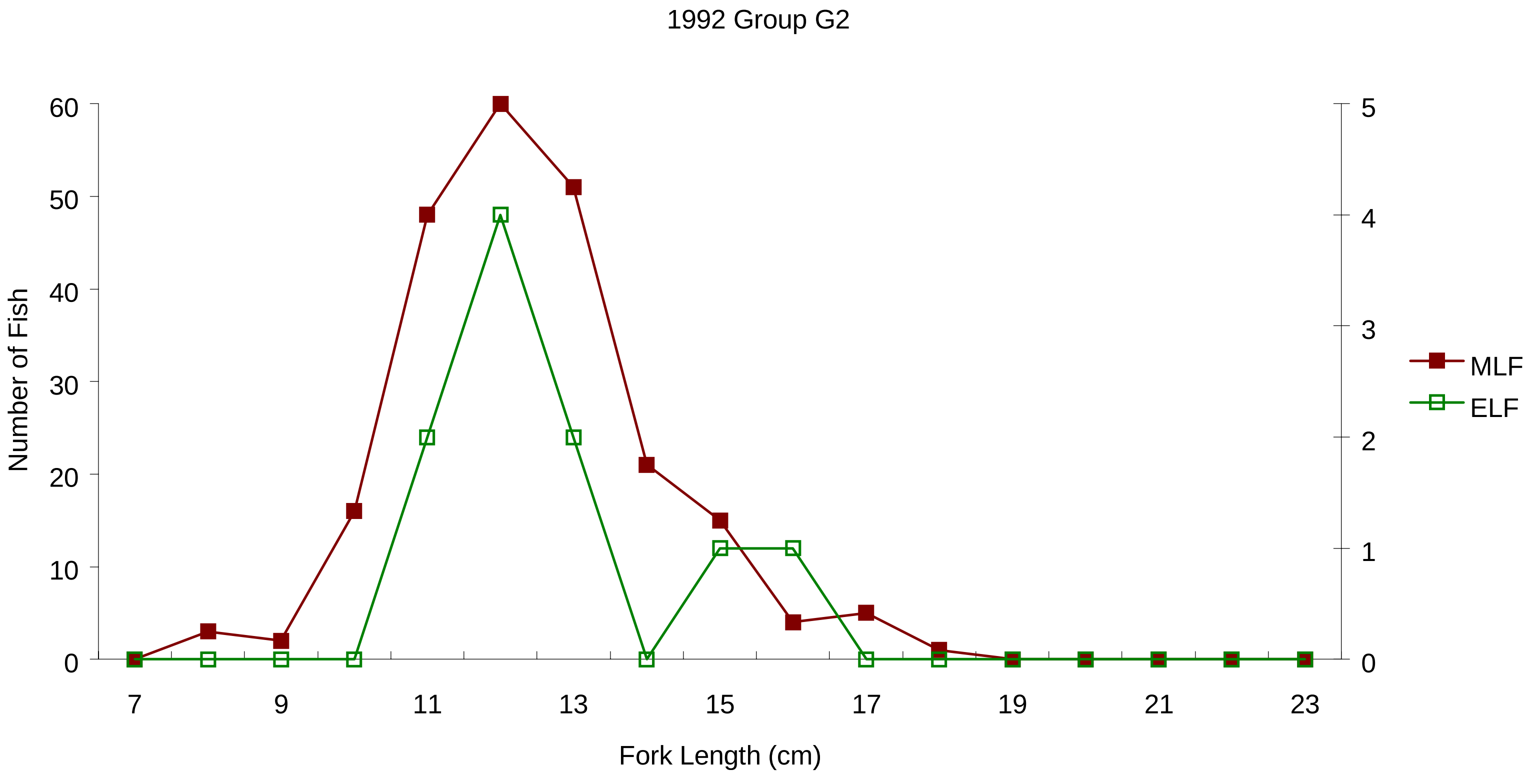
1992 Group F Combined
Number of Fish
140
120
100
80
60
40
20
0
10
8
6
4
2
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF

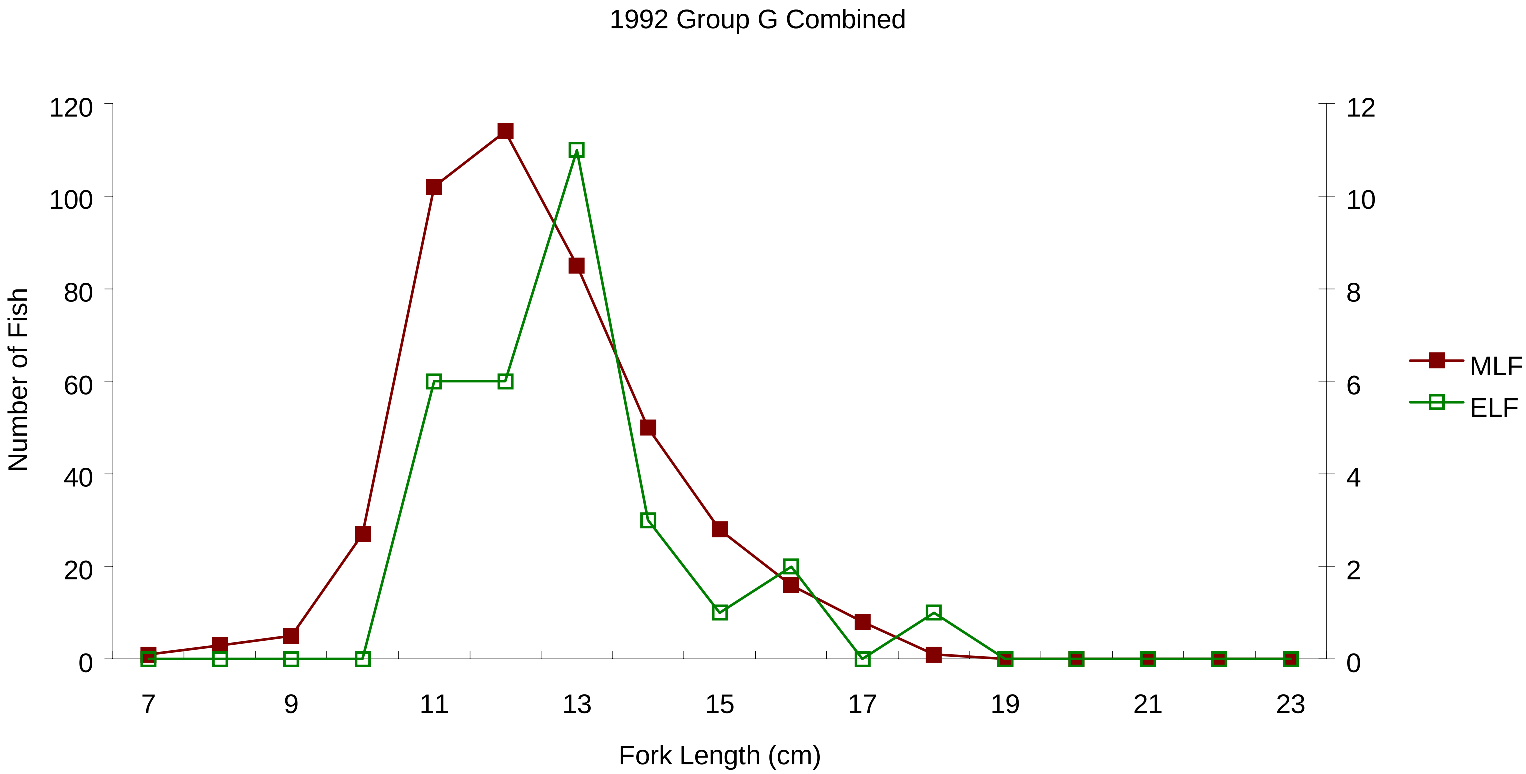

1991 Group G1
Number of Fish
60
50
40
30
20
10
0
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF


1991 Group G2
Number of Fish
60
50
40
30
20
10
0
2
1
0
MLF
ELF
7
9
11
13
15
17
19
21
23
Fork Length (cm)


1991 Group G Combined
Number of Fish
100
90
80
70
60
50
40
30
20
10
0
3
2
1
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF


1992 Group G1
Number of Fish
60
50
40
30
20
10
0
10
8
6
4
2
0
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF


1992 Group G2
Number of Fish
Fork Length (cm)
MLF
ELF
0
10
20
30
40
50
60
0
1
2
3
4
5
7
9
11
13
15
17
19
21
23


1992 Group G Combined
Number of Fish
0
20
40
60
80
100
120
0
2
4
6
8
10
12
7
9
11
13
15
17
19
21
23
Fork Length (cm)
MLF
ELF