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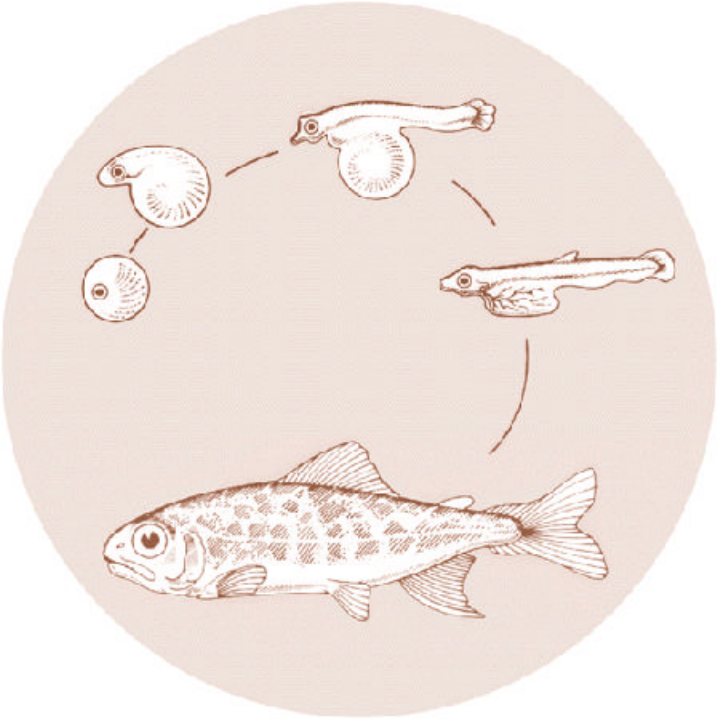
ANNUAL PROGRESS REPORT - FISH CULTURE SECTION BIOENGINEERING EVALUATION OF RETROFITTED OXYGEN SUPPLEMENTATION IN SURFACE WATER PROJECT

Final Report 2000



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Annual Progress Report
Fish Culture Section

Bioengineering Evaluation of Retrofitted Oxygen Supplementation in Surface Water Project

Final Report 2000

Prepared by:

R. D. Ewing
Biotech Research and Consulting, Inc.

Project No. 1988-160-00
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June 2000

ANNUAL PROGRESS REPORT

FISH CULTURE SECTION

PROJECT TITLE: Willamette Oxygen Supplementation Studies -- Analysis of Adult Returns

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EXECUTIVE SUMMARY

The Willamette Oxygen Supplementation Project was designed to answer one major question concerning the decreasing salmon runs in the Columbia Basin: Can available technology be used to increase runs of chinook salmon in the Columbia basin in existing hatcheries. It was recognized that the restoration of salmon runs would require both hatchery supplementation and protection of wild salmon habitat. The large financial outlay required for construction of new hatcheries makes this choice undesirable. If the production of existing hatcheries could be augmented by the use of increased densities with oxygen supplementation, this would be the preferred procedure.

Willamette Hatchery was chosen for conducting the experimental releases of chinook salmon reared at high densities with oxygen supplementation for several reasons: 1) It was located far upstream, simulating the long migration distances required for Columbia River salmon; 2) Salmon were not required to navigate through a series of dams, which might make the returns less interpretable; 3) Willamette Hatchery had excellent returns, nearly 2 % survival, in the years previous to the experiment; 4) Willamette Hatchery had a history of low disease incidence; 5) Willamette Hatchery had a manager and crew interested in the experiment.

The experiment was begun with the 1989 brood of spring chinook salmon and continued for the next four years. Each year in July, the fish were marked with coded wire tags and fin clips

and transferred into the appropriate raceways. Two types of raceways were used, the conventional raceway and the baffled raceway system used in Michigan. Densities were adjusted at that time with unmarked fish. Oxygen was added to the raceways through contact columns at an amount that would replace what the fish used for metabolism. Water quality parameters were taken at weekly intervals and the growth and feeding of the fish were carefully followed. Results from the growth of the fish has been published in the North American Journal of Aquaculture. Water quality parameters have been described in a number of annual reports to Bonneville Power Administration.

In 1999, the last of the adult salmon from the experiment returned to the hatchery. From analyses of these returns, a number of conclusions were reached:

1) Numbers of fish surviving to adulthood increased with increased rearing densities and oxygen supplementation;
2) Percent yield, a measure of the efficiency of rearing, decreased with increased rearing density;
3) Baffled raceways were very poor for raising spring chinook salmon;
4) Oxygen supplementation seemed to increase production, even in the lower densities;
5) The most cost-effective method of rearing spring chinook salmon was rearing at high densities with oxygen supplementation.

The conclusion of the project answers the question posed at the onset of the study. Available technology of oxygen supplementation can be used to permit rearing of chinook salmon at high densities to increase hatchery production.

INTROUCTION

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 of 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 been described in earlier reports (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 became available. Previous reports analyzed ammonia production (Ewing 1995), growth, mortalities, and feeding (Ewing 1996), oxygen consumption (Ewing 1997), and carbon dioxide production (Ewing 1998) of fish in the fourteen experimental raceways and water chemistry of the water flowing into the hatchery from Salmon Creek (Ewing 1998). Last years report (Ewing 1999) analyzed scales from returning experimental fish to determine the effects of bimodality and

experimental conditions at release on the survival of size classes of fish at ocean entrance. Manuscripts summarizing these analyses are being prepared for publication (Appendix A).

The present report continues the analysis of the six million data points collected during the project. In this report, the last of the series, we examine the adult returns resulting from experimental conditions at Willamette Hatchery. Returns are examined as percent returns, total number of fish from each group, yield per cubic meter of rearing space, and yield per unit of water inflow. In addition, we summarize the location of recoveries and the age classes of recoveries. The summary attempts to answer the questions originally posed when this projects was begun: Will increased densities promote greater survival of chinook salmon? Is oxygen supplementation useful for this increased survival? Will Michigan raceways provide a means for increasing production in hatcheries? Is the increased production cost effective?

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.

Tag Recovery

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 maturity. 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

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

snouts of marked fish 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 from September to 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 stored on computer.

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. Returns were corrected for hatchery losses and tag losses prior to release, as described in the text of the results section.

Chinook juveniles that entered the ocean and returned to freshwater as mature fish are classified by the number of years spent in the ocean. Juveniles which enter the ocean in spring as

yearlings and return the same year are called mini-jacks. All of these fish are males and are typically only 20 to 30 cm long. The extent of return of these is difficult to determine because they are not captured by any of the fisheries, carcasses are not easily seen, and often hatchery numbers are low because they are discarded without being counted. Numbers of these reported are therefore minimum numbers and may be lower than the actual number in the populations.

Juveniles that enter the ocean in spring as yearlings and stay for a single year in the ocean before returning are called jacks. These are, by definition, less than 50 cm long. Again, all are males. These, however, are caught in the fisheries and are reported at the hatcheries.

Juveniles that enter the ocean in spring as yearlings and spend 2, 3, 4, or 5 years at sea before returning to freshwater are called adults and are both male and female. Female adults tend to outnumber the male adults because precociousness may remove some males from the breeding population, and jacks and mini-jacks reduce the numbers of returning males.

Numbers of minijacks, jacks, and adults captured in the various fisheries are expanded to compensate for the intensity of

the population sampling. These expansions are, by necessity, estimates of numbers in the total population, but represent the best guesses for the total numbers for each experimental group. Unfortunately, some of the expansions look strange in table form. If only a tenth of the population is estimated to have been sampled, for instance, and the actual recapture of a fish with a particular tag code was 1, this may be expanded to 10. Nevertheless, this is the best guess of the total numbers in the population and this expanded number is the one that will be used for all the following analyses.

RESULTS

Corrections of Release Numbers

Analysis of the survival of hatchery-released fish requires an accurate estimate of the number of fish released from the hatchery. A number of factors influence the final number of tagged fish that are released. This section examines some of these factors.

The number of fish which are tagged is determined from counters associated with each coded-wire tag machine. These numbers are reported on summary sheets provided to the experimenters from the tagging crews and are presented in Table 3 for the 16 experimental raceways of the Willamette Oxygen Supplementation Project.

Numbers of unmarked fish were added to each of the experimental ponds to achieve the desired rearing densities and loads (Table 3). Of these, a number of them died in the normal course of rearing (see Table 7, Ewing 1996). When the fish were loaded in liberation trucks for hauling to the release point below Dexter Dam, numbers were estimated from specific gravities of the fish and water displacement in the trucks. These calculations gave the numbers of fish released, as indicated in Table 3. The percent mortalities presented in Table 3 were calculated from the numbers originally ponded and the numbers released. These numbers are higher than those presented in Table 7 of Ewing (1996) because they include both rearing and unaccounted mortalities. For a

Table 3. Numbers of fish marked with coded wire tags, numbers of fish ponded, and number of fish released in experimental groups reared at Willamette Hatchery, 1989-1992 broods. Number tagged is derived from tagging reports. Number ponded is from inventory reports. Number released for experimental ponds is calculated from water displacement in transport trucks. Number release from Dexter ponds is from inventory reports. NA: data not available.

Brood Year, group	Tag Code	Number Tagged	Number Ponded	Number Released
1989 Brood				
A1	07-55-14	33,307	38,841	37,895
A2	07-55-06	33,110	39,448	33,300
B1	07-55-17	20,684	20,684	19,609
B2	07-55-18	20,031	20,031	18,264
C1	07-54-63	33,034	39,196	37,699
C2	07-55-03	32,640	39,643	38,960
D1	07-55-07	33,450	118,465	117,889
D2	07-55-08	33,975	118,184	100,792
E1	07-55-09	32,997	59,417	47,260
E2	07-55-10	33,083	59,007	52,509
F1	07-55-11	32,994	59,299	50,480
F2	07-55-12	32,954	59,626	54,943
G1	07-55-05	32,891	59,221	49,341
G2	07-55-13	32,977	59,114	47,675
Dex1	07-55-16	33,277	NA	NA
Dex2	07-55-15	32,993	NA	NA
1990 Brood				
A1	07-56-32	33,055	39,330	38,881
A2	07-56-31	33,136	39,728	38,511
B1	07-40-44	20,540	20,540	19,345
B2	07-40-43	20,076	20,076	21,546
C1	07-56-34	33,090	39,689	37,420
C2	07-56-33	33,235	39,504	37,474
D1	07-56-36	33,139	118,763	113,436
D2	07-56-35	32,886	118,565	120,854

Table 3 (cont.)

Brood Year, group	Tag Code	Number Tagged	Number Ponded	Number Released
1990 Brood				
E1	07-56-37	32,947	59,532	58,016
E2	07-56-38	33,030	59,369	53,524
F1	07-56-39	32,960	59,347	51,952
F2	07-56-40	32,989	59,389	55,455
G1	07-56-41	33,196	59,610	58,804
G2	07-56-42	33,226	59,643	57,627
Dex1	07-56-43	33,082	NA	NA
Dex2	07-56-44	33,045	NA	NA
1991 Brood				
A1	07-59-21	32,281	39,437	37,014
A2	07-59-22	31,708	39,542	36,480
B1	07-59-35	19,992	19,992	19,792
B2	07-59-36	19,972	19,972	19,968
C1	07-59-23	32,117	39,436	38,211
C2	07-59-24	31,547	39,993	38,023
D1	07-59-25	31,538	118,549	101,943
D2	07-59-26	31,506	119,759	105,792
E1	07-59-27	31,523	59,271	42,883
E2	07-59-28	31,804	59,137	44,016
F1	07-59-29	31,597	58,456	50,580
F2	07-59-30	31,503	58,342	47,500
G1	07-59-31	31,569	59,229	52,786
G2	07-59-32	31,460	59,115	49,191
Dex1	07-59-33	31,647	NA	NA
Dex2	07-59-34	31,505	NA	NA

Table 3 (cont.)

Brood Year, group	Tag Code	Number Tagged	Number Ponded	Number Released
1992 Brood				
A1	07-63-23	32,055	39,619	38,955
A2	07-63-22	32,358	39,572	36,525
B1	07-63-37	20,106	20,106	17,550
B2	07-63-36	20,140	20,140	17,550
C1	07-63-24	32,070	39,645	36,704
C2	07-63-25	31,981	39,976	33,082
D1	07-63-26	32,037	116,978	116,110
D2	07-63-27	32,046	116,964	108,378
E1	07-63-28	32,049	59,621	44,505
E2	07-01-28	32,000	59,024	41,760
F1	07-01-29	32,000	59,025	50,460
F2	07-01-30	32,031	59,055	49,077
G1	07-01-31	32,060	59,644	53,235
G2	07-01-32	32,119	59,740	51,136
Dex1	07-01-33	32,000	154,364	154,364
Dex2	07-01-34	31,852	154,363	154,363

discussion of the origin of unaccounted mortalities, see the section on Apparent Mortalities, p. 172, in Ewing (1996).

If it is assumed that tagged and untagged fish die at equal rates, the percent mortality can be used to correct for the number of tagged fish released from the hatchery (Table 4).

In addition to the loss of tagged fish due to mortalities, tags can also be lost through poor tagging procedures or tagging errors. These errors are evaluated prior to release by passing large numbers of fish through coded-wire tag detectors. The number of fish with adipose fin clips but no tags and the number of fish with tags but no adipose fin clips are determined. Percentages of fish with these errors were calculated from raw data from tag retention checks (Table 5).

Fish with an adipose fin-clip but no coded-wire tag generally have not had the tag placed properly so that it falls out. Those with a tag but no fin-clip generally result from mistakes by fin-clippers. In the former case, the snout is taken but cannot be assigned to a group and is discarded. In the latter case, the snout is never taken because no one realizes it is there. Both errors therefore result in a lower number of effectively tagged fish released. Corrections for both errors result in the final effective number of tagged fish released (shown in Table 6).

Table 4. Corrections of numbers of fish marked with coded wire tags for mortalities that occurred in experimental groups reared at Willamette Hatchery, 1989-1992 broods. Number tagged is derived from tagging reports. Number released from experimental ponds assumes that tagged and untagged fish die at similar rates. Number released from Dexter ponds is from inventory reports. NA = data not available

Brood Year, group	Tag Code	Number Tagged	Percent Mortality	Number Tagged Fish Released
1989 Brood				
A1	07-55-14	33,307	2.44	32,494
A2	07-55-06	33,110	15.59	27,948
B1	07-55-17	20,684	5.20	19,609
B2	07-55-18	20,031	8.82	18,264
C1	07-54-63	33,034	3.82	31,772
C2	07-55-03	32,640	1.72	32,079
D1	07-55-07	33,450	0.49	33,286
D2	07-55-08	33,975	14.72	28,974
E1	07-55-09	32,997	20.46	26,246
E2	07-55-10	33,083	11.01	29,441
F1	07-55-11	32,994	14.87	28,088
F2	07-55-12	32,954	7.85	30,367
G1	07-55-05	32,891	16.68	27,405
G2	07-55-13	32,977	19.35	26,596
Dex1	07-55-16	33,277	NA	NA
Dex2	07-55-15	32,993	NA	NA
1990 Brood				
A1	07-56-32	33,055	1.14	32,678
A2	07-56-31	33,136	2.53	32,298
B1	07-40-44	20,540	5.82	19,345
B2	07-40-43	20,076	NA	20,076
C1	07-56-34	33,090	5.72	31,197
C2	07-56-33	33,235	5.14	31,527
D1	07-56-36	33,139	4.49	31,651
D2	07-56-35	32,886	NA	32,886

Table 4 (cont.)

Brood Year, group	Tag Code	Number Tagged	Percent Mortality	Number Tagged Fish Released
1990 Brood				
E1	07-56-37	32,947	2.55	32,107
E2	07-56-38	33,030	9.85	29,777
F1	07-56-39	32,960	12.46	28,853
F2	07-56-40	32,989	6.62	30,805
G1	07-56-41	33,196	1.35	32,748
G2	07-56-42	33,226	3.38	32,103
Dex1	07-56-43	33,082	0.88	32,792
Dex2	07-56-44	33,045	0.83	32,870
1991 Brood				
A1	07-59-21	32,281	6.14	30,299
A2	07-59-22	31,708	7.74	29,254
B1	07-59-35	19,992	1.00	19,792
B2	07-59-36	19,972	0.02	19,968
C1	07-59-23	32,117	3.11	31,118
C2	07-59-24	31,547	4.93	29,992
D1	07-59-25	31,538	14.01	27,120
D2	07-59-26	31,506	11.66	27,832
E1	07-59-27	31,523	27.65	22,807
E2	07-59-28	31,804	25.57	23,672
F1	07-59-29	31,597	13.47	27,341
F2	07-59-30	31,503	18.58	25,650
G1	07-59-31	31,569	11.88	27,819
G2	07-59-32	31,460	16.79	26,178
Dex1	07-59-33	31,647	NA	31,647
Dex2	07-59-34	31,505	NA	31,505

Table 4 (cont.)

Brood Year, group	Tag Code	Number Tagged	Percent Mortality	Number Tagged Fish Released
1992 Brood				
A1	07-63-23	32,055	1.68	31,516
A2	07-63-22	32,358	7.70	29,866
B1	07-63-37	20,106	12.71	17,550
B2	07-63-36	20,140	12.86	17,550
C1	07-63-24	32,070	7.42	29,690
C2	07-63-25	31,981	17.25	26,464
D1	07-63-26	32,037	0.74	31,800
D2	07-63-27	32,046	7.34	29,694
E1	07-63-28	32,049	25.35	23,925
E2	07-01-28	32,000	28.96	22,733
F1	07-01-29	32,000	14.51	27,357
F2	07-01-30	32,031	16.90	26,618
G1	07-01-31	32,060	10.75	28,614
G2	07-01-32	32,119	14.40	27,494
Dex1	07-01-33	32,000	0.84	31,687
Dex2	07-01-34	31,852	0.38	31,730

Table 5. Tagging errors measured by passing large numbers of marked and unmarked fish by coded-wire-tag detectors just before release from Willamette Hatchery, 1989-1992 broods. Number tagged is derived from tagging reports.

Brood Year, group	Tag Code	Number Tagged	Percent Tagged No Clip	Percent Clipped No Tag
1989 Brood				
A1	07-55-14	33,307	5.62	0.00
A2	07-55-06	33,110	1.21	0.41
B1	07-55-17	20,684	5.69	5.69
B2	07-55-18	20,031	4.59	0.00
C1	07-54-63	33,034	1.60	0.00
C2	07-55-03	32,640	4.63	0.77
D1	07-55-07	33,450	0.14	0.00
D2	07-55-08	33,975	1.66	0.41
E1	07-55-09	32,997	1.63	0.27
E2	07-55-10	33,083	0.00	0.00
F1	07-55-11	32,994	0.97	0.48
F2	07-55-12	32,954	1.03	0.00
G1	07-55-05	32,891	1.61	0.64
G2	07-55-13	32,977	1.43	0.24
Dex1	07-55-16	33,277	1.33	0.00
Dex2	07-55-15	32,993	1.75	0.00
1990 Brood				
A1	07-56-32	33,055	1.36	0.00
A2	07-56-31	33,136	0.39	0.39
B1	07-40-44	20,540	0.50	0.00
B2	07-40-43	20,076	0.00	0.48
C1	07-56-34	33,090	0.52	1.53
C2	07-56-33	33,235	0.73	2.55
D1	07-56-36	33,139	0.00	0.30
D2	07-56-35	32,886	0.00	0.44

Table 5 (cont.)

Brood Year, group	Tag Code	Number Tagged	Percent Tagged No Clip	Percent Clipped No Tag
1990 Brood				
E1	07-56-37	32,947	1.02	0.00
E2	07-56-38	33,030	0.88	0.00
F1	07-56-39	32,960	1.23	0.25
F2	07-56-40	32,989	0.45	0.00
G1	07-56-41	33,196	0.83	0.29
G2	07-56-42	33,226	0.67	0.00
Dex1	07-56-43	33,082	0.00	1.92
Dex2	07-56-44	33,045	0.00	0.98
1991 Brood				
A1	07-59-21	32,281	0.46	0.00
A2	07-59-22	31,708	2.51	4.30
B1	07-59-35	19,992	0.48	0.48
B2	07-59-36	19,972	0.87	2.60
C1	07-59-23	32,117	0.00	1.01
C2	07-59-24	31,547	0.00	1.71
D1	07-59-25	31,538	0.25	0.00
D2	07-59-26	31,506	0.25	0.25
E1	07-59-27	31,523	0.84	3.16
E2	07-59-28	31,804	1.40	0.00
F1	07-59-29	31,597	0.97	1.36
F2	07-59-30	31,503	1.00	0.75
G1	07-59-31	31,569	0.00	0.64
G2	07-59-32	31,460	1.43	0.71
Dex1	07-59-33	31,647	0.95	1.90
Dex2	07-59-34	31,505	0.95	1.90

Table 5 (cont.)

Brood Year, group	Tag Code	Number Tagged	Percent Tagged No Clip	Percent Clipped No Tag
1992 Brood				
A1	07-63-23	32,055	0.00	18.60
A2	07-63-22	32,358	3.18	14.65
B1	07-63-37	20,106	0.00	18.38
B2	07-63-36	20,140	0.00	18.63
C1	07-63-24	32,070	0.00	8.13
C2	07-63-25	31,981	0.59	9.47
D1	07-63-26	32,037	0.00	3.47
D2	07-63-27	32,046	0.00	12.82
E1	07-63-28	32,049	0.00	4.44
E2	07-01-28	32,000	0.49	1.96
F1	07-01-29	32,000	0.00	1.36
F2	07-01-30	32,031	0.00	3.08
G1	07-01-31	32,060	0.00	2.38
G2	07-01-32	32,119	0.00	2.38
Dex1	07-01-33	32,000	5.15	9.44
Dex2	07-01-34	31,852	4.18	10.88

These corrected numbers are those used for the calculations for the rest of this report.

One item should be noted for the record of errors in tagging of 1992 brood fish. Tagging errors in this brood of fish approached 20% in groups A and B and near 10% in groups C and D. These errors were due to a single tagger who could not manage to tag the fish correctly and who was eventually dismissed.

A summary of the numbers of marked and unmarked fish released from the hatchery is shown in Table 7. Unmarked fish, those with no adipose fin clip, are calculated from the difference between final numbers of fish released, as estimated from liberation truck displacements (Table 3), and the number of fish marked with adipose fin clips, corrected for mortalities and tagging errors (Table 6). Unmarked fish have a small error in numbers because this group contains fish with an adipose fin clip but no tag. While these are not strictly "unmarked", they will not be counted as marked fish during recapture but will contribute to rearing density during hatchery rearing.

The numbers presented in Table 7 are similar but not identical to those of release data from the PSMFC data base (Table 8). One difference is that in this report, both types of tagging errors are summed to reduce the number of tagged fish released. In the PSMFC data base, it is assumed that tagged fish with no clip will appear similar to unclipped fish with no tag. It ignores the fact that the tag will be counted during tagging

Table 6. Final numbers of tagged fish released from Willamette Hatchery, 1989-1992 broods. Number tagged is derived from tagging reports. Corrections for mortalities are estimated from Table 4. Corrections for tagging errors are derived from Table 5, assuming that both types of tagging error decrease the number of tagged fish released.

Brood Year, group	Tag Code	Number Tagged	Release Numbers: Corrected for Mortalities	Release Numbers: Corrected for Tagging Error
1989 Brood				
A1	07-55-14	33,307	32,494	31,435
A2	07-55-06	33,110	27,948	27,495
B1	07-55-17	20,684	19,609	17,377
B2	07-55-18	20,031	18,264	17,426
C1	07-54-63	33,034	31,772	31,264
C2	07-55-03	32,640	32,079	30,347
D1	07-55-07	33,450	33,286	33,239
D2	07-55-08	33,975	28,974	32,686
E1	07-55-09	32,997	26,246	25,747
E2	07-55-10	33,083	29,441	29,441
F1	07-55-11	32,994	28,088	27,681
F2	07-55-12	32,954	30,367	30,054
G1	07-55-05	32,891	27,405	26,788
G2	07-55-13	32,977	26,596	26,152
Dex1	07-55-16	33,277	33,277*	32,834
Dex2	07-55-15	32,993	32,993*	32,416
1990 Brood				
A1	07-56-32	33,055	33,055	32,605
A2	07-56-31	33,136	32,298	32,046
B1	07-40-44	20,540	19,345	19,248
B2	07-40-43	20,076	20,076	19,982
C1	07-56-34	33,090	31,197	30,557
C2	07-56-33	33,235	31,527	30,493
D1	07-56-36	33,139	31,651	31,556
D2	07-56-35	32,886	32,886	32,741

Table 6 (cont.)

Brood Year, group	Tag Code	Number Tagged	Release Numbers: Corrected for Mortalities	Release Numbers: Corrected for Tagging Error
1990 Brood				
E1	07-56-37	32,947	32,107	31,780
E2	07-56-38	33,030	29,777	29,515
F1	07-56-39	32,960	28,853	28,426
F2	07-56-40	32,989	30,805	30,666
G1	07-56-41	33,196	32,748	32,381
G2	07-56-42	33,226	32,103	31,887
Dex1	07-56-43	33,082	33,082*	32,447
Dex2	07-56-44	33,045	33,045*	32,721
1991 Brood				
A1	07-59-21	32,281	30,299	30,160
A2	07-59-22	31,708	29,254	27,262
B1	07-59-35	19,992	19,792	19,602
B2	07-59-36	19,972	19,968	19,275
C1	07-59-23	32,117	31,118	30,804
C2	07-59-24	31,547	29,992	29,479
D1	07-59-25	31,538	27,120	27,052
D2	07-59-26	31,506	27,832	27,693
E1	07-59-27	31,523	22,807	21,895
E2	07-59-28	31,804	23,672	23,341
F1	07-59-29	31,597	27,341	26,704
F2	07-59-30	31,503	25,650	25,201
G1	07-59-31	31,569	27,819	27,641
G2	07-59-32	31,460	26,178	25,618
Dex1	07-59-33	33,363	33,363*	32,412
Dex2	07-59-34	33,363	33,363*	32,412

Table 6 (cont.)

Brood Year, group	Tag Code	Number Tagged	Release Numbers: Corrected for Mortalities	Release Numbers: Corrected for Tagging Error
1992 Brood				
A1	07-63-23	32,055	31,516	25,654
A2	07-63-22	32,358	29,866	24,541
B1	07-63-37	20,106	17,550	14,324
B2	07-63-36	20,140	17,550	14,280
C1	07-63-24	32,070	29,690	27,276
C2	07-63-25	31,981	26,464	23,802
D1	07-63-26	32,037	31,800	30,697
D2	07-63-27	32,046	29,694	25,893
E1	07-63-28	32,049	23,925	22,863
E2	07-01-28	32,000	22,733	22,278
F1	07-01-29	32,000	27,357	26,985
F2	07-01-30	32,031	26,618	25,793
G1	07-01-31	32,060	28,614	27,933
G2	07-01-32	32,119	27,494	26,834
Dex1	07-01-33	32,000	31,687	27,064
Dex2	07-01-34	31,852	31,730	26,951

*No mortality data available.

Table 7. Final numbers of tagged and untagged fish released from Willamette Hatchery, 1989-1992 broods. Number tagged fish released from the hatchery is that indicated in Table 6. Number of untagged fish released is the difference between the total number of fish released from Table 3 minus the number of tagged fish.

Brood Year, group	Tag Code	Final Number Tagged Fish	Final Number Untagged Fish	Total Released
1989 Brood				
A1	07-55-14	31,435	6,460	37,895
A2	07-55-06	27,495	5,805	33,300
B1	07-55-17	17,377	2,232	19,609
B2	07-55-18	17,426	838	18,264
C1	07-54-63	31,264	6,435	37,699
C2	07-55-03	30,347	8,613	38,960
D1	07-55-07	33,239	84,650	117,889
D2	07-55-08	32,686	68,106	100,792
E1	07-55-09	25,747	21,513	47,260
E2	07-55-10	29,441	23,068	52,509
F1	07-55-11	27,681	22,799	50,480
F2	07-55-12	30,054	24,889	54,943
G1	07-55-05	26,788	22,553	49,341
G2	07-55-13	26,152	21,523	47,675
Dex1	07-55-16	32,834	19,645	52,479
Dex2	07-55-15	32,416	14,841	47,257
1990 Brood				
A1	07-56-32	32,605	6,276	38,881
A2	07-56-31	32,046	6,465	38,511
B1	07-40-44	19,248	97	19,345
B2	07-40-43	19,982	1,564	21,546
C1	07-56-34	30,557	6,863	37,420
C2	07-56-33	30,493	6,981	37,474
D1	07-56-36	31,556	81,880	113,436
D2	07-56-35	32,741	88,113	120,854

Table 7 (cont.)

Brood Year, group	Tag Code	Final Number Tagged Fish	Final Number Untagged Fish	Total Released
1990 Brood				
E1	07-56-37	31,780	26,236	58,016
E2	07-56-38	29,515	24,009	53,524
F1	07-56-39	28,426	23,526	51,952
F2	07-56-40	30,666	24,789	55,455
G1	07-56-41	32,381	26,423	58,804
G2	07-56-42	31,887	25,740	57,627
Dex1	07-56-43	32,447	161,738	194,185
Dex2	07-56-44	32,721	161,465	194,186
1991 Brood				
A1	07-59-21	30,160	6,854	37,014
A2	07-59-22	27,262	9,218	36,480
B1	07-59-35	19,602	190	19,792
B2	07-59-36	19,275	693	19,968
C1	07-59-23	30,804	7,407	38,211
C2	07-59-24	29,479	8,544	38,203
D1	07-59-25	27,052	74,891	101,943
D2	07-59-26	27,693	78,099	105,792
E1	07-59-27	21,895	20,988	42,883
E2	07-59-28	23,341	20,675	44,016
F1	07-59-29	26,704	23,876	50,580
F2	07-59-30	25,201	22,299	47,500
G1	07-59-31	27,641	25,145	52,786
G2	07-59-32	25,618	23,573	49,191
Dex1	07-59-33	32,412	158,600	191,012
Dex2	07-59-34	32,412	158,600	191,012

Table 7 (cont.)

Brood Year, group	Tag Code	Final Number Tagged Fish	Final Number Untagged Fish	Total Released
1992 Brood				
A1	07-63-23	25,654	13,301	38,955
A2	07-63-22	24,541	11,984	36,525
B1	07-63-37	14,324	3,226	17,550
B2	07-63-36	14,280	3,270	17,550
C1	07-63-24	27,276	9,428	36,704
C2	07-63-25	23,802	9,240	33,082
D1	07-63-26	30,697	85,413	116,110
D2	07-63-27	25,893	82,485	108,378
E1	07-63-28	22,863	21,642	44,505
E2	07-01-28	22,278	19,482	41,760
F1	07-01-29	26,985	23,475	50,460
F2	07-01-30	25,793	23,284	49,077
G1	07-01-31	27,933	25,302	53,235
G2	07-01-32	26,834	24,302	51,136
Dex1	07-01-33	27,064	127,300	154,364
Dex2	07-01-34	26,951	127,412	154,363

Table 8. Final numbers of tagged and untagged fish released from Willamette Hatchery, 1989-1992 broods, as reported on the PSMFC database.

Brood Year, group	Tag Code	Final Number Tagged Fish	Final Number Untagged Fish	Total Released
1989 Brood				
A1	07-55-14	29,753	8,154	37,907
A2	07-55-06	26,682	5,834	32,516
B1	07-55-17	16,249	1,117	17,366
B2	07-55-18	17,899	181	18,080
C1	07-54-63	29,692	7,988	37,680
C2	07-55-03	31,302	7,326	38,788
D1	07-55-07	31,806	93,222	125,226
D2	07-55-08	26,980	19,568*	47,114
E1	07-55-09	25,191	21,809	47,128
E2	07-55-10	28,703	23,514	52,348
F1	07-55-11	26,696	22,694	49,629
F2	07-55-12	30,842	24,462	55,304
G1	07-55-05	28,361	71,504*	100,329
G2	07-55-13	25,580	22,321	48,552
Dex1	07-55-16	31,647	41,559	73,567
Dex2	07-55-15	31,647	41,559	73,567
1990 Brood				
A1	07-56-32	32,483	6,398	38,881
A2	07-56-31	30,592	7,613	38,211
B1	07-40-44	19,250	96	19,346
B2	07-40-43	21,342	0	21,342
C1	07-56-34	31,068	5,963	37,031
C2	07-56-33	28,720	6,843	35,563
D1	07-56-36	31,387	81,376	112,763
D2	07-56-35	27,881	92,974	120,855

Table 8 (cont.)

Brood Year, group	Tag Code	Final Number Tagged Fish	Final Number Untagged Fish	Total Released
1990 Brood				
E1	07-56-37	31,520	25,312	56,832
E2	07-56-38	29,219	23,364	52,583
F1	07-56-39	28,683	23,009	51,692
F2	07-56-40	30,755	24,700	55,455
G1	07-56-41	32,450	26,026	58,476
G2	07-56-42	31,961	25,667	57,628
Dex1	07-56-43	32,148	161,394	193,542
Dex2	07-56-44	32,610	161,315	192,925
1991 Brood				
A1	07-59-21	30,674	6,340	37,014
A2	07-59-22	25,614	6,986	34,540
B1	07-59-35	19,505	96	19,697
B2	07-59-36	18,671	259	19,449
C1	07-59-23	30,722	6,721	37,827
C2	07-59-24	27,254	9,439	37,358
D1	07-59-25	26,258	75,685	101,943
D2	07-59-26	26,750	78,504	105,523
E1	07-59-27	21,080	19,089	41,526
E2	07-59-28	24,412	19,603	44,015
F1	07-59-29	25,683	23,519	49,891
F2	07-59-30	23,095	23,690	47,142
G1	07-59-31	22,315	29,791	52,446
G2	07-59-32	22,550	25,939	48,840
Dex1	07-59-33	31,783	157,964	190,379
Dex2	07-59-34	31,783	157,964	190,379

Table 8 (cont.)

Brood Year, group	Tag Code	Final Number Tagged Fish	Final Number Untagged Fish	Total Released
1992 Brood				
A1	07-63-23	20,073	6,988	33,008
A2	07-63-22	19,753	8,199	32,238
B1	07-63-37	11,830	392	14,886
B2	07-63-36	10,958	86	14,297
C1	07-63-24	23,615	8,501	34,410
C2	07-63-25	20,014	2,812	27,954
D1	07-63-26	27,986	86,040	115,068
D2	07-63-27	21,826	79,026	104,615
E1	07-63-28	20,688	21,798	43,495
E2	07-01-28	20,111	20,829	41,350
F1	07-01-29	28,195	21,475	50,065
F2	07-01-30	21,869	25,771	48,359
G1	07-01-31	23,531	28,540	52,653
G2	07-01-32	24,293	25,629	50,529
Dex1	07-01-33	24,075	124,275	151,357
Dex2	07-01-34	23,525	123,939	150,914

* These numbers seemed to be exchanged in the release data from the PSMFC database but not confused in the return data.

operations but be lost from the recovered population.

An additional difference results from the calculation of numbers of fish released based on total pounds of fish hauled (to the nearest 50 pounds) and numbers of fish per pound. These numbers were calculated using different assumptions by the hatchery personnel and by the research team at Willamette Hatchery. However, most of the numbers are within 5% of each other (Table 8) so these differences do not cause major difficulties with analysis (see discussion on p. 33 in Ewing (1996)).

Numbers of tagged fish used for all calculation in the rest of this report are those presented in Table 6, using the assumptions of the research team at Willamette Hatchery.

Survival Analyses for Experimental Groups

Percent Yield of Experimental Groups

The most common method of analysis for determining efficiency of hatchery operations is the percent yield, the ratio of the number of tags recovered from adults to the number of tagged fish released (Table 9). For 1989 brood fish, best returns of experimental groups was found in the Dexter release group (Figure 1). At Willamette Hatchery, best returns were found in the B group. Poorest returns were from fish in the G group. The order of percent yield was: Dex > B > C > A > D > F > E > G.

For 1990 brood fish, best return from fish in all experimental groups was found in the Dexter release group (Figure 2). At Willamette Hatchery, best returns were found in the B group. Poorest returns were from fish in the E group. The order of percent yield was: Dex > B > A > D > C > G > F > E.

For 1991 brood fish, best returns of experimental groups was found in the Dexter release group (Figure 3). At Willamette Hatchery, best returns were found in the B group. Poorest returns were from fish in the E group. The order of percent yield was: Dex > B > C > A > D > F > G > E.

For 1992 brood fish, best returns from fish in all experimental groups was found in the Dexter release group (Figure 4). At Willamette Hatchery, best returns were found

Table 9. Percent yield of adult fish derived from experimental groups released from Willamette Hatchery, 1989-1992 broods. 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 Yield
1989 Brood				
A1	07-55-14	31,435	195	0.620
A2	07-55-06	27,495	160	0.582
B1	07-55-17	17,377	168	0.967
B2	07-55-18	17,426	201	1.153
C1	07-54-63	31,264	270	0.864
C2	07-55-03	30,347	257	0.847
D1	07-55-07	33,239	133	0.400
D2	07-55-08	32,686	165	0.505
E1	07-55-09	25,747	4	0.016
E2	07-55-10	29,441	27	0.092
F1	07-55-11	27,681	9	0.033
F2	07-55-12	30,054	34	0.113
G1	07-55-05	26,788	2	0.007
G2	07-55-13	26,152	12	0.046
Dex1	07-55-16	32,834	449	1.367
Dex2	07-55-15	32,416	408	1.259
1990 Brood				
A1	07-56-32	32,605	5	0.015
A2	07-56-31	32,046	68	0.212
B1	07-40-44	19,248	8	0.042
B2	07-40-43	19,982	60	0.300
C1	07-56-34	30,557	10	0.033
C2	07-56-33	30,493	6	0.020
D1	07-56-36	31,556	6	0.019
D2	07-56-35	32,741	19	0.058
E1	07-56-37	31,780	0	0.000
E2	07-56-38	29,515	2	0.007
F1	07-56-39	28,426	2	0.007
F2	07-56-40	30,666	5	0.016
G1	07-56-41	32,381	0	0.000
G2	07-56-42	31,887	16	0.050
Dex1	07-56-43	32,447	103	0.317
Dex2	07-56-44	32,721	127	0.388

[a]Refers to the number of tagged fish released (Table 6). This number is determined by the number of fish initially tagged minus the mortalities during rearing and the tag loss determined before release.

Table 9. (cont.)

Group	Tag Code	Number Released[a]	Number Recovered	Percent Yield
1991 Brood				
A1	07-59-21	30,160	83	0.275
A2	07-59-22	27,262	116	0.426
B1	07-59-35	19,602	81	0.413
B2	07-59-36	19,275	92	0.477
C1	07-59-23	30,804	107	0.347
C2	07-59-24	29,479	131	0.444
D1	07-59-25	27,052	48	0.177
D2	07-59-26	27,693	82	0.296
E1	07-59-27	21,895	23	0.105
E2	07-59-28	23,341	6	0.026
F1	07-59-29	26,704	34	0.127
F2	07-59-30	25,201	8	0.032
G1	07-59-31	27,641	35	0.127
G2	07-59-32	25,618	6	0.023
Dex1	07-59-33	32,412	256	0.790
Dex2	07-59-34	32,412	230	0.710
1992 Brood				
A1	07-63-23	25,654	65	0.253
A2	07-63-22	24,541	38	0.155
B1	07-63-37	14,324	32	0.223
B2	07-63-36	14,280	31	0.217
C1	07-63-24	27,276	52	0.191
C2	07-63-25	23,802	63	0.265
D1	07-63-26	30,697	52	0.169
D2	07-63-27	25,893	31	0.120
E1	07-63-28	22,863	27	0.118
E2	07-01-28	22,278	28	0.126
F1	07-01-29	26,985	36	0.133
F2	07-01-30	25,793	33	0.128
G1	07-01-31	27,933	39	0.140
G2	07-01-32	26,834	36	0.134
Dex1	07-01-33	27,064	217	0.802
Dex2	07-01-34	26,951	185	0.686

[a]Refers to the number of tagged fish released (Table 6). This number is determined by the number of fish initially tagged minus the mortalities during rearing and the tag loss determined before release.

Figure 1. Percent yield of 1989 brood fish from various experimental groups at Willamette Hatchery and from Dexter Rearing Ponds. Yield represents expanded values from all fisheries and from hatchery returns.

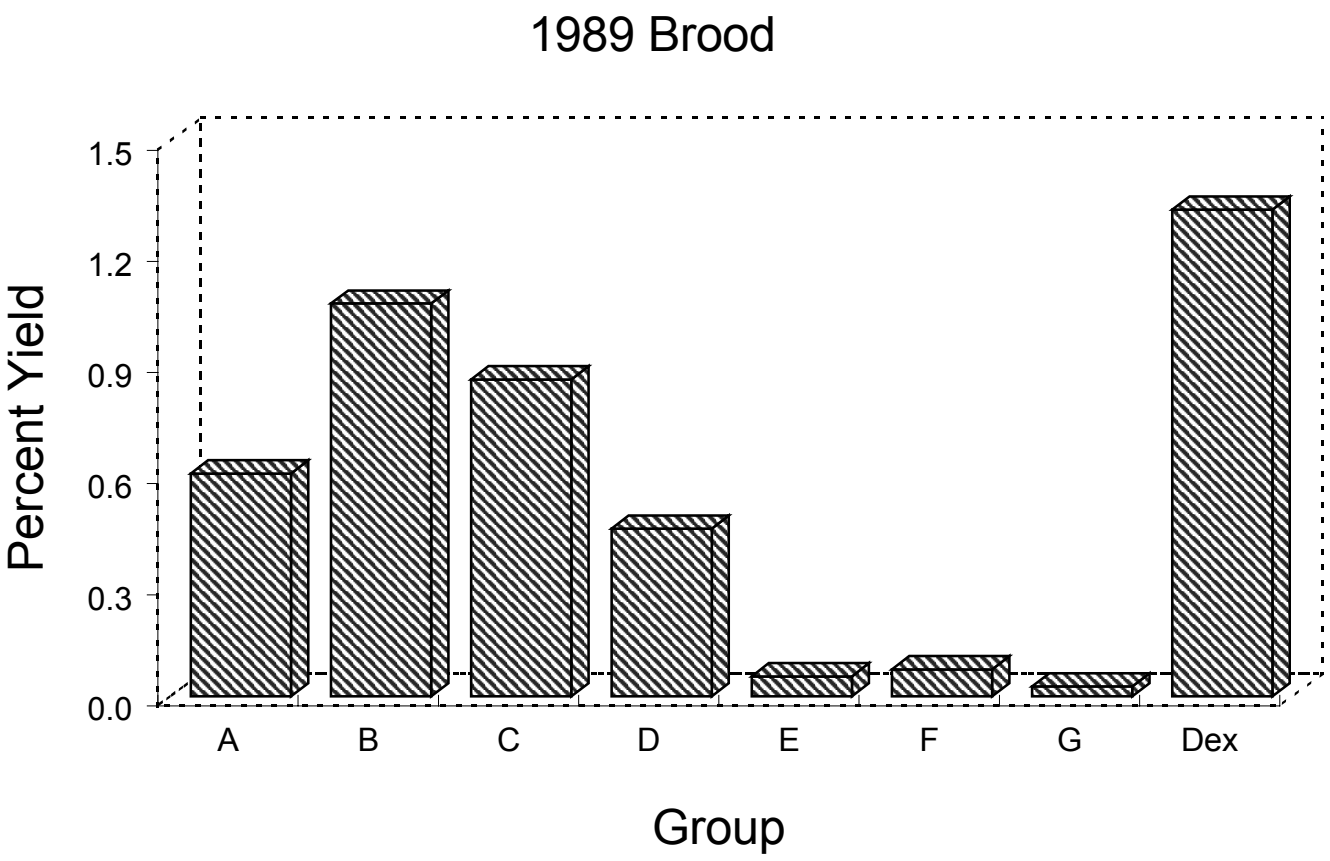

1989 Brood
Percent Yield
1.5
1.2
0.9
0.6
0.3
0.0
A
B
C
D
E
F
G
Dex
Group

Figure 2. Percent yield of 1990 brood fish from various experimental groups at Willamette Hatchery and from Dexter Rearing Ponds. Yield represents expanded values from all fisheries and from hatchery returns.

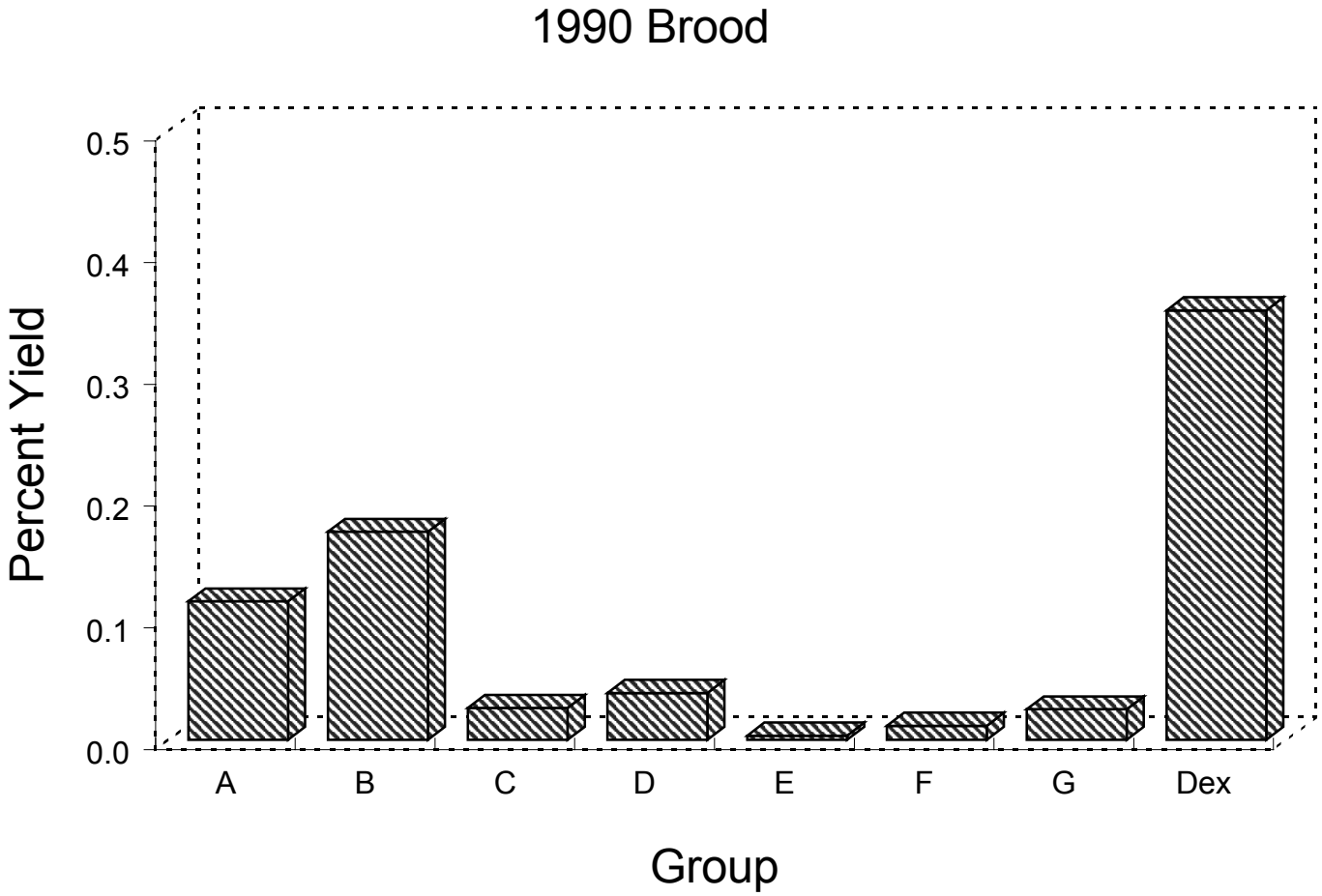

1990 Brood
Percent Yield
0.5
0.4
0.3
0.2
0.1
0.0
A
B
C
D
E
F
G
Dex
Group

Figure 3. Percent yield of 1991 brood fish from various experimental groups at Willamette Hatchery and from Dexter Rearing Ponds. Yield represents expanded values from all fisheries and from hatchery returns.

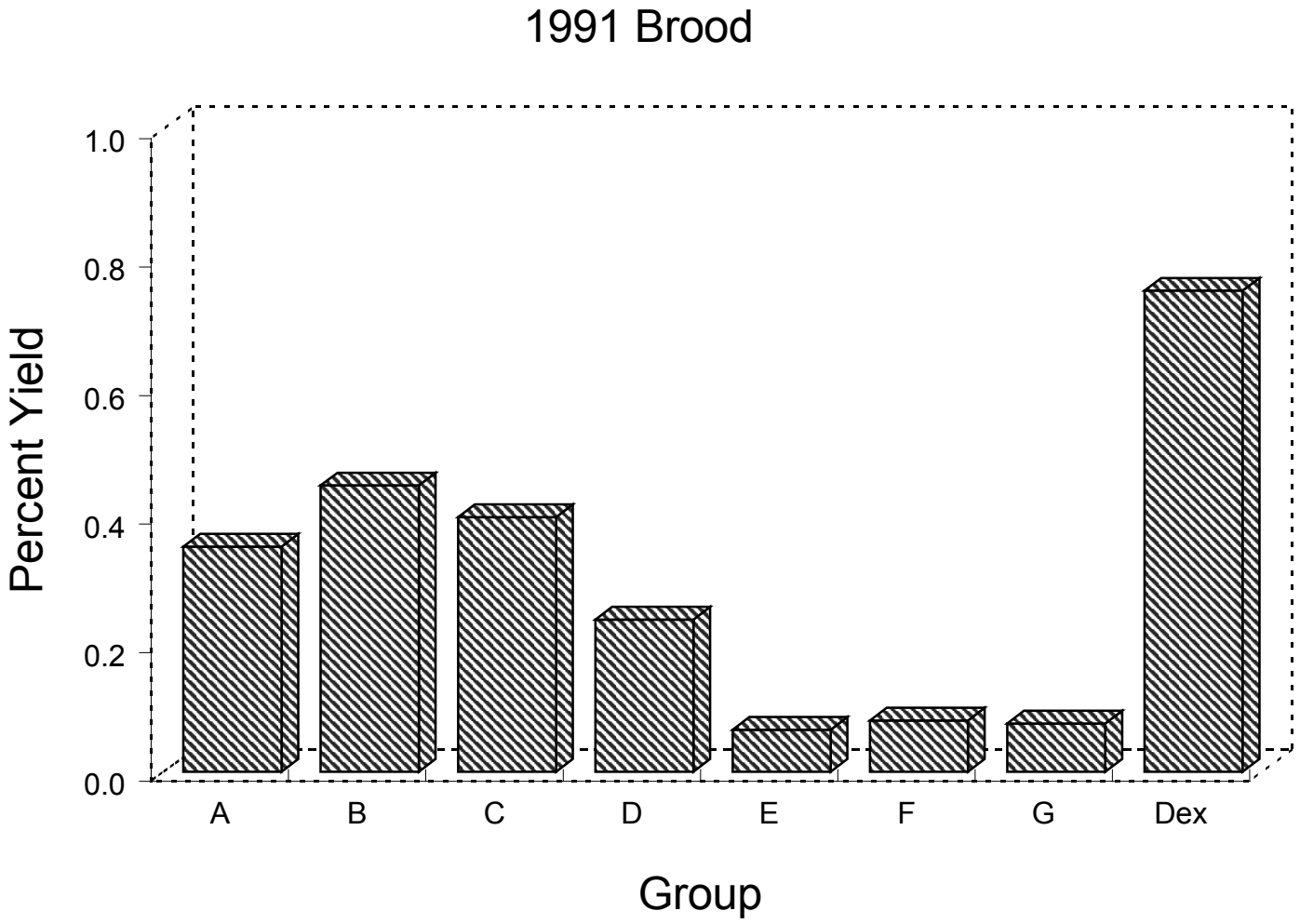
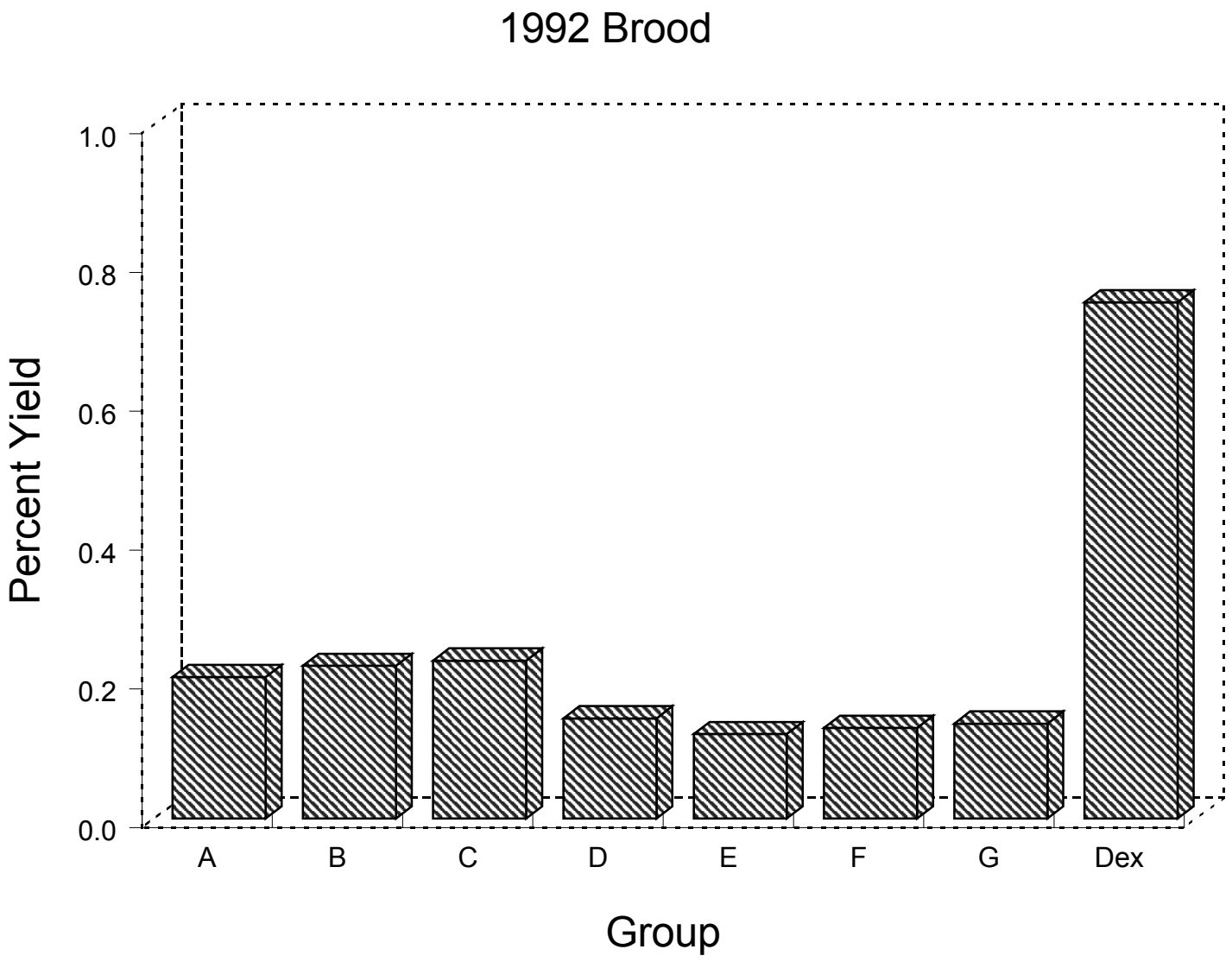

1991 Brood
Percent Yield
1.0
0.8
0.6
0.4
0.2
0.0
A
B
C
D
E
F
G
Dex
Group

Figure 4. Percent yield of 1992 brood fish from various experimental groups at Willamette Hatchery and from Dexter Rearing Ponds. Yield represents expanded values from all fisheries and from hatchery returns.


1992 Brood
Percent Yield
1.0
0.8
0.6
0.4
0.2
0.0
A
B
C
D
E
F
G
Dex
Group

in the C group. Poorest returns were from fish in the E group. The order of percent yield was: Dex > C > B > A > D > G > F > E.

Average percent yield for the four brood years (Figure 5) showed a pattern very much like the 1989 brood fish. Best percent yield was found in the Dexter release group. At Willamette Hatchery, best percent yield was found in the B group and worst was found in the E group. The order of percent yield was: Dex > B > C > A > D > F > G > E.

For analysis of variance to determine significant difference between groups, percent yields of experimental groups (Table 9) were converted to arcsines to provide a normal distribution (Zar 1984) and tested by one-way analysis of variance for the following hypotheses:

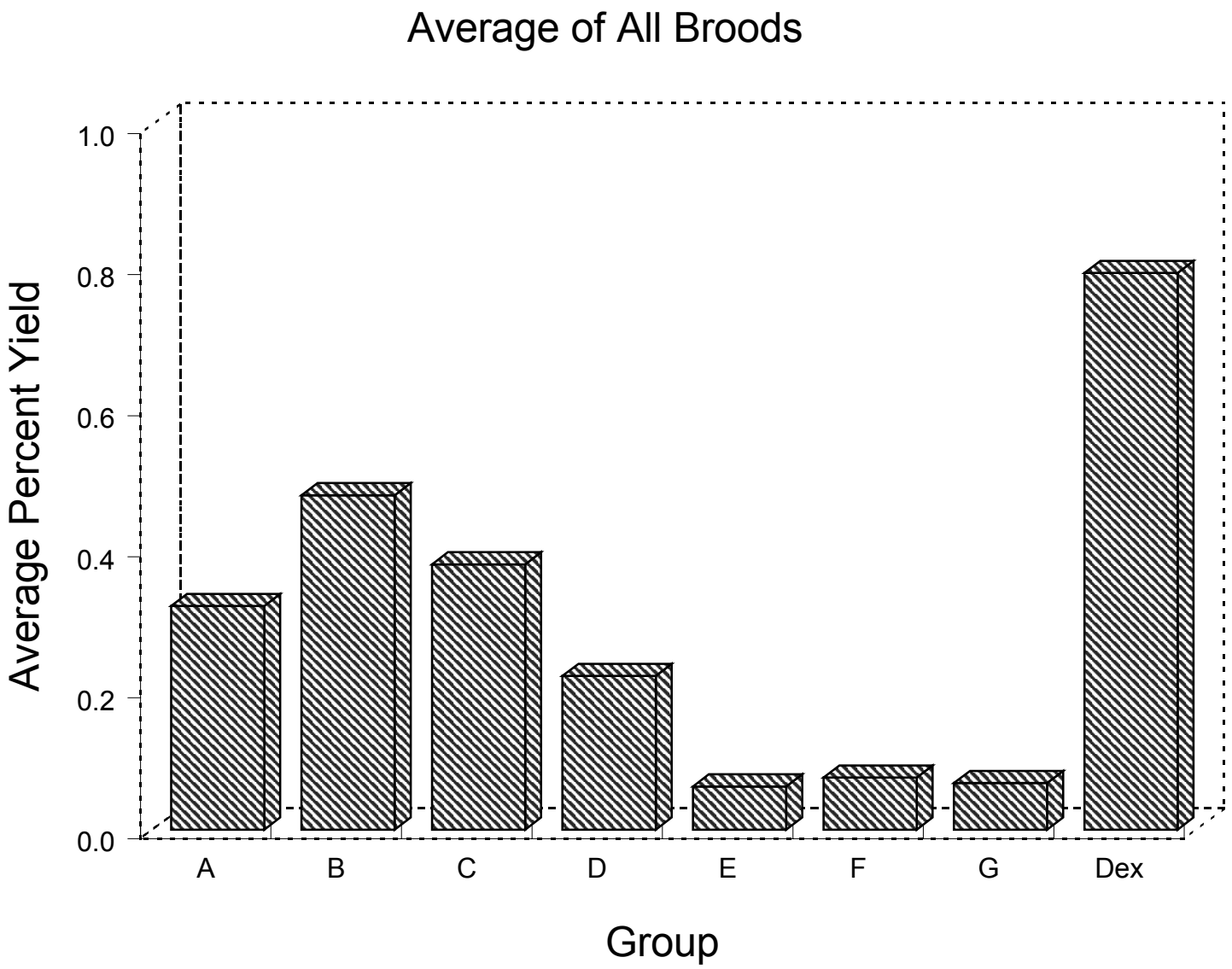
H_0 = All arcsine percent yields from all experimental groups are equal.

H_a = Arcsine percent yield from experimental groups are not equal.

When all groups were examined for the four brood years, there were significant differences between groups ($F = 11.54$, $F(0.05,6,57) = 2.29$). Because percent yield varied between 0 and 1.15 %, this finding was not surprising. Tukey's test indicated the following relationships between groups:

B C A D F G E

Figure 5. Average percent yield of all four broods of fish from various experimental groups at Willamette Hatchery and from Dexter Rearing Ponds. Yield represents expanded values from all fisheries and from hatchery returns.


Average of All Broods
Average Percent Yield
1.0
0.8
0.6
0.4
0.2
0.0
A
B
C
D
E
F
G
Dex
Group

where underlined groups are not significantly different.

Pairwise comparisons from Tukey's test for overall yield of groups indicated no significant difference in survival between fish from Dexter and from group B. No significant differences were found between groups A, B, C, and D. No significant differences were also found between A, C, D, F and G. No significant differences were found between groups A, D, F, G, and E.

Analyses of variance were performed on arcsine percent yield from individual brood years, followed by Tukey's test when significant differences were detected. Results of the analyses are presented in Table 10. Significant differences between groups was found in two of the four brood years. In the 1989 brood years, significant differences occurred between each group (Table 10).

The effect of rearing density on percent yield in all the experimental groups can be seen in Figure 6. While there is some relationship between density and yield, the R^2 value is only 0.317 (Table 11). All Michigan raceways tended to have low survival for reasons other than rearing density. When those were removed from the data set, the relationship did not improve (Figure 7, Table 11).

The effects of load (kg of fish per liter of water per minute) were also examined for the relationship with percent yield. The relationship was not significantly different from zero (Figure 8, Table 11). Removal of data for Michigan raceways did

Table 10. Results from one-way analyses of variance between arcsines of percent yields from different experimental release groups.

Brood Year	F Value	F(0.05)		Sequence
Overall	11.54	2.29	Sig.	B C A D F G E
1989	49.98	3.79	Sig.	B C A D F G E
1990	0.672	3.79	NS	B A D C G E E
1991	6.438	3.79	Sig.	B C A D G F E
1992	3.158	3.79	NS	C B A D G F E

Sig. indicates significant differences between groups. NS indicates no significant differences between groups. Sequence refers to the sequence of means of replicates in descending order. Groups underlined are not significantly different by Tukey's test ($P \leq 0.05$).

Figure 6. Relationship between rearing density in kg/m^3 and percent yield for all experimental groups and all brood years.

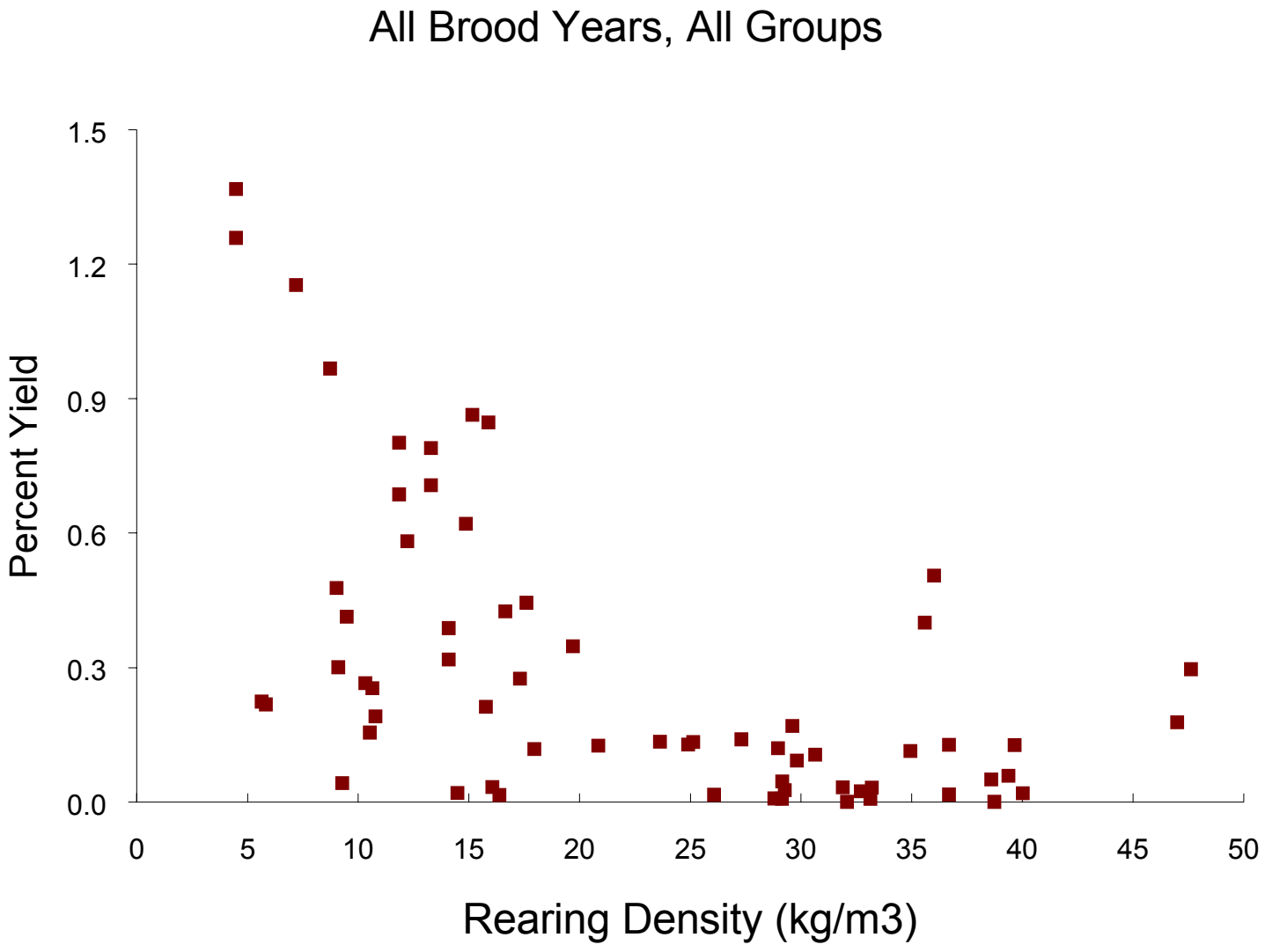

All Brood Years, All Groups
Percent Yield
1.5
1.2
0.9
0.6
0.3
0.0
0
5
10
15
20
25
30
35
40
45
50
Rearing Density (kg/m3)

Table 11. Relationships between percent yield and rearing density or load for various experimental release groups. Relationships significantly different from zero are marked with an asterisk.

Conditions, Group	Equation	R^2
Rearing Density		
All groups	-0.0161 X + 0.654	0.317*
Raceways only	-0.0119 X + 0.640	0.151*
Raceways only, without Dexter	-0.0062 X + 0.464	0.069*
Load		
All groups	0.1046 X + 0.185	0.079*
Raceways only	0.0188 X + 0.409	0.003
Raceways only without Dexter	-0.1126 X + 0.464	0.069*
1/Rearing Density, Raceways only, by Brood year		
1989	4.2550 X + 0.417	0.848*
1990	1.9416 X + 0.011	0.136*
1991	3.3584 X + 0.222	0.245*
1992	-0.1521 X + 0.323	0.0009
Load, Raceways only, by Brood year		
1989	-0.2827 X + 1.148	0.223*
1990	0.0658 X + 0.036	0.281*
1991	0.0676 X + 0.321	0.168*
1992	0.1853 X + 0.084	0.658*

Figure 7. Relationship between rearing density in kg/m^3 and percent yield for all brood years, with raceways only.

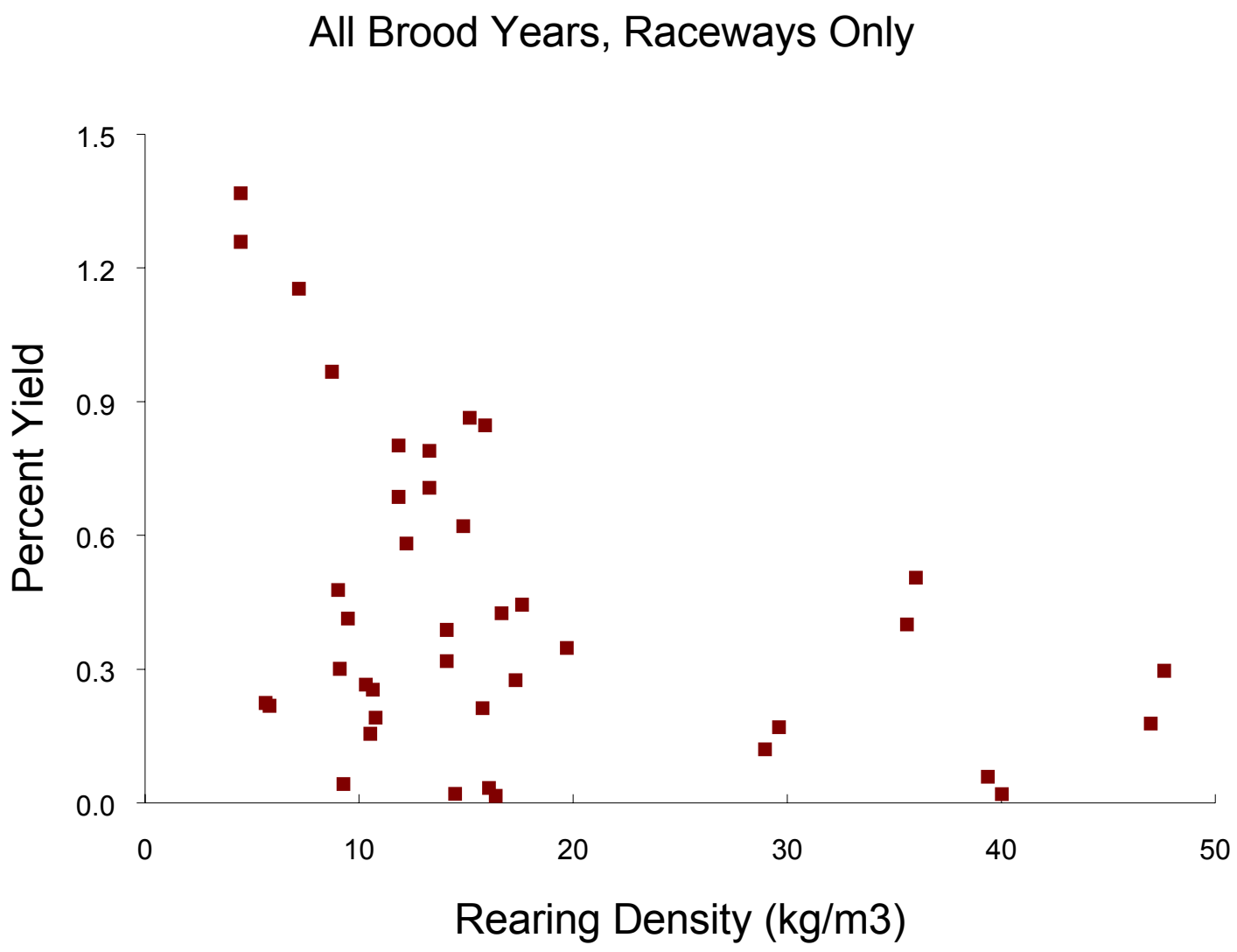
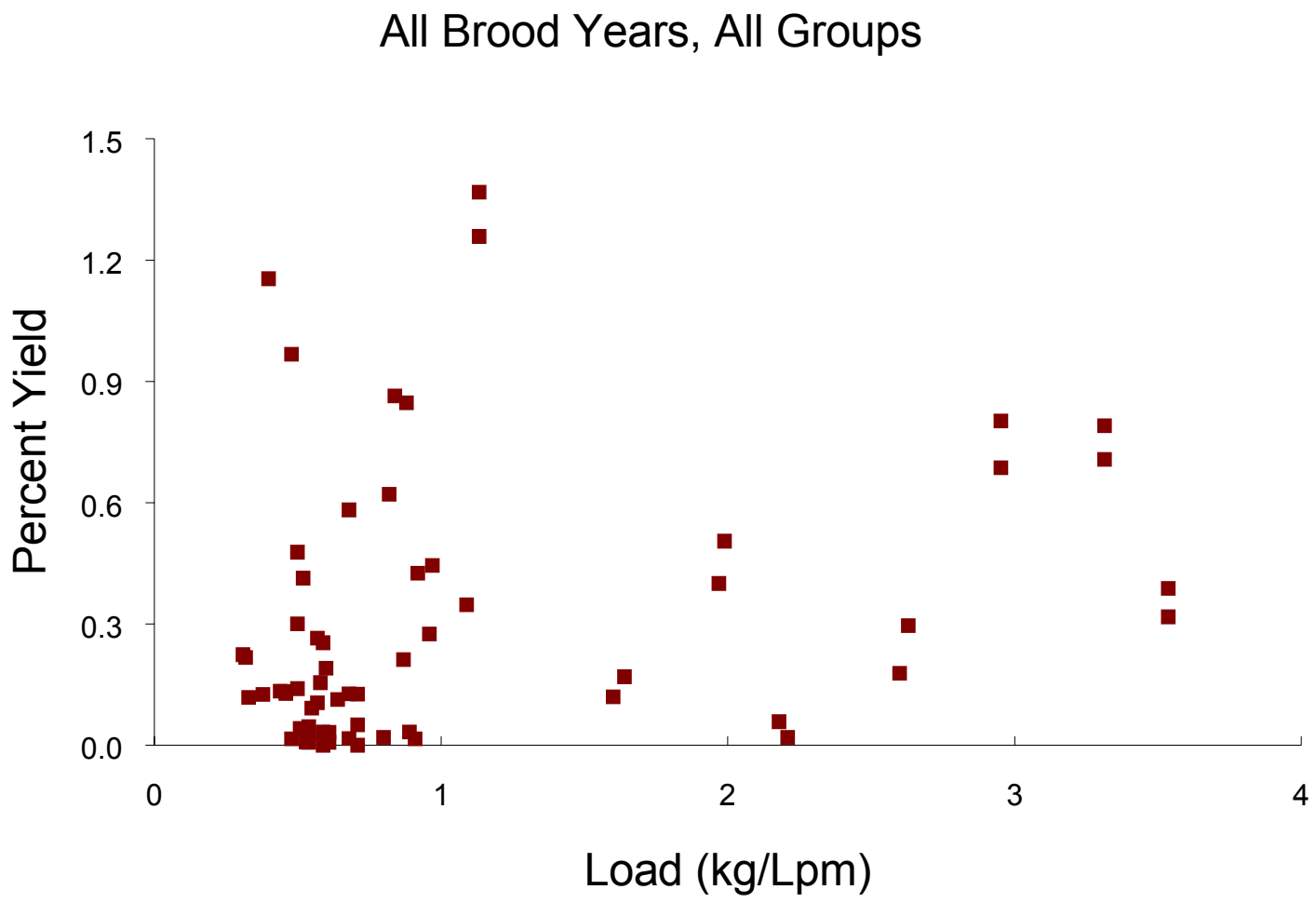

All Brood Years, Raceways Only
Percent Yield
1.5
1.2
0.9
0.6
0.3
0.0
0
10
20
30
40
50
Rearing Density (kg/m3)

Figure 8. Relationship between load in kg/Lpm and percent yield for all brood years and all experimental groups.


All Brood Years, All Groups
Percent Yield
1.5
1.2
0.9
0.6
0.3
0.0
0
1
2
3
4
Load (kg/Lpm)

not improve the relationship (Figure 9).

Examining the relationship between rearing density and percent yield for individual brood years showed a good relationship for 1989 brood (Figure 10) but not for 1990 brood (Figure 11), 1991 brood (Figure 12), or 1992 brood (Figure 13). Correlations between reciprocals of rearing density and percent yield were significant for 1989, 1990, and 1991 broods but not for 1992 brood (Table 11).

Variability in the percent returns between groups for each brood year was probably more responsible for the poor relationship between rearing density and percent yield than the difference in percent yield between years. When returns were normalized using the percent yield of Dexter-reared fish as 1.00, the relationship between rearing density and percent yield was only slightly better, regardless of whether all groups were included (R^2 = 0.377) (Figure 14), or only raceways were included (R^2 = 0.183) (Figure 15).

In summary, best percent yields were obtained from fish reared at the lowest densities. Dexter fish had the highest percent yields. Worst percent yields were obtained from fish reared in Michigan ponds. A good relationship between rearing density and percent yield was found for 1989 brood fish, but poor relationships were found for the other three brood years.

Figure 9. Relationship between load in kg/Lpm and percent yield for all brood years, with raceways only.

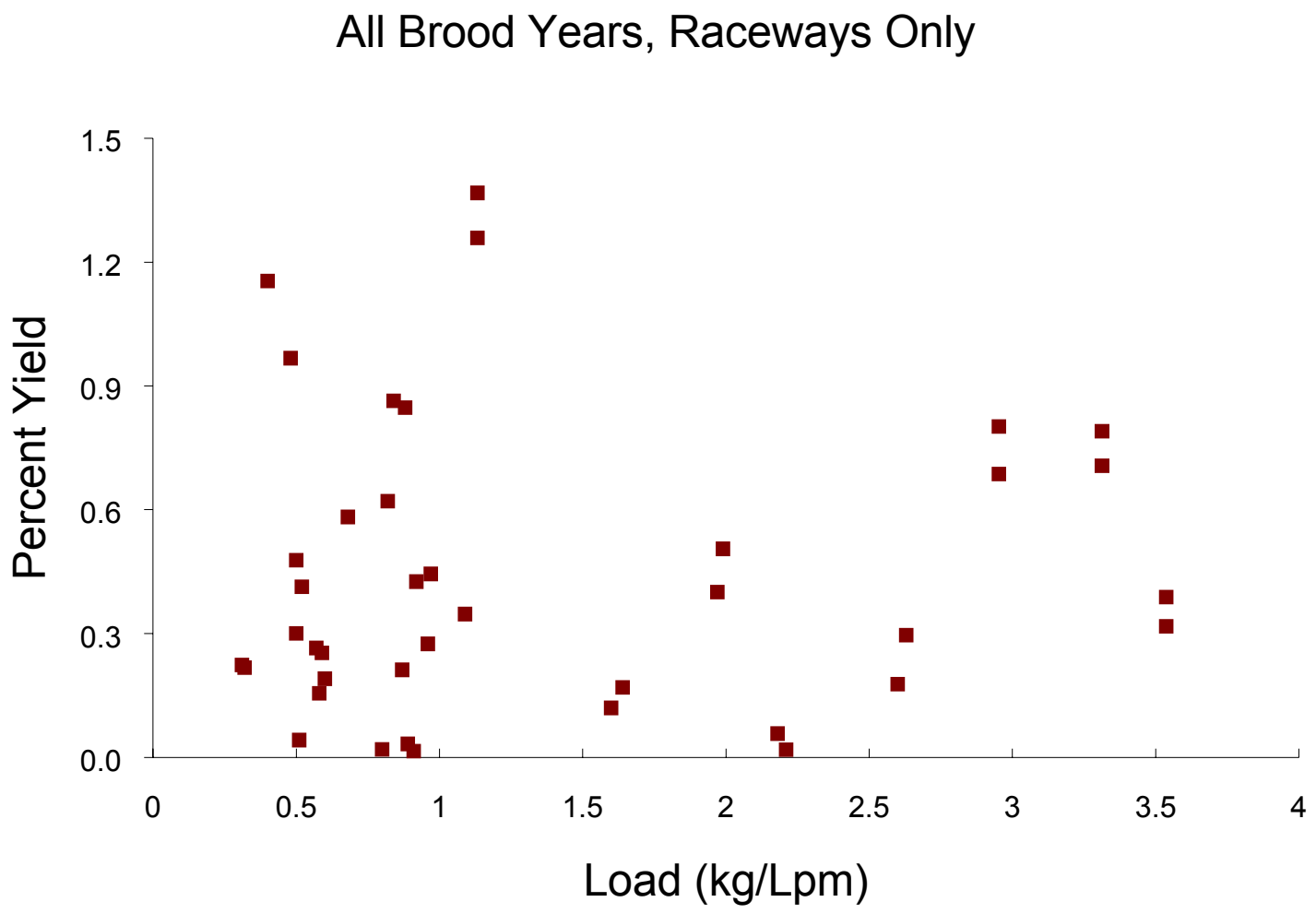

All Brood Years, Raceways Only
Percent Yield
1.5
1.2
0.9
0.6
0.3
0.0
0
0.5
1
1.5
2
2.5
3
3.5
4
Load (kg/Lpm)

Figure 10. Relationship between rearing density in kg/m^3 and percent yield for all experimental groups for the 1989 brood year.

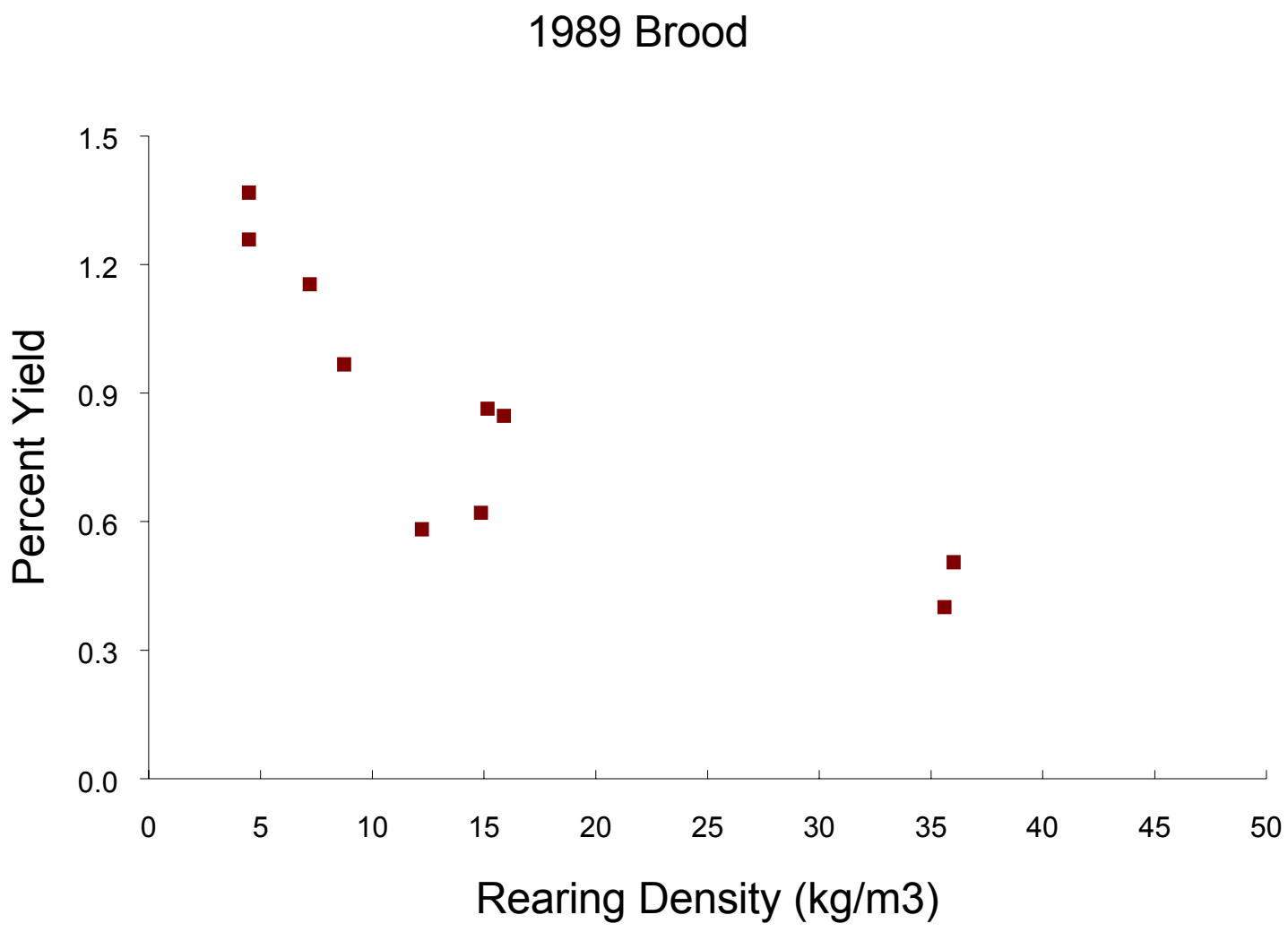

1989 Brood
Percent Yield
1.5
1.2
0.9
0.6
0.3
0.0
0
5
10
15
20
25
30
35
40
45
50
Rearing Density (kg/m3)

Figure 11. Relationship between rearing density in kg/m^3 and percent yield for all experimental groups for the 1990 brood year.

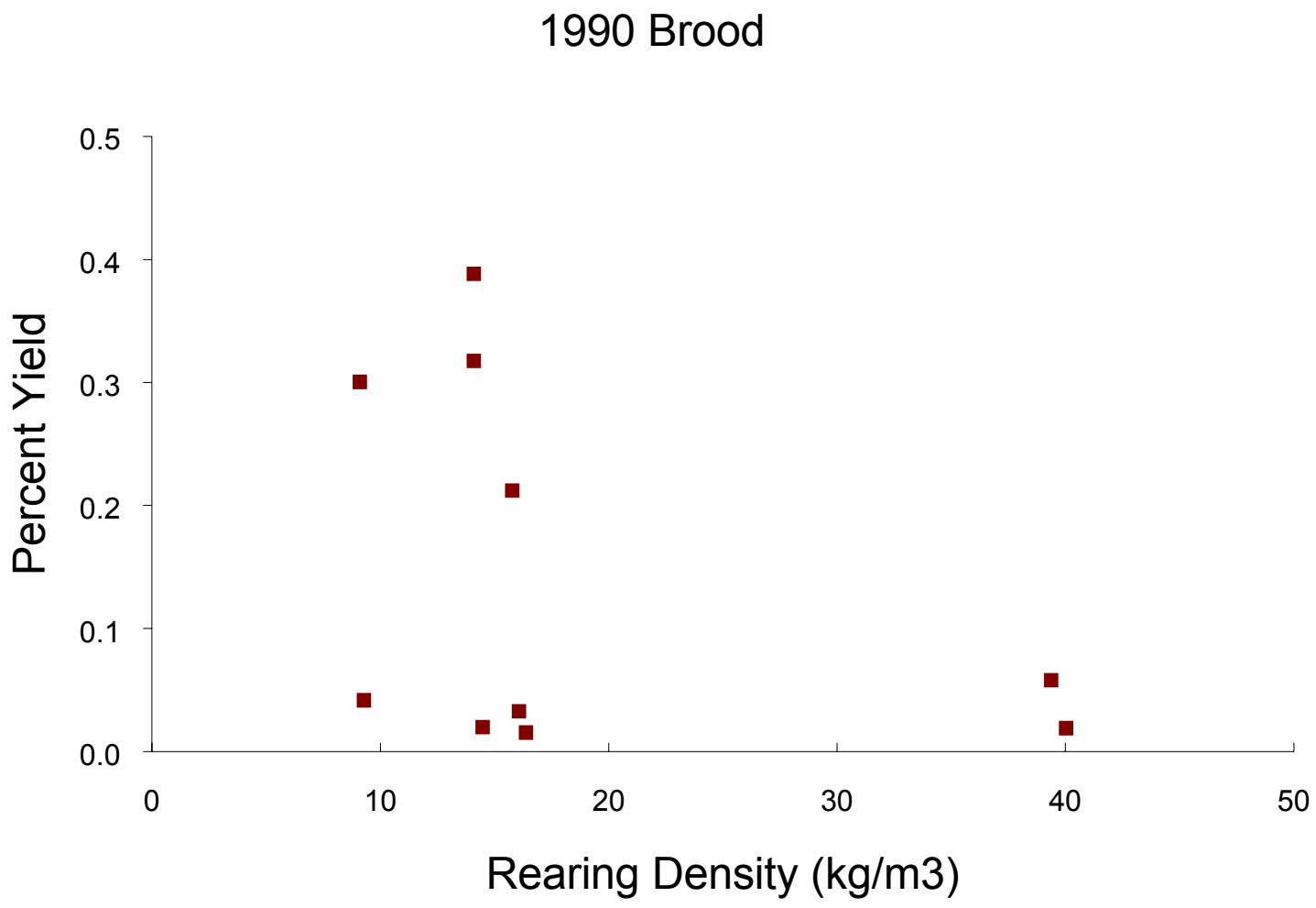

1990 Brood
Percent Yield
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
Rearing Density (kg/m3)

Figure 12. Relationship between rearing density in kg/m^3 and percent yield for all experimental groups for the 1991 brood year.

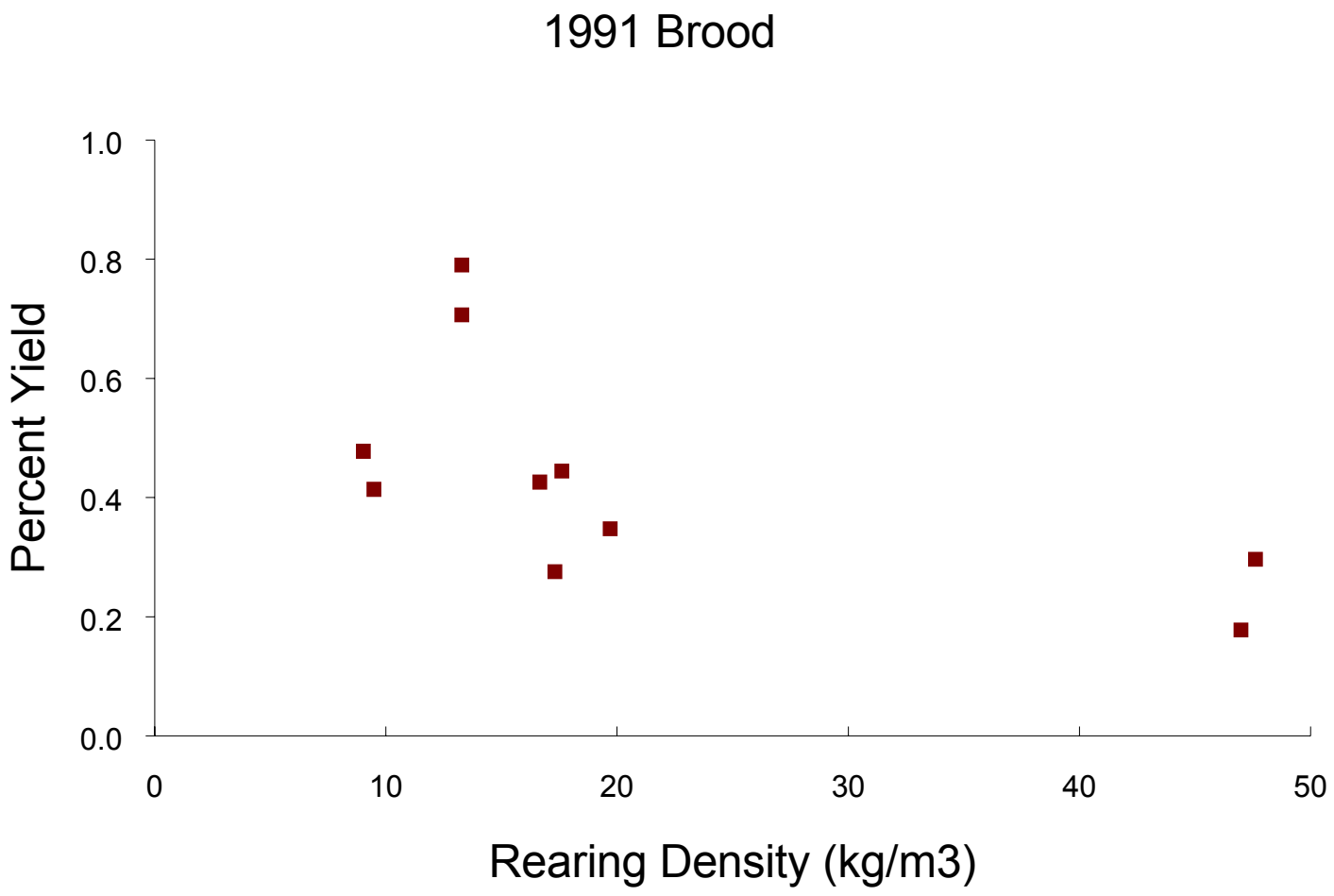

1991 Brood
Percent Yield
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
Rearing Density (kg/m3)

Figure 13. Relationship between rearing density in kg/m^3 and percent yield for all experimental groups for the 1992 brood year.

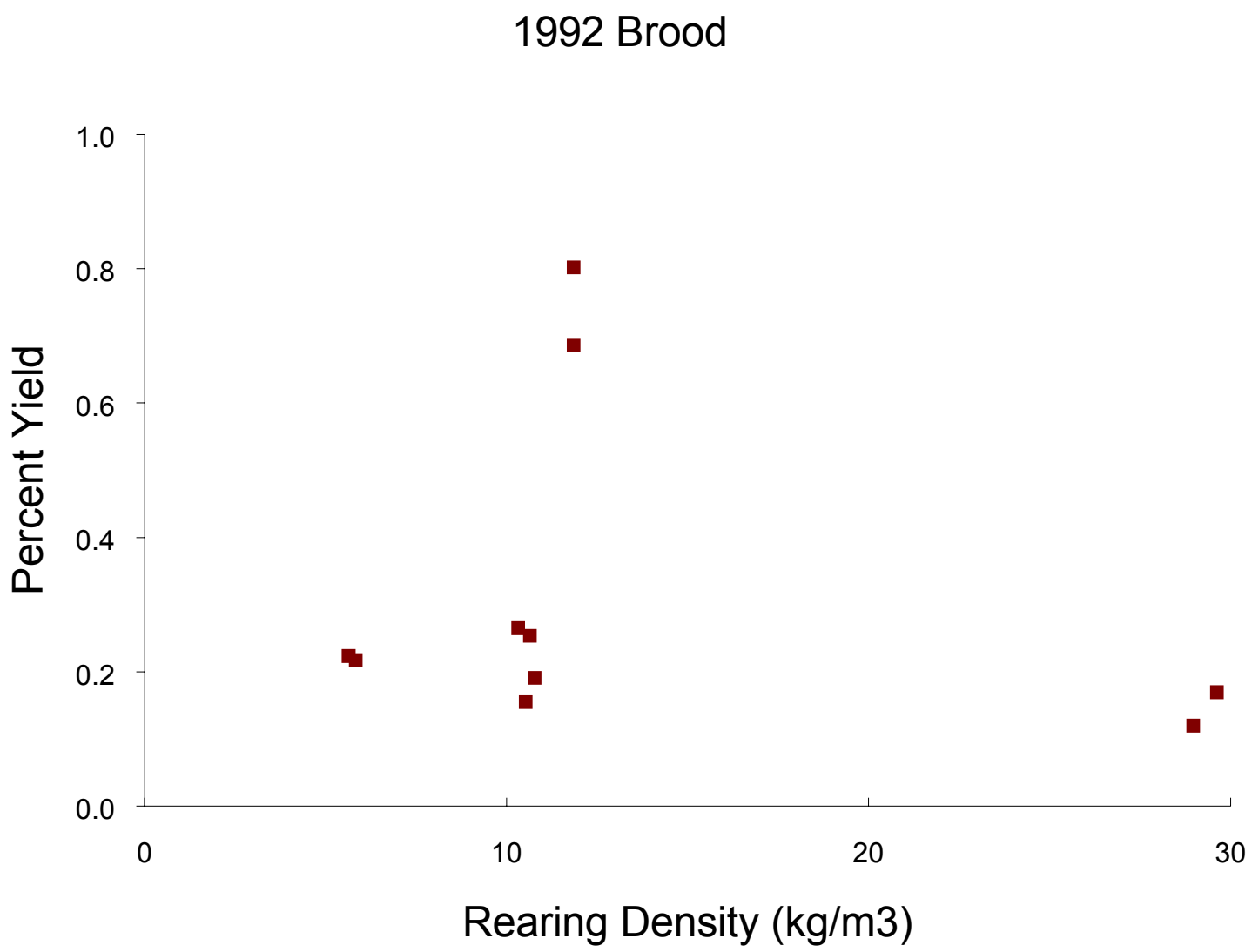

1992 Brood
Percent Yield
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
Rearing Density (kg/m3)

Figure 14. Relationship between rearing density in kg/m^3 and percent yield for all experimental groups for all brood years. Percent yields were normalized such that Dexter fish had a percent yield of 1.0 for all years

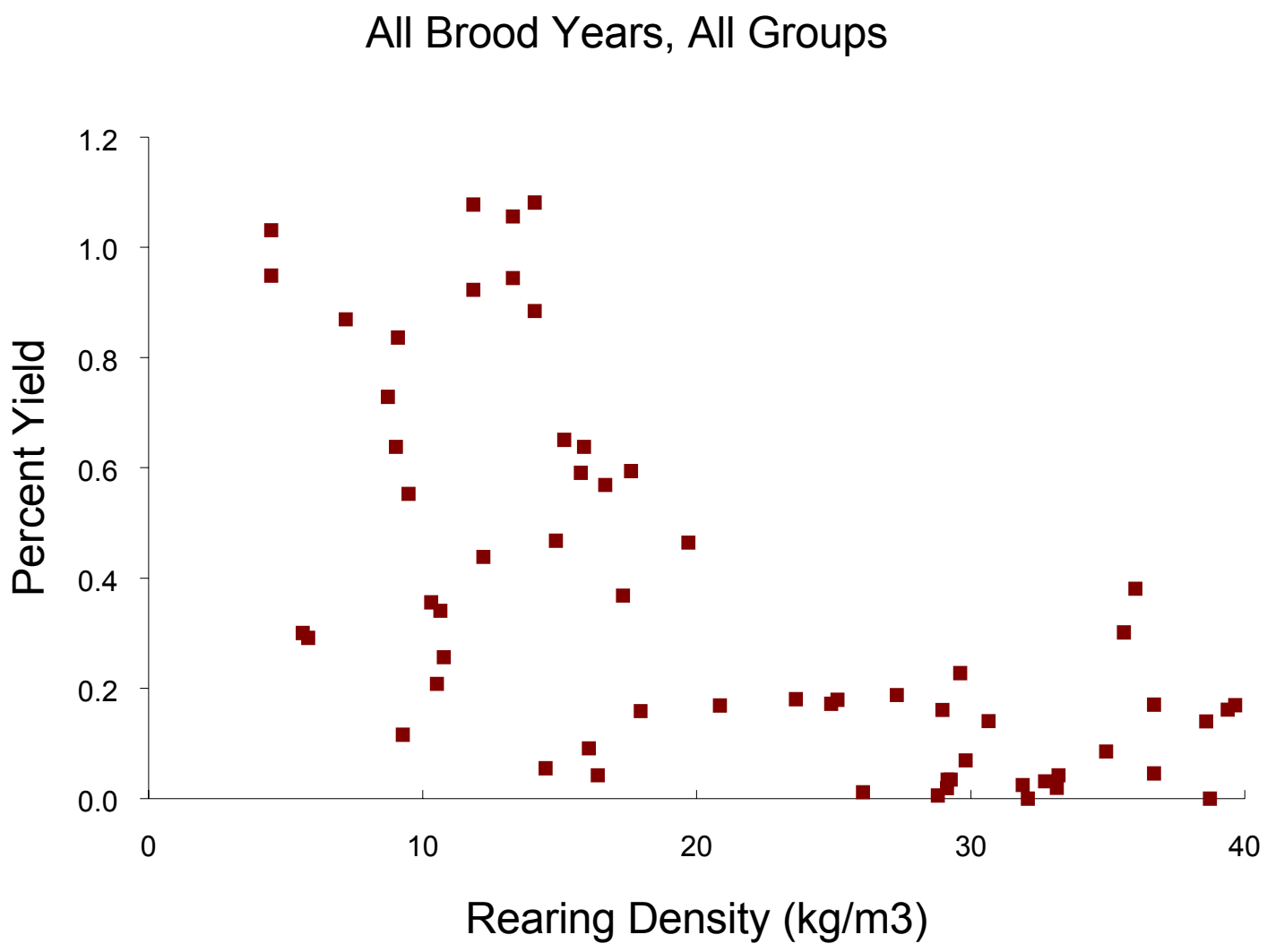
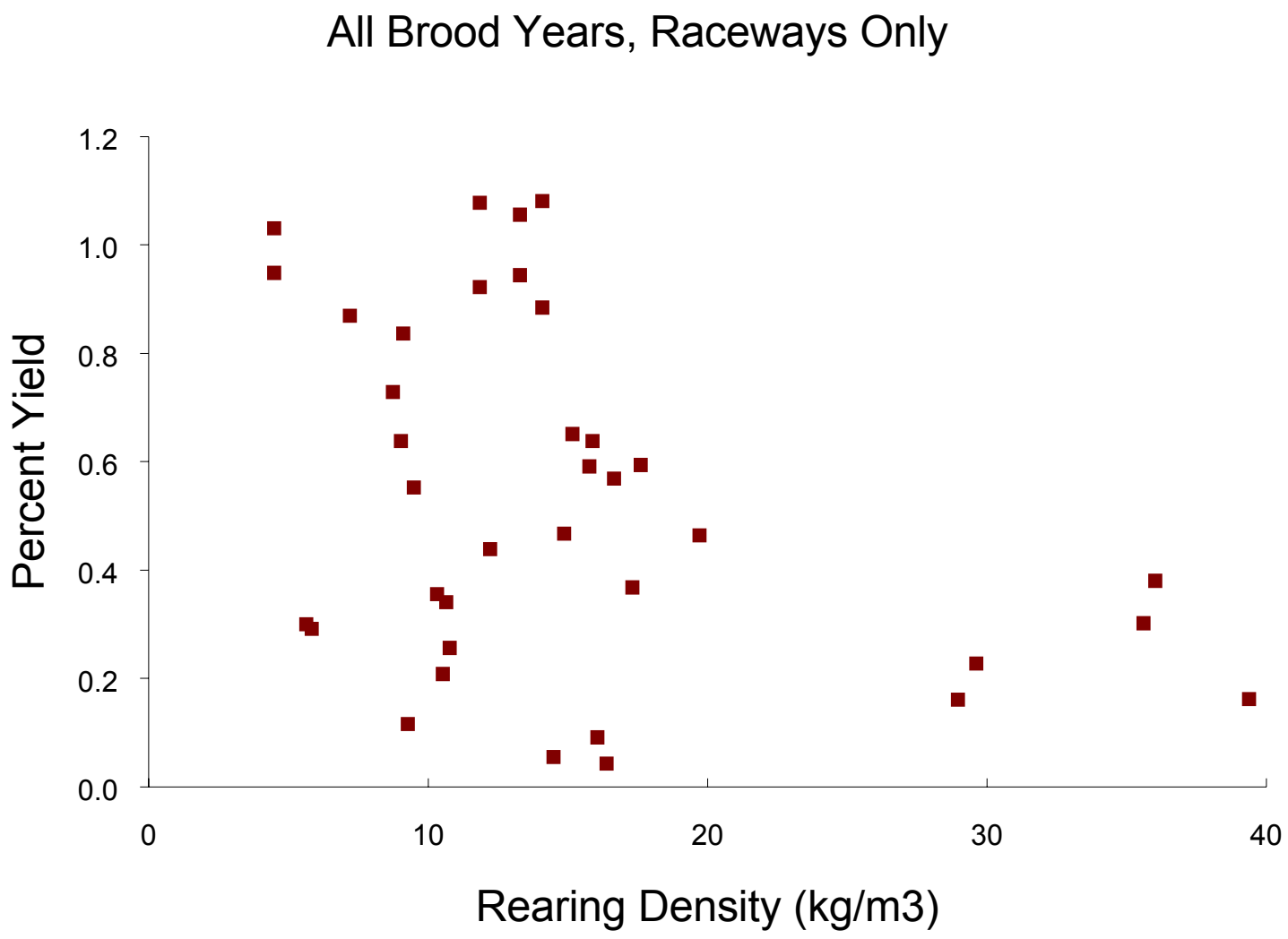

All Brood Years, All Groups
Percent Yield
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
Rearing Density (kg/m3)

Figure 15. Relationship between rearing density in kg/m^3 and percent yield for raceway groups for all brood years. Percent yields were normalized such that Dexter fish had a percent yield of 1.0 for all years


All Brood Years, Raceways Only
Percent Yield
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
Rearing Density (kg/m3)

Numbers of Adults from Experimental Groups

The present project was based on the question, Can increased densities and oxygen supplementation increase the runs of spring chinook salmon? The analysis which best serves to address this question is that of total numbers of adults surviving from each experimental group. To calculate this number, percent yield for each experimental group is multiplied by the total number of fish (both tagged and untagged) released from the raceway. A summary of these numbers is shown in Table 12.

For 1989 brood fish, greatest numbers returned from the Dexter release group (Figure 16). At Willamette Hatchery, greatest numbers of returns were found in the D group. Least number of returns were from fish in the G group. The order of returns from greatest to least was: Dex > D > C > A > B > F > E > G.

For 1990 brood fish, greatest numbers of fish returned from the Dexter release group (Figure 17). At Willamette Hatchery, greatest numbers of adults were recovered from the D group. Fewest adults were recovered from the E group. The order of returns from greatest to least was: Dex > D > A > B > C > G > F > E.

For 1991 brood fish, greatest numbers of fish returned from the Dexter release group (Figure 18). At Willamette Hatchery, greatest numbers of adults were recovered from the D group. Fewest adults were recovered from the E group.

Table 12. Estimated number of recovered adult fish from experimental groups. Estimates were derived from percent yield and total number of fish released from Willamette Hatchery, 1989-1992 broods.

Group	Brood Year			
	1989	1990	1991	1992
A1	235	6	102	99
A2	194	82	155	57
B1	190	8	82	39
B2	211	65	95	38
C1	326	12	133	70
C2	330	7	170	88
D1	472	22	181	197
D2	509	70	313	130
E1	7	0	45	53
E2	48	4	11	52
F1	16	4	64	67
F2	62	9	15	63
G1	4	0	67	74
G2	22	29	12	69
Dex1	718	616	1509	1238
Dex2	595	754	1350	1060

Figure 16. Average number of adults from 1989 brood experimental releases that were recaptured in various fisheries or at the hatchery.

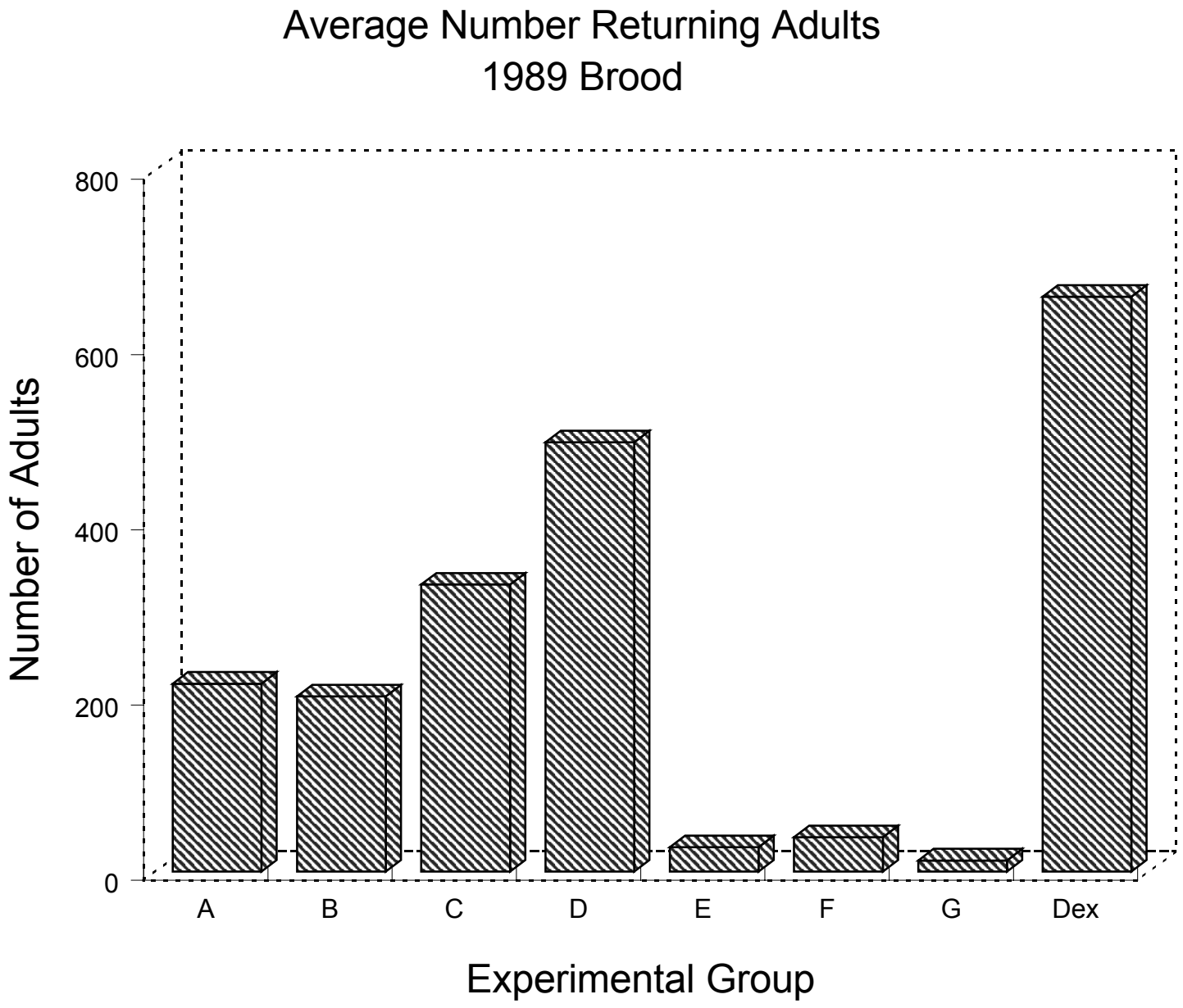

Average Number Returning Adults
1989 Brood
Number of Adults
800
600
400
200
0
A
B
C
D
E
F
G
Dex
Experimental Group

Figure 17. Average number of adults from 1990 brood experimental releases that were recaptured in various fisheries or at the hatchery.

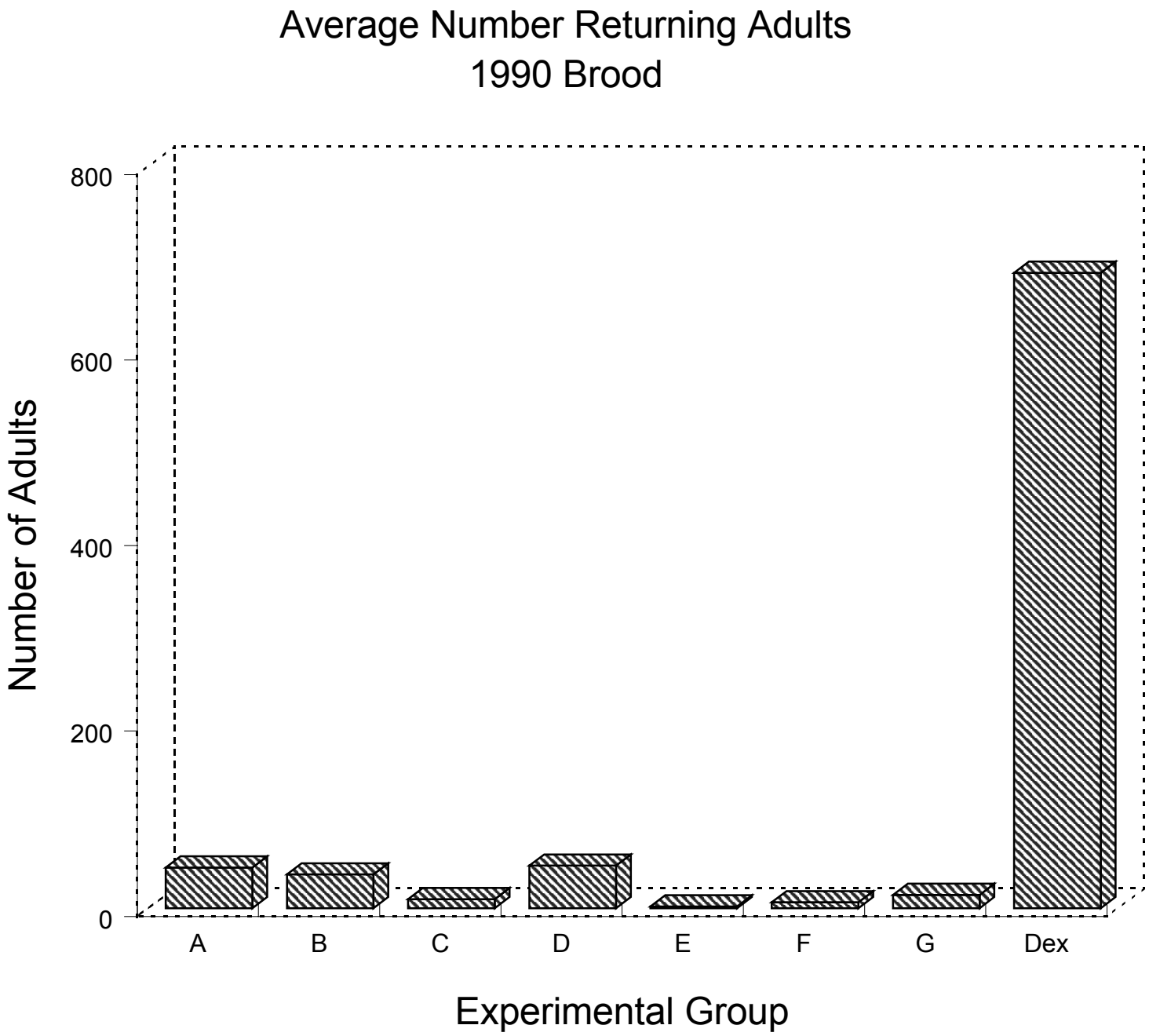
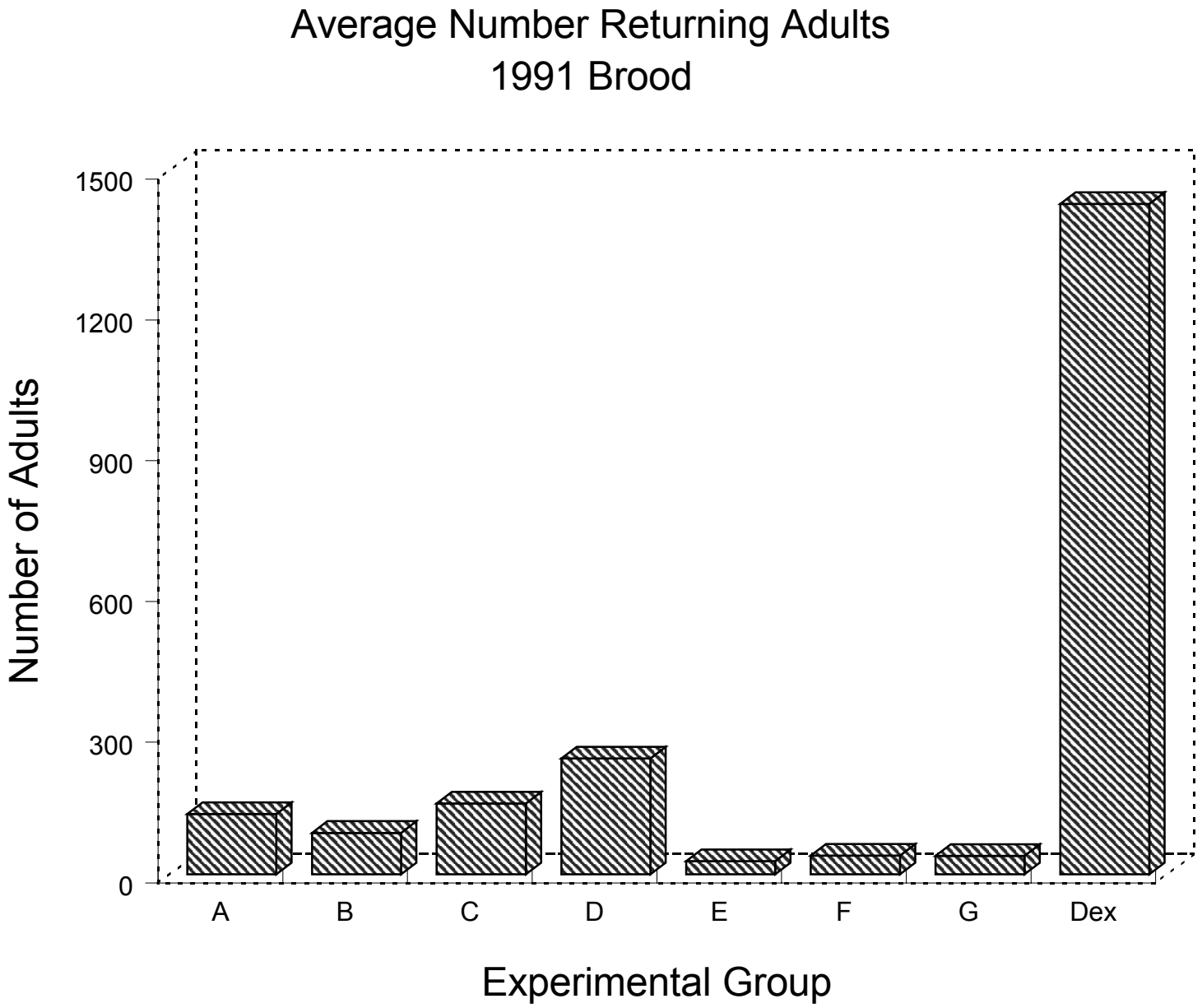

Average Number Returning Adults
1990 Brood
Number of Adults
800
600
400
200
0
A
B
C
D
E
F
G
Dex
Experimental Group

Figure 18. Average number of adults from 1991 brood experimental releases that were recaptured in various fisheries or at the hatchery.


Average Number Returning Adults
1991 Brood
Number of Adults
1500
1200
900
600
300
0
A
B
C
D
E
F
G
Dex
Experimental Group

The order of returns from greatest to least was: Dex > D > C > A > B > F > G > E.

For 1992 brood fish, greatest numbers of fish returned from the Dexter release group (Figure 19). At Willamette Hatchery, greatest numbers of adults were recovered from the D group. Fewest adults were recovered from the B group. The order of returns from greatest to least was: Dex > D > C > A > G > F > E > B.

Average number recovered for the four brood years (Figure 20) showed a pattern very much like the 1989 brood fish. Greatest numbers of adults were recovered from the Dexter release group. At Willamette Hatchery, greatest numbers of adults were recovered from the D group and fewest numbers were recover from the E group. The order of adult recoveries from greatest to least was: Dex > D > C > A > B > F > G > E.

Numbers of adults recovered were tested by one-way analysis of variance for the following hypothesis:

H_0 = Numbers of adults recovered from all experimental groups are equal.

H_a = Numbers of adults recovered from experimental groups are not equal.

When numbers of adults recovered for all groups were examined for the four brood years, there were significant differences between groups ($F = 6.75$, $F(0.05,6,57) = 2.28$). Analyses of variance were performed on individual brood years, followed by Tukey's test when significant differences were detected.

Figure 19. Average number of adults from 1992 brood experimental releases that were recaptured in various fisheries or at the hatchery.

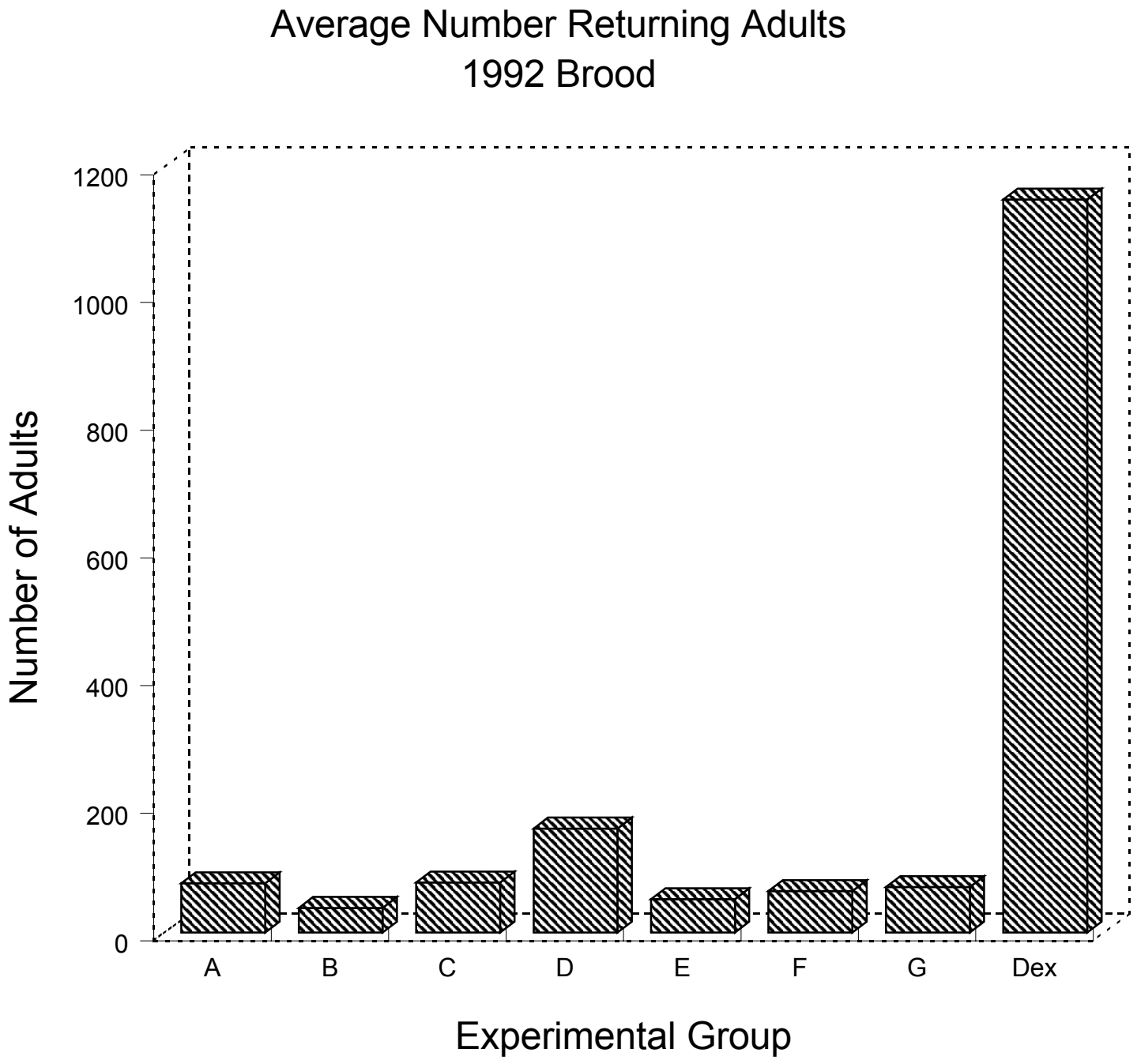
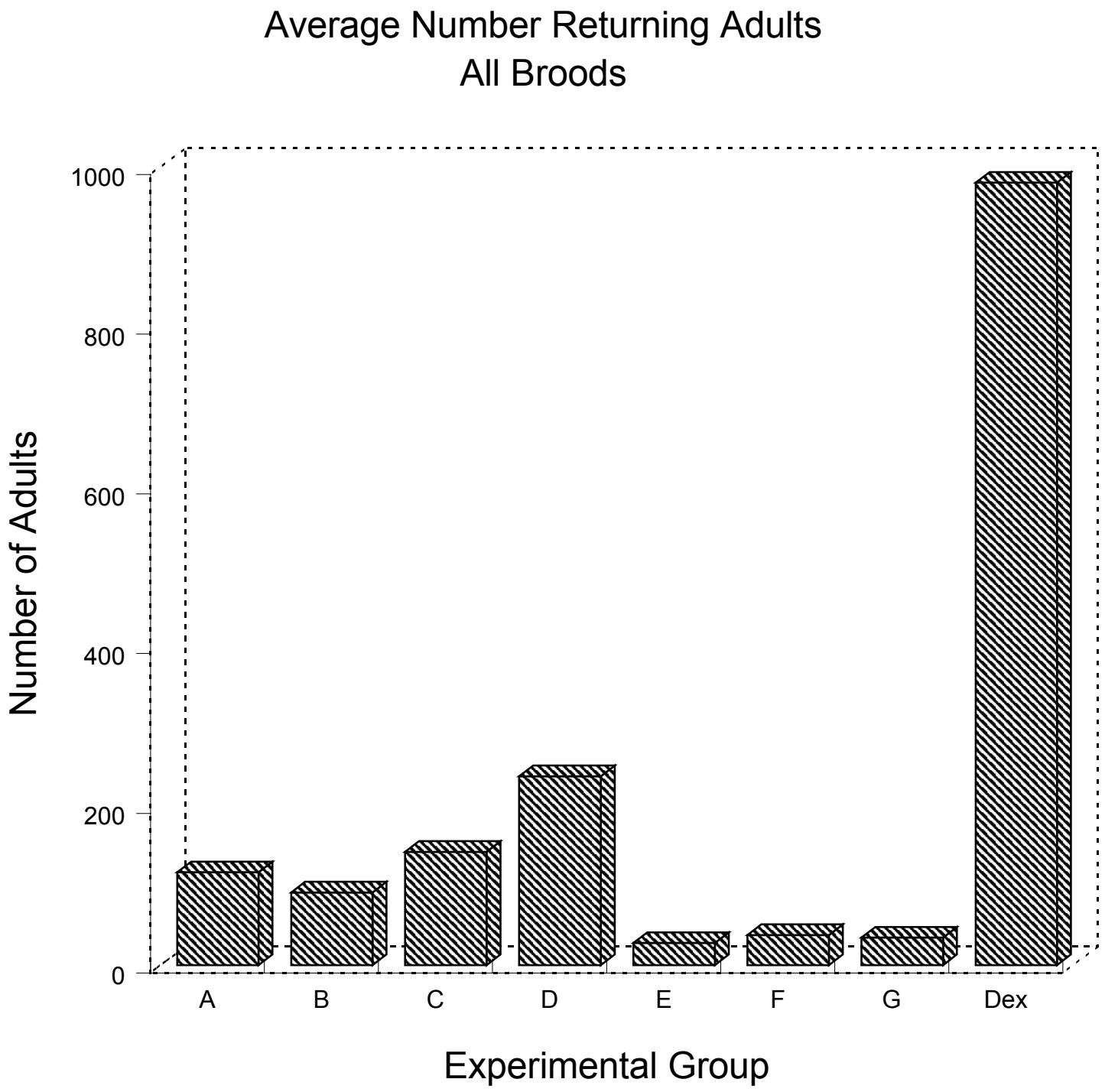

Average Number Returning Adults
1992 Brood
Number of Adults
1200
1000
800
600
400
200
0
A
B
C
D
E
F
G
Dex
Experimental Group

Figure 20. Average number of adults from experimental releases from all broods that were recaptured in various fisheries or at the hatchery.


Average Number Returning Adults
All Broods
Number of Adults
1000
800
600
400
200
0
A
B
C
D
E
F
G
Dex
Experimental Group

Significant differences between groups was found in three of the four brood years (Table 13). In the 1990 brood year, no significant difference occurred between any of the groups (Table 13).

The effect of rearing density on numbers of adults captured from all the experimental groups can be seen in Figure 21. Little relationship was found between rearing density and numbers of adults recovered. The R^2 value for this relationship was only 0.097 (Table 14). All Michigan raceways tended to have low survival. This was not apparently due to rearing densities because all survivals in Michigan ponds were much lower than the same densities or loads in conventional ponds. When recoveries from Michigan ponds were removed from the data set, the relationship did not improve (Figure 22, Table 14).

The effects of load (kg of fish per liter of water per minute) were also examined for the relationship with percent yield. The relationship was not significantly different from zero (Table 14). Removal of data for Michigan raceways did not improve the relationship.

Examining the relationship between the reciprocal of rearing density and numbers of recovered adults for individual brood years showed poor relationships for all broods (Table 14). Most of the relationship was attributable to the large numbers of returning adults to Dexter rearing ponds.

Table 13. Results from one-way analyses of variance between numbers of adults captured from different experimental release groups.

Brood Year	F Value	F(0.05)		Sequence
Overall	6.75	2.28	Sig.	D C A B G F E
1989	116.6	3.87	Sig.	D C A B F E G
1990	0.808	3.87	NS	D A B G C F E
1991	6.195	3.87	Sig.	D C A B G F E
1992	6.861	3.87	Sig	D C A G F E B

Sig. indicates significant differences between groups. NS indicates no significant differences between groups. Sequence refers to the sequence of means of replicates in descending order. Groups underlined are not significantly different by Tukey's test ($P \leq 0.05$).

Figure 21. Relationship between rearing density in kg/m^3 and number of recovered adults for all experimental groups and all brood years.

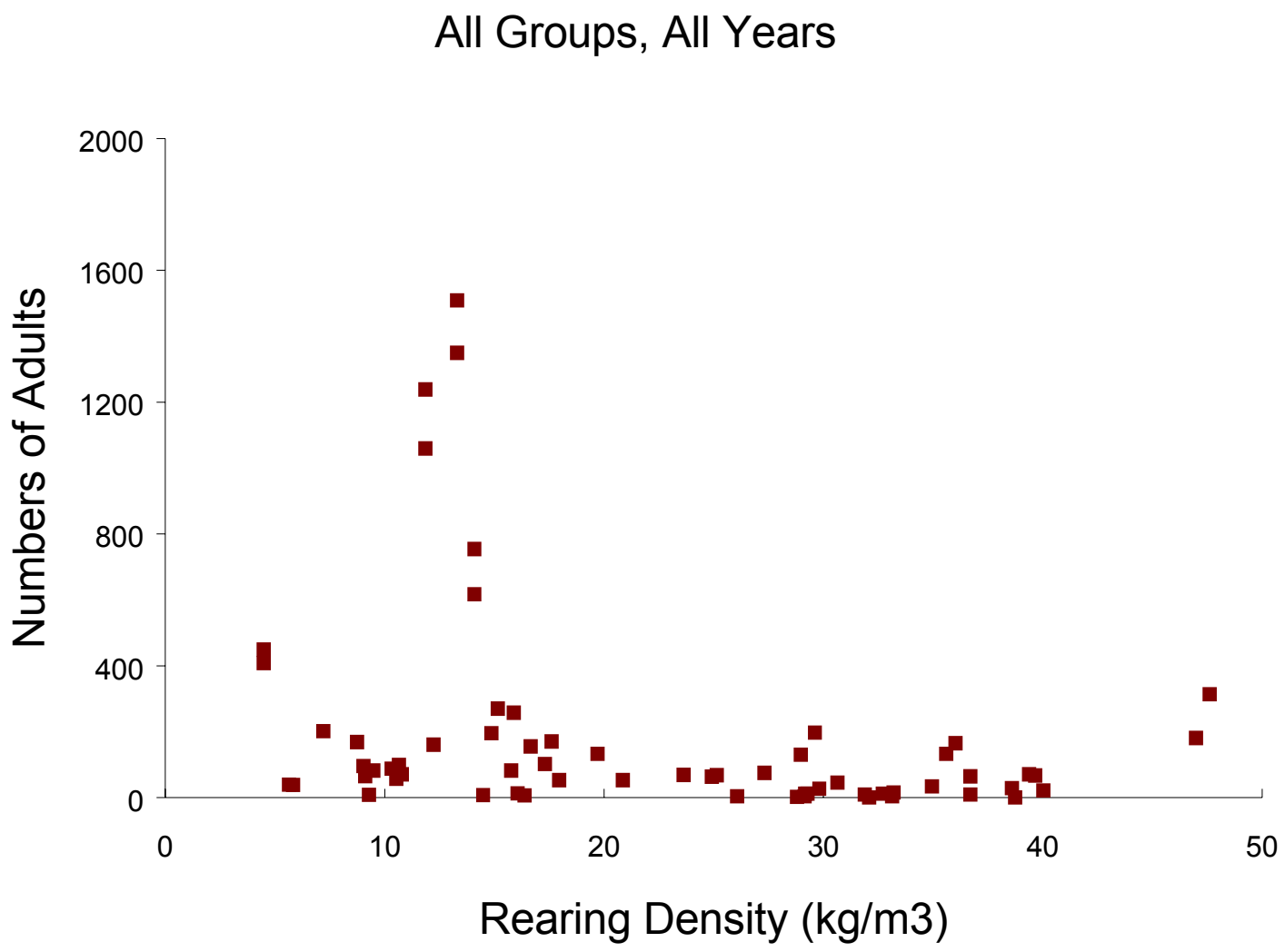
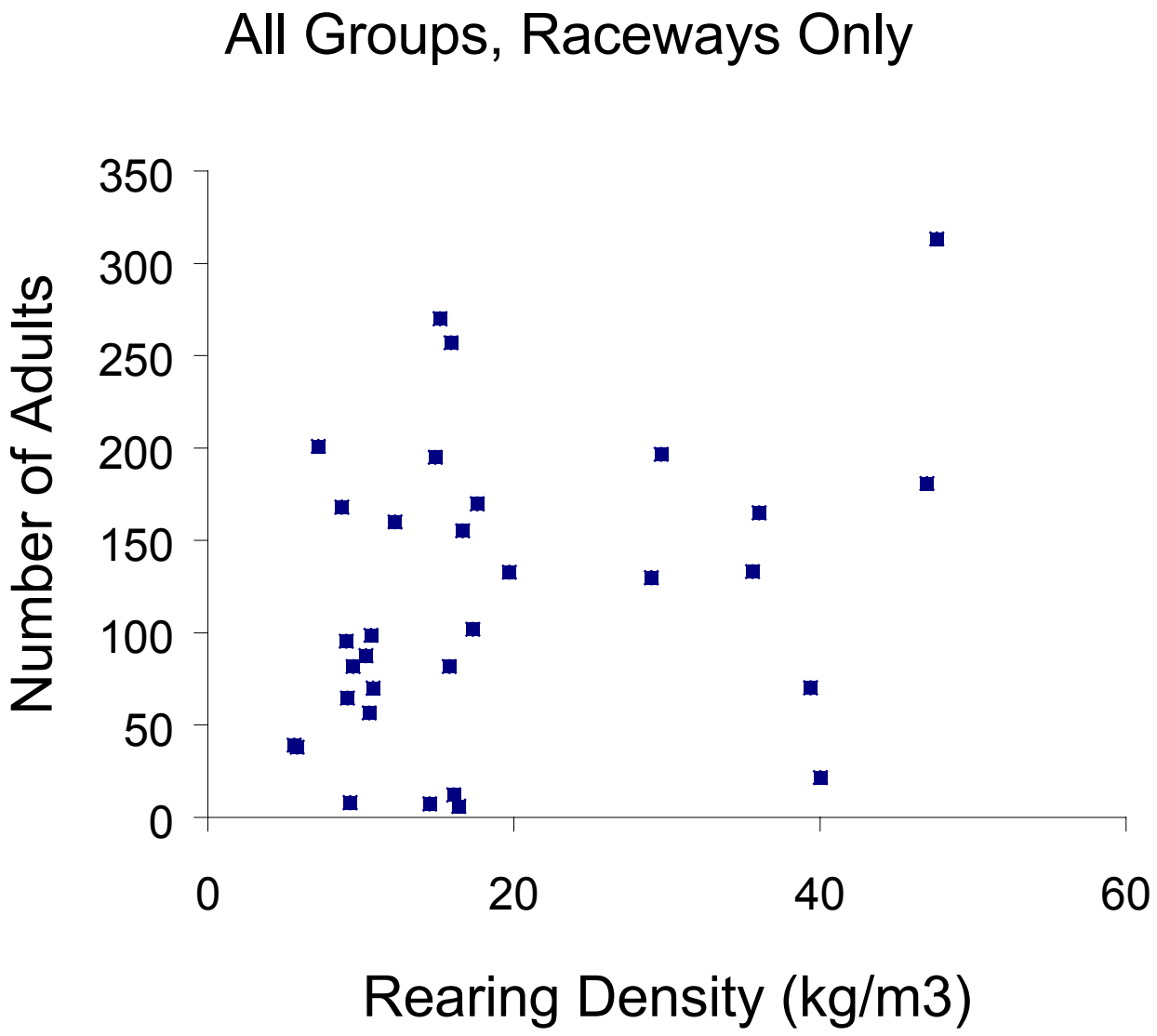

All Groups, All Years
Numbers of Adults
2000
1600
1200
800
400
0
0
10
20
30
40
50
Rearing Density (kg/m3)

Table 14. Relationships between numbers of recovered adults and rearing density or load for various experimental release groups.

Conditions, Group	Equation	R^2
Rearing Density		
All groups	-8.632 X + 377.3	0.097*
Raceways only	-4.484 X + 356.2	0.019*
Raceways only, without Dexter	2.141 X + 77.4	0.106*
Load		
All groups	283.6 X - 118.7	0.615*
Raceways only	280.9 X - 108.9	0.559*
Raceways only without Dexter	38.74 X + 77.40	0.106*
1/Rearing Density, Raceways only, by Brood year		
1989	1259.7 X + 110.5	0.696*
1990	711.8 X + 116.8	0.005
1991	2080.4 X + 77.0	0.013
1992	- 2104.1 X + 504.3	0.049
Load, Raceways only, by Brood year		
1989	- 14.7 X + 255.7	0.006
1990	200.5 X - 155.4	0.738*
1991	384.7 X - 238.0	0.657*
1992	404.0 X - 188.1	0.854*

Figure 22. Relationship between rearing density in kg/m^3 and numbers of recovered adults for all brood years, with raceways only.


All Groups, Raceways Only
Number of Adults
350
300
250
200
150
100
50
0
0
20
40
60
Rearing Density (kg/m3)

Numbers of Adults Per Unit Rearing Space for Experimental Groups

This measure of rearing efficiency is important when limited space is available for salmonid production. The measure is calculated by dividing the number of returning adults by the rearing volume of their raceway. In experimental raceways, the rearing volume was 104.8 cubic meters. In Michigan raceways, the rearing volume was 52.4 cubic meters. In Dexter Rearing Ponds, the rearing volume was 1538 cubic meters. Fish produced per cubic meter for all experimental raceways and Dexter Rearing Ponds are shown in Table 15.

For 1989 brood, Group D gave the greatest number of recovered adults per cubic meter of rearing space (Figure 23). Using this parameter, the most dramatic change in the relationship between groups was that of Dexter Rearing Ponds. The number of recovered adults per cubic meter of rearing space in Dexter Rearing Ponds was actually lower than that of Michigan raceways. Numbers per cubic meter in decreasing order were: D > C > A > B > F > E > Dex > G.

For 1990 brood, groups A, D, and Dexter Rearing Ponds all had similar numbers of recovered adults per cubic meter of rearing space (Figure 24). Numbers per cubic meter were found, in decreasing order: D > Dex > A > B > G > F > C > E

For 1991 brood, group D had the greatest number of recovered adults per cubic meter of rearing space (Figure 25).

Table 15. Numbers of recovered adult fish per cubic meter of rearing space for juveniles released from experimental groups at Willamette Hatchery, 1989-1992 broods.

Group	Brood Year				
	1989	1990	1991	1992	Average
A1	2.24	0.06	0.97	0.94	1.05
A2	1.85	0.78	1.48	0.54	1.16
B1	1.81	0.08	0.78	0.37	0.76
B2	2.01	0.62	0.91	0.36	0.98
C1	3.11	0.12	1.27	0.67	1.29
C2	3.15	0.07	1.62	0.84	1.42
D1	4.50	0.21	1.73	1.88	2.08
D2	4.85	0.67	2.99	1.24	2.44
E1	0.14	0.00	0.86	1.00	0.50
E2	0.92	0.07	0.22	1.00	0.55
F1	0.31	0.07	1.23	1.28	0.72
F2	1.19	0.17	0.29	1.20	0.71
G1	0.07	0.00	1.28	1.42	0.69
G2	0.42	0.55	0.22	1.31	0.62
Dex1	0.47	0.40	0.98	0.80	0.66
Dex2	0.39	0.49	0.88	0.69	0.61

Figure 23. Average number of recovered adults per cubic meter of rearing space in experimental raceways, 1989 brood.

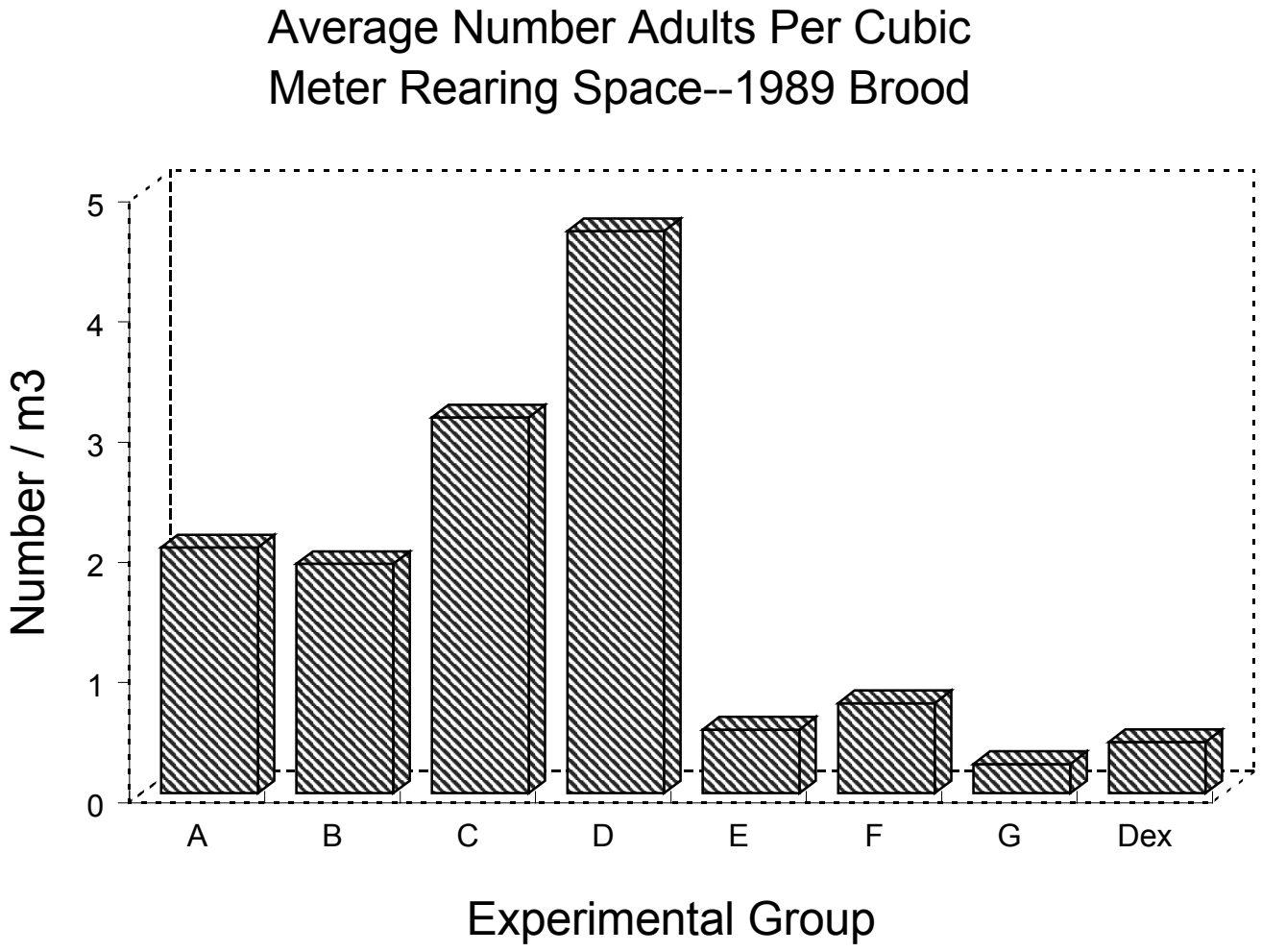
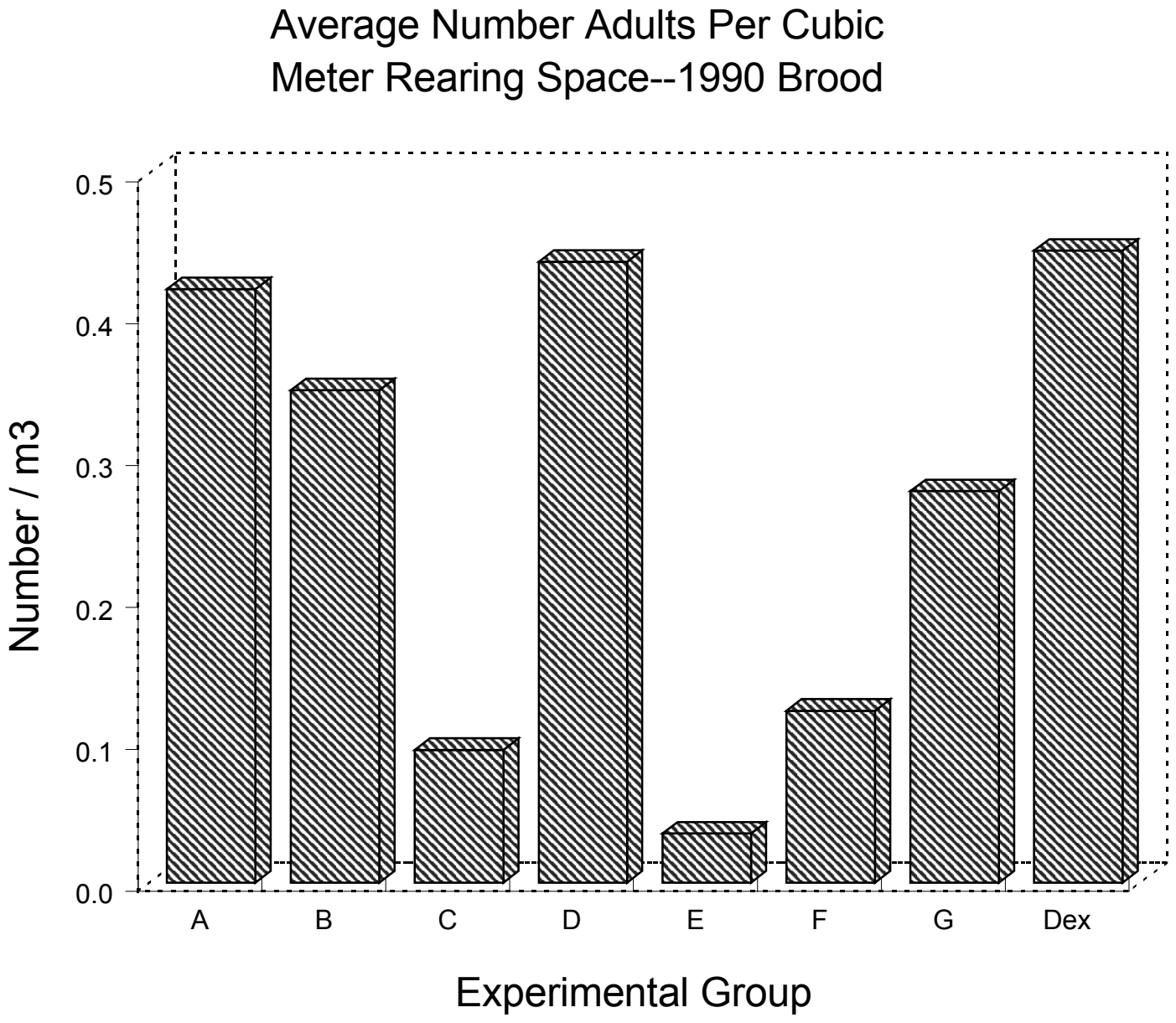

Average Number Adults Per Cubic Meter Rearing Space--1989 Brood
Number / m3
0
1
2
3
4
5
A
B
C
D
E
F
G
Dex
Experimental Group

Figure 24. Average number of recovered adults per cubic meter of rearing space in experimental raceways, 1990 brood.


Average Number Adults Per Cubic Meter Rearing Space--1990 Brood
Number / m3
0.5
0.4
0.3
0.2
0.1
0.0
A
B
C
D
E
F
G
Dex
Experimental Group

Numbers per cubic meter in decreasing order were: D > C > A > Dex > B > F > G > E.

For 1992 brood, group D had the greatest number of recovered adults per cubic meter of rearing space (Figure 26). Numbers per cubic meter in decreasing order were: D > G > F > E > C > Dex > A > B.

When all broods were averaged (Figure 27), group D had the greatest number of recovered adults per cubic meter of rearing space. Numbers at Dexter were similar to those from Michigan raceways. Numbers per cubic meter in decreasing order were: D > C > A > B > F > G > Dex > E.

Analysis of variance showed significant differences between the brood years ($F = 7.38$, $F(0.05,3,60) = 2.76$). Significant differences between groups was found during two of the four brood years (Table 16). When the data for all four years were combined, a significant difference was found between groups.

The conclusion from these analyses is that, when rearing space is limited, rearing chinook salmon under conditions of tripled density with oxygen supplementation will result in the most efficient use of the available space.

Numbers of Adults Per Unit Flow for Experimental Groups

This measure of rearing efficiency is important when the water supply to the hatchery is limited. The measure is

Figure 25 Average number of recovered adults per cubic meter of rearing space in experimental raceways, 1991 brood.

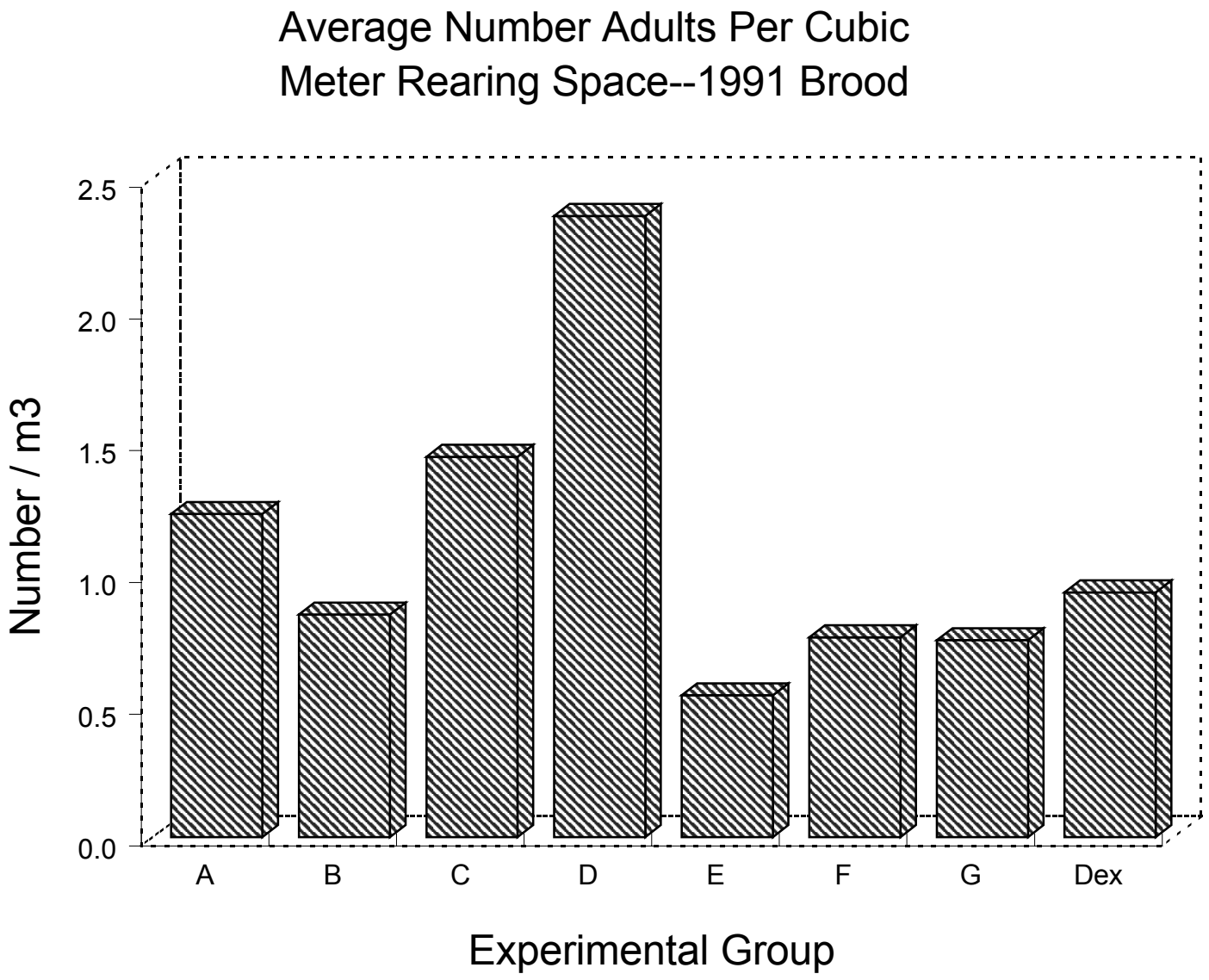

Average Number Adults Per Cubic Meter Rearing Space--1991 Brood
Number / m3
2.5
2.0
1.5
1.0
0.5
0.0
A
B
C
D
E
F
G
Dex
Experimental Group

Figure 26. Average number of recovered adults per cubic meter of rearing space in experimental raceways, 1992 brood.

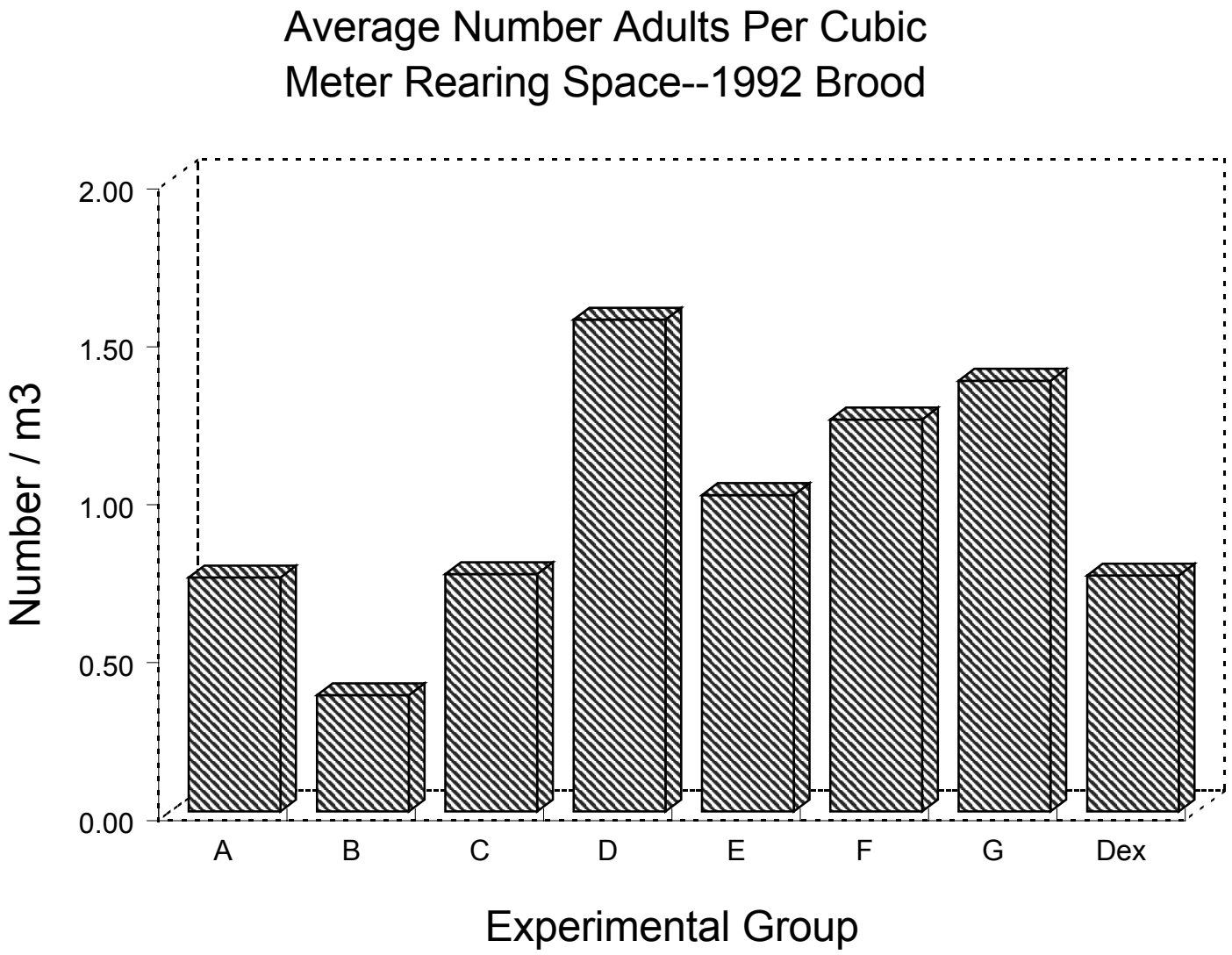

Average Number Adults Per Cubic Meter Rearing Space--1992 Brood
Number / m3
2.00
1.50
1.00
0.50
0.00
A
B
C
D
E
F
G
Dex
Experimental Group

Figure 27. Average number of recovered adults per cubic meter of rearing space in experimental raceways, all broods.

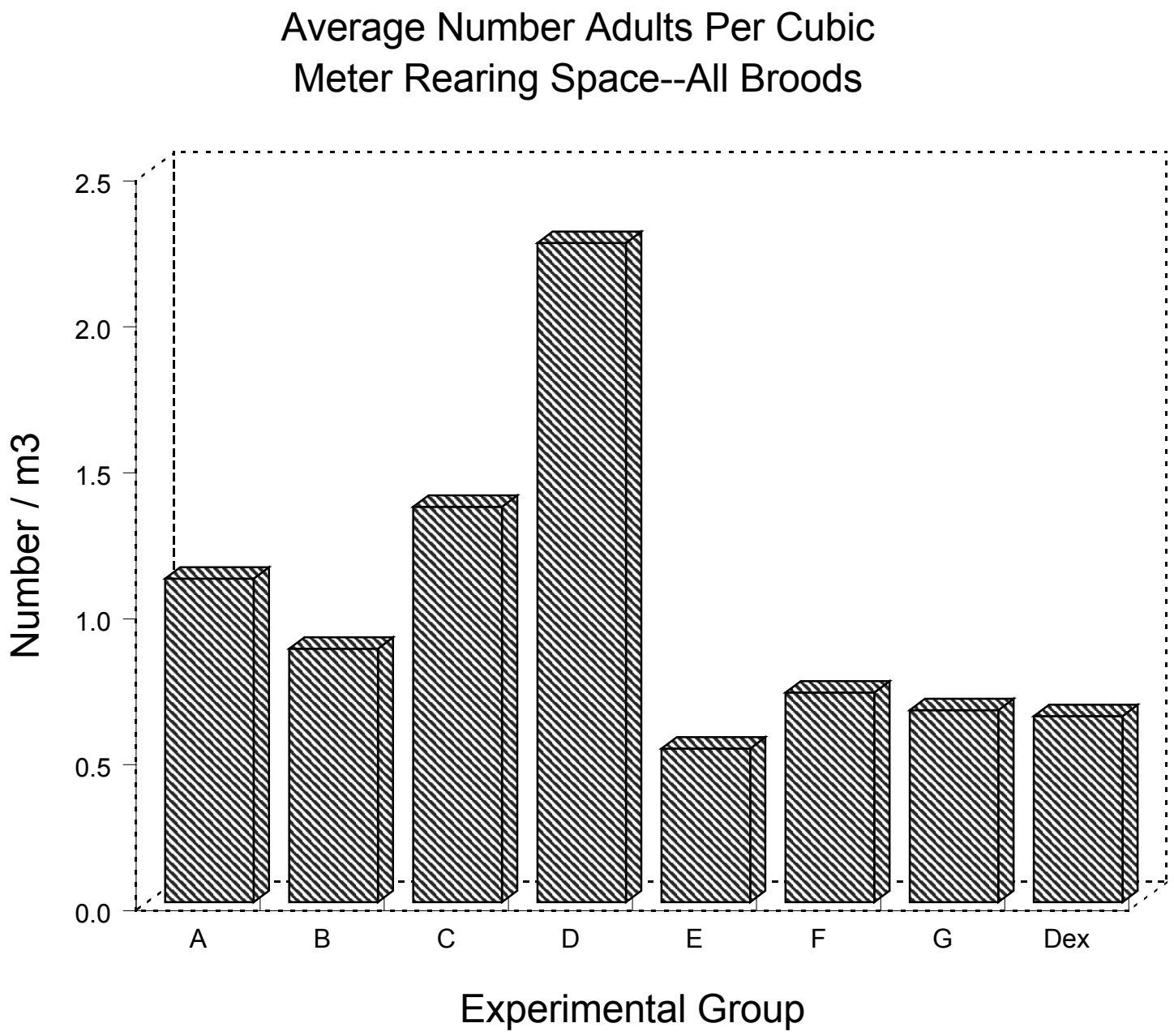

Average Number Adults Per Cubic Meter Rearing Space--All Broods
Number / m3
2.5
2.0
1.5
1.0
0.5
0.0
A
B
C
D
E
F
G
Dex
Experimental Group

Table 16. Results from one-way analyses of variance between numbers of adults produced per cubic meter of rearing space from different experimental release groups.

Brood Year	F Value	F(0.05)		Sequence
Overall	3.19	2.28	Sig.	D C A B F G Dex E
1989	38.87	3.87	Sig.	D C A B F E Dex G
1990	0.57	3.87	NS	D Dex A B G F C E
1991	2.47	3.87	NS	D C A Dex B F G E
1992	7.83	3.87	Sig	D G F E C Dex A B

Sig. indicates significant differences between groups. NS indicates no significant differences between groups. Sequence refers to the sequence of means of replicates in descending order. Groups underlined are not significantly different by Tukey's test ($P \leq 0.05$).

calculated by dividing the number of returning adults by the water flow in liters to the raceway in which they were reared. In experimental raceways at Willamette Hatchery, the flow was 500 gpm or 1895 Lpm. In Michigan raceways, the flow was 750 gpm or 2842.5 Lpm. In Dexter Rearing Ponds, the flow was 23,312 gpm or 88,352.5 Lpm. Fish produced per Lpm for all experimental raceways and Dexter Rearing Ponds are shown in Table 17

For 1989 brood, Group D gave the greatest number of recovered adults per unit of water flow (Figure 28). As with the adult recovery per cubic meter of rearing space, the main changes in relationships between groups occurred in Dexter Rearing Ponds. The number of recovered adults per cubic meter of rearing space was actually lower than that of two of the Michigan raceways. Numbers per unit of water flow in decreasing order were: D > C > A > B > F > E > Dex > G.

For 1990 brood, experimental groups had variable numbers of recovered adults per unit of water flow (Figure 29). Numbers per unit of water flow in decreasing order were: D > A > B > Dex > G > C > F > E

For 1991 brood, group D had the greatest number of recovered adults per unit of water flow (Figure 30). Numbers of adults per unit of water flow in decreasing order were: D > C > A > B > Dex > F > G > E.

For 1992 brood, group D had the greatest number of recovered adults per unit of water flow (Figure 31).

Table 17. Numbers of recovered adult fish per liter per minute of flow (x 100) for juveniles released from experimental groups at Willamette Hatchery, 1989-1992 broods.

Group	Brood Year				
	1989	1990	1991	1992	Average
A1	12.40	0.31	5.37	5.21	5.83
A2	10.23	4.31	8.19	2.98	6.43
B1	10.00	0.42	4.32	2.07	4.20
B2	11.12	3.41	5.03	2.01	5.39
C1	17.18	0.65	7.00	3.69	7.13
C2	17.41	0.39	8.96	4.62	7.84
D1	24.89	1.14	9.55	10.38	11.49
D2	26.85	3.70	16.53	6.85	13.48
E1	0.26	0.00	1.58	1.85	0.92
E2	1.69	0.13	0.40	1.85	1.02
F1	0.58	0.13	2.27	2.37	1.33
F2	2.19	0.32	0.53	2.21	1.31
G1	0.13	0.00	2.35	2.61	1.27
G2	0.77	1.02	0.41	2.41	1.15
Dex1	0.81	0.70	1.71	1.40	1.15
Dex2	0.67	0.85	1.53	1.20	1.06

Figure 28. Average number of recovered adults per liter per minute of flow for experimental raceways, 1989 brood.

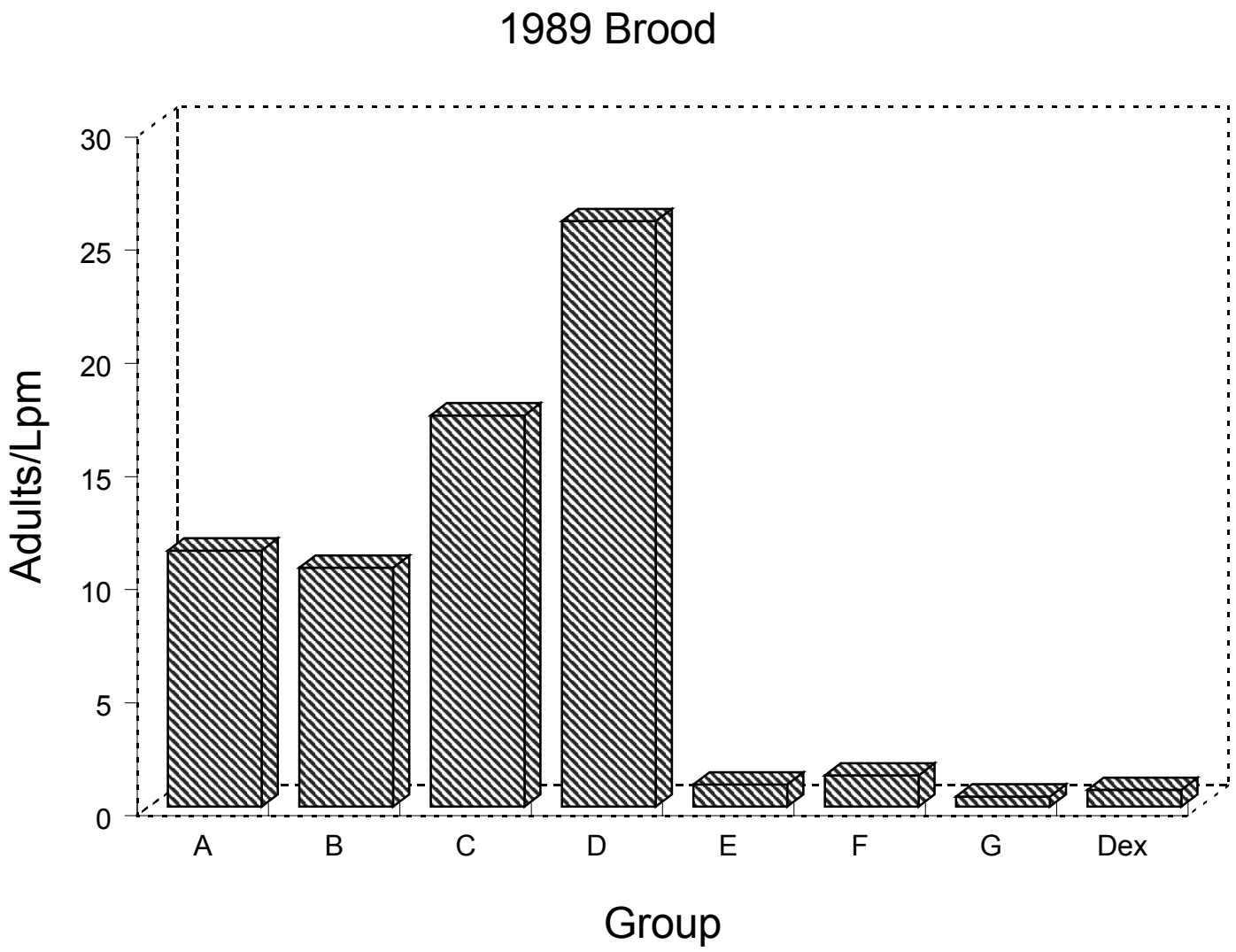

1989 Brood
Adults/Lpm
30
25
20
15
10
5
0
A
B
C
D
E
F
G
Dex
Group

Figure 29. Average number of recovered adults per liter per minute of flow for experimental raceways, 1990 brood.

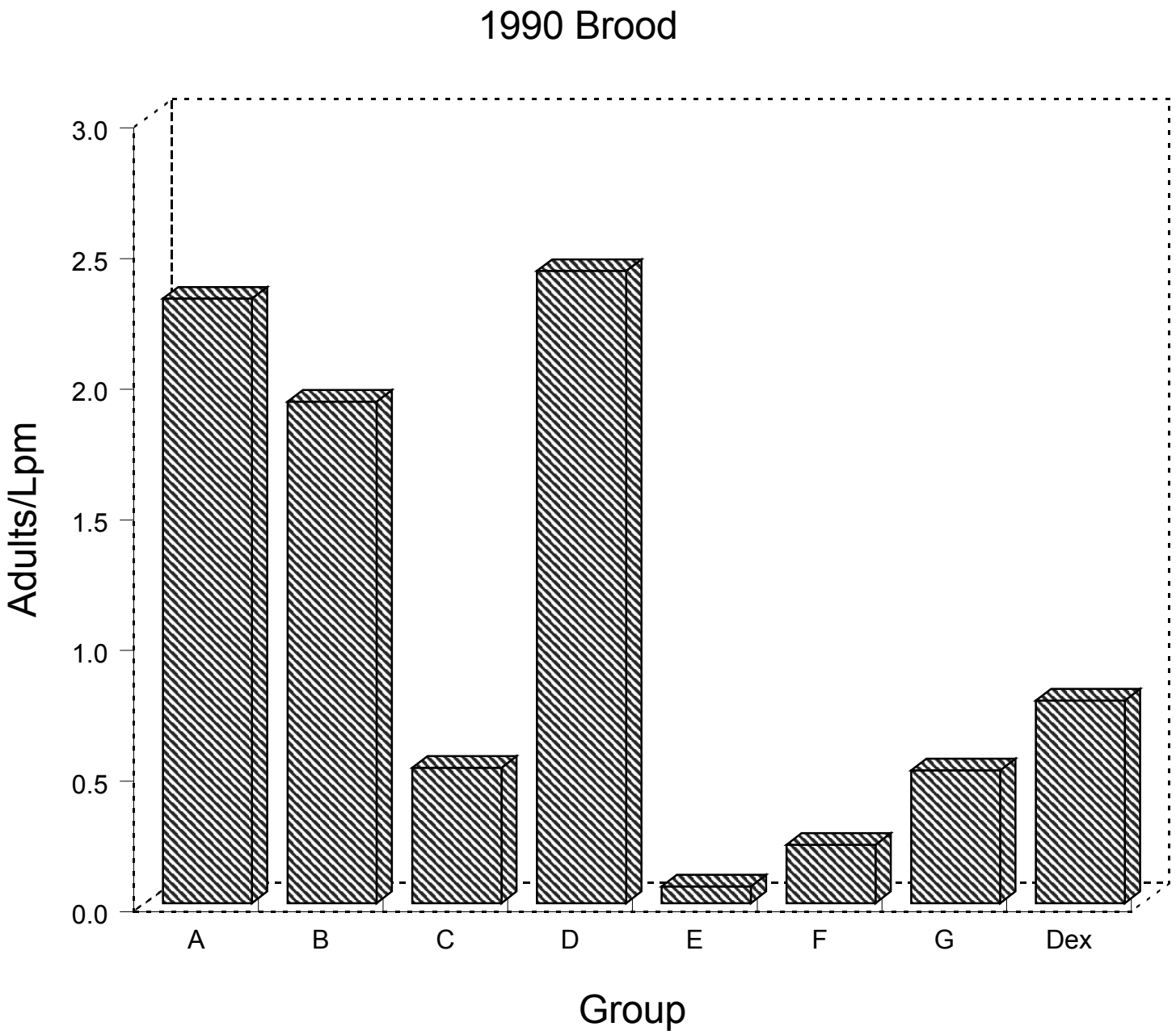

1990 Brood
Adults/Lpm
3.0
2.5
2.0
1.5
1.0
0.5
0.0
A
B
C
D
E
F
G
Dex
Group

Figure 30. Average number of recovered adults per liter per minute of flow for experimental raceways, 1991 brood.

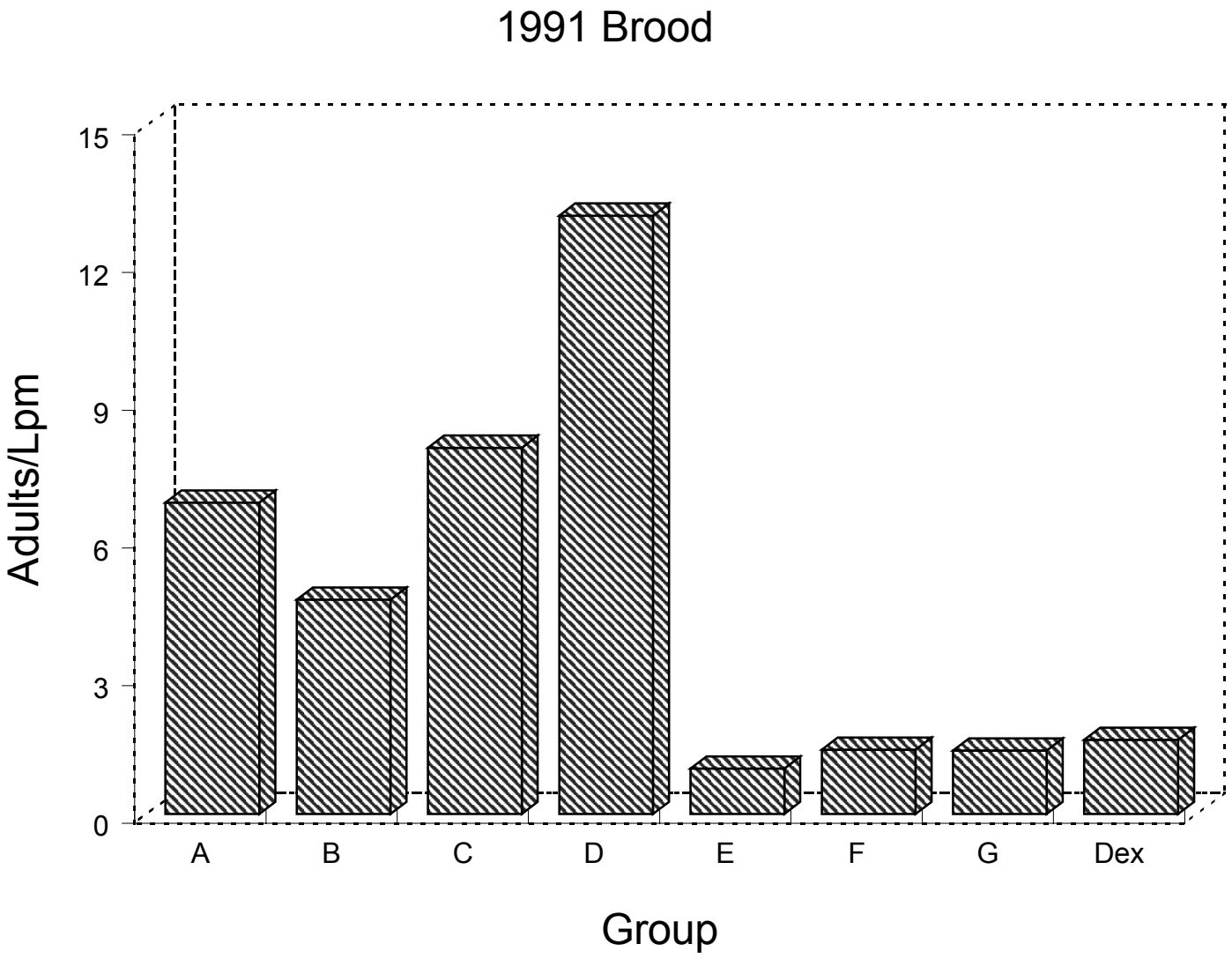
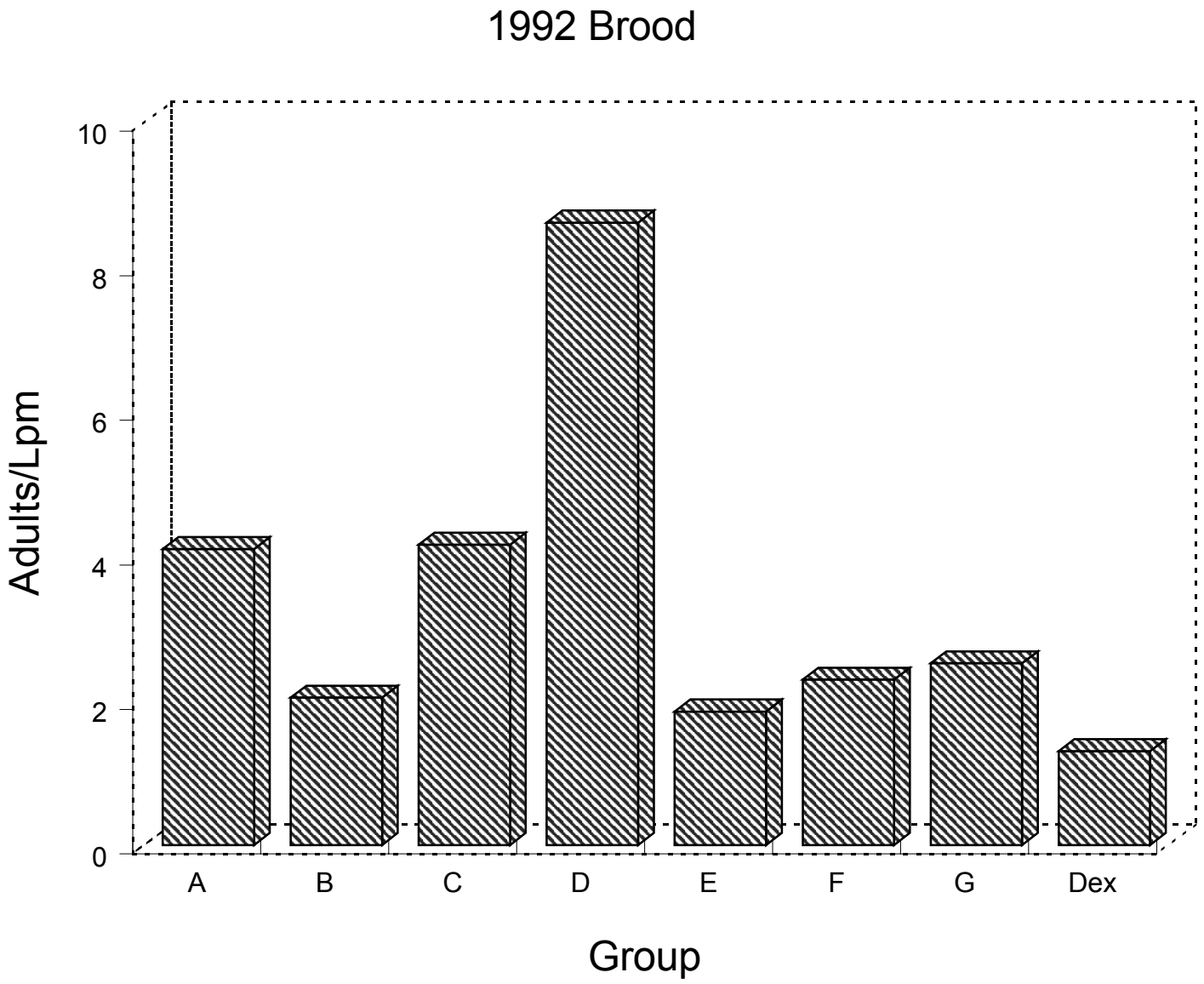

1991 Brood
Adults/Lpm
15
12
9
6
3
0
A
B
C
D
E
F
G
Dex
Group

Figure 31. Average number of recovered adults per liter per minute of flow for experimental raceways, 1992 brood.


1992 Brood
Adults/Lpm
10
8
6
4
2
0
A
B
C
D
E
F
G
Dex
Group

Numbers of adults per unit of water flow in decreasing order were: D > C > A > G > F > B > E > Dex.

When numbers of adults recovered per unit of water flow were averaged for all four brood years, group D had the greatest number of recovered adults per unit of water flow (Figure 32). Numbers of adults per unit of water flow in decreasing order were: D > C > A > B > F > G > Dex > E.

Analysis of variance showed significant differences between the brood years ($F = 5.68$, $F(0.05,3,60) = 2.76$). Significant differences between groups were found during three of the four brood years (Table 18). When the data for all four years were combined, a significant difference was found between groups.

The conclusion from these analyses is that, when water flow is limited, rearing chinook salmon under conditions of tripled density with oxygen supplementation will result in the most efficient use of the available space.

Cost Analysis of Oxygen Supplementation and Increased Density

An interesting but difficult analysis of the experimental results is the comparison of the cost per fish for fish reared at increased densities with oxygen supplementation (such as Group D or Groups E, F, and G) and the cost per fish for those reared under normal hatchery conditions (Groups A, B, or Dexter). Because of constantly changing prices, salaries, and expenses, monetary values for various rearing practices vary continuously.

Figure 32. Average number of recovered adults per liter per minute of flow for experimental raceways, all broods.

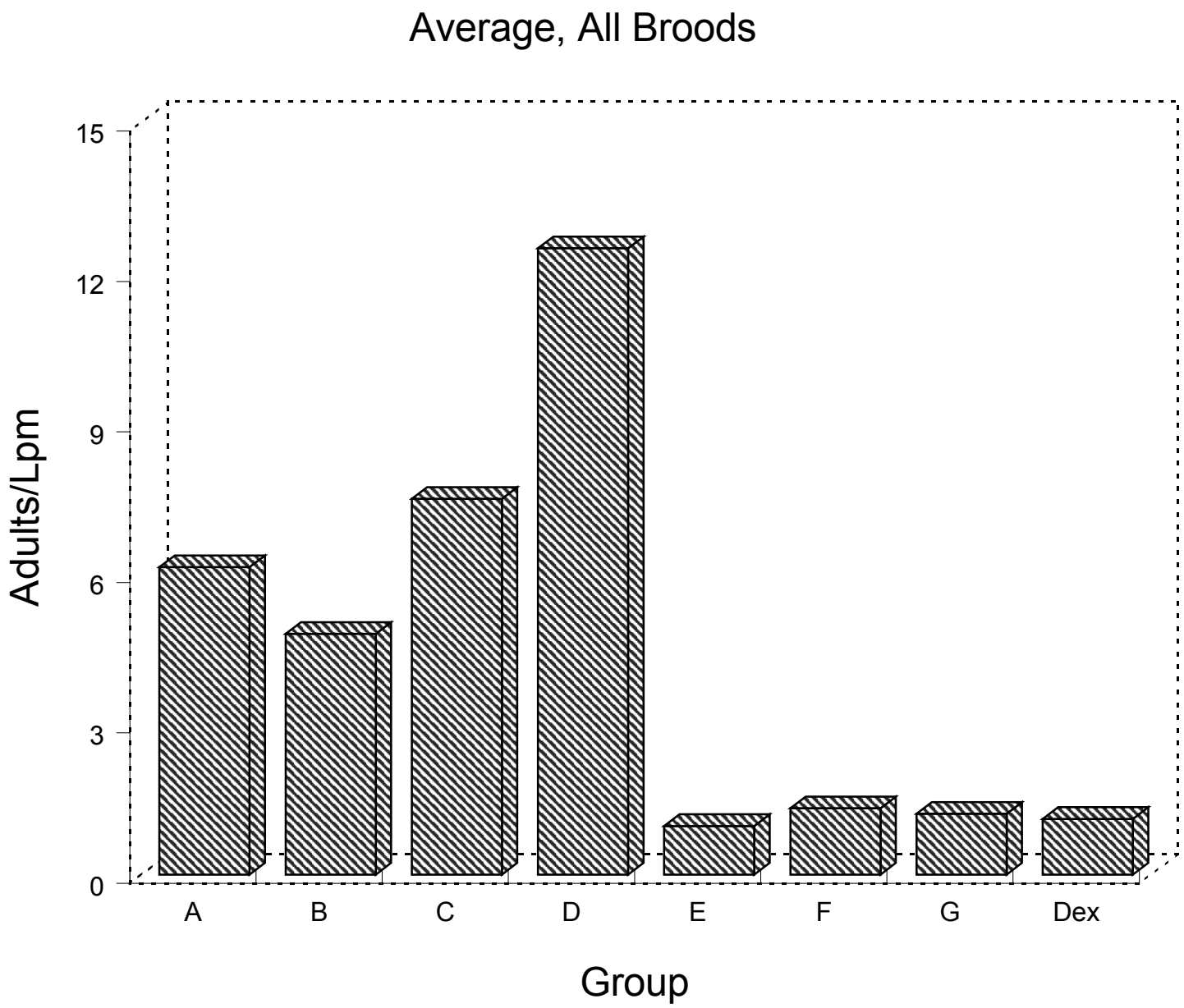

Average, All Broods
Adults/Lpm
15
12
9
6
3
0
A
B
C
D
E
F
G
Dex
Group

Table 18. Results from one-way analyses of variance between numbers of adults produced per liter per minute flow from different experimental release groups.

Brood Year	F Value	F(0.05)		Sequence
Overall	7.77	2.29	Sig.	D C A B F G Dex E
1989	250.65	3.37	Sig.	D C A B F E Dex G
1990	1.19	3.87	NS	D A B Dex C G F E
1991	11.26	3.87	Sig	D C A B Dex F G E
1992	12.69	3.87	Sig	D C A G F B E Dex

Sig. indicates significant differences between groups. NS indicates no significant differences between groups. Sequence refers to the sequence of means of replicates in descending order. Groups underlined are not significantly different by Tukey's test ($P \leq 0.05$).

For the following analyses, we have made a number of assumptions to simplify the calculations. While these assumptions are violated in the real world, they do serve to compare costs of the various experimental conditions.

1) It is assumed that the yearly costs throughout the study remained the same as those of a typical rearing year, 1992-1993 (Table 19).

2) It is assumed that the capital equipment and construction (Table 20) can be amortized over a 20 year period. For comparison, capital equipment costs were also calculated for the four years of the project.

3) It is assumed that many non-expendable items purchased on this project, such as tagging equipment and liberation trucks, will be owned by the hatchery and should not be calculated into expenses. It is also assumed that smaller non-expendable items, such as pH meters and computers, will be owned by the hatchery and not calculated into expenses.

4) It is assumed that personnel requirements were similar for all experimental raceways.

5) It is assumed that feed requirements remain proportional to the final poundage of fish released.

Using these assumptions, costs were estimated for rearing each experimental group with construction and equipment costs amortized over the four years of rearing portion of the

Table 19. Yearly expenses at Willamette Hatchery that are attributed to normal rearing and to rearing with oxygen supplementation.

	Normal	Supplementation
Personnel	269,000	269,000
Services and Supplies	227,000	271,000
Capital Improvements	--	27,000
Non-Expendable Equipment[a]	--	20,650
Total	496,000	587,650

Expenses due to Oxygen Supplementation

	Per Month	Per Year
Utilities	960	7,680
Liquid Oxygen	6000	20,370
Oxygen Tank Rental	390	4,680
Refrigerator Rental	725	8.700
Pump Repair		1,190
Waste Removal		1,200
HAZMAT Fee		275
Total		44,095

[a]Initial equipment expenditures amortized over 20 years.

Table 20. Capital expenditures for modification of Willamette Hatchery for testing oxygen supplementation and Michigan raceway conformations for rearing spring chinook salmon. Total expenditures are estimates from a Fish Pro, Inc., memo dated 26 April 1989 to Engineering Department, Oregon Department of Fish and Wildlife. Estimates for raceways and Michigan raceways are the costs apportioned to each aspect of hatchery modification

	Raceways	Michigan Raceways	Total
Raceway modifications			
Sump construction	--	20,000	20,000
Pumps	--	20,000	20,000
Pond screens	--	29,000	29,000
Baffles	--	30,000	30,000
Pond dividers	--	18,000	18,000
Pipes and fittings	34,800	52,200	87,000
Electrical modifications for pumps and alarms	16,000	91,000	107,000
Liquid oxygen storage	3,000	9,000	12,000
Continuous monitoring system	14,800	11,200	26,000
Total	100,600	312,400	413,000
Amortized, 20 years	5,030	15,620	
Amortized, per raceway	1,260	2,600	

project or over a twenty year period (Table 21). Using the numbers of adults recovered per raceway (Table 12), it was then possible to calculate the cost per adult for each of the experimental groups, using either the four year amortization of initial hatchery modifications (Table 22) or the twenty-year amortization (Table 23).

Graphic representation of the cost per recovered adult had to be divided between raceways and Michigan raceways because the scale was very different for each group. All graphs shown are for the twenty-year amortization of hatchery modifications. For 1989 brood, Group D had the least cost per recovered adult (Figure 33). Groups A and B were similar in cost per recovered adult. Cost per recovered adult in increasing order were: D < C < A < B.

For 1990 brood, experimental groups had much higher costs per recovered adult because of the lower survival of the released fish (Figure 34). Costs per recovered adult in increasing order were: D < B < A < C.

For 1991 brood, group D had the least cost per recovered adult (Figure 35). Costs per recovered adult in increasing order were: D < C < A < B.

For 1992 brood, group D had the least cost per recovered adult (Figure 36). Costs per recovered adult in increasing order were: D < A < C < B.

When costs per recovered adult were averaged for all brood years, group D had the least cost (Figure 37). Costs

Table 21. Estimated cost of rearing juvenile spring chinook salmon in experimental raceways at Willamette Hatchery and the cost per adult, using numbers recovered per raceway from Table 12.

Group		Cost Per Raceway[a] Over 4 Years	Over 20 Years
A	(1/14 base budget)	37,357	37,357
B	(1/14 base budget)[b]	35,357	35,357
C	Personnel	19,214	19,214
	S & S	20,512	20,512
	Capital Improvement	1,929	1,929
	Hatchery Modif.	12,576	2,520
	Total	54,231	44,175
D	Personnel	19,214	19,214
	S & S	23,646	23,646
	Capital Improvement	1,929	1,929
	Hatchery Modif.	12,576	2,520
	Total	57,365	47,309
E	Personnel	19,214	19,214
	S & S	24,046	24,046
	Capital Improvement	1,929	1,929
	Hatchery Modif.	26,034	5,200
	Total	71,223	50,389
F,G	Personnel	19,214	19,214
	S & S	28,481	28,481
	Capital Improvement	1,929	1,929
	Hatchery Modif.	26,034	5,200
	Total	75,658	54,824

[a]Cost of hatchery modifications amortized over 4 or 20 years.
[b]Estimate of cost of each half-density raceways based on 1/14 of base $523,000 yearly budget minus $2000 in fish food costs.

Table 22. Estimated cost per experimental raceway, numbers of captured adults from each raceway, and estimated cost per recaptured adult, based on amortization of costs of hatchery modification over the four-year period of experimental rearing.

Group	Cost per Raceway	Numbers of Adults	Cost per Adult
1989 Brood			
A1	$37,357	235	$158.92
A2		194	192.78
Average			175.85
B1	35,357	190	186.50
B2		211	167.83
Average			177.17
C1	54,231	326	166.57
C2		330	164.37
Average			165.47
D1	57,365	472	121.61
D2		509	112.75
Average			117.18
E1	71,223	7	9,700.48
E2		48	1,479.02
Average			5,589.75
F1	75,658	16	4,609.72
F2		62	1,217.21
Average			2,913.47
G1	75,658	4	20,537.96
G2		22	3,458.50
Average			11,998.23
1990 Brood			
A1	$37,357	6	6,265.40
A2		82	457.14
Average			3,361.27
B1	35,357	8	4,397.46
B2		65	546.51
Average			2,471.99
C1	54,231	12	4,428.48
C2		7	7,354.73
Average			5,891.60

Table 22 (cont.)

Group	Cost per Raceway	Numbers of Adults	Cost per Adult
1990 Brood			
D1	57,365	22	2,659.66
D2		70	817.95
Average			1,738.80
E1	71,223	0	--
E2		4	19,637.42
Average			--
F1	75,658	4	20,698.47
F2		9	8,367.61
Average			14,533.04
G1	75,658	0	--
G2		29	2,616.51
Average			--
1991 Brood			
A1	$37,357	102	$366.74
A2		155	240.67
Average			303.70
B1	35,357	82	432.32
B2		95	370.98
Average			401.65
C1	54,231	133	408.59
C2		170	319.44
Average			364.01
D1	57,365	181	317.14
D2		313	183.13
Average			250.13
E1	71,223	45	1,581.07
E2		11	6,294.74
Average			3,937.91
F1	75,658	64	1,174.83
F2		15	5,017.52
Average			3,096.17
G1	75,658	67	1,131.94
G2		12	6,566.94
Average			3,849.44

Table 22 (cont)

Group	Cost per Raceway	Numbers of Adults	Cost per Adult
1992 Brood			
A1	$37,357	99	$378.49
A2		57	660.53
Average			519.51
B1	35,357	39	901.80
B2		38	928.04
Average			914.92
C1	54,231	70	775.02
C2		88	619.34
Average			697.18
D1	57,365	197	291.66
D2		130	442.11
Average			366.88
E1	71,223	53	1,355.13
E2		52	1,356.99
Average			1,356.06
F1	54,824	67	1,123.90
F2		63	1,204.94
Average			1,164.42
G1	54,824	74	1,017.91
G2		69	1,102.84
Average			1,060.37

Table 23. Estimated cost per experimental raceway, numbers of captured adults from each raceway, and estimated cost per recaptured adult, based on amortization of costs of hatchery modification over a twenty-year period.

Group	Cost per Raceway	Numbers of Adults	Cost per Adult
1989 Brood			
A1	$37,357	235	$158.92
A2		194	192.78
Average			175.85
B1	35,357	190	186.50
B2		211	167.83
Average			177.17
C1	44,175	326	135.68
C2		330	133.89
Average			134.79
D1	47,309	472	100.29
D2		509	92.98
Average			96.64
E1	50,389	7	6,862.92
E2		48	1,046.38
Average			3,954.65
F1	54,824	16	3,340.34
F2		62	882.03
Average			2,111.18
G1	54,824	4	14,882.40
G2		22	2,506.13
Average			8,694.27
1990 Brood			
A1	$37,357	6	6,265.40
A2		82	457.14
Average			3,361.27
B1	35,357	8	4,397.46
B2		65	546.51
Average			2,471.99
C1	44,175	12	3,607.31
C2		7	5,990.95
Average			4,799.13

Table 23 (cont.)

Group	Cost per Raceway	Numbers of Adults	Cost per Adult
1990 Brood			
D1	47,309	22	2,193.43
D2		70	674.56
Average			1,433.99
E1	50,389	0	--
E2		4	13,893.13
Average			--
F1	54,824	4	14,998.72
F2		9	6,063.41
Average			10,531.07
G1	54,824	0	--
G2		29	1,896.00
Average			--
1991 Brood			
A1	$37,357	102	$366.74
A2		155	240.67
Average			303.70
B1	35,357	82	432.32
B2		95	370.98
Average			401.65
C1	44,175	133	332.82
C2		170	260.21
Average			296.51
D1	47,309	181	261.54
D2		313	151.02
Average			206.28
E1	50,389	45	1,118.58
E2		11	4,453.42
Average			2,786.00
F1	54,824	64	851.31
F2		15	3,635.84
Average			2,243.58
G1	54,824	67	820.23
G2		12	4,758.60
Average			2,789.42

Table 23 (cont)

Group	Cost per Raceway	Numbers of Adults	Cost per Adult
1992 Brood			
A1	$37,357	99	$378.49
A2		57	660.53
Average			519.51
B1	35,357	39	901.80
B2		38	928.04
Average			914.92
C1	44,175	70	631.31
C2		88	504.50
Average			567.90
D1	47,309	197	240.53
D2		130	364.61
Average			302.57
E1	50,389	53	958.73
E2		52	960.05
Average			959.39
F1	54,824	67	814.41
F2		63	873.13
Average			843.77
G1	54,824	74	737.61
G2		69	799.15
Average			768.38

Figure 33. Average cost of rearing (dollars/fish) for recovered adult salmon derived from experimental raceways at Willamette Hatchery, 1989 brood. Cost includes 20-year amortization of the cost of hatchery modifications.

1989 Brood
Cost, dollars/fish
1000
800
600
400
200
0
A
B
C
D
Group

Figure 34. Average cost of rearing (dollars/fish) for recovered adult salmon derived from experimental raceways at Willamette Hatchery, 1990 brood. Cost includes 20-year amortization of the cost of hatchery modifications.

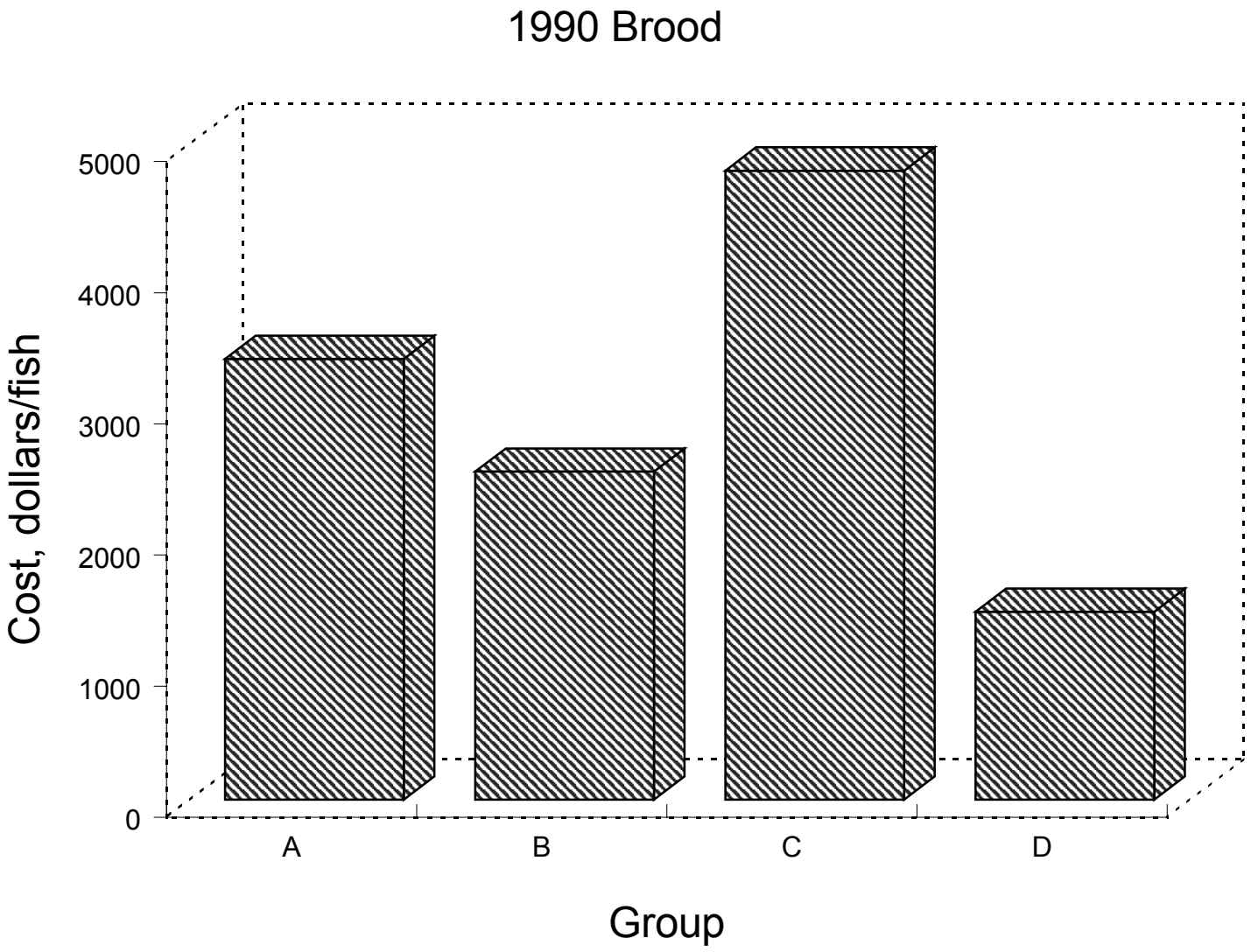

1990 Brood
Cost, dollars/fish
5000
4000
3000
2000
1000
0
A
B
C
D
Group

Figure 35. Average cost of rearing (dollars/fish) for recovered adult salmon derived from experimental raceways at Willamette Hatchery, 1991 brood. Cost includes 20-year amortization of the cost of hatchery modifications.

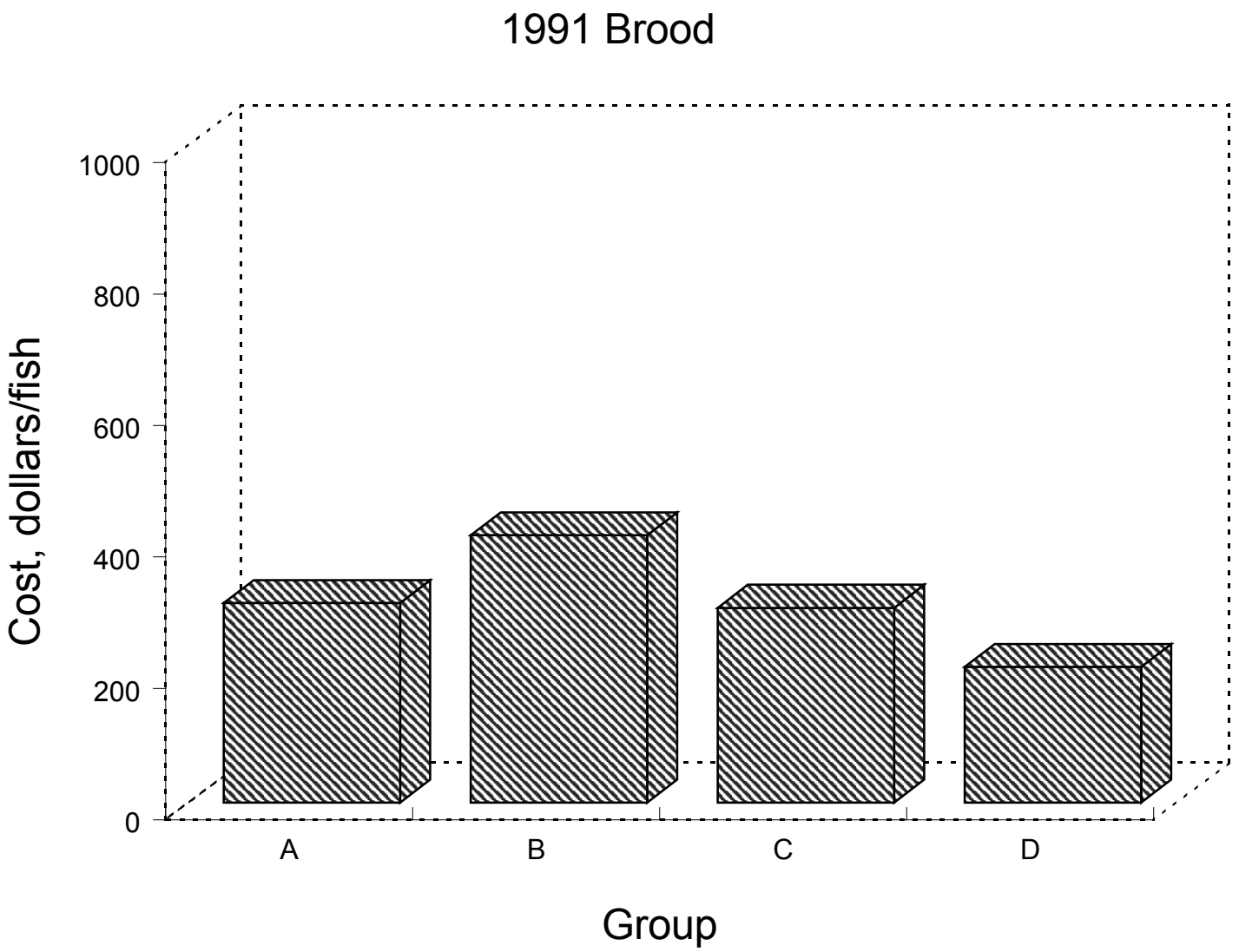

1991 Brood
Cost, dollars/fish
1000
800
600
400
200
0
A
B
C
D
Group

Figure 36. Average cost of rearing (dollars/fish) for recovered adult salmon derived from experimental raceways at Willamette Hatchery, 1992 brood. Cost includes 20-year amortization of the cost of hatchery modifications.

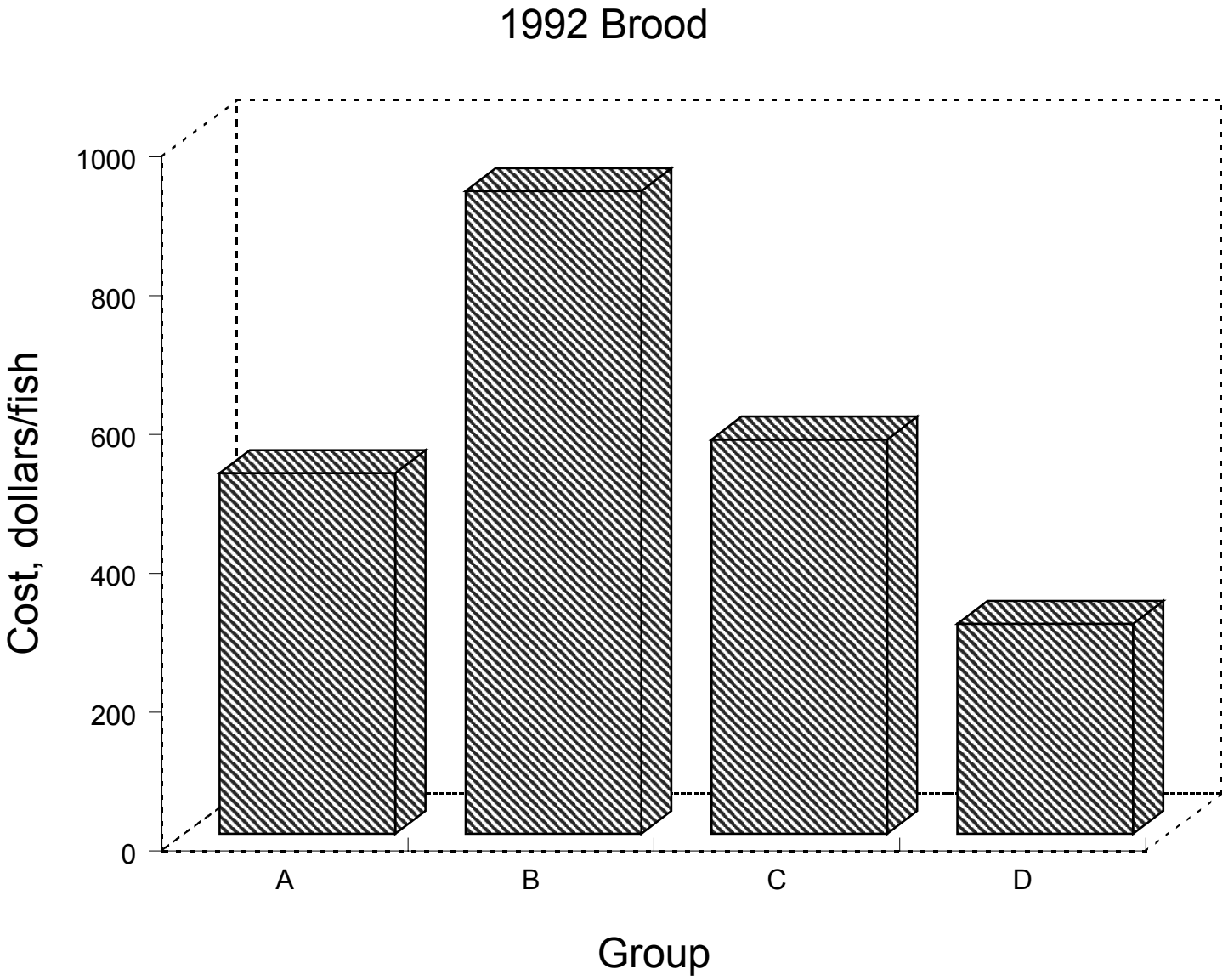
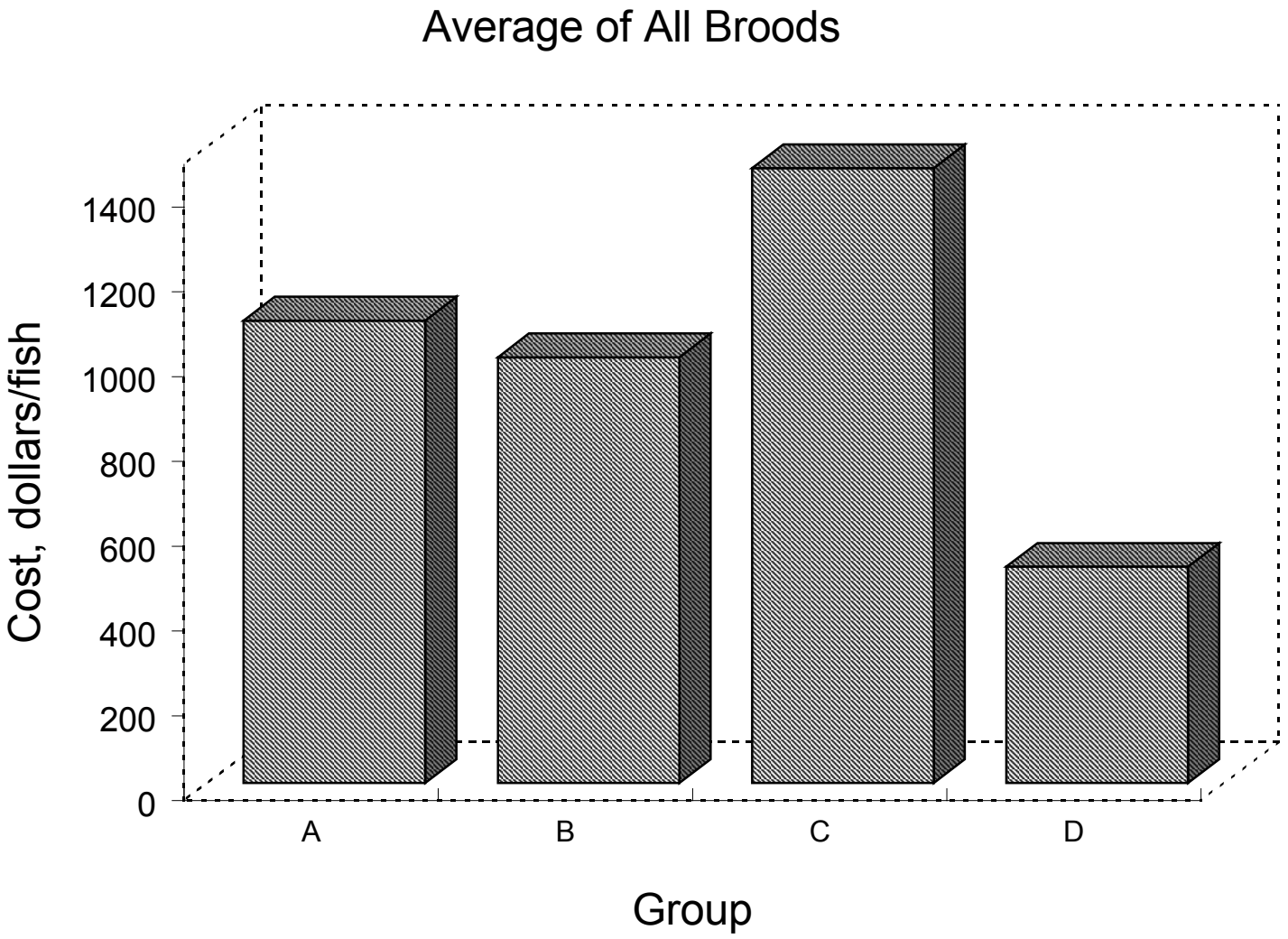

1992 Brood
Cost, dollars/fish
1000
800
600
400
200
0
A
B
C
D
Group

Figure 37. Average cost of rearing (dollars/fish) for recovered adult salmon derived from experimental raceways at Willamette Hatchery from all four brood years. Cost includes 20-year amortization of the cost of hatchery modifications.


Average of All Broods
Cost, dollars/fish
1400
1200
1000
800
600
400
200
0
A
B
C
D
Group

per recovered adult in increasing order were: D < B < A < C.

The cost per recovered adult for fish reared in Michigan raceways was over ten-fold higher than those reared in conventional raceways. This increased cost was partly due to the increased cost of raceway modification, partly due to increased operation expenses, and partly due to the fewer numbers of adults resulting from fish reared in these raceways (Tables 21 and 23).

For 1989 brood, group F had the lowest cost/fish, followed by group E and group G (Figure 38). For the 1990 brood, group G had the lowest cost/fish, followed by group F and group E (Figure 39). For the 1991 brood, group F had the lowest cost/fish, followed by group E and group G (Figure 40). For the 1992 brood, group G had the lowest cost/fish, followed by group F and group E (Figure 41). When costs/fish were averaged over the four years, group G had the lowest average cost/fish, followed by group F and group E (Figure 42).

Because many assumptions were involved in the calculation of cost/fish, no statistical analyses were performed on this parameter.

In summary, group D consistently had the lowest cost per adult produced, even though rearing the juveniles cost more because of increased feed, construction of contact columns, and use of oxygen supplementation. Highest costs were encountered in the fish reared in Michigan raceways, where costs were usually many thousands of dollars per adult recovered.

Figure 38. Average cost of rearing (dollars/fish) for recovered adult salmon derived from Michigan raceways at Willamette Hatchery, 1989 brood. Cost includes 20-year amortization of the cost of hatchery modifications.

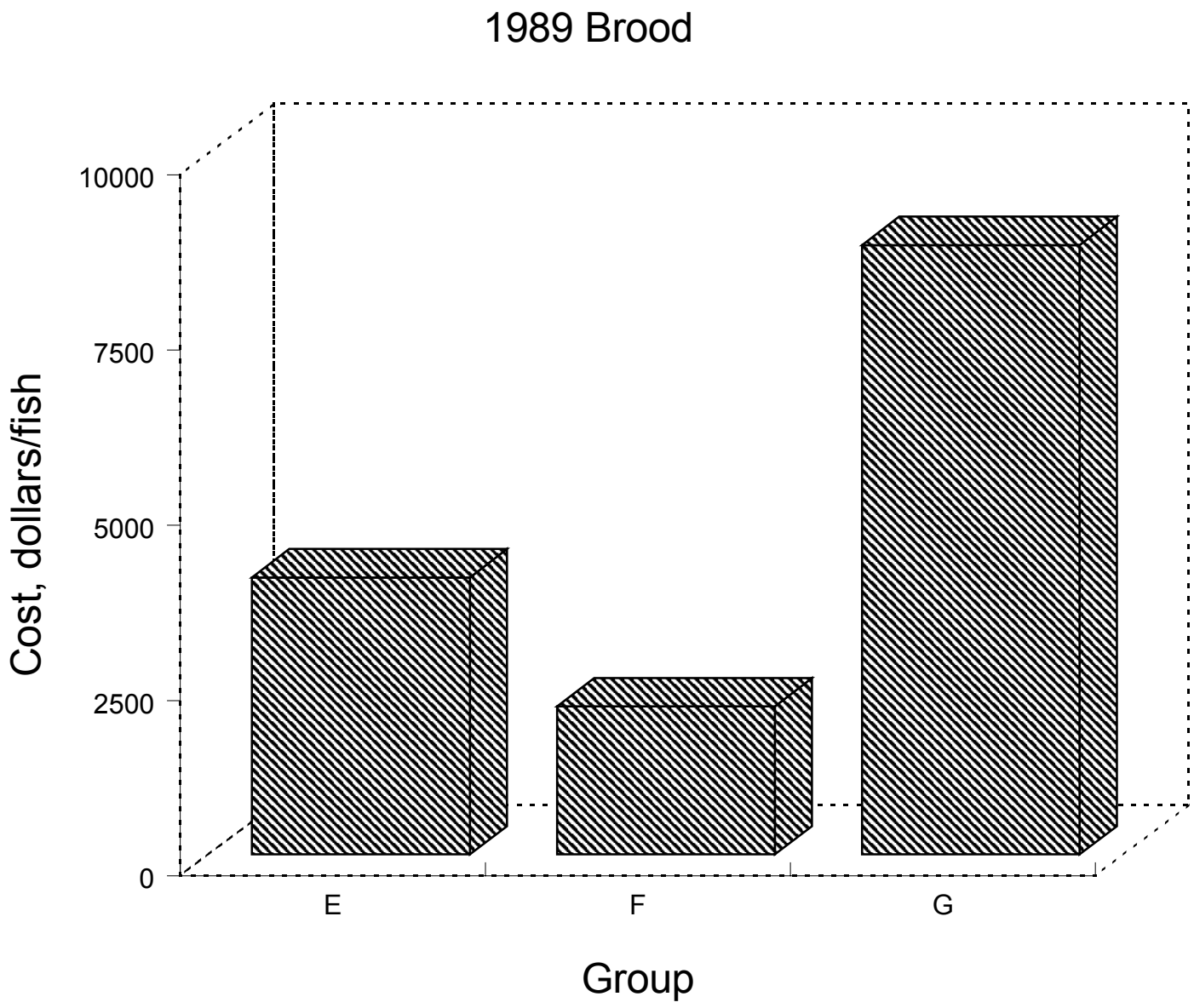

1989 Brood
10000
7500
5000
2500
0
Cost, dollars/fish
E
F
G
Group

Figure 39. Average cost of rearing (dollars/fish) for recovered adult salmon derived from Michigan raceways at Willamette Hatchery, 1990 brood. Cost includes 20-year amortization of the cost of hatchery modifications.

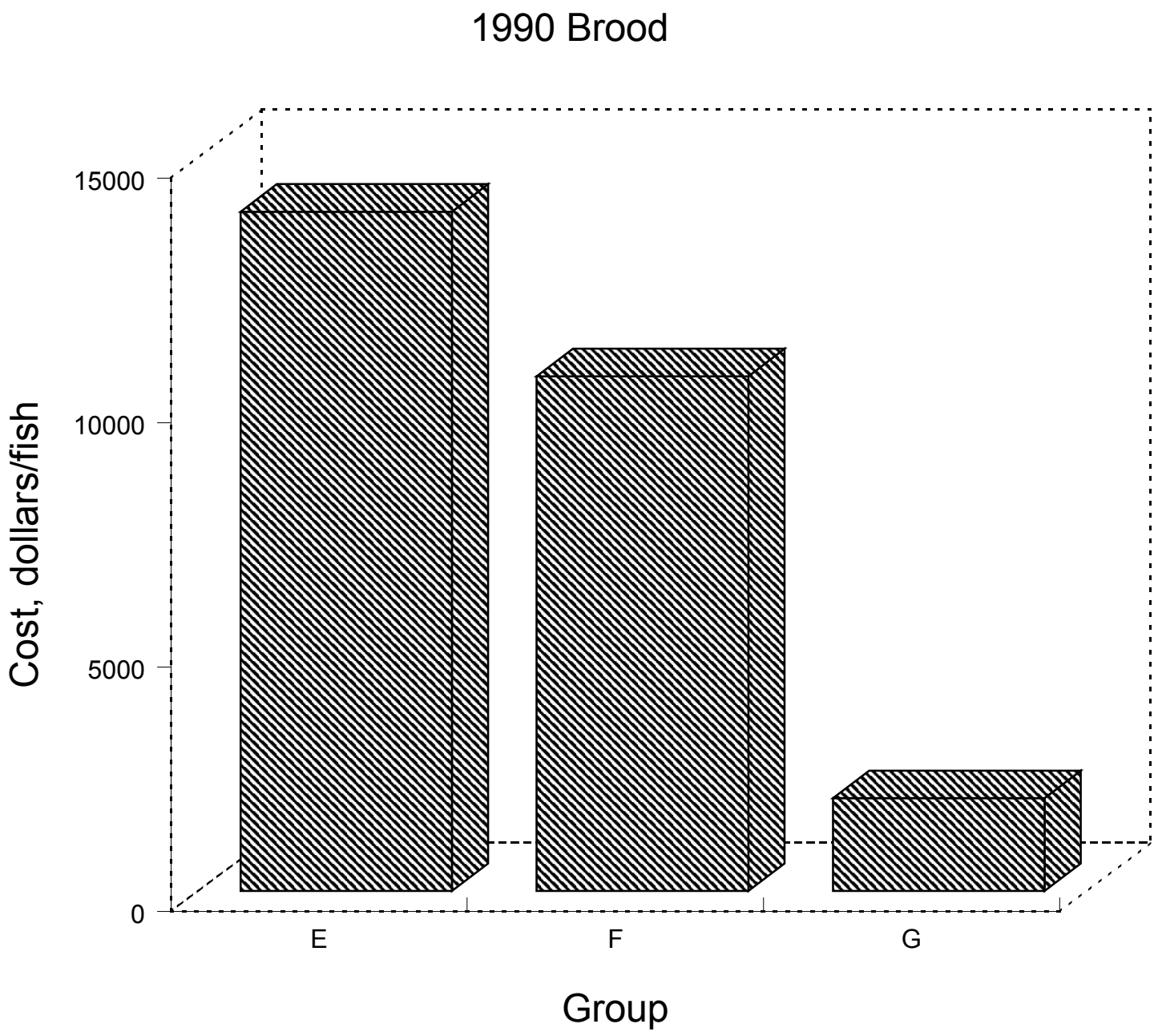

1990 Brood
15000
10000
5000
0
Cost, dollars/fish
E
F
G
Group

Figure 40. Average cost of rearing (dollars/fish) for recovered adult salmon derived from Michigan raceways at Willamette Hatchery, 1991 brood. Cost includes 20-year amortization of the cost of hatchery modifications.

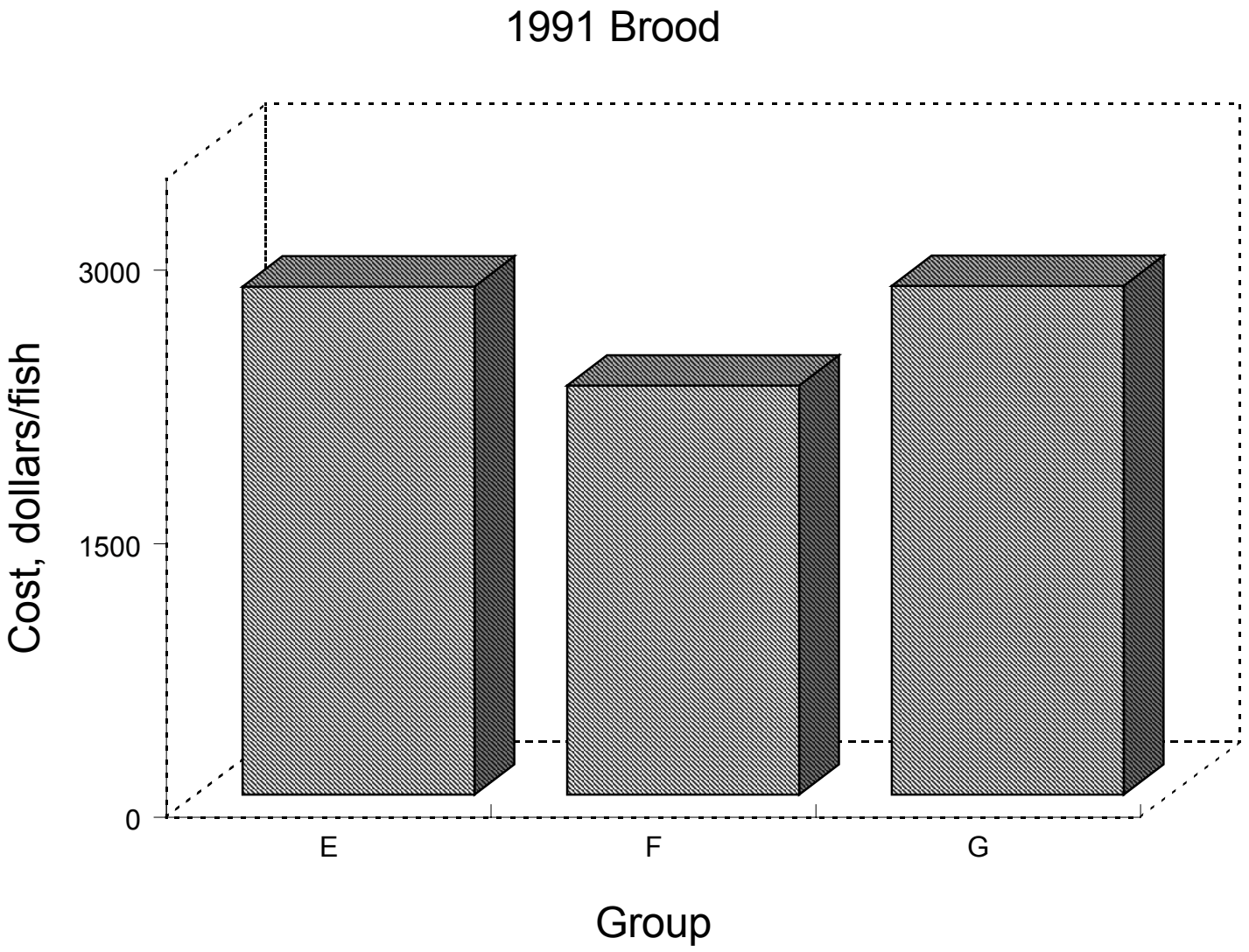

1991 Brood
Cost, dollars/fish
3000
1500
0
E
F
G
Group

Figure 41. Average cost of rearing (dollars/fish) for recovered adult salmon derived from Michigan raceways at Willamette Hatchery, 1992 brood. Cost includes 20-year amortization of the cost of hatchery modifications.

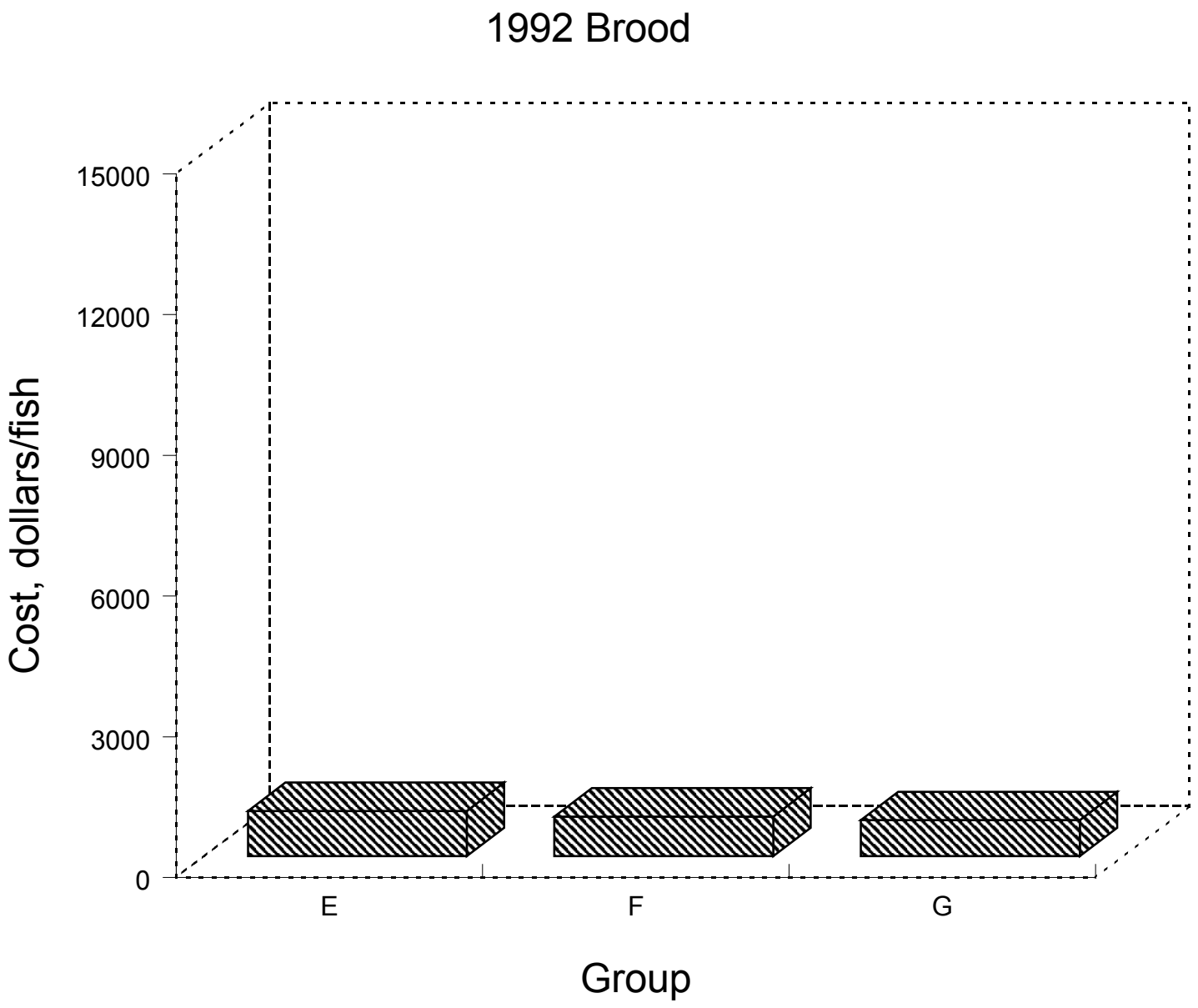
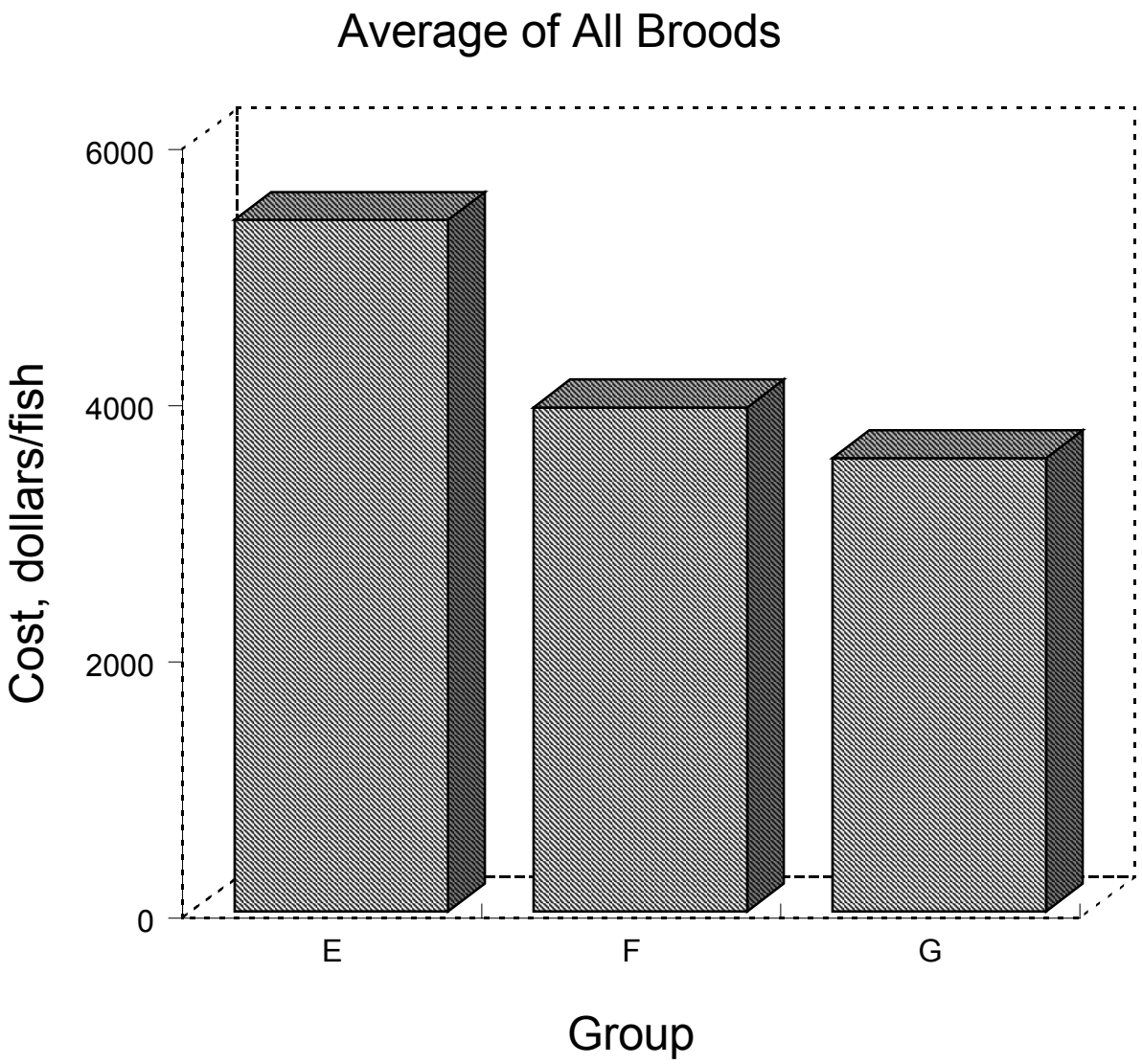

1992 Brood
15000
12000
9000
6000
3000
0
Cost, dollars/fish
E
F
G
Group

Figure 42. Average cost of rearing (dollars/fish) for recovered adult salmon derived from Michigan raceways at Willamette Hatchery from all four broods. Cost includes 20-year amortization of the cost of hatchery modifications.


Average of All Broods
6000
4000
2000
0
Cost, dollars/fish
E
F
G
Group

Effect of Disease on Percent Yield

The incidence of disease in a raceway of fish reduces their survival to adulthood. Increased rearing densities often have their greatest effects on the incidence of disease. In the presence of supplemental oxygen, however, it is not clear whether the direct relationship between disease incidence and rearing density persists and whether this relationship has any effect on survival to adulthood. The relationship between rearing density and disease incidence was examined earlier (Ewing 1996). No significant correlations were found between rearing density and disease incidence. In this section, the relationship between disease incidence and survival to adulthood is examined.

Because the number of mortalities from disease is a function of the number of fish in a raceway, the parameter used to normalize the death rate was percent mortality. Percent yield to adulthood is used as the dependent variable by the same reasoning (Table 24). When correlations between percent mortality and percent yield were examined for each brood year of fish, significant relationships were found for three of the four brood years (Table 25). Relationship of average of all groups was significant. When Michigan raceways were excluded from the relationship, percent yield still showed a significant relationship with mortalities of juveniles while rearing in three of the four brood years (Table 25).

Table 24. Percent mortality of juvenile fish during rearing and percent yield of adult fish derived from experimental groups released from Willamette Hatchery, 1989-1992 broods.

Group	Tag Code	Percent Mortality	Percent Recovery
1989 Brood			
A1	07-55-14	0.30	0.620
A2	07-55-06	0.42	0.582
B1	07-55-17	0.40	0.967
B2	07-55-18	0.64	1.153
C1	07-54-63	0.43	0.864
C2	07-55-03	0.45	0.847
D1	07-55-07	0.47	0.400
D2	07-55-08	0.30	0.505
E1	07-55-09	0.29	0.016
E2	07-55-10	0.22	0.092
F1	07-55-11	0.44	0.033
F2	07-55-12	0.30	0.113
G1	07-55-05	0.56	0.007
G2	07-55-13	0.34	0.046
1990 Brood			
A1	07-56-32	0.72	0.015
A2	07-56-31	0.33	0.212
B1	07-40-44	0.59	0.042
B2	07-40-43	0.54	0.300
C1	07-56-34	0.54	0.033
C2	07-56-33	0.45	0.020
D1	07-56-36	0.52	0.019
D2	07-56-35	0.56	0.058
E1	07-56-37	0.15	0.000
E2	07-56-38	0.13	0.007
F1	07-56-39	0.12	0.007
F2	07-56-40	0.16	0.016
G1	07-56-41	0.49	0.000
G2	07-56-42	0.62	0.050

Table 24. (cont.)

Group	Tag Code	Percent Mortality	Percent Recovery
1991 Brood			
A1	07-59-21	1.06	0.275
A2	07-59-22	0.63	0.426
B1	07-59-35	1.39	0.413
B2	07-59-36	1.40	0.477
C1	07-59-23	0.85	0.347
C2	07-59-24	0.61	0.444
D1	07-59-25	0.59	0.177
D2	07-59-26	0.66	0.296
E1	07-59-27	0.80	0.105
E2	07-59-28	2.80	0.026
F1	07-59-29	1.06	0.127
F2	07-59-30	5.09	0.032
G1	07-59-31	0.91	0.127
G2	07-59-32	3.94	0.023
1992 Brood			
A1	07-63-23	0.64	0.253
A2	07-63-22	0.49	0.155
B1	07-63-37	0.78	0.223
B2	07-63-36	0.74	0.217
C1	07-63-24	0.51	0.191
C2	07-63-25	0.55	0.265
D1	07-63-26	0.61	0.169
D2	07-63-27	0.58	0.120
E1	07-63-28	0.37	0.118
E2	07-01-28	0.25	0.126
F1	07-01-29	0.40	0.133
F2	07-01-30	0.27	0.128
G1	07-01-31	0.33	0.140
G2	07-01-32	0.42	0.134

Table 25. Relationships between percent mortalities in rearing ponds and percent yield of adults for experimental groups released from Willamette Hatchery, 1989-1992 broods.

Brood Year	Equation	R^2	t value[a]	
All groups				
1989	1.518 X + 0.157	0.188	5.96	Sig.
1990	0.078 X + 0.023	0.033	1.48	N.S.
1991	-0.071 X + 0.347	0.355	9.27	Sig.
1992	0.220 X + 0.060	0.504	12.54	Sig.
Average	-0.123 X + 0.315	0.056	3.10	Sig.
Raceways Only				
1989	1.144 X + 0.128	0.365	4.91	Sig.
1990	-0.396 X + 0.298	0.169	2.93	Sig.
1991	0.123 X + 0.247	0.171	2.94	Sig.
1992	0.168 X + 0.096	0.123	2.39	N.S.
Average	0.503 X + 0.036	0.398	5.39	Sig.

[a]Significant t value at P = 0.05 for all raceways (D. F.= 12) is 2.18. Significant t value at P = 0.05 for raceways only (D. F. = 6) is 2.45. Sig, significantly different from zero at P = 0.05, N.S., not significantly different from zero at P = 0.05.

Much of the mortality of the juveniles during rearing was due to the onset of bacterial kidney disease, although data is not available for a complete analysis. A particular example of the effect of disease on percent yield occurred in the 1991 brood when a group of juveniles infected with bacterial kidney disease were detected in group E2 but not group E1 in the Michigan raceways. The bacteria spread throughout the series, causing mortalities to be much higher in the E2-F2-G2 series than in the E1-F1-G1 series (Figure 43). Percent yields from the second series were much lower than from the first series (Figure 44).

Disease incidence detectable in the hatchery therefore played a role in the percent yield obtained from the experimental raceways. Significant relationships between percent mortality of juveniles during rearing and percent yield of adults were found in three of four brood years. However, the slope of the relationship in most cases was positive, suggesting that the disease may have culled out the weaker fish and caused a higher percent yield in the fish that were finally released. The similarity between the percent mortalities in the different groups for all brood years but 1991 suggest that the differences in percent yield were due more to density effects than to the onset of disease.

Figure 43. Percent mortalities in the Michigan pond series infected (E2-F2-G2) and not infected (E1-F1-G1) with bacterial kidney disease.

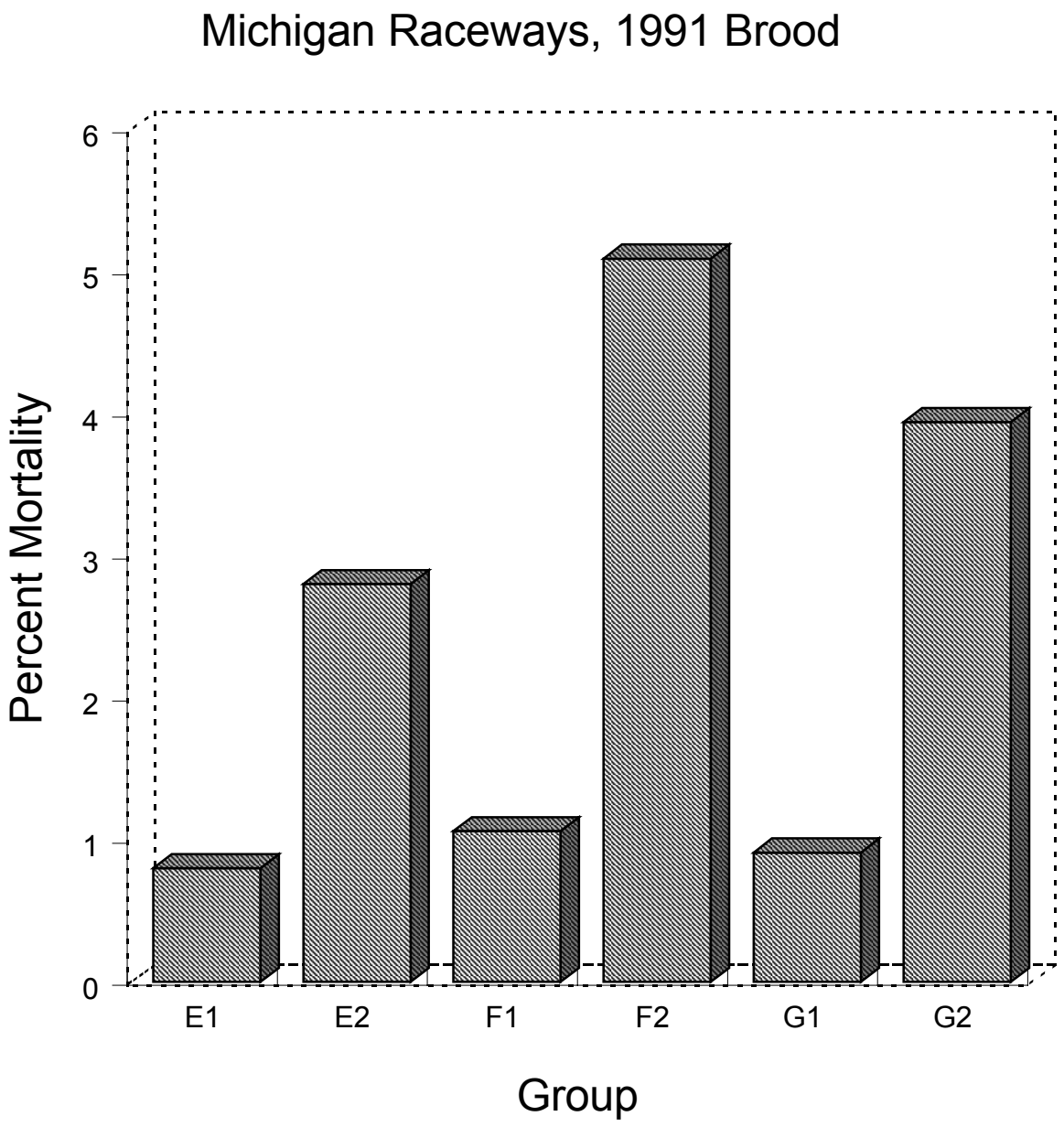
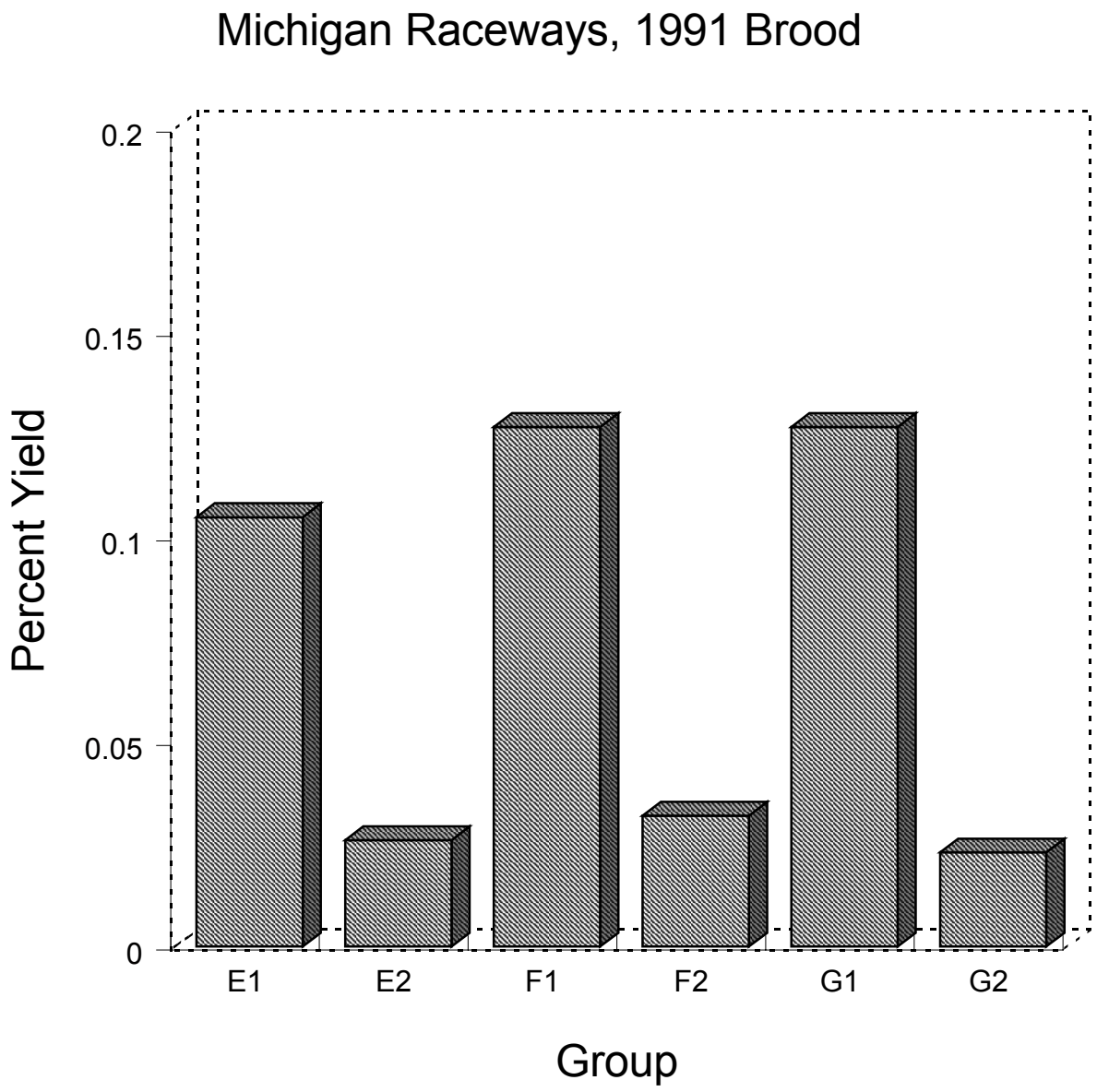

Michigan Raceways, 1991 Brood
Percent Mortality
0
1
2
3
4
5
6
E1
E2
F1
F2
G1
G2
Group

Figure 44. Percent yield of adults from the Michigan pond series infected (E2-F2-G2) and not infected (E1-F1-G1) with bacterial kidney disease.


Michigan Raceways, 1991 Brood
Percent Yield
0.2
0.15
0.1
0.05
0
E1
E2
F1
F2
G1
G2
Group

Catch Distribution

Distribution of recovery of adults was tabulated by state where adults were captured (Table 26) and by the fishery in which the fish were captured (Table 27). Most of the fish were captured in Oregon in the freshwater fisheries. Alaska caught a number of the adults in their ocean fisheries. No adults were captured in California from any of the brood years, and only a few were captured in Washington and British Columbia. Numbers captured were small and statistical analysis were not possible.

Catch distribution in various fisheries (Table 27) showed that most of the tagged fish were recovered either in the freshwater sport fishery or at the hatchery. Two parameters are of particular interest: percent harvest and the ratio of sport catch to escapement. Because fish from the 1990 brood returned in such small numbers, average percent harvests for 1989, 1991, and 1992 brood years were calculated separately (Table 28).

From Table 27, nearly half of all surviving adults are caught in the various fisheries. Most of this is in the freshwater sport fishery of Oregon. No significant differences were apparent between percent harvest of fish reared in raceways or those reared in Michigan raceways. An interesting aspect of these results is that fish reared at Dexter seem to have a lower percent harvest than those reared at Willamette Hatchery, although the difference

Table 26. Numbers of adult fish derived from experimental groups released from Willamette Hatchery, 1989-1992 broods, that were captured in various state fisheries.

Group	Tag Code	State of Capture					
		Calif.	Oreg	Wash.	Br. Col.	Alas.	Total
1989 Brood							
A1	07-55-14	0	180	1	5	9	195
A2	07-55-06	0	137	2	3	18	160
B1	07-55-17	0	135	14	0	19	168
B2	07-55-18	0	189	0	4	8	201
C1	07-54-63	0	246	8	2	14	270
C2	07-55-03	0	231	0	5	21	257
D1	07-55-07	0	112	1	4	16	133
D2	07-55-08	0	146	0	0	19	165
E1	07-55-09	0	1	0	0	3	4
E2	07-55-10	0	27	0	0	0	27
F1	07-55-11	0	9	0	0	0	9
F2	07-55-12	0	21	0	11	2	34
G1	07-55-05	0	2	0	0	0	2
G2	07-55-13	0	11	1	0	0	12
Dex1	07-55-16	0	408	11	13	17	449
Dex2	07-55-15	0	353	19	11	25	408
1990 Brood							
A1	07-56-32	0	5	0	0	0	5
A2	07-56-31	0	67	0	0	1	68
B1	07-40-44	0	8	0	0	0	8
B2	07-40-43	0	32	22	0	6	60
C1	07-56-34	0	7	0	0	3	10
C2	07-56-33	0	6	0	0	0	6
D1	07-56-36	0	6	0	0	0	6
D2	07-56-35	0	19	0	0	0	19
E1	07-56-37	0	0	0	0	0	0
E2	07-56-38	0	2	0	0	0	2
F1	07-56-39	0	2	0	0	0	2
F2	07-56-40	0	5	0	0	0	5
G1	07-56-41	0	0	0	0	0	0
G2	07-56-42	0	11	0	5	0	16
Dex1	07-56-43	0	94	0	0	9	103
Dex2	07-56-44	0	112	0	5	10	127

Table 26 (cont.)

Group	Tag Code	State of Capture					
		Calif.	Oreg	Wash.	Br. Col.	Alas.	Total
1991 Brood							
A1	07-59-21	0	72	0	6	5	83
A2	07-59-22	0	104	0	7	5	116
B1	07-59-35	0	77	0	0	4	81
B2	07-59-36	0	76	0	0	16	92
C1	07-59-23	0	101	0	0	6	107
C2	07-59-24	0	100	22	2	7	131
D1	07-59-25	0	48	0	0	0	48
D2	07-59-26	0	68	0	0	14	82
E1	07-59-27	0	21	0	2	0	23
E2	07-59-28	0	6	0	0	0	6
F1	07-59-29	0	31	0	0	3	34
F2	07-59-30	0	8	0	0	0	8
G1	07-59-31	0	33	0	0	2	35
G2	07-59-32	0	5	0	0	1	6
Dex1	07-59-33	0	243	0	4	9	256
Dex2	07-59-34	0	222	0	3	5	230
1992 Brood							
A1	07-63-23	0	52	0	0	13	65
A2	07-63-22	0	36	0	2	0	38
B1	07-63-37	0	27	0	0	5	32
B2	07-63-36	0	29	0	0	2	31
C1	07-63-24	0	47	0	0	5	52
C2	07-63-25	0	56	0	0	7	63
D1	07-63-26	0	51	0	0	1	52
D2	07-63-27	0	26	0	0	5	31
E1	07-63-28	0	27	0	0	0	27
E2	07-01-28	0	22	0	3	3	28
F1	07-01-29	0	28	0	5	3	36
F2	07-01-30	0	32	0	0	1	33
G1	07-01-31	0	39	0	0	0	39
G2	07-01-32	0	28	0	6	2	36
Dex1	07-01-33	0	214	0	3	0	217
Dex2	07-01-34	0	164	0	13	8	185

Table 27. Numbers of adult fish derived from experimental groups released from Willamette Hatchery, 1989-1992 broods, that were captured in various types of fisheries.

Group	Tag Code	Types of Fisheries										
		Ocean Troll	Ocean Sport	Commercial. Seine	Mixed Net&Sein	Col. R. Gillnet	Fr. W Sport	Dead Fish Survey	Treaty Ceremonial	Test Fishery	Hatchery	Percent Harvest
1989 Brood												
A1	07-55-14	15	0	0	0	9	104	1	2	0	64	65.6
A2	07-55-06	21	2	0	0	5	62	0	5	0	65	56.3
B1	07-55-17	28	0	1	0	2	83	1	0	0	53	67.9
B2	07-55-18	12	0	0	0	2	108	1	2	3	73	60.7
C1	07-54-63	25	0	0	2	14	115	1	5	0	108	57.8
C2	07-55-03	23	0	3	0	10	136	0	3	0	82	66.9
D1	07-55-07	21	0	0	0	2	66	0	1	0	43	66.9
D2	07-55-08	19	0	0	0	9	81	0	1	0	55	66.1
E1	07-55-09	3	0	0	0	0	0	0	0	0	1	75.0
E2	07-55-10	0	0	0	0	0	20	0	0	0	7	74.1
F1	07-55-11	0	0	0	0	0	7	0	0	0	2	77.8
F2	07-55-12	13	0	0	0	0	14	0	0	0	7	79.4
G1	07-55-05	0	0	0	0	0	0	0	0	0	2	0.0
G2	07-55-13	1	0	0	0	0	6	0	0	0	5	58.3
Dex1	07-55-16	30	4	0	2	0	176	2	3	1	231	47.2
Dex2	07-55-15	42	0	0	1	7	156	1	3	0	198	50.5
1990 Brood												
A1	07-56-32	0	0	0	0	0	0	0	0	0	5	0.0
A2	07-56-31	0	0	1	0	0	48	1	1	0	17	72.1
B1	07-40-44	0	0	0	0	0	0	0	1	0	7	0.0
B2	07-40-43	0	0	6	0	0	27	0	3	1	23	55.0
C1	07-56-34	3	0	0	0	0	1	0	1	0	5	40.0
C2	07-56-33	0	0	0	0	0	1	0	0	0	5	16.7
D1	07-56-36	0	0	0	0	0	0	0	2	0	4	0.0
D2	07-56-35	0	0	0	0	0	10	0	0	0	9	52.6
E1	07-56-37	0	0	0	0	0	0	0	0	0	0	0.0
E2	07-56-38	0	0	0	0	0	0	0	1	0	1	0.0
F1	07-56-39	0	0	0	0	0	0	0	0	0	2	0.0
F2	07-56-40	0	0	0	0	0	5	0	0	0	0	100.0
G1	07-56-41	0	0	0	0	0	0	0	0	0	0	0.0
G2	07-56-42	5	0	0	0	0	10	0	0	0	1	93.8
Dex1	07-56-43	0	1	8	0	0	35	0	0	0	59	42.7
Dex2	07-56-44	11	0	2	2	2	43	1	2	0	64	47.2

Table 27 (cont.)

Group	Tag Code	Ocean Troll	Ocean Sport	Commercial. Seine	Mixed Net&Sein	Col. R. Gillnet	Fr. W Sport	Dead Fish Survey	Treaty Ceremonial	Test Fishery	Hatchery	Percent Harvest
		Types of Fisheries										
1991 Brood												
A1	07-59-21	8	0	0	3	0	16	0	0	1	55	32.5
A2	07-59-22	4	8	0	0	0	53	0	1	0	50	56.0
B1	07-59-35	4	0	0	0	0	35	2	0	0	40	48.1
B2	07-59-36	4	0	12	0	0	42	0	1	0	33	63.0
C1	07-59-23	6	0	0	0	0	40	1	0	0	60	43.0
C2	07-59-24	4	0	3	2	2	58	0	0	0	62	52.7
D1	07-59-25	0	0	0	0	0	16	0	1	0	31	33.3
D2	07-59-26	14	0	0	0	0	36	0	0	0	32	61.0
E1	07-59-27	0	0	0	2	2	12	0	0	0	7	69.6
E2	07-59-28	0	0	0	0	0	5	0	0	0	1	83.3
F1	07-59-29	3	0	0	0	0	15	0	0	0	16	52.9
F2	07-59-30	0	0	0	0	0	0	0	0	0	8	0.0
G1	07-59-31	2	0	0	0	2	13	0	0	0	18	48.6
G2	07-59-32	1	0	0	0	0	1	0	0	0	4	33.3
Dex1	07-59-33	7	0	6	0	0	92	1	0	0	150	41.0
Dex2	07-59-34	8	0	0	0	1	49	0	0	0	171	25.2
1992 Brood												
A1	07-63-23	6	0	7	0	2	4	2	0	0	44	29.2
A2	07-63-22	0	0	0	2	0	4	0	0	0	32	15.8
B1	07-63-37	5	0	0	0	1	4	0	0	0	22	31.3
B2	07-63-36	2	0	0	0	1	0	0	0	0	28	9.7
C1	07-63-24	5	0	0	0	1	9	1	0	0	36	28.8
C2	07-63-25	7	0	0	0	0	12	1	0	1	42	30.2
D1	07-63-26	1	0	0	0	0	14	1	0	0	35	28.8
D2	07-63-27	5	0	0	0	3	1	1	0	0	21	29.0
E1	07-63-28	0	0	0	0	0	4	1	0	0	22	14.8
E2	07-01-28	6	0	0	0	0	5	0	0	0	17	46.4
F1	07-01-29	8	0	0	0	1	1	1	0	0	25	27.8
F2	07-01-30	0	1	0	0	1	9	0	0	0	22	33.3
G1	07-01-31	0	0	0	0	0	8	0	0	1	30	20.5
G2	07-01-32	2	0	0	6	0	1	0	0	0	27	25.0
Dex1	07-01-33	3	0	0	0	0	29	1	0	1	183	14.7
Dex2	07-01-34	12	0	0	9	1	14	1	0	0	148	19.5

Table 28. Average percent harvests derived from data in Table 27.

Group	Average ± SE All Brood Years	Average ± SE 1989, 1991, 1992 Broods
A1	31.8 ± 13.4	42.4 ± 11.6
A2	50.1 ± 12.0	42.7 ± 13.5
A	40.9 ± 9.0	42.6 ± 8.0
B1	36.8 ± 14.4	49.1 ± 10.6
B2	47.1 ± 12.6	44.5 ± 17.4
B	42.0 ± 9.1	46.8 ± 9.2
C1	42.4 ± 6.0	43.2 ± 8.4
C2	41.6 ± 11.2	49.9 ± 10.7
C	42.0 ± 5.9	46.6 ± 6.3
D1	32.3 ± 13.7	43.0 ± 12.0
D2	52.2 ± 8.2	52.0 ± 11.6
D	42.2 ± 8.3	47.5 ± 7.7
E1	39.9 ± 19.0	53.1 ± 19.2
E2	51.0 ± 18.7	67.9 ± 11.1
E	45.4 ± 12.5	60.5 ± 10.5
F1	39.6 ± 16.7	52.8 ± 14.4
F2	53.2 ± 22.6	37.6 ± 23.0
F	46.4 ± 13.2	45.2 ± 12.6
G1	17.3 ± 11.5	23.0 ± 14.1
G2	52.6 ± 15.5	38.9 ± 10.0
G	34.9 ± 11.1	31.0 ± 8.5
Dex1	36.4 ± 7.4	34.3 ± 10.0
Dex2	35.6 ± 7.8	31.7 ± 9.5
Dexter	36.0 ± 5.0	33.0 ± 6.2
Overall	41.2 ± 2.4	44.1 ± 2.6
Raceways	41.8 ± 2.7	45.9 ± 1.4
Michigan Raceways	42.3 ± 5.6	45.6 ± 6.4

is not significant due to the large error terms for fish reared at Willamette Hatchery. Only the fish from group G have such a low percent harvest. The reason for this low percent harvest is not known at present.

Sport catch to escapement ratios measure the relative harvest by sport fishermen to the number of adults capable of spawning. In general, one would hope that as many fish escaped to spawn as were caught in the sport fishery. This seems to occur in most of the experimental groups (Table 29) because ratios of sport catch to escapement were reasonably close to 1.0. In fish from the 1989 brood, however, ratio of sport catch to escapement were significantly greater than 1.0, while in fish from the 1992 brood, the ratios were significantly lower than 1.0. This corresponds to a gradual reduction in fishing effort that occurred from 1991 to 1995 (Dixon et al. 1998).

In summary, commercial catch of experimental groups was limited mostly to Alaska, with only a few fish captured in British Columbia or Washington. No fish were recovered from the California fishery. Of the catch reported in Oregon, most came from the sport catch. About as many adults from experimental groups were captured in the sport catch as returned to the river for spawning. Sport catch declined with each brood year, reflecting the reduced fishing effort during the time when adults were returning to spawn.

Table 29. Ratios of sport catch to escapement for experimental groups of adult spring chinook salmon.

Group	Brood Year 1989	1990	1991	1992	Average ± SE All Broods	Average ± SE 1989,1991, 1992 Broods
A1	1.55	0.00	0.29	0.09	0.48 ± 0.36	0.64 ± 0.46
A2	0.89	2.53	1.04	0.13	1.14 ± 0.50	0.68 ± 0.28
A	1.22	1.26	0.66	0.11	0.81 ± 0.36	0.66 ± 0.24
B1	1.54	0.00	0.83	0.18	0.64 ± 0.35	0.85 ± 0.39
B2	1.37	1.04	1.24	0.00	0.91 ± 0.31	0.87 ± 0.44
B	1.45	0.52	1.03	0.09	0.77 ± 0.26	0.86 ± 0.26
C1	1.01	0.17	0.66	0.24	0.52 ± 0.20	0.64 ± 0.22
C2	1.60	0.20	0.94	0.27	0.75 ± 0.66	0.94 ± 0.38
C	1.30	0.18	0.80	0.26	0.64 ± 0.21	0.79 ± 0.21
D1	1.50	0.00	0.50	0.39	0.60 ± 0.32	0.80 ± 0.35
D2	1.45	1.11	1.13	0.05	0.93 ± 0.31	0.87 ± 0.42
D	1.47	0.56	0.81	0.22	0.76 ± 0.25	0.83 ± 0.25
E1	0.00	--	1.71	0.17	0.63 ± 0.47	0.63 ± 0.54
E2	2.86	0.00	5.00	0.29	2.04 ± 1.18	2.72 ± 1.36
E	1.43	0.00	3.36	0.23	1.43 ± 0.85	1.67 ± 0.80
F1	3.50	0.00	0.94	0.04	1.12 ± 0.82	1.49 ± 1.04
F2	2.00	--	0.00	0.41	0.80 ± 0.53	0.80 ± 0.61
F	2.75	0.00	0.47	0.22	0.98 ± 0.59	1.15 ± 0.56
G1	0.00	--	0.72	0.26	0.33 ± 0.18	0.33 ± 0.21
G2	1.20	10.00	0.25	0.04	2.87 ± 2.39	0.50 ± 0.36
G	0.60	10.00	0.49	0.15	1.78 ± 1.63	0.41 ± 0.19
Dex1	0.74	0.59	0.61	0.16	0.53 ± 0.13	0.50 ± 0.18
Dex2	0.77	0.64	0.29	0.09	0.45 ± 0.16	0.38 ± 0.20
Dexter	0.76	0.62	0.45	0.13	0.49 ± 0.11	0.44 ± 0.12
Ave	l.37	1.25	1.01	0.18	0.92 ± 0.17	0.85 ± 0.14
Raceways					0.75 ± 0.08	0.79 ± 0.04
Michigan Raceways					1.30 ± 0.40	1.08 ± 0.37

Age-Class Distribution

Chinook salmon spend a variable number of years at sea after leaving the river system. For that reason, the age class structure is one of the important characteristics of a population. Age class structure is determined by a number of physiological and genetic factors. A physiological factor that is controlled in part by the hatchery rearing is growth rate. Because growth rate is often a function of rearing density, changes in age class structure may occur in the experimental fish reared at Willamette Hatchery.

Age distribution of the jacks and adults derived from experimental groups at Willamette Hatchery is shown in Table 30. Predominant age classes were 4-year-old and 5-year-old fish, comprising 54% and 40% of the population, respectively (Table 31). Only a few 2-year-old (1.87%) and 6-year-old (0.73%) fish were captured. An interesting observation was that the percentage of two-year old fish and the percentage of six-year-old fish were inversely related (R^2 = 0.908) (Figure 45).

Rearing density often causes changes in growth rate which results in changes in age class. In the present experiment, no relationship between rearing density (kg/m^3) and percent of fish in a particular age class was found. Highest R^2 calculated was only 0.106 for 2-year-old fish. Other relationships had R^2 values of less than 0.1 and often less than 0.01. This is not too surprising because growth rates were controlled to prevent large differences in size at release (Ewing 1996).

Table 30. Numbers of adult fish in various age classes derived from experimental groups released from Willamette Hatchery, 1989-1992 broods. Numbers include data from ocean troll and river sport fisheries as well as returns to various hatcheries.

Group	Tag Code	Age at Capture					
		2	3	4	5	6	Total
1989 Brood							
A1	07-55-14	0	7	89	98	1	195
A2	07-55-06	0	3	72	83	2	160
B1	07-55-17	0	1	110	56	1	168
B2	07-55-18	3	1	98	97	2	201
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	3	0	0	4
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	0	0	2
G2	07-55-13	0	0	5	7	0	12
Dex1	07-55-16	0	19	275	154	1	449
Dex2	07-55-15	0	14	238	141	15	408
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	0	8
B2	07-40-43	0	1	20	39	0	60
C1	07-56-34	0	2	6	2	0	10
C2	07-56-33	0	0	1	5	0	6
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	47	46	1	103
Dex2	07-56-44	7	6	49	64	1	127

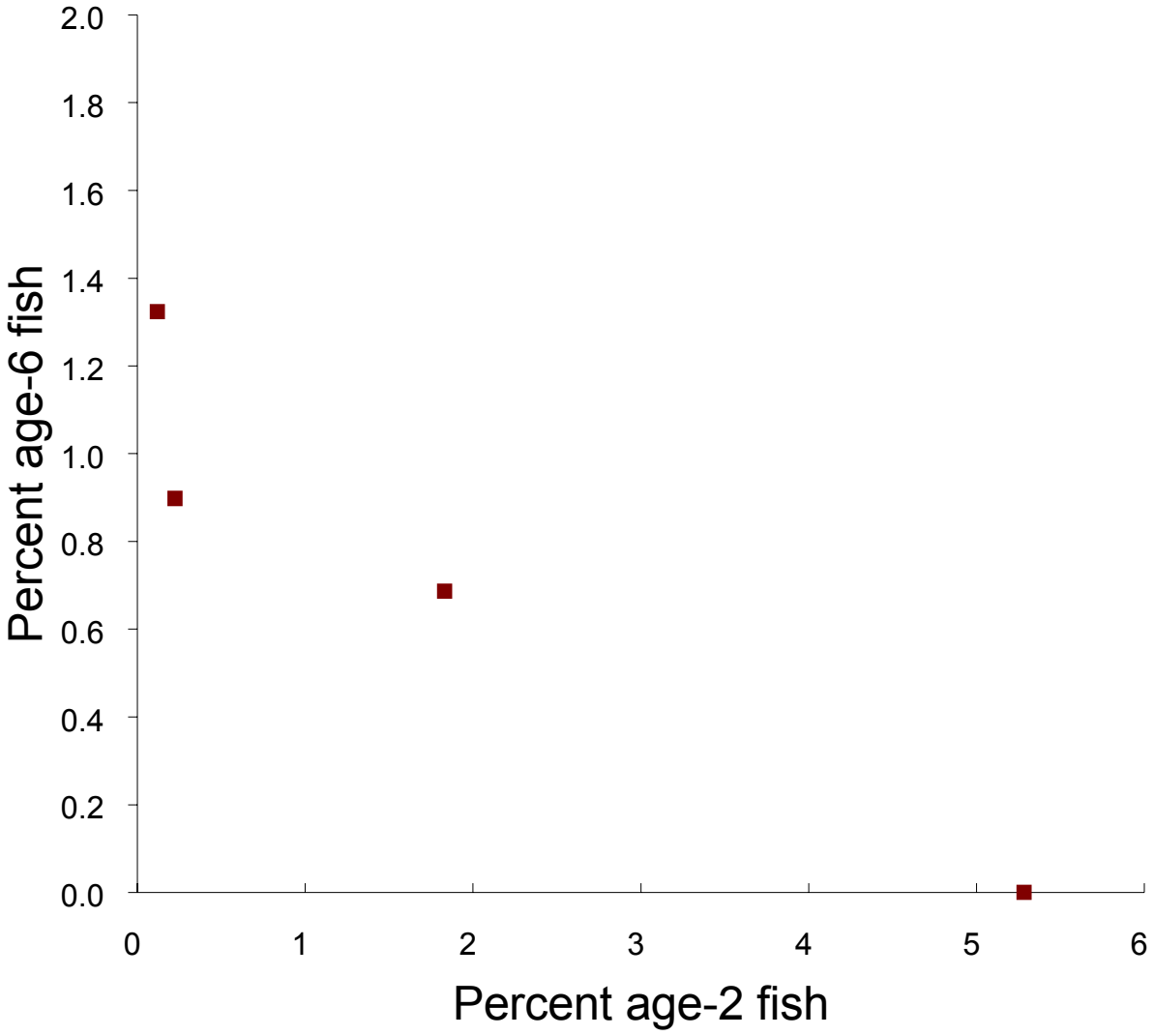
Table 30 (cont.)

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	39	3	107
C2	07-59-24	0	7	92	32	0	131
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	141	83	0	229
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	4	12	12	0	28
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	18	11	0	36
Dex1	07-01-33	20	5	121	71	0	217
Dex2	07-01-34	17	16	92	60	0	185

Table 31. Percent of adult fish captured from each age class.

Brood	Age at Capture				
	2	3	4	5	6
1989 Brood	0.1	2.9	56.4	39.2	1.3
1990 Brood	1.8	5.5	43.0	49.0	0.7
1991 Brood	0.2	2.5	65.1	31.3	0.9
1992 Brood	5.3	4.8	51.2	38.8	0.0
Average	1.87	3.93	53.92	39.56	0.73
Standard Error	1.21	0.71	4.63	3.63	0.28

Figure 45. Relationship between the percentage of age 2 fish and the percentage of age 6 fish in each brood year.


2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Percent age-6 fish
0
1
2
3
4
5
6
Percent age-2 fish

Ocean Conditions

Ocean conditions are thought to play a large role in the final survival of release groups. The conditions of warmer water resulting from the El Nino-Southern Oscillation (ENSO) event of 1983 caused poor survival of juvenile coho salmon smolts, poor growth of adults in the ocean, and reduced fecundity (Johnson 1988; Pearcy 1992). A recent website, www.iphc.wash.edu\Staff\hare\html\papers\ei\abst_ei.html, presents ocean conditions that occurred in the summers of 1991 to 1994 when the juveniles from experimental raceways were released. El Nino conditions have been recurrent in recent years, with warm water trends in 1986-87, 1991-1992, 1993, and 1994. In 1991, chinook smolts from the Willamette Oxygen Supplementation project entered the ocean into a warmer-than-usual temperature. In spite of this warmer temperature, the 1989 brood showed the strongest returns to the fisheries and to the hatchery. However, the strongest warming trend occurred from summer of 1991 to spring of 1992, when the second group of experimental fish (1990 brood) entered the ocean. This group had the poorest survival of any of the four groups. During spring of 1993, the ocean temperature was still elevated, but to a lesser degree than the previous year. Survival of the 1991 brood fish was intermediate between 1989 and 1990.

A comparison of returns of spring chinook salmon to Willamette Hatchery is shown in Table 32. Survival to adulthood for comparable sized fish released at similar times ranged from 0.55% to 2.9%. The very low returns occurred before a series of time and

size of release experiments in the mid 70s and 80s increased the percent survival of the juveniles. One of these improvements was the conditioning of the fish at Dexter Rearing Ponds for four months before release. This relieved the hauling stresses that probably accounted for the large differences in survival between fish reared at Willamette Hatchery and released into the Willamette River in March and those reared at Dexter Rearing Pond before release into the Willamette River.

Whether the El Nino conditions encountered in the ocean environment increased or decreased the sensitivity of the experiment at Willamette Hatchery is a matter of conjecture. Common sense would suggest that the poor ocean conditions was the main source of mortality to the juvenile chinook salmon and consequently the effect of the various treatments on survival to adulthood was greatly diminished. However, preliminary evidence from rearing experiments in hatcheries suggests that the effects of hatchery practices do not appear when ocean conditions are good. Only when ocean conditions are poor do the hatchery practices have significant impacts on survival. This is an area which has profound implications for the design and execution of experiments in hatcheries.

Comprehensive study of past experiments and the ocean conditions present at the time should resolve these questions and greatly modify the way in which hatchery experiments are carried out.

Table 32. Size, time of release, and percent survival of various broods reared at Willamette Hatchery from 1977 to 1992. Groups shown were selected for comparable release conditions. From 1978 brood to 1988 brood, fish were reared at Willamette Hatchery until November, then transferred to Dexter Rearing Pond to rear until release in March. Those from 1989 to 1992 broods were reared at Dexter Rearing Pond for a full year.

Brood Year	Size at Release (g)	Date of Release	Percent Survival
1977	53.35	3/20/79	1.666
1978	49.84	3/10/80	2.874
1979	50.94	3/16/81	2.674
1980	48.25	3/16/82	2.253
1984	40.85	3/12/86	2.334
1985	57.41	3/09/87	2.917
1986	44.03	3/01/87	2.530
1987	48.25	3/06/89	0.550
1988	40.13	3/07/90	1.400
Average	48.12	3/11	2.130
1989	47.24	3/01/91	1.313
1990	55.99	3/04/92	0.353
1991	53.36	3/14/93	0.750
1992	58.90	2/28/94	0.744
Average	53.87	3/05	0.790

DISCUSSION

Two recent studies have examined the effects of rearing salmonids in baffled Michigan raceways, as described by Boersen and Westers (1986). In the first study, Wagner (1993) reared rainbow trout (O. mykiss) in replicated baffled raceways and non-baffled raceways. Conditions of flow and density remained constant in the two experimental treatments. Wagner found no difference in growth or health and condition profiles between the two types of raceway. Distribution of oxygen was found to be similar in both treatments. No agonistic behavior was observed in either treatment. Subsequent survival of the trout upon release was not measured.

Tipping (1998) reared cutthroat trout (O. clarki) in gravel-bottomed ponds, concrete raceways, and baffled raceways. Juveniles were released at a target length of 22-24 cm in mid-April. Rearing densities were about 35 times greater in the raceways than in the ponds, while the flows were about 2.5 times greater in the ponds than in the raceways. Returns of adults from juveniles reared in ponds were significantly greater than that from juveniles reared in conventional raceways. Similarly, returns of adults from juveniles reared in conventional raceways were significantly greater than those from juveniles reared in baffled raceways.

Our results with spring chinook salmon showed that juveniles reared in baffled raceways did not produce adults efficiently by any of the parameters used to estimate adult production. Juveniles reared in conventional raceways were far better for producing adult salmon.

A number of studies have examined the effects of rearing density on chinook salmon. One of the best was that of Banks (1994) who examined the effects of rearing density and flow on survival of spring chinook salmon at Carson National Fish Hatchery. Survival of Banks' chinook salmon was only about 0.26%, nearly 10-fold lower than that of Willamette Hatchery at this time (Table 32). In contrast to the present study, Banks found that increased rearing density caused a decrease in percent yield. Numbers of fish recovered per raceway either did not change significantly (for 1982 and 1985 broods) or decreased (1983 and 1984 broods) with increased rearing density. In the present study, we found that only the 1989 brood showed an inverse relationship between percent yield and rearing density. The other brood years showed no significant relationship. Also in contrast to Banks (1994), fish reared at Willamette Hatchery at the greatest densities had the greatest number of fish recovered. It is possible that ocean conditions determined the different outcomes from these density experiments.

Another well-conducted experiment with spring chinook salmon was that of Hopley (1980) at Cowlitz Hatchery in Washington. Hopley found that adult yield varied inversely with rearing density, that is, the highest rearing densities produced the smallest percent yield. When he examined adults produced per pond with rearing density, he found that the highest rearing densities produced the greatest number of returning adults.

Results from a number of hatchery-release experiments with chinook and coho salmon reared at different densities were reviewed

by Ewing and Ewing (1995). These covered the period from 1975 to 1994. In 14 of 15 experimental brood years of chinook salmon, there was a negative relationship between the rearing density of the juveniles and the percent yield of adults. The relationship between adult yield per raceway and rearing density was not as clear cut. In 7 of the 15 brood years, no relationship was found, in 4 brood years, the relationship was negative, and in 4 brood years the relationship was positive. The present experiment adds another 4 experimental brood years to indicate that increased rearing densities produce greater numbers of adults.

At the time that this experiment was undertaken in 1988, two other experiments on rearing density was started: one at the Abernathy Salmon Culture Technology Center and one at Umatilla. Both were unable to maintain their experimental designs. The experiment at Abernathy had to be modified after the first year, when ocean conditions limited the number of brood fish returning to the hatchery. To maintain sufficient brood for the following years, the experimental design was significantly changed. At Umatilla Hatchery (Hayes et al. 1994,1995), compromises in rearing strategies left the experiment examining multiple simultaneous variables. In particular, conventional (Oregon) raceways and Michigan raceways were reared at different densities and loads, so that two variables were operating simultaneously. Consequently, the ability to reach firm conclusions about the better of the two raceway styles or the effects of rearing density or load was compromised.

The experimental design in the present experiment could be replicated reasonably well for the four rearing years of the project. Consequently, the data could be interpreted and analyzed, even though the fish were released into the warm waters of El Nino for all four release years. These allowed us to answer the four questions posed in the introduction to this report:

Will increased rearing densities promote greater survival of hatchery-reared chinook salmon? From the data reported here, the answer is yes. The numbers of recovered adults was directly related to the rearing density of the juveniles. Efficiency of rearing, as measured by the percent yield, was decreased at increased rearing densities, although this effect was weak in all but the first brood year. The results from this and other studies on the effect of rearing density on chinook salmon suggests that increased numbers of chinook salmon returning to the Columbia Basin could be achieved by the use of higher rearing densities.

Is oxygen supplementation useful for this increased production? Again, the answer is yes. Juvenile chinook salmon reared at increased densities will reach limiting amounts of oxygen by the time they are ready for release. Without supplemental oxygen, the juveniles will probably be stressed and may not show the desired increases in production. Water quality parameters were rarely shown in previous density studies (Ewing and Ewing 1995) so it is possible that the variable results from these studies could be ascribed to oxygen availability. There is some indication that oxygen supplementation in this study assisted survival even at normal rearing densities (see Figures 5 and 16)

Will Michigan raceways provide a means for increasing production of chinook salmon? The answer is No. Michigan raceways did very poorly, compared to conventional raceways. The reason for the poor performance in these raceways is unknown. Respiratory parameters were increased in fish in these raceways, suggesting that the fish may have had to work harder to maintain their position. Whether this extra effort constitutes a stress or positive exercise component is not known. However, Tipping (1998) found that cutthroat trout (Oncorhynchus clarki) also did not survive as well in Michigan raceways as in conventional raceways.

Is the increased production cost-effective? The answer is yes. Estimates of cost per adult were lowest for fish reared in conventional raceways at the highest rearing densities, even though these raceways required modifications for introduction of oxygen. These costs could possibly be reduced with the purchase of oxygen generators rather than liquid oxygen.

If the goal is to increase hatchery production in the Columbia River, the recommendations from these results are the following:

1) Oxygen generators could be installed in existing Columbia River hatcheries.
2) Rearing densities could be increased.
3) Oxygen concentrations in the raceways should be maintained near the saturation point of oxygen.
4) As little handling as possible should be done to the fish.
5) Further studies should be initiated to determine if further increases in rearing density with oxygen

supplementation can result in further increases in adult survival.

It is recognized that these recommendations are not those adopted for rearing fish in Washington and in the National Fish Hatcheries. Based on the relationship between increased rearing density and decreased percent yield, these agencies have embarked on a policy of reduction of rearing density. The two measures of hatchery rearing must be balanced, recognizing their strengths and weaknesses. If fish numbers are low and each fish is precious, then low densities provide the most efficient rearing, that is, the fewest juveniles produce the most adults. If fish numbers are good and there are more fish than are needed for brood stock, it might make sense to rear increased densities of chinook salmon with oxygen supplementation to provide more fish to the offshore fisheries and the sport fisheries.

In conclusion, we feel that the experiment performed at Willamette Hatchery indicates that increased rearing density with oxygen supplementation could be used to pursue the Power Planning Council's stated goal of doubling the size of the chinook salmon run in the Columbia River. This obviously is not a major solution to reduced runs, but would provide a cheaper alternative to the construction of new hatchery facilities in the Columbia Basin.

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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. (in preparation) Accuracy and variance associated with estimations of oxygen consumption rates using Liao's equations.

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 Aquaculture.

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 Aquaculture.

Ewing, R. D. and H. W. Lorz. (in preparation). Adult spring chinook salmon (Oncorhynchus tshawytscha) contribution from juveniles reared at different rearing densities and raceway conformations at Willamette Hatchery, Oregon. To Aquaculture.