Volume 101
Article 08

FISHERY RESEARCH

DETERMINATION OF KOKANEE EGG-TO-FRY SURVIVAL AND SPAWNING HABITAT USE, THE EFFECTS OF LAND-USE ACTIVITIES ON SPAWNING HABITAT AND INCUBATION SUCCESS, AND THE POTENTIAL FOR CREATING SPAWNING HABITAT IN THE NORTH FORK OF THE PAYETTE RIVER, IDAHO

F-73-R-16

Subproject V, Study IX
Completion Report

By:

David H. Bennett
Frank O. Frost

University of Idaho
Moscow, Idaho 83843

IDFG 95-19
May 1995

ERRATA

1. Page 3, second paragraph, first sentence should read: "Peak flows, caused by evacuation of upstream reservoirs, were 2.7 and 3.8 m^3/s in 1992 and 1993, respectively."
   Page 3, second paragraph, second sentence should read: "Peak flows occurred immediately prior to peak migrations of adult kokanee and lasted one day followed by a rapid flow decrease to base flow (0.4 m^3/s) within about 2 weeks."

2. Page 21, second paragraph, second sentence should read: "Flows increased sharply on 30 August 1992 to 2.7 m^3/s as a result of water releases from upstream reservoirs."
   Page 21, second paragraph, fourth sentence should read: "After the hydrograph peak, flows subsided gradually to a base flow around 0.34 m^3/s."
   Page 21, second paragraph, sixth sentence should read: "Flows began to increase sharply on 4 September, peaked on 7 September at 3.8 m^3/s, and gradually subsided to a base flow between 0.34 and 0.4 m^3/s."

3. Page 104, second paragraph, sixth sentence should read: "Our study site was located in Idaho batholith geology and observations of spawning were at river flows of 0.92 to 1.4 m^3/s, whereas, Parsons and Huberts's sudy sites were 1.6 (Sheep Creek) and 24 m^3/s (Green River)."

4. Page 108, second paragraph, seventh sentence should read: "Stream-width data collected at transects at a flow of 1.01 m^3/s were used to construct the river model."

5. Page 114, first paragraph, second sentence should read: "Data collection was conducted at flows that normally occur during spawning (0.42-2.89 m^3/s)

6. Page 177, second paragraph, fourth sentence should read: "During kokanee migration in 1992 and 1993, peak flow was 2.7 and 3.8 m^3/s, respectively."
   Page 177, second paragraph, fifth sentence should read: "Base-flow was similar at about 0.4 m^3/s for both years."
   Page 177, fourth paragraph, first sentence should read: "Habitat available to kokanee in two principal spawning areas in the NFPR increased rapidly between baseflow and approximately 0.93 m^3/s (Figure 63)."
   Page 177, fourth paragraph, second sentence should read: "The amount of available area increased slightly at discharges >1.14 m^3/s."

TABLE OF CONTENTS

Page

ABSTRACT 1

INTRODUCTION 5

OBJECTIVES 11

STUDY AREA 11

OBJECTIVE 1. To estimate kokanee spawning escapement and potential egg deposition in the North Fork of the Payette River for the 1992 and 1993 brood years.

INTRODUCTION 12

METHODS 13

Spawning Escapement 13
Egg Deposition 15
Egg Retention 15
Time of Spawning 16

RESULTS 17

Spawning Escapement 17
Egg Deposition 23
Egg Retention 23
Time of Spawning 29

DISCUSSION 32

Spawning Escapement 32
Egg Deposition 36
Egg Retention 38
Time of Spawning 39

OBJECTIVE 2. To estimate egg-to-fry survival of the 1992 and 1993 kokanee broods and to evaluate the growth, condition, and developmental stage of migrating fry.

INTRODUCTION 42

METHODS 44

Seasonal and Diurnal Emigration Timing 44
Trap Efficiency 47
Recruitment and Egg-to-Fry Survival 49
Fry Size, Condition, and Developmental Stage 50

RESULTS 51

Seasonal and Diurnal Emigration Timing 51
Trap Efficiency 60
Recruitment and Egg-to-Fry Survival 64

TABLE OF CONTENTS

Page

Fry Size, Condition, and Developmental Stage 64

DISCUSSION 70

Seasonal and Diurnal Emigration Timing 70
Trap Efficiency 75
Recruitment and Egg-to-Fry Survival 77
Fry Size, Condition, and Developmental Stage 79

OBJECTIVE 3. To determine kokanee survival to pre-emergence in relation to substrate size composition.

INTRODUCTION 82

METHODS 84

Density and Survival 84
Substrate Composition 86

RESULTS 88

Density and Survival 88
Substrate Composition 90

DISCUSSION 91

Density and Survival 91
Substrate Composition 99

OBJECTIVE 4. To quantify kokanee spawning distribution in relation to available habitat and to analyze use of spawning habitat in relation to availability.

INTRODUCTION 103

METHODS 106

Habitat Availability and Use 108
Habitat Availability 108
Spawning Distribution and Habitat Use 108
Statistical Analysis 111
Microhabitat Availability and Use 112
Microhabitat by Habitat Type 115

RESULTS 115

Habitat Availability and Use 115
Habitat Availability 115
Spawning Distribution and Habitat Use 127
Statistical Analysis 151
Microhabitat Availability and Use 153
Microhabitat by Habitat Type 157

TABLE OF CONTENTS

Page

DISCUSSION 160

Habitat Availability and Use 160
Habitat Availability 160
Spawning Distribution and Habitat Use 165
Statistical Analysis 166
Microhabitat Availability and Use 168
Microhabitat by Habitat Type 170

OBJECTIVE 5. To assess the effects of flow alterations on kokanee survival to pre-emergence and the availability of spawning habitat in areas of intensive spawning use.

INTRODUCTION 173

METHODS 174

RESULTS 177

DISCUSSION 177

OBJECTIVE 6. To describe the potential for rehabilitating kokanee spawning habitat in the North Fork of the Payette River with the objective of increasing fry production.

INTRODUCTION 182

METHODS 182

Substrate Scarification 182
Boulder Placement 183
Potential Fry Production 184

RESULTS 185

Substrate Scarification 185
Boulder Placement 185
Potential Fry Production 190

DISCUSSION

Substrate Scarification 190
Boulder Placement 193
Potential Fry Production 194

GENERAL DISCUSSION 197

SUMMARY 200

REFERENCES 203

LIST OF TABLES

Page

Table 1. Number of Kokanee spawners counted on foot survey sin the North Fork of the Payette River, Idaho during the 1992 and 1993 spawning runs 19

Table 2. Nontarget species trapped and counted from the adult kokanee weir in 1993 in the North Fork of the Payette River, Idaho 22

Table 3. Fecundity and potential egg deposition for the 1992 kokanee brood in the North Fork of the Payette River, Idaho 24

Table 4. Fecundity and potential egg deposition for the 1993 kokanee brood in the North Fork of the Payette River, Idaho 25

Table 5. Age distribution and size at age (fork length (by sex) for the 1992 and 1993 kokanee broods in the North Fork of the Payette River, Idaho 26

Table 6. Egg retention frequency distribution and overall mean number of eggs retained by age class in female Kokanee collected in the North Fork of the Payette River, Idaho, for brood years 1992 and 1993 28

Table 7. Mean egg retention by age class and statistics used to compute total egg loss due to egg retention for the 1992 and 1993 kokanee broods at the North Fork of the Payette River, Idaho. Sample sizes are indicated in parentheses 30

Table 8. Fry classification scheme used to classify migrant kokanee in the North Fork of the Payette River, Idaho, during 1993 and 1994 sampling periods. Adopted from Canadian Department of Fisheries and Oceans (Shepherd 1990) 52

Table 9. Relative river state and number of kokanee fry marked, released, and recaptured for assessing trap efficiency in the North Fork of the Payette River, Idaho, from 4 April to 4 May 1993 at trap site 1 61

Table 10. Relative river state and number of kokanee fry marked, released, and recaptured for assessing trap efficiency in the North Fork of the Payette River, Idaho, from 4 April to 2 June 1994 at trap site 2 61

Table 11. Relative river state and number of Kokanee fry marked, released, and recaptured for assessing trap efficiency in the North Fork of the Payette River, Idaho, after 2 June 1994 at trap site 3 61

Table 12. Total egg disposition and egg-to-fry survival for the 1992 and 1993 kokanee broods at Payette Lake, Idaho. Ninety-five percent confidence limits are indicated in parentheses 65

LIST OF TABLES

Page

Table 13. Average length, developmental stage, and condition factor comparisons for 1993 migrant kokanee in the North Fork of the Payette River, Idaho. Within each category, means sharing a common letter are not significantly different (P>0.05) 71

Table 14. Average length, developmental stage, and condition factor comparisons for 1994 migrant kokanee in the North Fork of the Payette River, Idaho. Within each category, means sharing a common letter are not significantly different (P>0.05) 71

Table 15. Reported kokanee and sockeye salmon Oncorhynchus nerka egg-to-fry survivals in various locations. All survivals were determined from egg deposition to emigrant fry 78

Table 16. Gravel statistics of five kokanee spawning areas that were highly utilized in 1992 and 1993 in the North Fork of the Payette River. Figures detailing locations are indicated in column one. Ranges of statistics are indicated in parentheses. Locations A and E were in spring habitat 92

Table 17. Water depth and velocity measured in kokanee spawning areas. None of the investigators reported use of substrate for spawning 105

Table 18. Habitat classification scheme used to classify aquatic habitat in the North Fork of the Payette River, Idaho. Criteria for pools, glides, and riffles (Orth 1983) 110

Table 19. Available aquatic habitat by area and total for the entire kokanee spawning distribution in the North Fork of the Payette River, Idaho. Total for each habitat type were used to calculate expected usage in the use-availability analysis. Units are m^2..... 116

Table 20. Spawning distribution by area and total for the 1993 kokanee spawning run tin the North Fork of the Payette River, Idaho 128

Table 21. Observed kokanee counts (N) and the percent area available that was used by kokanee for spawning by area, habitat type, and total for the 1993 spawning by run in the North Fork of the Payette River, Idaho. Total observed counts were used in the use-availability analysis 150

Table 22. Habitat use-availability analysis of aquatic habitat within kokanee spawning distribution in the North Fork of the Payette River, Idaho 152

Table 23. Available and used water depths in four habitat types throughout the kokanee spawning distribution in the North Fork of the Payette River, Idaho during 1992 and 1993 158

LIST OF TABLES

Pace

Table 24. Water velocities available and used by kokanee for spawning in four habitat types throughout the kokanee spawning distribution in the North Fork of the Payette River, Idaho during 1992 and 1993 159

Table 25. Area (m^2), dominant substrate, and peak spawner count in 1993 for treated habitat plots in the North Fork of the Payette River, Idaho 188

Table 26. Estimated fry production expected as a result of spawning habitat rehabilitation (substrate scarification) in the North Fork of the Payette River, Idaho 191

Appendix Table 1. Statistics for gravel samples collected in kokanee spawning areas in the North Fork of the Payette River, Idaho 216

LIST OF FIGURES

Page

Figure 1. Study area map of the North Fork of the Payette River, Idaho. Shading in left figure indicates kokanee spawning distribution 6

Figure 2. Number of kokanee trapped daily during the 1992 spawning run in the North Fork of the Payette River, Idaho, in relation to river flow ($m^{3/s}$) and water temperature (°C) 18

Figure 3. Number of kokanee trapped daily during the 1993 spawning run in the North Fork of the Payette River, Idaho, in relation to river flow ($m^{3/s}$) and water temperature (°C) 20

Figure 4. Length distributions of kokanee by sex and brood year from the North Fork of the Payette River, Idaho. Age numerals indicate mean length of spawners 27

Figure 5. Accumulated thermal units for five areas of the North Fork of the Payette River, Idaho, during incubation 1993/1994 31

Figure 6. Kokanee spawner counts for three areas of the North Fork of the Payette River, Idaho, for which temperature data was collected during 1993/1994 33

Figure 7. Sampling sites at the bridge on Eastside Drive used in 1993 and 1994 for sampling kokanee fry migrating in the North Fork of the Payette River, Idaho 45

LIST OF FIGURES

Page

Figure 8. Daily estimates of Kokanee fry migrating in the North Fork of the Payette River, Idaho, during spring 1993 53

Figure 9. Daily estimates of Kokanee fry migrating in the North Fork of the Payette River, Idaho, during spring 1994 55

Figure 10. Water temperature and daily estimates of the 1993 kokanee fry migration in the North Fork of the Payette River, Idaho. Temperature data is from Thurow and King, unpublished data 56

Figure 11. Water temperature and daily estimates of the 1994 kokanee fry migration in the North Fork of the Payette River, Idaho 57

Figure 12. Diel timing of the March to May, 1993, kokanee fry migrations in the North Fork of the Payette River, Idaho 58

Figure 13. Diel timing of the March through June, 1994, kokanee fry migrations in the North Fork of the Payette River, Idaho 59

Figure 14. Thermal units accumulated by kokanee during 1992/1993 and 1993/1994 and cumulative estimates of fry migrating in the North Fork of the Payette River, Idaho 67

Figure 15. Length and Fulton's condition factor of kokanee fry during the 1993 and 1994 fry migrations in the North Fork of the Payette River, Idaho 68

Figur3 16. Length distributions of kokanee fry for 1993 and 1994 migrations in the North Fork of the Payette River, Idaho 69

Figure 17. Developmental stage of kokanee fry and river stage during the 1993 and 1994 fry migrations from the North Fork of the Payette River, Idaho 70

Figure 18. Histograms of survival to pre-emergence as determined from hydraulic sampling in the North Fork of the Payette River in 1993 and 1994 89

Figure 19. Substrate sampling sites in spawning Locations A and B of the North Fork of the Payette River, Idaho. Location B was classified as spring habitat 93

Figure 20. Substrate sampling sites in spawning Locations C and D of the North Fork of the Payette River 94

LIST OF FIGURES

Page

Figure 21. Substrate sampling sites in spawning Location E of the North Fork of the Payette River. Location E was classified as spring habitat 95

Figure 22. Ten areas of the North Fork of the Payette River, Idaho, used to depict kokanee spawning distribution and available spawning habitat 109

Figure 23. Available aquatic habitat in Area 1, Fisher Creek, of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 16.5 m 117

Figure 24. Available aquatic habitat in Area 2, of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 46 m 118

Figure 25. Available aquatic habitat in Area 3 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 35 m 119

Figure 26. Available aquatic habitat in Area 4 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 14 m 120

Figure 27. Available aquatic habitat in Area 5 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 27 m 121

Figure 28. Available aquatic habitat in Area 6 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 14 m 122

Figure 29. Available aquatic habitat in Area 7 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 15 m 123

Figure 30. Available aquatic habitat in Area 8 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 16 m 124

Figure 31. Available aquatic habitat in Area 8 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 15 m 125

Figure 32. Available aquatic habitat in Area 8 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 28 m 126

Figure 33. Kokanee spawning distribution in Area 1, Fisher Creek, of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm =16 m 129

Figure 34. Kokanee spawning distribution in Area 2 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm =46 m 130

Figure 35. Kokanee spawning distribution in Area 3 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm =16 m 131

LIST OF FIGURES

Page

Figure 36. Kokanee spawning distribution in Area 4 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 14 m 132

Figure 37. Kokanee spawning distribution in Area 5 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 27 m 133

Figure 38. Kokanee spawning distribution in Area 6 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 14 m 134

Figure 39. Kokanee spawning distribution in Area 7 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 15 m 135

Figure 40. Kokanee spawning distribution in Area 8 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 16 m 136

Figure 41. Kokanee spawning distribution in Area 9 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 15 m 137

Figure 42. Kokanee spawning distribution in Area 10 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 28 m 138

Figure 43. Habitat used by kokanee for spawning in Area 1, Fisher Creek, of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 16 m 140

Figure 44. Habitat used by kokanee for spawning in Area 2 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat maps. Scale is 1 cm = 46 m. All spawning above Fisher Creek was in riffles 141

Figure 45. Habitat used by kokanee for spawning in Area 3 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 35 m 142

Figure 46. Habitat used by kokanee for spawning in Area 4 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 14 m 143

Figure 47. Habitat used by kokanee for spawning in Area 5 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 27 m 144

LIST OF FIGURES

Page

Figure 48. Habitat used by kokanee for spawning in Area 6 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 14 m 145

Figure 49. Habitat used by kokanee for spawning in Area 7 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 15 m 146

Figure 50. Habitat used by kokanee for spawning in Area 8 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 16 m 147

Figure 51. Habitat used by kokanee for spawning in Area 9 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 15 m 148

Figure 52. Habitat used by kokanee for spawning in Area 10 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 28 m 149

Figure 53. Frequency histograms of available water depth in the North Fork of the Payette River, Idaho, and water depths used by kokanee for spawning in 1992 and 1993. Also shown is the probability curve derived from use data 154

Figure 54. Frequency histograms of available water velocity in the North Fork of the Payette River, Idaho, and velocities used by kokanee for spawning in 1992 and 1993. Also shown is the probability curve derived from use data 155

Figure 55. Frequency histograms of available substrate in the North Fork of the Payette River, Idaho, and substrate used by kokanee for spawning in 1992 and 1993. Probability curve is shown for use data. S=silt (<0.5 mm); FS=fine sand (>0.5-3 mm); CS=coarse sand (>3-6 mm); SG=small gravel (>6-26 mm); LG=large gravel (>26-50 mm); C=cobble (>50-150 mm); B=boulder (>150 mm); BR=bedrock 156

Figure 56. Frequency histograms of available substrate in pools in the North Fork of the Payette River, Idaho, and substrate used by kokanee for spawning in 1992 and 1993. Probability curve is shown for use data. S=silt (<0.5 mm); FS=fine sand (>0.5-3 mm); CS=coarse sand (>3-6 mm); SG=small gravel (>6-26 mm); LG=large gravel (>26-50 mm); C=cobble (>50-150 mm); B=boulder (>150 mm); BR=bedrock 161

LIST OF FIGURES

Page

Figure 57. Frequency histograms of available substrate in glides in the North Fork of the Payette River, Idaho, and substrate used by kokanee for spawning in 1992 and 1993. Probability curve is shown for use data. S=silt (<0.5 mm); FS=fine sand (>0.5-3 mm); CS=coarse sand (>3-6 mm); SG=small gravel (>6-26 mm); LG=large gravel (>26-50 mm); C=cobble (>50-150 mm); B=boulder (>150 mm); BR=bedrock 162

Figure 58. Frequency histograms of available substrate in riffles in the North Fork of the Payette River, Idaho, and substrate used by kokanee for spawning in 1992 and 1993. Probability curve is shown for use data. S=silt (<0.5 mm); FS=fine sand (>0.5-3 mm); CS=coarse sand (>3-6 mm); SG=small gravel (>6-26 mm); LG=large gravel (>26-50 mm); C=cobble (>50-150 mm); B=boulder (>150 mm); BR=bedrock 163

Figure 59. Frequency histograms of available substrate in springs in the North Fork of the Payette River, Idaho, and substrate used by kokanee for spawning in 1992 and 1993. Probability curve is shown for use data. S=silt (<0.5 mm); FS=fine sand (>0.5-3 mm); CS=coarse sand (>3-6 mm); SG=small gravel (>6-26 mm); LG=large gravel (>26-50 mm); C=cobble (>50-150 mm); B=boulder (>150 mm); BR=bedrock 164

Figure 60. Boundary of the study site in Area 4 of the North Fork of the Payette River used to determine relationship between spawning habitat availability and river flow (m^3/s) 175

Figure 61. Boundary of the study site in Area 6 of the North Fork of the Payette River used to determine relationship between spawning habitat availability and river flow (m^3/s) 176

Figure 62. Estimated flows (m^3/s) during the 1992 and 1993 sampling seasons in the North Fork of the Payette River, Idaho 178

Figure 63. Amount of spawnable area (m^2) in relation to river flow in two principal kokanee spawning areas in the North Fork of the Payette River, Idaho 179

Figure 64. Habitat rehabilitation treatment plots, potential habitat, and location of experimental boulders 5 and 6 in Area 5 of the North Fork of the Payette River, Idaho 186

Figure 65. Habitat rehabilitation treatment plots and potential habitat in Area 8 of the North Fork of the Payette River, Idaho 187

Figure 66. Location of experimental boulders 1 - 4 in Area 2 of the North Fork of the Payette River, Idaho 189

ACKNOWLEDGMENTS

We thank the Idaho Department of Fish and Game for financial support. The long hours in the field and laboratory were made possible by many dedicated people. A special thanks to Brad Johnson, Steve Brink, Mike Mosher, Kelley Gillogly, Jim Roll, Matt Campbell, Robert Vowel, Suzanne Edwards, and Pete Cleary. Also, thanks to Don Anderson, Paul Janssen, Cindy Weston, and Joel Patterson, Idaho Department of Fish and Game, McCall, for their assistance. Toru Ottawa and Craig Rindlisbacher assisted extensively with Arc/Info and Mike Coffey and Mike Radco provided essential assistance with Global Positioning Systems.

ABSTRACT

Personnel of the Idaho Department of Fish and Game (IDF&G) initially identified the quantity and quality of salmonid spawning habitat in the North Fork of the Payette River (NFPR) as the probable factors limiting kokanee Oncorhvnchus nerka abundance in Payette Lake, Idaho. Low kokanee densities (lakes of similar productivity were 2-3 times higher than Payette Lake densities), large size of adults (maximum 395 mm), and low angler success all suggested the need to evaluate spawning and incubation conditions in the NFPR to ultimately improve the sport fishery in Payette Lake. We evaluated kokanee spawning habitat, spawning success, egg-to-fry survival, and potential to create or enhance spawning habitat in the NFPR to determine whether early life stages were limiting factors for the kokanee population.

Payette Lake is located in west-central Idaho adjacent to the city of McCall. Silvicultural activities in the Payette Lake drainage, conducted on steep slopes and erosion prone soils, by the U.S. Forest Service and Idaho Department of Lands, could negatively affect kokanee egg-to-fry survival. Also, fluctuating flows in the NFPR as a result of three small upstream reservoirs may dewater redds. Kokanee spawn annually August to October in a 7.2 km (low gradient, flat valley bottom) reach about 3 km upstream of Payette Lake.

Kokanee spawning escapement into the NFPR was 31,920 and 59,310 in 1992 and 1993, respectively. Egg depositions, calculated from estimates of escapement, sex ratio, fecundity, and egg retention, were 13.3 million (95% bound +/- 0.462 x 10^6) and 18.6 million (95% bound +/- 0.712 x 10^6) in 1992 and 1993, respectively. Egg deposition was high as

egg retention observed in moribund females was insignificant during both years.

Kokanee survival to the pre-emergent stage was 63.0%, 66.6%, and 70.2% in 1992, 1993, and 1994, respectively. Higher survival in 1994 was probably related to time of sampling as embryos had gained significantly fewer thermal units than in 1993. Fry recruitment to Payette Lake was estimated at 2.51 million (95% bound +/- 0.491 x 10^6) and 4.53 million (95% bound +/- 1.16 x 10^6) in 1993 and 1994, respectively. Kokanee fry began emigrating in late March and until late June. Survival to the emigrant fry stage was 18.9% (95% bound +/- 3.7%) and 24.4% (95% bound +/- 6.3%) for the 1992 and 1993 brood years, respectively. Our data suggests significant mortality occurred from late incubation stages to emigration toward Payette Lake, although overall egg-to-fry survival rates were generally higher than those reported for other kokanee and sockeye salmon populations.

Pool habitat was the most abundant habitat type by area (m^2) available to kokanee in the NFPR followed by glide, riffle, slough, and spring. Spawning was clustered in three short reaches where 69% of kokanee spawners were counted in 1993. Spawning habitat use among habitat types differed significantly from that expected based on availability (X^2=13,930; $p<0.001$). Pool and slough habitat was used less than expected based on availability while glide, riffle, and spring habitats were selected based on availability.

Habitat assessments indicated kokanee selected specific microhabitat attributes. Mean water depth and velocity in kokanee spawning areas was 41 cm (range=3-159 cm; n=1,051) and 28 cm/s (range=0-130 cm/s; N=1,051), respectively. Habitat use curves showed the highest

probability of use occurred at depths of 30 to 42 cm, at velocities of 0 to 6 cm/s, and in substrates dominated by large gravel (>26-50 mm). Water depths used for *spawning* was consistent with that reported in the literature, while water velocities selected for spawning were lower in the NFPR than those previously reported for kokanee.

Peak flows, caused by evacuation of upstream reservoirs, were 29 and 41 m^3/s in 1992 and 1993, respectively. Peak flows occurred immediately prior to peak migrations of adult kokanee and lasted one day followed by a rapid flow decrease to base flow (4.7 m^3/s) within about 2 weeks. Spawnable area (m^2) at two principal kokanee spawning areas changed by 24 and 26% between peak and base flows. Dewatered redds were uncommon and survival in dewatered areas averaged 66.1%, similar to areas not dewatered. Although current upstream reservoir management does not cause significant kokanee mortality in the NFPR, simultaneous water releases from all three reservoirs could have adverse affects on spawning success.

We successfully created kokanee spawning habitat in reaches not previously used by kokanee in the NFPR. In 1993, kokanee spawned in five test plots treated by scarification with a backhoe and behind five of six boulders placed in midstream in 1994. Potential fry production from all improved sites was estimated to be 338,420, or about 15.0 and 8.3% of fry recruitment to Payette Lake in 1993 and 1994, respectively. Estimated total cost of creating all potential habitat in 1993 was $2,667 (U.S.).

We believe spawning habitat rehabilitation or other efforts to increase fry production from the NFPR are not currently necessary. Survivals to emigrant fry observed in this study will produce adequate

numbers of kokanee fry to optimally seed Payette Lake with moderately high escapements (>30,000). The availability of a few high quality spawning sites in the NFPR is adequate for sustaining this population and an abundant kokanee sport fishery in Payette Lake.

INTRODUCTION

Sockeye salmon Oncorhynchus nerka historically existed in Payette Lake, Valley County, Idaho (Everman 1896). Sockeye returned to the lake from the Pacific Ocean as adults, spawned in tributaries, reared in the lake as juveniles, and migrated to the Pacific Ocean to grow. Commercial fishing and dam construction in the Payette and Snake rivers led to the extirpation of sockeye in the Payette basin in the 1930s. In many lakes throughout the distribution of sockeye salmon, a nonanadromous form, the kokanee, developed from sockeye that failed to migrate to the sea (Ricker 1940). Kokanee are known to have historically coexisted with sockeye in the basin (Everman 1896) and were presumably derived from the now extinct anadromous stock. Today kokanee exist in Payette Lake where they are sustained completely by natural reproduction. Spawning occurs annually from August to October in the North Fork of the Payette River (NFPR), the largest tributary which enters the north end of Payette Lake (Figure 1). Kokanee support a popular sport fishery in Payette Lake and provide forage for other salmonid sport fish such as lake Salvelinus namaycush and cutthroat trout O. clarki.

Kokanee fisheries represent important fish resources in the western USA and Canada, as populations have been introduced or are supported by hatchery supplementation in many lakes and reservoirs (Wydoski and Bennett 1981). The kokanee fishery at Payette Lake has been limited by low numbers. Idaho Department of Fish and Game (IDF&G) manages the kokanee fishery at Payette Lake and has recently increased efforts to improve the fishery. A daily creel limit of kokanee on Payette Lake, five per angler, is conservative. Other managed kokanee

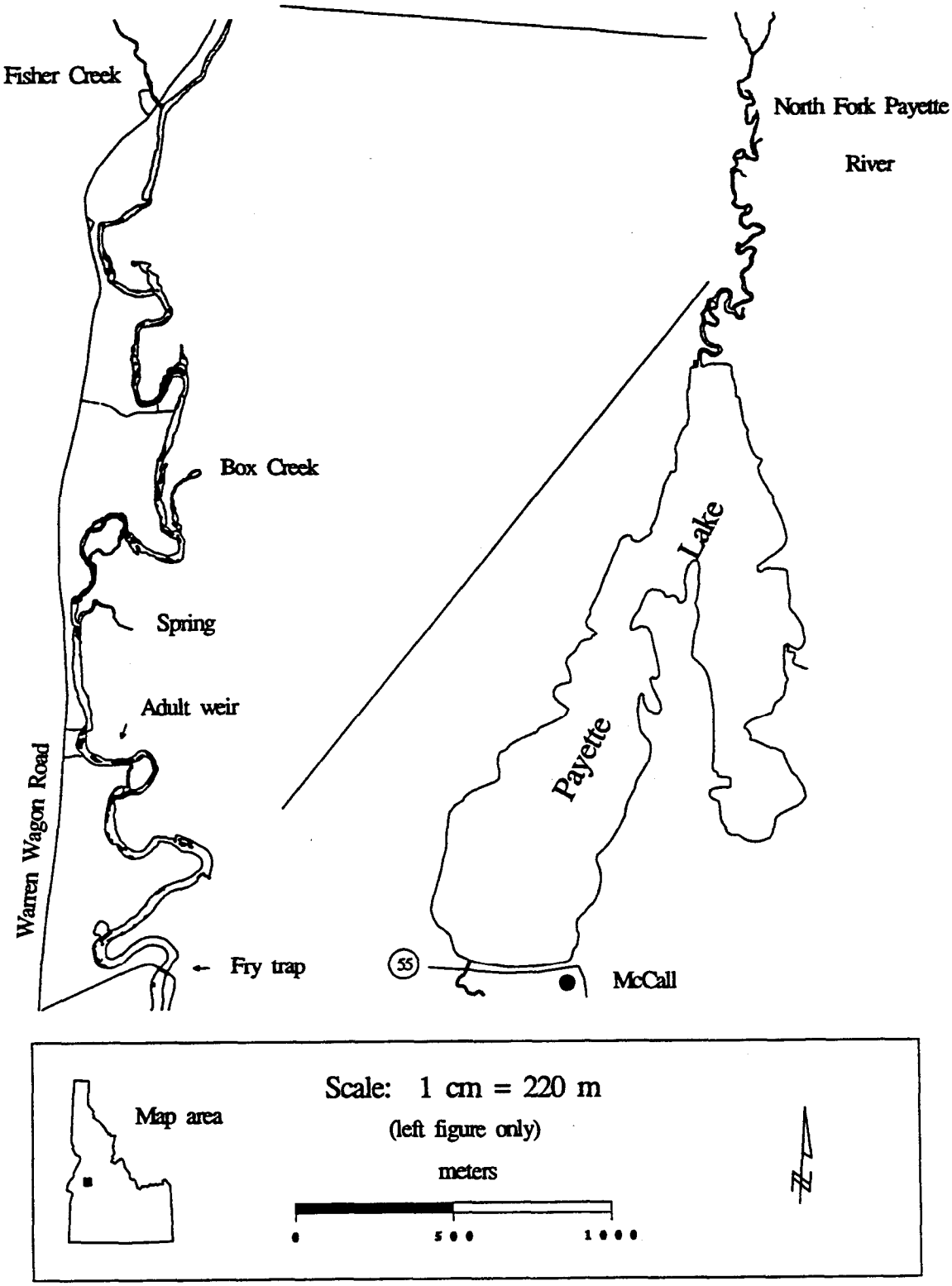

Figure 1. Study area map of the North Fork of the Payette River, Idaho. Shading in left figure indicates kokanee spawning distribution.

populations in Idaho (Pend Oreille and Coeur d' Alene lakes) have a daily limit of 25 per angler. Hatchery fish have been used to supplement the naturally reproducing fish in Payette Lake with no apparent success in improving the fishery, and therefore was suspended in 1994. Research on kokanee growth and lake productivity in Idaho (Rieman and Meyers 1992) indicated kokanee abundance in Payette Lake was approximately half what could potentially be supported by available habitat. Observations of kokanee spawning in Payette Lake during the late 1980s evoked concern on the amount of available spawning habitat (Grunder et al. 1990). Biologists hypothesized that spawning conditions (habitat availability and incubation success) in the NFPR were limiting the lake population, and spawning habitat improvements might be necessary to improve the lake fishery. This project developed in response to these initial observations and concerns and evaluated spawning and incubating conditions in the NFPR.

Rationale for Study

Size of adult kokanee indicated a low kokanee population in Payette Lake. Adults in the spawning run averaged approximately 320 mm in length with individuals as large as 395 mm. Kokanee approaching 275 to 325 mm in length indicate low densities for Idaho waters and suggest caution to avoid population collapse (Rieman and Meyers 1990). While studying the effects of fish density and lake productivity on kokanee growth in Idaho waters, Rieman and Meyers (1992) found evidence that growth is strongly influenced by the productivity of the rearing environment. Kokanee densities from Payette Lake were consistently lower for all age classes than those in other lakes of similar

productivity (Secchi transparency >7 m). Densities for Idaho lakes of comparable productivity (Alturas, Redfish, and Priest) were 2.0 times higher for age 1, 2.7 times higher for age 2, and 2.6 times higher for age 3 kokanee than in Payette Lake. These low densities suggest numbers of kokanee could be approximately doubled in Payette Lake to optimally seed lake habitat. Growth and adult size might be reduced and maintained at a level anglers deem acceptable. Doubling the abundance of kokanee ages 2 and 3 would improve this fishery by making more fish available for harvest. Ultimately kokanee numbers are controlled by the amount and productivity of lake rearing habitat, however, the available habitat in Payette Lake has not been optimally seeded in recent years. Therefore, kokanee numbers in Payette Lake could be limited by other factors prior to lake residence, namely survival during incubation in the NFPR or during initial lake residence.

Human activities known to negatively impact salmonid spawning habitat and incubation success occur in the watershed upstream of Payette Lake. The two major factors of concern are timber management and water flow management. These activities could be negatively impacting kokanee spawning and fry production by affecting the quality of the intragravel environment. The upper reaches of the NFPR drainage have historically been managed for timber which has damaged fish habitat, particularly with increased delivery of fine sediment (U.S. Forest Service 1991). The U.S. Forest Service and Idaho Department of Lands have conducted timber sales in the watershed, and recently conducted accelerated salvage harvests within the drainage as a result of insect infestation. The negative effects of increased fine sediment on survival and emergence of salmonid embryos in the substrate is

documented by many laboratory and field studies (Wickett 1954; Cordone and Kelley 1961; McNeil and Ahnell 1964; Mason 1969; Koski 1975; Tappel and Bjornn 1983; Irving and Bjornn 1984; Sowden and Power 1985). Increased sedimentation can indirectly reduce the quality of the substrate where embryos are deposited as well as cause entrapment in the gravel. Reduced gravel porosity decreases intragravel water flow; the delivery of oxygen to and the removal of metabolic waste products from developing embryos and alevins is reduced. Hypoxic stress may result under these conditions and cause higher incubation mortality.

River flow in the NFPR is controlled by three reservoirs equipped with low head dams: Granite Lake on Fisher Creek, Box Lake on Box Creek, and Upper Payette Lake. Also, Payette Lake water levels are controlled by a dam on the outlet of the lake. These impoundments serve downstream irrigation needs as well as flood control and recreational benefits (Idaho Department of Fish and Game 1991). Impacts to kokanee may occur during each fall when the reservoirs are emptied. Recently, biologists observed high water levels during early September, the time when kokanee begin spawning. Later, as flows dropped, some redds became dewatered. The relative magnitude of lost habitat and its overall effect on the population is unknown. Altered river flows can negatively affect salmonid incubation success (Fraley et al. 1986) and the amount of available spawning habitat (Hamilton and Buell 1976; Reiser and Bjornn 1979).

Previous work with kokanee in Payette Lake used mid-water trawling to determine abundance of juveniles (Bowler 1981; Grunder et al. 1990; Grunder and Anderson 1991), creel surveys (Grunder et al. 1990), and annual estimation of kokanee spawning escapement (Grunder et al. 1990;

Grunder and Anderson 1991; Janssen and Anderson 1994). During 1988, IDF&G initiated efforts to measure gravel quality with sediment core samples and enhance several spawning areas by physically manipulating the substrate (Grunder et al. 1990). Kokanee did not show a preference for the treated sites during the 1988 spawning run. During 1989, attempts to quantify total wild/natural fry production from the NFPR was unsuccessful (Grunder and Anderson 1991), although it showed that kokanee fry migration to Payette Lake begins in mid- to late March.

OBJECTIVES

1. To estimate kokanee spawning escapement and potential egg deposition in the North Fork of the Payette River for the 1992 and 1993 brood years;

2. To estimate egg-to-fry survival of the 1992 and 1993 kokanee broods and to evaluate the growth, condition, and developmental stage of migrating fry;

3. To determine kokanee survival to pre-emergence in relation to substrate size composition;

4. To quantify kokanee spawning distribution in relation to available habitat and to analyze use of spawning habitat in relation to availability;

5. To assess the effects of flow alterations on kokanee survival to pre-emergence and the availability of habitat in areas of intensive spawning use; and

6. To describe the potential for rehabilitating kokanee spawning habitat in the North Fork of the Payette River with the objective of increasing fry production.

STUDY AREA

Payette Lake (2,024 ha) is located in Valley County, Idaho and lies within the central Idaho batholith, an area 16,000 mi^2 composed of intrusive granite rock. The NFPR drainage (113,000 km^2) is north of Payette Lake and the NFPR flows into the north end of Payette Lake. Idaho Department of Lands owns 10% of the drainage, from North Beach to above Fisher Creek encompassing the entire spawning area for kokanee, and the remainder of the drainage lies within the Payette National Forest. Five large and many small impoundments exist in the Payette basin for irrigation, flood control and recreation. Three small impoundments exist above all kokanee spawning areas in the NFPR; Upper Payette Lake, Granite Lake on Fisher Creek, and Box Lake on Box Creek. The Lake-Reservoir Irrigation District controls water releases from the reservoirs.

Objective 1. To estimate kokanee spawning escapement and potential egg deposition in the North Fork of the Payette River for the 1992 and 1993 brood years.

INTRODUCTION

Estimates of egg deposition are important statistics for managing salmonid stocks. Stock-recruit relationships (Ricker 1975) and egg-to-fry survivals are common uses that require egg deposition estimates. Estimates of spawning escapement, sex ratio, mean fecundity, and egg retention are all needed to quantify egg deposition. Spawning escapement is the most difficult to measure. Many methods have been used to estimate escapement and much work has been done in the Pacific Northwest and Canada, but little is available in the published literature (Cousens et al. 1982). Fence counts are usually regarded as the most accurate and reliable technique available because they include total numbers of fish passing the sampling point. Foot surveys are one of the oldest techniques used for *obtaining spawning* population estimates (Cousens et al. 1982), and they are used to avoid costly logistical problems associated with operating fences and weirs. The peak live count or the peak live plus dead count has been used as an index of abundance (Cousens et al. 1982). Another method involves summing the area of a curve depicting several counts over time divided by the estimated residence time of individuals to estimate total abundance. Other methods involve an adjustment at or near the time of peak *spawning* to account for the turnover in spawners (Cousens et al. 1982). One method of this type uses the peak live plus dead count multiplied by some expansion factor to estimate total abundance. The conversion between the partial count and total abundance is addressed by

simultaneous comparisons with weir counts or Petersen mark/recapture estimates. Some problems exist with most techniques, particularly the consistent underestimation of escapement with foot surveys, although many techniques have been adapted to local conditions. We estimated kokanee egg deposition for the 1992 and 1993 brood years using estimates of spawning escapement, sex ratio, fecundity, and egg retention. Egg deposition estimates were needed to calculate egg-to-fry survivals (Objective 2).

METHODS

Spawning Escapement

We used a picket weir to estimate kokanee spawning escapement into the NFPR during 1992 and 1993. The weir was constructed of galvanized conduit pickets (1.6 cm dia), set vertically through rectangular metal frames (4-5 m long), spaced 1.1 cm, and pounded 8 cm into the substrate. One meter fence posts were driven into the substrate on the downstream side to support the frames. Approximately 60 burlap bags filled with gravel and sand lined the downstream side of the weir to prevent substrate washouts under the pickets. The weir blocked upstream fish movement, and it was built in a V-formation designed to guide fish to midchannel and through a vertical slot formed by removing five pickets. The slot was equipped with an Alaskan model plastic fish entrance (Neptune Marine Products, Seattle, Washington) that reduced escapement from the trap and improved holding efficiency. Once through the entrance, fish were confined in a box trap (1.5 m x 3.6 m) constructed of pickets and short frames. The trap could hold up to 1,200 spawners for a 3-hour period.

We operated the trap during the kokanee spawning run from late August to early October 1992 and 1993. The trap was generally checked four times daily at which time all kokanee were sexed, counted, and released upstream. Other species were identified, recorded, and released. Morphological differences between male and female kokanee were used to determine sex. Also, to assess the success of recent hatchery supplementation, all kokanee in 1993 were examined for a missing adipose fin indicating a fish of hatchery origin. The trap required nearly constant attention during the peak of the run and later when large amounts of debris (mostly leaf drop) accumulated on the pickets.

Kokanee not migrating to the weir in 1993 were enumerated by foot surveys and in 1992 when the weir was inefficient during high flows. Foot surveys were conducted at 3 to 4 day intervals by a single observer walking upstream along the same route and counting all live kokanee. Polarized glasses were used as an aid to counting. Dead kokanee were not counted due to large numbers of live fish, difficulty in observing dead fish, and consumption by mammalian and avian predators. To obtain total estimates from foot surveys, the highest observed counts of live kokanee were expanded using an expansion factor of 1.73. The expansion factor was developed for this population by simultaneous operation of the weir and counts during the same year (Frost and Bennett 1994; Janssen and Anderson 1994). Total escapement in 1993 was determined by summing the weir count and the estimate of total kokanee spawning below the weir.

Egg Deposition

Fecundity estimates were determined by randomly selecting approximately 30 green females each year. Intact ovaries were removed from each female and preserved in a 10% formalin solution. In the laboratory, ovaries were teased apart with forceps and all eggs were counted to estimate total fecundity for each individual. To estimate potential egg deposition (PED), we used the equation for estimating a population total PED = $\Sigma(N_iF_i)$ where N_i is total number of females in age class i and F_i is mean fecundity of age class i (Scheaffer et al. 1990). Ninety-five percent bounds on the estimates were calculated using $2\{[\Sigma N_i^2(s_i^2/n_i)]^{0.5}\}$ where Ni is total number of females in age class i, s_i^2 is variance in fecundity for age class i, and n_i is sample size of females in age class i. Sagittae otoliths were removed from a random sample of moribund females, as well as females selected for fecundity estimates and males sampled for age and size at maturity, to determine female and male age and size distribution. Otoliths were stored in coin envelopes, air dried for at least a month, and a single observer counted annuli for each fish. A second observer verified ages on a random sample of 50 fish.

Egg Retention

Moribund females sampled for age were also examined for egg retention. We examined egg retention in kokanee as a variable in calculating egg deposition and as an indicator of spawning success (Chapman et al. 1986). Twelve and 10 surveys were made in 1992 and 1993 throughout the spawning run commencing when significant numbers of spawners began to die (usually about 10 days after peak arrival at the

adult trap). Standard lengths were converted to fork lengths using a relationship determined from 41 fish sampled at the weir. The observer made an incision from the vent to the isthmus, anterior to the pectoral fins, exposing viscera, evacuated ovaries, and any eggs not expelled during spawning. The body cavity was thoroughly examined for unvoided ova which, if present, were counted and recorded. Egg retention data were analyzed by age class. Only nonzero retention counts were used in our analyses. To estimate mean retention, counts were first transformed with a square root to stabilize variances and were untransformed (square) before being used to calculate total age-specific retention. Mean egg retention by age class (untransformed) was multiplied by the estimated number retaining eggs. The percent retaining eggs by age class was used to determine the total number in the population retaining eggs by age class (escapement x sex ratio x percent by age x percent by age retaining eggs). Age class totals were summed to determine total egg retention for each brood year.

Time of Spawning

During incubation of the 1993 brood, we installed five thermographs throughout the NFPR within the kokanee spawning distribution reported in the past (Grunder et al. 1990) and observed in 1992: North Fork lower, near the lower limit of spawning; the Spring, large area of ground water influence; Box Creek, tributary to North Fork; North Fork upper, near the upper limit of spawning; and Fisher Creek, tributary of the North Fork. Time of spawning was related to the temperature regime of the natal stream in nine Fraser River sockeye stocks (Brannon 1987). Early spawning stocks did so in rivers with a

relatively lower temperature regime than did later spawning stocks. Fry emergence timing was the principal evolutionary influence that determined time of sockeye salmon spawning in a stream (Brannon 1984; Miller and Brannon 1982). Barns (1969) reported an optimum time of lake entry exists for fry as determined by food availability and growth potential in the lake. Since length of incubation is determined by the temperature regime of the stream, spawning time becomes relatively fixed for each population (Brannon 1987). With previous knowledge of varying temperature regimes used by kokanee in the NFPR, we hypothesized the Payette Lake stock consists of substocks that may be identified with time and location of spawning. Time of spawning in areas monitored with thermographs was compared to temperature data (accumulated thermal units) to determine if areas with widely different temperature regimes were used at different times. If substocks exist, we expected to observe earlier spawning in cold areas and later spawning in warm areas.

RESULTS

Spawning Escapement

Kokanee spawning escapement into the NFPR was 31,920 and 59,310 in 1992 and 1993, respectively. In 1992, the weir was inefficient during high flow, but we counted 11,003 kokanee through the trap (Figure 2). Escapement was determined by applying the expansion factor (1.73) to the peak live count of 18,451 observed on 8 September 1992 (Table 1). In 1993 the weir successfully collected kokanee during high flows. Escapement above the weir was 42,280 kokanee (Figure 3). Kokanee spawning below the weir were estimated using the expansion factor (1.73) and the peak live count of 9,842 (Table 1). Hatchery origin fish

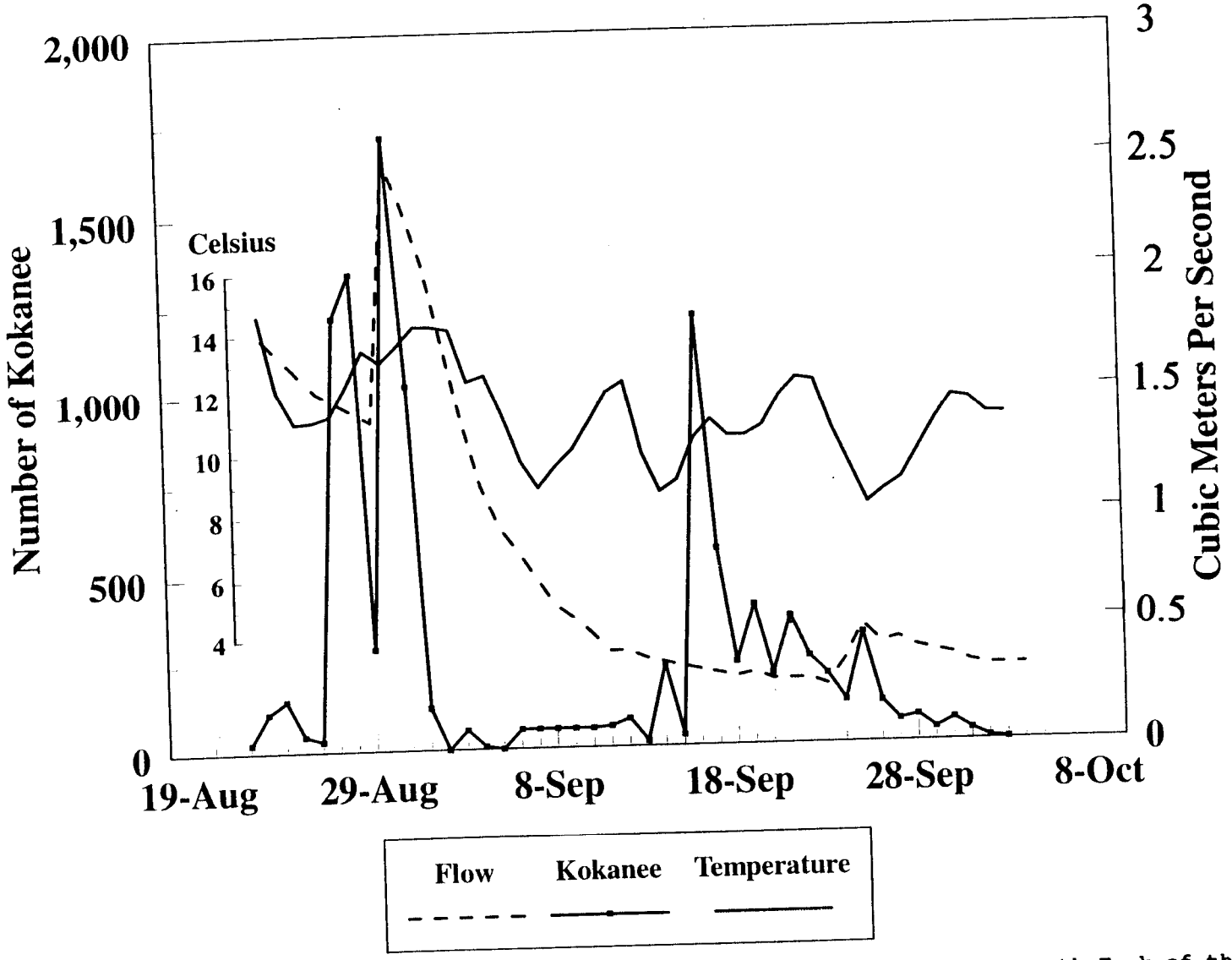

Figure 2. Number of kokanee trapped daily during the 1992 spawning run in the North Fork of the Payette River, Idaho, in relation to river flow (m^3/s) and water temperature (°C).

Table 1. Number of Kokanee spawners counted on foot surveys in the North Fork of the Payette River, Idaho during the 1992 and 1993 spawning runs.

1992		1993		
Date	Total	Date	Above weir	Below weir
26 August	3,288	28 August	55	40
29 August	3,000	1 September	215	571
1 September	11,822	5 September	1,581	568
8 September	18,451	8 September	6,323	2,435
14 September	13,776	12 September	13,974	4,900
21 September	1,037	16 September	20,148	7,650
9 October	1,887	20 September	18,412	8,905
		25 September	23,149	9,505
		29 September	25,152	9,842
		3 October	17,345	5,250
		7 October	12,619	4,016
		12 October	6,562	1,809

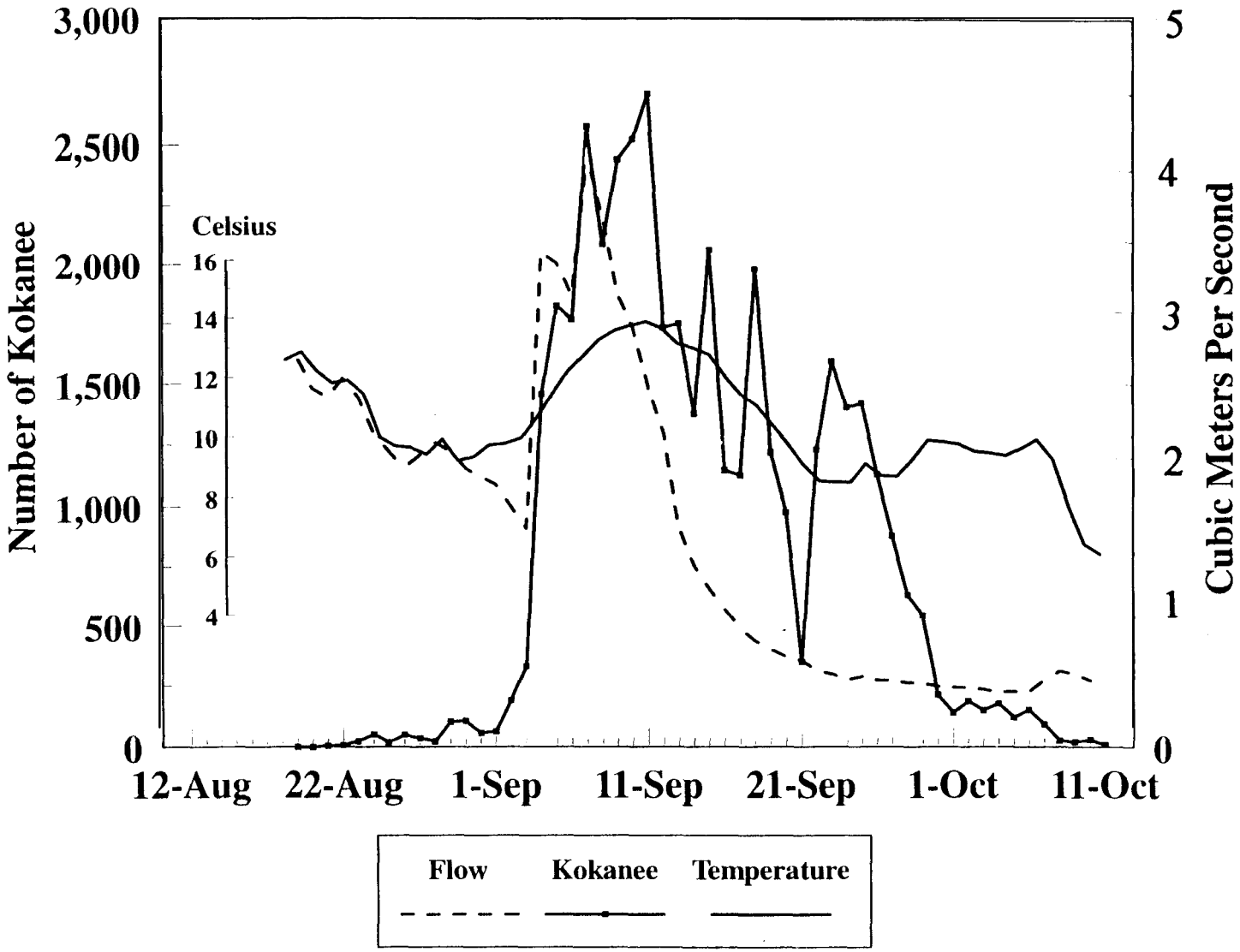

Figure 3. Number of kokanee trapped daily during the 1993 spawning run in the North Fork of the Payette River, Idaho, in relation to river flow (m^3/s) and water temperature (°C).

comprised a small portion (0.65%) of kokanee escapement above the weir in 1993 as 306 males and 77 females with adipose marks were collected. Additional hatchery fish could have spawned below the weir.

Upstream migration of large numbers of kokanee during both years occurred at times of increasing flows caused by upstream dam releases (Figures 2 and 3). Flows increased sharply on 30 August 1992 to 29 m^3/s as a result of water releases from upstream reservoirs. Increased flows coincided with the washout under the weir and many kokanee bypassing without being counted. After the hydrograph peak, flows subsided gradually to a base flow around 3.7 m^3/s. Peak flows in 1993 were higher than in 1992 (Figure 3). Flows began to increase sharply on 4 September, peaked on 7 September at 41 m^3/s, and gradually subsided to a base flow between 3.7 and 4.7 m^3/s. Water temperatures during spawning were similar during 1992 and 1993 (Figures 2 and 3). Spawning was initiated at temperatures of about 10 to 12•C and peaked when the temperature reached 14°C. Temperatures ranged from 6 to 8°C near the end of spawning. Temperatures during both years increased slightly with increasing flows from upstream dam releases.

Species other than kokanee were captured in the trap (Table 2). Cutthroat and rainbow trout O. mykiss were the most abundant non-target salmonid species. Two ripe mountain whitefish Prosopium williamsoni were captured on the final day (11 October) of trap operation in 1993. Similar species were also captured in the adult trap during 1992, but in much lower abundance than in 1993.

Table 2. Nontarget species trapped and counted from the adult kokanee weir in 1993 in the North Fork of the Payette River, Idaho.

Common name	- Scientific name	Number trapped
cutthroat trout	Oncorhynchus clarki	202
rainbow trout	Oncorhynchus mykiss	124
suckers	Catostomidae spp.	88
splake	Salvelinus namaycush x S fontinalis	18
northern squawfish	Ptychocheilus oregonensis	13
brook trout	S. fontinalis	2
mountain whitefish	Prosopium williamsoni	2

Egg Deposition

Egg deposition and sex ratios of the spawning population varied between years during 1992 and 1993. During both years male to female ratios indicated slightly more males in the spawning population, but the spawning population in 1992 had a higher male to female ratio - 1.28:1 compared to 1.10:1 in 1993. Potential egg deposition was 13.3 million (95% bound +/- 0.462 x 10^6; Table 3) in 1992 and 18.6 million (95% bound +/- 0.712 x 10^6; Table 4) in 1993. Deposition for both years was dominated by age 4 kokanee as 66 and 84% of PED was observed in this age class in 1992 and 1993 (Tables 3 and 4).

Age composition varied slightly between years and size at age differed. Age 4 kokanee dominated the run in both years and sexes except for males in 1992 which were dominated by age 3 (58.3%; Table 5). Age 3, the second most abundant age class, and age 5 were present in both sexes during both years. Age 2 males and age 6 females in 1992 were present in low numbers (Table 5). Spawners of similar age and sex were smaller in 1993 than in 1992 (Figure 4; Table 5). Males were generally smaller than females in 1992, but in 1993 this trend was reversed. Size differences between years were more pronounced in females than males as the mean length of age 4 females decreased from 327 mm in 1992 to 289 mm in 1993, while that for age 4 males decreased from 319 mm in 1992 to 293 mm in 1993 (Table 5). Males during both years exhibited a wider range in size than females (Figure 4).

Egg Retention

Egg retention in females ranged from zero to nearly 500 (Table 6). The occurrence of near total spawning failure (>300 retained eggs)

Table 3. Fecundity and potential egg deposition for the 1992 kokanee brood in the North Fork of the Payette River, Idaho.

Age	Percent (n)	Number of females[a]	Fecundity[b] (n; SD)	Subtotal
3	31.1 (65)	4,354	795 (10; 205)	3,461,400
4	60.8 (127)	8,512	1,039 (12; 242)	8,844,000
5	7.70 (16)	1,078	896 (3; 42)	965,890
6	0.500 (1)	70	1,060 (1; 1,249)	74,200
			Total:	13.3 million

[a] determined using escapement 31,920 and 1.28:1 male to female ratio.
[b] fecundity (F) determined using relationship developed from sample of 60 green females F=(5.695)L-921.5 where L is fork length.

Table 4. Fecundity and potential egg deposition for the 1993 kokanee brood at the North Fork of the Payette River, Idaho.

Age	Percent (n)	Number of females[&]	Fecundity[b] (n; SD)	Subtotal
3	18.4 (36)	5,197	512 (10; 82)	2,660,700
4	80.1 (157)	22,623	692 (24; 162)	15,655,000
5	1.53 (3)	432	725 (3; 762)	313,284
			Total:	18.6 million

a determined using escapement 59,310 and 1.10:1 male to female ratio.
[b] fecundity (F) determined using relationship developed from sample of 35 green females F=(4.625)L-672.2 where L is fork length.

Table 5. Age distribution and size at age (fork length) by sex for the 1992 and 1993 kokanee broods in the North Fork of the Payette River, Idaho.

		Males			Females		
Year	Age	Percent	Mean length (mm)	n	Percent	Mean length (mm)	n
1992	2	2.08	180	1	-	-	0
"	3	58.3	275	28	31.1	276	65
"	4	31.3	319	15	60.8	327	127
"	5	8.33	353	4	7.66	331	16
"	6	-	-	0	0.478	348	1
1993	2	-	-	0	-	-	0
"	3	33.1	246	47	20.0	245	47
"	4	64.8	293	92	78.3	289	184
"	5	2.11	312	3	1.28	302	3
"	6	-	-	0	-	-	0

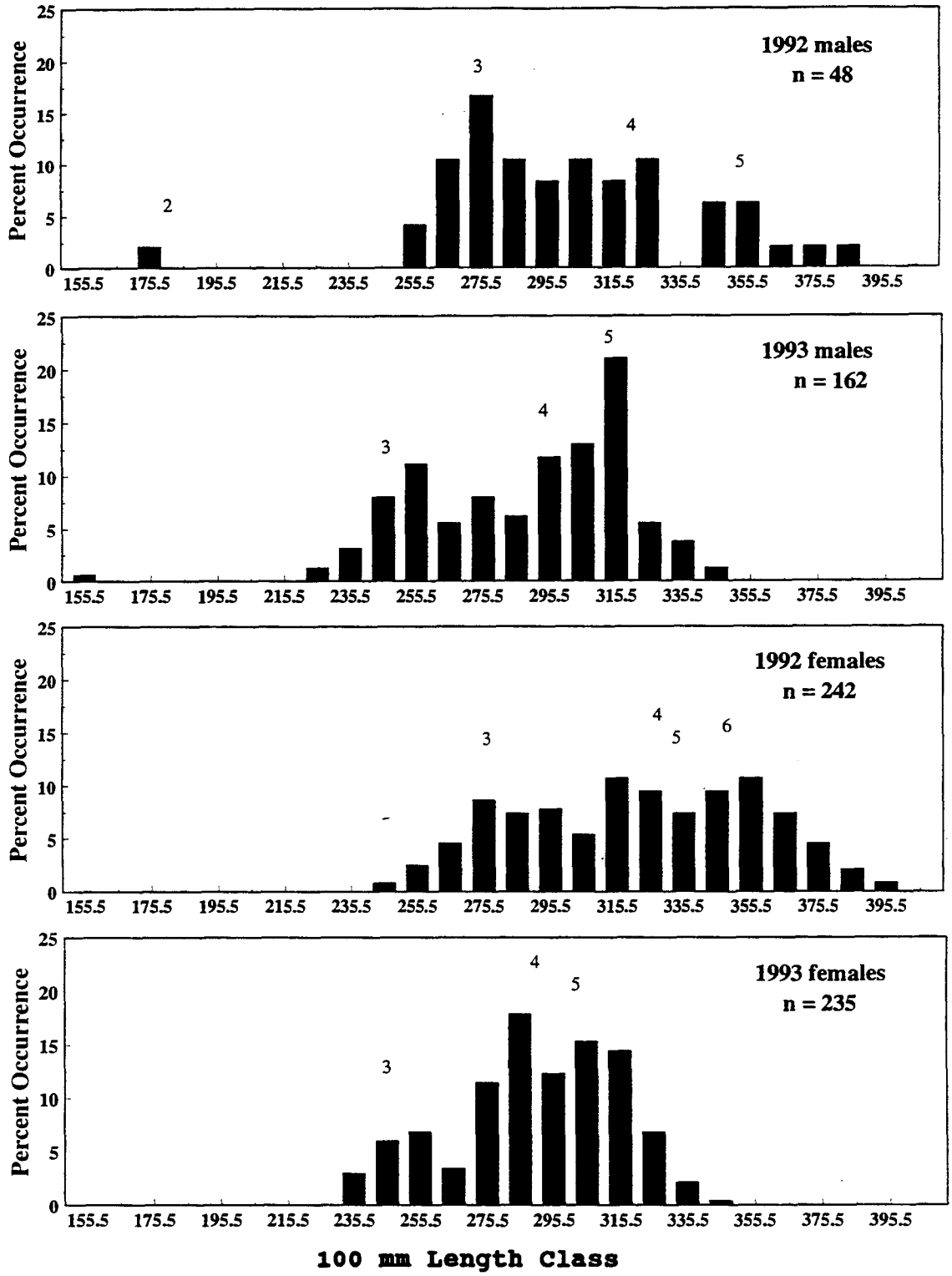

Figure 4. Length distributions of kokanee by sex and brood year from the North Fork of the Payette River, Idaho. Age numerals indicate mean length of spawners.

Table 6. Egg retention frequency distribution and overall mean number of eggs retained by age class in female kokanee collected in the North Fork of the Payette River, Idaho, for brood years 1992 and 1993.

	1992			1993		
Number of	Age class			Age class		
eggs	3	4	5	3	4	5
0	40	86	9	21	100	3
1 - 5	7	15	3	10	49	0
6 - 20	1	5	1	3	7	0
21 - 100	1	5	1	3	1	0
101 - 300	2	2	0	0	0	0
301 - 500	0	0	0	0	2	0
Total	51	113	14	37	159	3
Mean	6	6	4	7	6	0

was zero in 1992 and low (0.53%) in 1993, and egg retention generally was low for both brood years (Table 6). A majority of females observed in all age classes in both years contained zero unvoided eggs, and 94 and 97% of females in 1992 and 1993, respectively, retained 20 eggs or less. Ten eggs retained by a female with average fecundity represented a 1.1 and 1.6% loss in potential individual egg deposition in 1992 and 1993, respectively. Egg retention did not represent a significant reduction in PED as < 0.4% of the available egg deposition was lost to egg retention in both years (Table 7).

Time of Spawning

Substantial differences in temperature regime were found in various spawning areas of the NFPR during 1993 and 1994 (Figure 5). Accumulated temperature units were calculated using an estimated time of egg deposition of 7 September 1993, the date of the peak adult trap count. Spawning areas in order of decreasing temperature regime were Spring > Fisher Creek > Lower North Fork > Upper North Fork > Box Creek (Figure 5). The curve representing accumulated thermal units for the Spring was relatively flat indicating temperatures were moderated during incubation by ground water seepage. On the first day of fry trapping in the NFPR (Objective 2), 27 March 1994 when kokanee fry were beginning to migrate, 1,195 thermal units had been accumulated in the Spring, the area with the highest temperatures during incubation and probably the area from which kokanee first migrated. On 1 June 1994 when 50% of fry migration had taken place, 435 (Box Creek) to 1,489 (Spring) thermal units had been acquired (Figure 5). Time of spawning was similar among

Table 7. Mean egg retention by age class and statistics used to compute total egg loss due to egg retention for the 1992 and 1993 kokanee broods at the North Fork of the Payette River, Idaho. Sample sizes are indicated in parentheses.

	1992			1993	
	Age 3	Age 4	Age 5	Age 3	Age 4
Percent age	28.65 (51)	63.48 (113)	7.865 (14)	18.59 (37)	79.90 (159)
Percent w/eggs retained	21.57	23.89	35.71	43.24	37.11
No. with eggs retained[a]	867 (10)	2,128 (27)	394 (5)	2,267 (16)	8,360 (59)
Mean retention[b]	21	12	8	8	5
(range)	(1, 250)	(1, 225)	(1, 45)	(1, 98)	(1, 457)
(95%CI)	(1, 72)	(4, 25)	(0, 33)	(2, 19)	(2, 10)
Subtotal[c]	18,206	25,536	3,153	18,136	41,798
Total		46,900		60,000	
Percent of egg deposition		0.353		0.323	

[a] determined from multiplying escapement, percent female, percent age,
[b] and percent with eggs retained.
mean only for females retaining > 0 eggs.
[c] determined by multiplying number with eggs retained by mean egg retention.

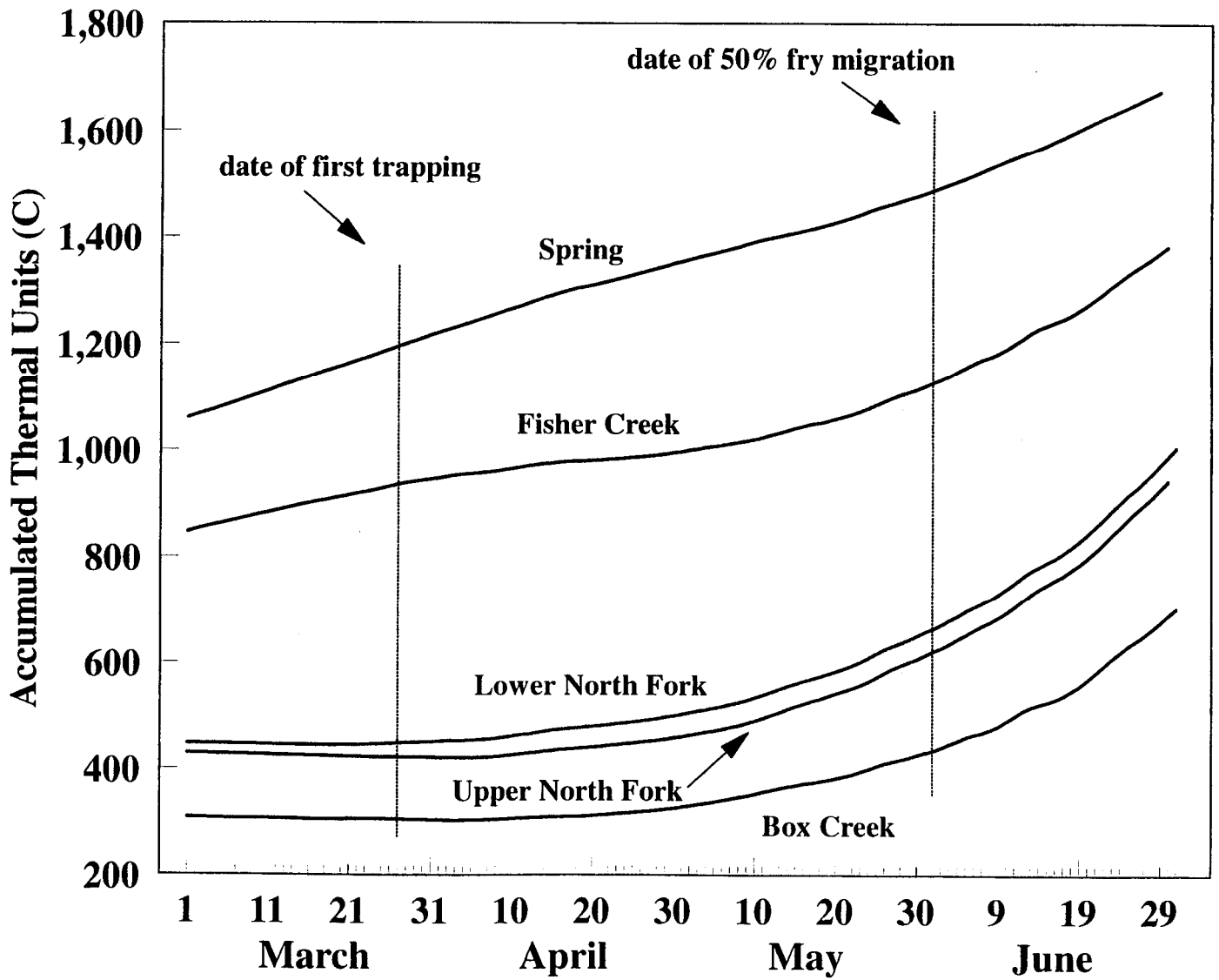

Figure 5. Accumulated thermal units for five areas of the North Fork of the Payette River, Idaho, during incubation 1993/1994.

the areas, but spawning in Box Creek began slightly earlier than the other areas which was consistent with our predictions (Figure 6).

DISCUSSION

Spawnina Escapement

Kokanee spawning escapements into the NFPR during this study were considerably higher than expected based on recent trends. The previous 4-year average was 20,800 adults (Janssen and Anderson 1994). Escapements in 1992 and 1993 were considerably larger than those from 1988 to 1991. Nearly 32,000 kokanee adults entered the NFPR in 1992, while in 1993 escapement nearly doubled that in 1992 indicating an increase in the kokanee population in Payette Lake over recent years. In determining spawning escapements for this study, we encountered mixed success in operating the weir. The weir failed for a short period in 1992 during rapidly increasing flows and resulted in many kokanee passing the weir without being counted. To estimate escapement in 1992, we used foot surveys that use the peak count observed during the run and an expansion factor developed for this population (Frost and Bennett 1994; Janssen and Anderson 1994). We believe the trap failed in 1992 due to poor site selection. The reach selected was narrow, had relatively steep gradient, and consisted of substrate (coarse sand and small gravel) that was easily scoured. These factors led to washout under the pickets during high flows. During 1993, we selected a reach upstream from the 1992 weir site which resulted in efficient operation throughout the run and peak flows were considerably higher in 1993 than 1992. The site selected in 1993 was wider, lower gradient and consisted of large gravel that resisted scouring.

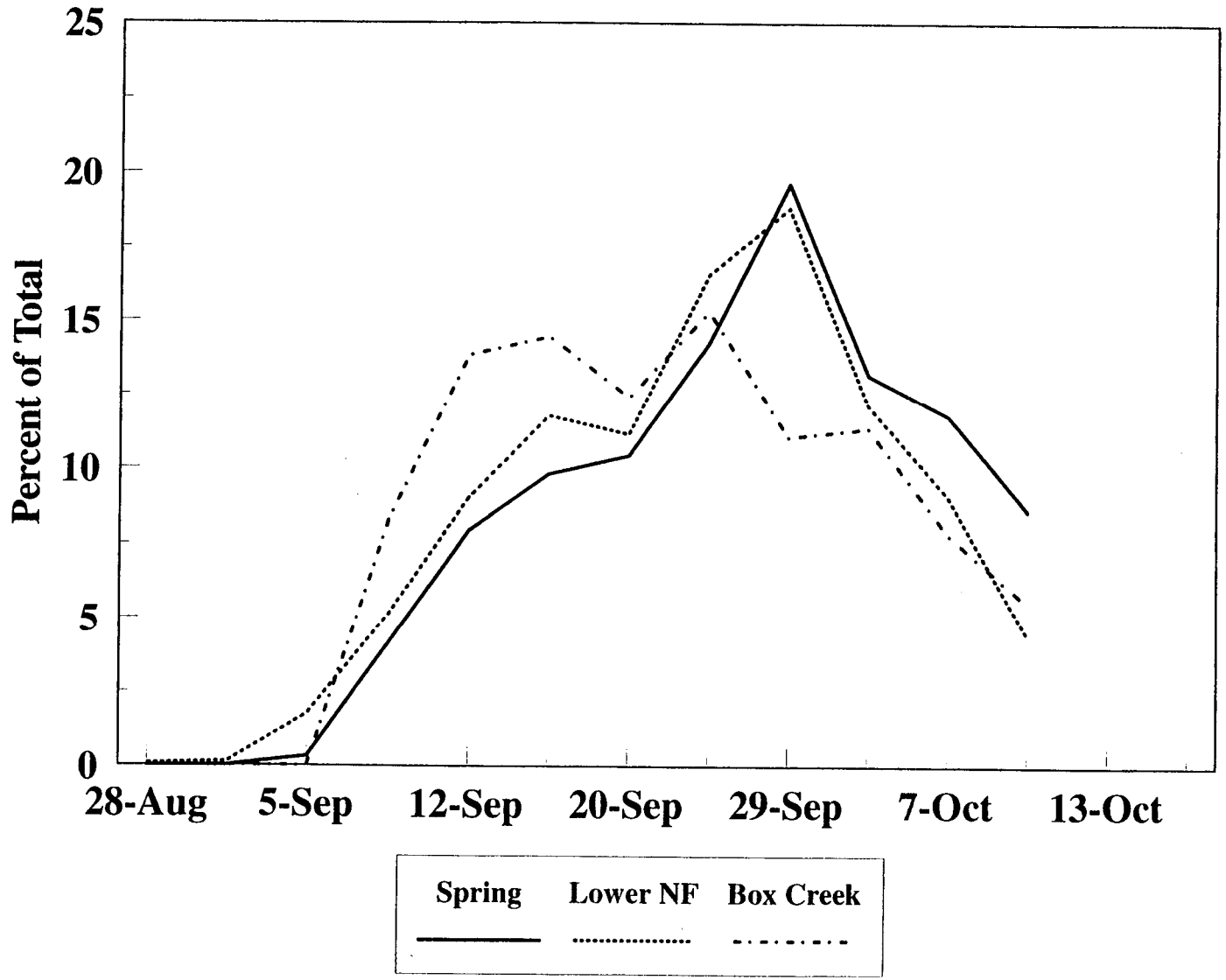

Figure 6. Kokanee spawner counts for three areas of the North Fork of the Payette River, Idaho, for which temperature data was collected during 1993/1994.

A significant amount of spawning occurred below the trap sites during both years of this study. Operation of the weir below our sites to capture those additional kokanee was impossible due to unsuitable operating conditions, particularly during the early part of the run. Each year Payette Lake is held at full pool until Memorial Day to satisfy recreational uses in the lake. At full pool Payette Lake influences river flow to immediately below the trap sites which converts otherwise riverine habitat into lake-like habitat; these conditions are not conducive to operating the weir. We relied on foot surveys to estimate spawners below the weir as some suitable spawning habitat existed below our trap sites. However, substantial spawning directly behind the weir was a result of fish being delayed for extended periods by the physical obstruction of the weir, particularly at the peak of the run. Similar behavior in kokanee has been observed in other studies involving weirs (P. Janssen, Idaho Department of Fish and Game, McCall, Idaho, personal communication). The problem is particularly acute in years of high escapement, as in 1993, when large numbers of fish migrate in a short time period, flood the trap area, and overwhelm the capacity of the trap. Potential alternatives to weir operations include Petersen mark/recapture methods described by Cousens et al. (1982).

Peak arrivals at the weir coincided with increasing flows during both years 1992 and 1993. Increased flows in late August and early September, caused by water releases from upstream reservoirs, stimulated kokanee to move upstream toward spawning areas. Prior to peak arrivals at the weir in both years, large numbers of kokanee were observed staging in deep pools below the trap sites. Small groups of kokanee left these large aggregations to migrate upstream as flows increased.

Although peak flow during spawning was significantly higher in 1993 than in 1992, the sudden increase in flow had similar effects on migratory behavior. The observed behavior was similar to that of sockeye salmon reported by Burgner (1991): "They [salmon] travel in schools, and during heavy migrations...they form a continuous moving band on one or both sides of the river, migrating steadily and uniformly close to the bottom where the current is slower."

Spawning occurred at water temperatures similar to those reported for kokanee and sockeye salmon. Sockeye generally spawn during periods of declining temperatures during late summer or autumn (Burgner 1991). Scott and Crossman (1973) reported kokanee spawning at temperatures between 5.0 and 10.5•C. Kokanee at Payette Lake spawn during a descending temperature regime in autumn. Temperatures during the initial part of the run were slightly higher than the reported range and increasing temperatures occurred after the initiation of spawning during both years. Increasing temperatures during the early part of the run, 13 to 14°C, were a result of warm surface water releases from upstream reservoirs.

Non-target species caught in the weir were mostly a result of hatchery programs in Payette Lake for the species observed. Cutthroat and rainbow trout are stocked in Payette Lake to support put-and-take fisheries. Splake S. namaycush x S. fontinalis are not stocked in Payette Lake but were apparently flushed from Upper Payette Lake Reservoir in 1993 during high flows before the outlet dam was closed. Some fish presumably moved downstream and entered Payette Lake (P. Janssen, Idaho Department of Fish and Game, McCall, Idaho, personal communication).

Egg Disposition

Males were more abundant than females in the 1992 and 1993 spawning populations. Females (52%) were more abundant than males (48%) in 1991 (Janssen and Anderson 1994). Males were slightly more abundant as the male to female ratio was 1.17:1 in 1988 (Grunder et al. 1990). Foerster (1968) reported equal numbers of both sexes should be present to achieve maximum fertilization of eggs in sockeye salmon. However, as Gilbert (1914) first noted, one male sockeye can service many females; therefore, maximum fertilization can potentially be achieved with fewer males than females. Nearly even sex ratios have been observed in kokanee (Lorz and Northcote 1965) and sockeye salmon (Mathisen 1962; Bjornn et al. 1968) spawning escapements. Altered sex ratios in sockeye salmon have been observed in populations subjected to intensive size selection in commercial gill net fisheries (Mathisen 1962). An observed sex ratio of 65% female and 35% male in 1946 in spawning rivers of Bristol Bay, Alaska, was considered severe and attributed to gill net selectivity toward males. Male to female ratios observed in this study, 1.28:1 and 1.10:1, likely do not represent significant deviations from an even sex ratio.

Kokanee in Payette Lake mature mostly at 4 years of age (3+). Janssen and Anderson (1994) reported a mean age of 4 years for the 1990 and 1991 brood years. Age 4 kokanee were most abundant during both years of this study. Age at maturity is generally higher at Payette Lake than in other kokanee populations in Idaho (S. Patterson, Idaho Department of Fish and Game, Orofino, Idaho, personal communication). Kokanee in Dworshak Reservoir, a fishery with much higher exploitation rates on kokanee, mature mostly at age 3. Differences could also be due

to stock origin (sockeye vs. kokanee). Kokanee size and vulnerability to harvest are related in Idaho (Rieman and Meyers 1990). Kokanee enter the sport fishery at 200 mm and vulnerability increases as they grow. Larger and older fish are harvested at high rates and thus are not available for reproduction. High exploitation of older fish in other populations has been found to cause a decrease in age at maturity (Schaffer and Elson 1975; Handford et al. 1977; Borisov 1978; Ricker 1981).

Kokanee size was an indicator of lower than optimum densities in Payette Lake in the late 1980s and early 1990s, but recently size of spawners may indicate densities are nearing optimum levels in Payette Lake. Rieman and Meyers (1990) claimed that for Idaho waters kokanee approaching 275 to 325 mm in length indicate low densities and fishery managers should use caution to avoid population collapse. Lengths of kokanee of both sexes in the spawning population ranged from 293 to 343 mm from 1988 to 1992. Mean length was 280 mm for females and 278 mm for males during 1993 indicating higher densities in the lake. Rieman and Meyers (1992) found evidence of strong density dependent growth particularly in older-aged kokanee. Growth decreases at high densities which is commonly thought to be a result of reduced food abundance and size caused by intense size selective predation (Goodlad et al. 1974; Kyle et al. 1988; Brocksen et al. 1970; Trippel and Beamish 1989; Hartman and Burgner 1972; Boisclair and Leggett 1989). Escapements and fish size observed during this study were consistent with those expected for varying densities. With larger escapements, as in 1993, we would expect reduced fish size due to higher densities in the lake. Size of spawners in 1993 were the lowest observed for the period 1988 to 1993.

We also observed increased size of spawners with increasing age within years. Generally, salmon maturing at younger ages do so at smaller sizes than those maturing later (Shearer 1972) and this trend was evident in 1992 and 1993.

Baa Retention

Investigations of juvenile salmonid production that involve egg deposition estimates require reliable information on egg retention (Manzer and Miki 1986). Foerster (1968) reported several investigations of egg retention in sockeye salmon. Retention usually represented a minor loss in overall egg deposition as all reported values were < 5%, while most were < 3% of deposition. Manzer and Miki (1986) found egg retention was 3.9% of individual fecundity among five stocks of British Columbia sockeye salmon. No information is readily available in the literature concerning egg retention in kokanee. However, we concluded egg retention was negligible for the two brood years we examined as total retention was < 0.4% of PED.

Egg retention in salmonids has also been used as an indicator of spawning success. Chapman et al. (1986) used egg retention in chinook salmon O. tshawvtscha spawning below Priest Rapids Dam on the Columbia River to determine whether dam operation caused spawning failure. Evidence of a density dependent relation between number of spawners and egg retention in females has been reported for sockeye salmon. Mathisen (1955) observed higher egg retention rates in pen-retained sockeye when fish were crowded. Egg retention was 0.63% in 11 pens with a mean of 79 m^2 available per female; however, egg retention was 13% in 2 pens with a mean of 3 m^2 available per female. Semko (1954) reported a decrease in

the number of eggs remaining in spawned-out sockeye with decreasing numbers on the spawning grounds: 312 eggs per female when spawning population was 7,123 to 7 eggs per female with a run size of 219. Mathisen (1962) observed higher than normal egg retention in pens with higher than natural spawning densities. Foerster (1968) and Semko (1954) hypothesized higher egg retention at increased spawning densities was a result of increased competition between females for spawning sites, thus reducing their ability to fully express eggs. Idaho Fish and Game was concerned with the quality and amount of available spawning habitat for kokanee in the NFPR (Grunder et al. 1990). A significantly higher escapement in 1993 provided for a comparison of egg retention with widely different numbers of kokanee competing for spawning sites in the NFPR. If the amount of spawning habitat was limiting, we expected to see higher egg retention with increased escapements. However, retention was similarly low between years. We did observe two females that showed evidence of near total spawning failure (>300 eggs retained) in 1993, while in 1992 we observed none in this class. However 2 females retained between 101 and 300 eggs in 1992, while no females were observed in this class in 1993. These results indicate spawning habitat in the NFPR is not limiting and the amount of habitat is capable of supporting nearly 60,000 spawners without significant spawning failure in the form of egg retention.

Time of Spawning

We did not observe differential time of spawning related to the temperature regime of the spawning areas which suggests this stock does not consist of substocks that could be identified by time of spawning.

Five areas of the NFPR and tributaries used by kokanee for spawning differed substantially in temperature and if substocks existed we expected spawners to be using each area at different times--colder areas relatively early and warmer areas relatively late. This rationale assumes the existence of an optimum time of lake entry, as described by Barns (1969), where food availability and growth potential act as selective forces affecting survival and determine the best time of lake entry. Miller and Brannon (1982) and Brannon (1984) identified timing of fry emergence as the principal evolutionary factor establishing the timing of sockeye salmon spawning in a stream. Also, Brannon (1987) observed temporal regularity in spawning time in nine Fraser River stocks which was directly related to the temperature regime of the stream. We did not observe a similar pattern from the kokanee stock at the NFPR. Possibly environmental conditions in Payette Lake do not favor an optimum time of lake entry for the fry, or there exists a wide time period of equally favorable conditions. Under these conditions, fish spawning at similar times at different temperatures, and thus emerging from the redds at different times, may survive equally well. Also, under a narrow-optimum window, some fry, such as those spawning in springs, may emerge early and rear in the river environment for an extended period then migrate at the appropriate time to enter the lake at the optimum time. Generally, kokanee and sockeye salmon fry spend little or no residence time in the stream after emergence. Spring areas in the Flathead River system, Montana, produced kokanee fry that remained up to 1 month before emigrating to the lake (Fraley and McMullin 1983). In the NFPR we also observed fry that had attained large size due to extensive feeding in the river after emergence.

Kokanee originating from relatively warm spring areas may experience equal survival after emergence and thus spawning time, which is a genetic characteristic of the stock (Brannon 1987), is not altered.

Objective 2. To estimate egg-to-fry survival of the 1992 and 1993 kokanee broods and to evaluate the growth, condition, and developmental stage of migrating fry.

INTRODUCTION

Egg-to-fry survival is necessary for managing salmonid (Salmonidae) stocks and evaluating the productivity of spawning habitat. Mortality during the incubation period is important because it is generally higher and more variable than in any other life stage of salmon (McNeil 1969). Numerous methods have been used to estimate salmonid survival during the egg-to-fry stage. McNeil (1964) excavated redds to estimate survival from egg deposition to the pre-emergent stage of pink salmon O. gorbuscha. Survival of green or eyed-eggs was observed in artificial structures, such as Whitlock-Vibert boxes (MacKenzie and Moring 1988), plastic cylinders (Scrivener 1988), and artificial redds (Gustafson-Marjanen and Moring 1984). Emergence traps (Phillips and Koski 1969; Porter 1973; Tagart 1984; Fraley et al. 1986) have been used to capture emerging fry on individual redds. These methods are particularly useful for evaluating variables that may influence incubation success (Fraley et al. 1986; Scrivener 1988), assessing differential survival between stages of the intragravel period (MacKenzie and Moring 1988), and comparing survival among different parental combinations.

In many situations, however, such as salmonids spawning in large rivers, such techniques are not practicable since high flows that normally occur during fry emergence render spawning sites inaccessible. Also, methods that measure survival prior to emergence (e.g. redd excavation) overlook two important sources of mortality; emergence failure due to entrapment by fine sediment (Koski 1966; Koski 1972) and

predation, particularly by piscivorous fish after emergence (Hartman et al. 1962). Various traps designed to capture migrating fry or smolts have been used in rivers to assess salmonid production (Wolf 1950; Craddock 1959; Meehan and Siniff 1962; Acara and Smith 1971; Clarke and Smith 1972; Davis et al. 1980; Quimby and Dudiak 1983; Milner and Smith 1985; Dempson and Stansbury 1991). Traps designed to sample salmonid juveniles depend on migratory behavior exhibited immediately after emergence (fry; e.g. Q. nerka) or at a later stage (smolt; e.g. Salmo salar), and they are placed in the migration path between spawning areas and the lake or estuary for which the fish are destined. Some trap designs capture a relatively small portion of the migrants and the researcher must use mark-recapture methods to estimate trap efficiency (Seelbach et al. 1985; Tsumura and Hume 1986; McMenemy and Kynard 1988; Dempson and Stansbury 1991). Results of efficiency tests are applied to partial count estimators to enumerate total number of juveniles. Although conditions such as flow, light, and suspended sediment change widely during spring runoff and may influence migratory behavior (Acara and Smith 1971), repetitive measurement of trap efficiency over time often receives inadequate attention. Most authors rely on small sample sizes and low numbers of marked individuals that are sometimes the consequence of working with small populations (Seelbach et al. 1985; Tsumura and Hume 1986; McMenemy and Kynard 1988). We determined kokanee fry recruitment to Payette Lake during 1993 and 1994 using a trap design that required estimates of trap efficiency to estimate total abundance. Kokanee egg-to-fry survival is compared with those determined for other populations of kokanee and sockeye salmon to determine the relative productiveness of spawning habitat available to the Payette Lake stock.

METHODS

Seasonal and Diurnal Emigration Timina

Fry sampling was conducted at a bridge located below all kokanee spawning areas in the NFPR during 1993 and 1994 (Figure 7). Stream width at the bridge was 26 m. Water depths ranged from 1 to 3.5 m and velocities ranged from 0.61 to 2.4 m/s during the study periods. Grunder and Anderson (1991) indicated kokanee begin moving downstream toward Payette Lake during the last 2 weeks in March. We began sampling the NFPR for kokanee fry during this time in 1993 and 1994. Fish moving downstream were captured in a trap operated from the bridge spanning the NFPR (Figure 1, Objective 1). A boat winch and boom (1 m high), bolted and clamped to the bridge railing, allowed easy, safe deployment and retrieval of the trap. The level of the bridge railing was approximately 6 m from the substrate of the river. Trapping was conducted at three different sites on the bridge during the two years of study (Figure 7). Different sites were used to avoid large amounts of debris that could clog the net and make sampling difficult. Also the trap was moved from the downstream to the upstream side of the bridge in June 1994 to take advantage of slightly higher velocities at site 1 (Figure 7). During 1994 sampling was conducted in 4 to 6 night periods followed by 2 to 3 nonsampling nights. Sampling was terminated in early July when catches decreased to zero. Sampling was not conducted after 8 May 1993 due to high flows. Flows were monitored with a staff gauge located directly beneath the bridge during the study periods. Water temperatures were recorded at 3-hour intervals with a Hobo-Temp Miniature Temperature Logger (Onset Instruments, Pocasset,

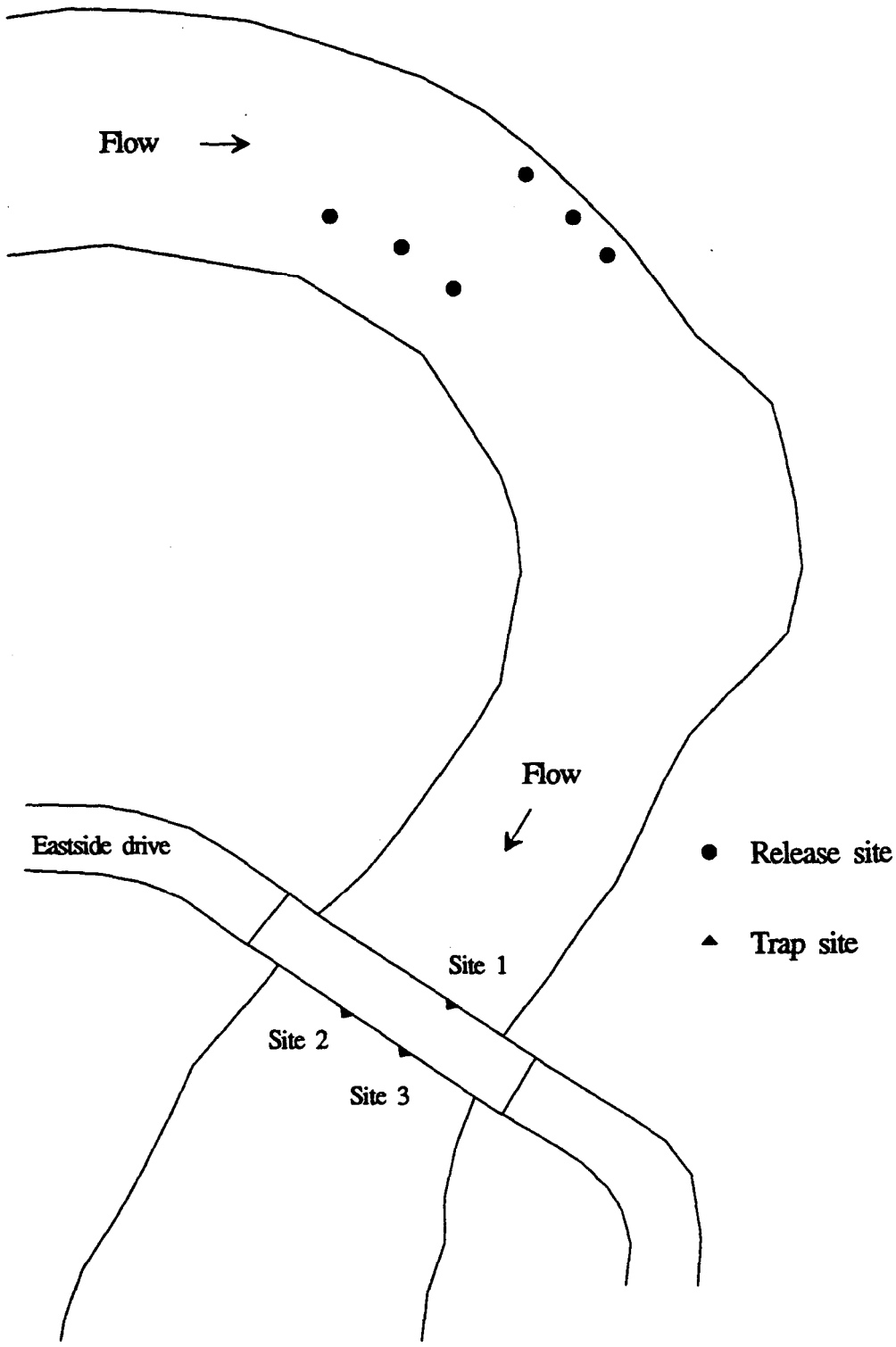

Figure 7. Sampling sites at the bridge on Eastside Drive used in 1993 and 1994 for sampling kokanee fry migrating in the North Fork of the Payette River, Idaho.

Massachusetts) located approximately 1.5 km upstream from the bridge. Seasonal distribution was described with respect to river stage and water temperature. Diurnal fry movement for 1993 and 1994 was examined by day sampling. Available literature documents sockeye salmon and kokanee fry migrations almost exclusively at night (McDonald 1960a; Hartman et al. 1962; Acara and Smith 1971; Fraley and Clancey 1988; Shepherd 1990). Nightly fry sampling was normally conducted within 30-minute intervals during each night sampled. Diurnal movement was depicted every 30 minutes as a percent of nightly totals during each of eight time periods beginning with the first sample date each year.

The trap design used to capture migrating fry was a form of the modified fyke net used for live trapping described by Conlin and Tutty (1979). The net measured 0.37 m^2 at the mouth, tapered to 15 cm (dia) at the cod-end, and totaled 4 m in length. The net was constructed of two nylon layers sewn together along four 16-mm nylon lines. The inner bag was 1.6-mm mesh through which kokanee fry could not escape. The small mesh bag was encircled by a nylon bag of 16-mm mesh. The net mouth was stretched open with a circular frame (16-mm dia steel) and fastened with cable ties. The trap was maneuvered with a standard boat winch, 5-mm steel cable, and a pulley attached to the end of the boom. The cable connected to the net frame at the center of a cross bar welded along its diameter. A 65-cm collection bottle constructed of 16 cm dia PVC pipe and fittings was attached to the cod end of the net with clamps. A screw cap on the downstream end of the bottle provided easy access for removing fish and cleaning debris from the net. Since high water pressure inside the bottle would have been hazardous to young kokanee fry; two small (50 cm^2), rectangular openings were cut from the

collection bottle and covered with window screen. Silicone was applied around the edges of the screen and to all crevices and rough areas within the bottle to reduce risk of injury to fish and to facilitate fish and debris removal. The trap was retrieved at the end of a fishing period, contents of the bottle were emptied into a bucket, and the net was rinsed with 10 L of water into a bucket. All fish species were sorted from debris, counted, and released downstream. The net was consistently fished so the top 10 to 15 cm of net extended above the water; the cross-sectional area of net under water was maintained at varying flows by the amount of cable released from the winch.

Trap Efficiency

We used mark-recapture methods to determine trap efficiency and to estimate total numbers of fry passing the bridge. Kokanee fry captured at night were immersed in a 1:60,000 solution (by weight) of Bismarck brown-R (dye content 40%), a vital stain, for a period of 2 to 3 hours. Several researches have successfully used Bismarck brown dyes to mark salmonid juveniles. Ward and Verhoeven (1963) exposed sockeye salmon fry for 3 hours to a 1:60,000 solution of Bismarck brown-Y (dye content 52%) with negligible mortality. Mundie and Traber (1983) used a 1:46,000 solution (dye content 51%) to mark coho salmon O. kisutch fingerlings. Bowles et al. (1987) used a 1:30,000 solution to stain kokanee. Survival of marked fish (99.3%) was not significantly different from that of control groups after 10 weeks. Fraley and Clancey (1988) also used a 1:30,000 solution for 50 minutes and reported low mortality. All studies report 100% dye retention of at least a week. During this study marked fry were released 90 to 110 m upstream

at sunrise, and all fry captured the following night were examined for the mark. Releases of fry were separated into six to eight subgroups and released in equal numbers on both sides of the stream to maximize dispersal and decrease risk of predation. The subgroups were released separately over a 15 to 20 m length of stream bank in depths of 0.75 to 1 m. We assumed marked kokanee did not immediately migrate upon release during daylight hours and all kokanee resumed migration the following night. Fraley and Clancey (1988) studied movements of kokanee fry using Bismarck brown and reported no captures of marked kokanee fry during daylight hours. Net efficiency was determined periodically during the study periods. River flows (m^3/s) could not be measured but river stage (cm), or the vertical height of water, was measured. The logarithm of river stage was used in statistical analyses, since flow is often a power function of river stage (J.H. Milligan, University of Idaho, Moscow, Idaho, personal communication). If correlations existed between stage and trap efficiency, catches of marked fry were pooled according to time periods and the pooled efficiency was used to expand nightly catches within each respective time period. Flows varied only slightly due to water retention in upstream and downstream reservoirs after 30 May 1994. Catches of marked kokanee between 3 June and 11 June and after 11 June were pooled, and pooled efficiencies were used to expand nightly totals. Efficiencies determined at different trap locations at the bridge (Figure 7) were never pooled and only used to expand nightly captures at each respective trap site.

Recruitment and EGG-to-Fry Survival

Our sampling effort was concentrated during nighttime hours; however, daytime sampling was conducted periodically to confirm published reports that indicate sockeye salmon and kokanee fry migrate predominantly at night (Hartman et al. 1962; Acara and Smith 1971; Fraley and Clancey 1988). Night sampling usually began at 2100 to 2200 hours, continued through the night, and ended at 0300 to 0600 hours. The net was set and retrieved at 30 minute intervals (e.g. 2330 to 2400). Kokanee numbers were time-adjusted each 30 minutes by dividing by the proportion of time fished. Sampling was always conducted during the peak hours of migration (2200 to 0300) when approximately 86% (mean of all nights sampled) of nightly totals occurred. One of five sampling nights, usually once per week determined randomly, were designated as "all night" sampling. On these nights sampling began early (2100) when catches were likely to be zero and terminated (usually by 0600) when catches were again zero. We assumed that on other nights during the same week kokanee migration time and behavior was similar to the "all-night" sample. To estimate the additional 10 to 20% not sampled, time-adjusted nightly catches were divided by the proportion of the nightly migration sampled.

Fry recruitment from the 1993 brood was sampled for the entire duration of migration from the NFPR whereas recruitment from the 1992 brood was sampled for a portion of downstream emigration. Egg-to-fry survivals were calculated using egg deposition estimates (Objective 1) and fry recruitment (recruitment as a percent of egg deposition). We summed all nightly estimates to estimate total recruitment of kokanee fry from the 1993 brood. Totals on nonsampling nights were estimated

with linear regression on three sampling nights before and after the nonsampling period. Bounds on the estimates were determined using the variance of a proportion $V(p) = pq/n-1$; where $V(p)$ is the variance, p is the proportion in question, q is $1 - p$, and n is the sample size (Scheaffer et al. 1990). Standard errors of the regressions were used to calculate bounds on nonsample nights. Fry recruitment from the 1992 brood was sampled only until 8 May 1993; after 8 May high flows destroyed the trap. To estimate total recruitment from the 1992 brood, we used accumulated temperature units during both years and the cumulative fry recruitment observed in 1994. We assumed similar proportions of total fry recruitment migrated at similar accumulated temperature units during both years. A temperature unit is defined as 1°C above freezing (zero) for a period of 24 hours. Mean daily temperatures were used to calculate temperature units. We used the date of the peak adult trap count for both years as the best estimate of time of egg deposition. The point at which 1993/1994 accumulated temperature units equaled temperature units on 8 May 1993 was used as the reference date. The cumulative proportion of the fry run that had occurred on this reference date was used to expand the partial count for 1993 recruitment (partial count divided by cumulative proportion).

Fry Size, Condition, and Developmental Stage

Random samples of kokanee fry were selected throughout the study period for length, weight, development stage, and condition factor comparisons with time. All samples were preserved in a 10% formalin solution and later measured in the laboratory. Fry and alevin lengths and wet weights were measured to the nearest tenth of a millimeter and

thousandth of a gram, respectively. Data were transformed to fresh sample measures by multiplying preserved alevin length by 1.03, alevin wet weight by 0.91, fry length by 1.05, and fry weight by 0.88 (Murray 1980). Kokanee were classified according to an arbitrary 5-stage development scale encompassing alevin (stage 1) to complete fusion of the midventral wall (stage 5; Table 8). Stages one, two, and three were considered alevin; stages four and five were considered fry. Length and weight data were used to calculate Fulton's R condition index (Anderson and Gutreuter 1983). We compared lengths, condition factors, and development stages between years with individual z-tests. We compared all 1993 data to 1994 data collected during similar accumulated temperature units as during 1993 to control for temporal differences in acquired thermal units. Yearly data were pooled in distinct periods (three in 1993; six in 1994) beginning with the first day of sampling and analyzed with one-way analysis of variance and the student-Newman-Keuls procedure for multiple comparisons (SAS Institute 1988). Statistical significance for all tests was considered at an alpha level of 0.05.

RESULTS

Seasonal and Diurnal Emicration Timinq

Downstream migration during 1993 and 1994 began in late March during relatively low river stage and temperatures. The 1993 run began earlier than 1994 as kokanee were captured on 20 March 1993. Fry numbers in 1993 increased with rising river stage; however, shortly before trapping was terminated in early May, river stage was relatively high, although fry numbers had not responded similarly (Figure 8). A

Table 8. Fry classification scheme used to classify migrant kokanee in the North Fork of the Payette River, Idaho, during 1993 and 1994 sampling periods. Adopted from Canadian Department of Fisheries and Oceans (Shepherd 1990).

Stage	Alevin / fry	Description
1	Alevin	Little or no absorption of posterior lobe of yolk sac
2	Alevin	Posterior lobe of yolk sac absorbed
3	Alevin	Yolk sac less than half visible in lateral view; top portion of yolk sac silver
4	Fry	Skin pigmentation on sides and lateral part of ventral surface; yolk visible in scar
5	Fry	Yolk sac scar is healed; no yolk visible externally

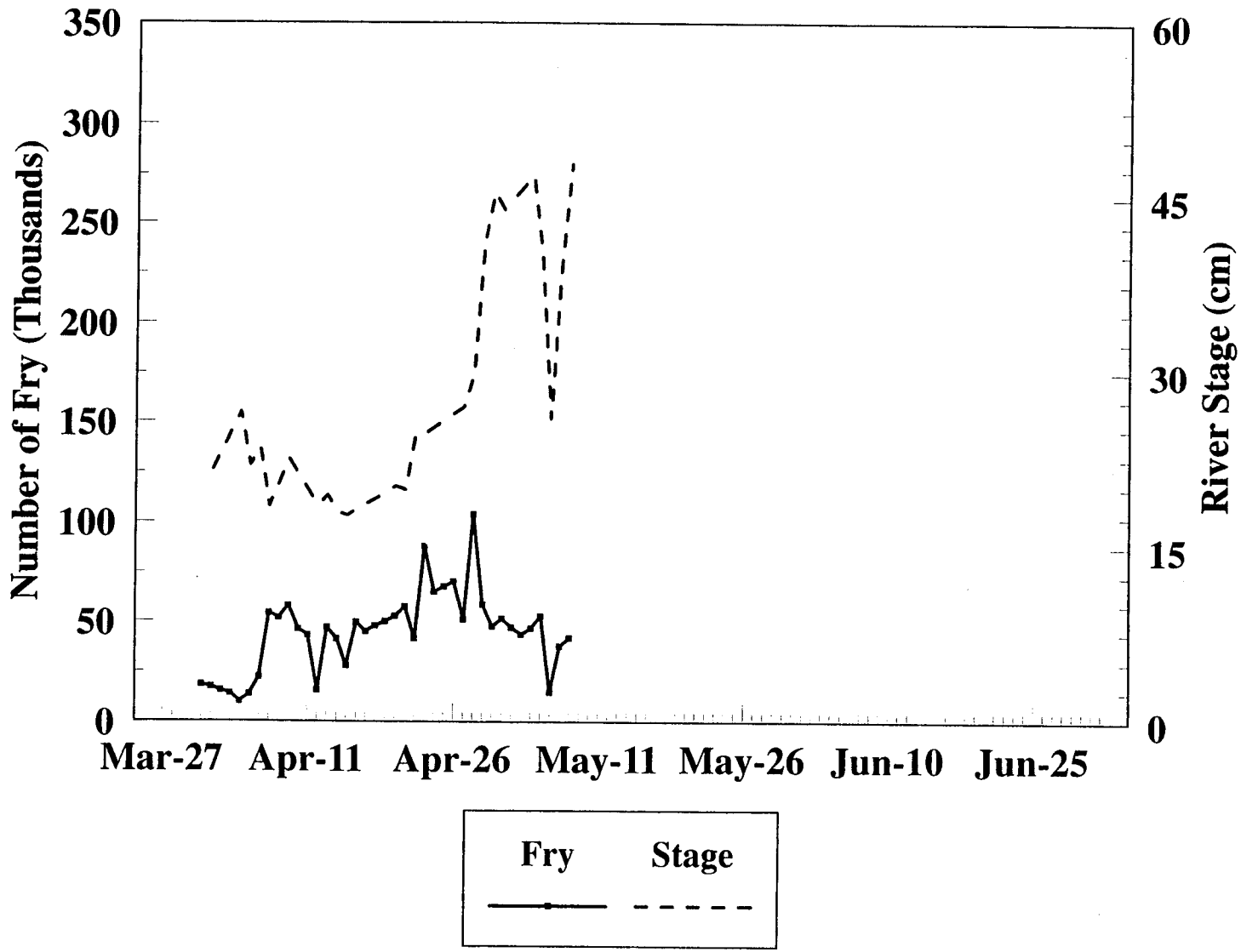

Figure 8. Daily estimates of kokanee fry migrating in the North Fork of the Payette River, Idaho, during spring 1993.

similar pattern was evident in the 1994 migration when fry numbers increased with rising stage, but not all peaks in flow were accompanied by similar increases in fry (Figure 9). The peak which occurred on 5 June (317,000) did not occur at the highest observed river stage, although smaller, earlier peaks on 6 May and 26 May did occur during periods of rising river stage. Water temperatures were similar during both years at the beginning of migration (Figures 10 and 11) as fry began migrating at temperatures slightly < 1•C after a long period of daily mean temperatures < 0•C. Increase in migration intensity throughout the 1994 run occurred during rising temperatures (Figure 11). The peak nightly fry estimate (5 June 1994) occurred at a water temperature of 9•C and during the final days of migration temperatures were nearly 15•C. Downstream migration of kokanee fry was predominantly nocturnal. During the 1993 sampling period we sampled 6 hours 38 minutes over 7 days during daylight hours. During 1994 we sampled 12 hours 43 minutes over 13 days. Daytime sampling was distributed over the entire sampling period each year. A majority of the sampling time was during light conditions immediately after dawn and prior to dusk. No kokanee fry were captured during daytime in 1993. Six kokanee were sampled in 1994, all but one occurred during either a post-dawn or pre-dusk period. The one captured during mid-day (1400 hours) was in an alevin stage of development (stage 3, Table 8).

The diurnal distribution of kokanee fry in the NFPR was similar during 1993 and 1994 (Figures 12 and 13). Migration was protracted over the entire night in March and early April during both years with indistinct peaks in abundance. Fry abundance peaked around 2300 hours as time progressed into April and early May. In 1994 the 2300-hour peak

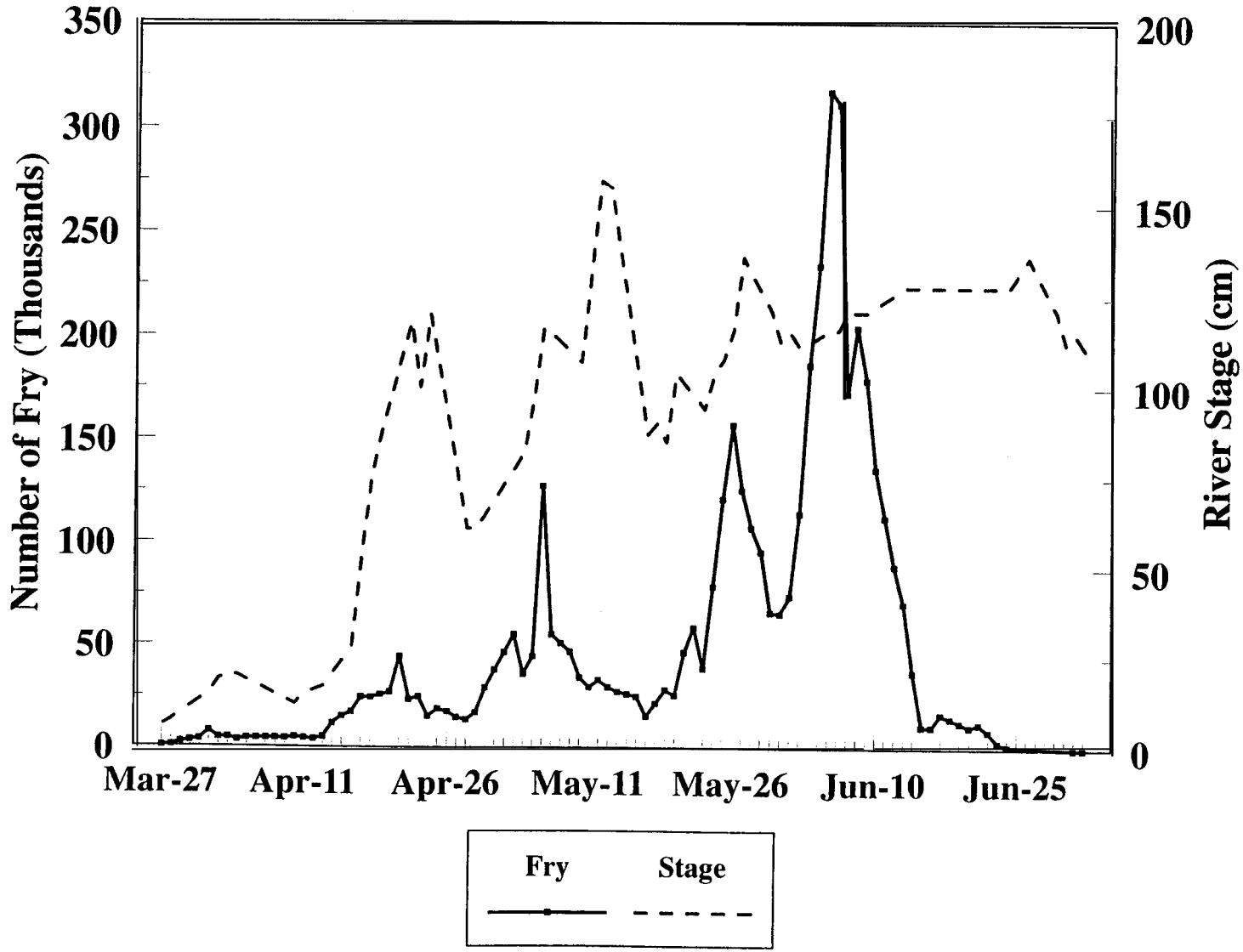

Figure 9. Daily estimates of kokanee fry migrating in the North Fork of the Payette River, Idaho, during spring 1994.

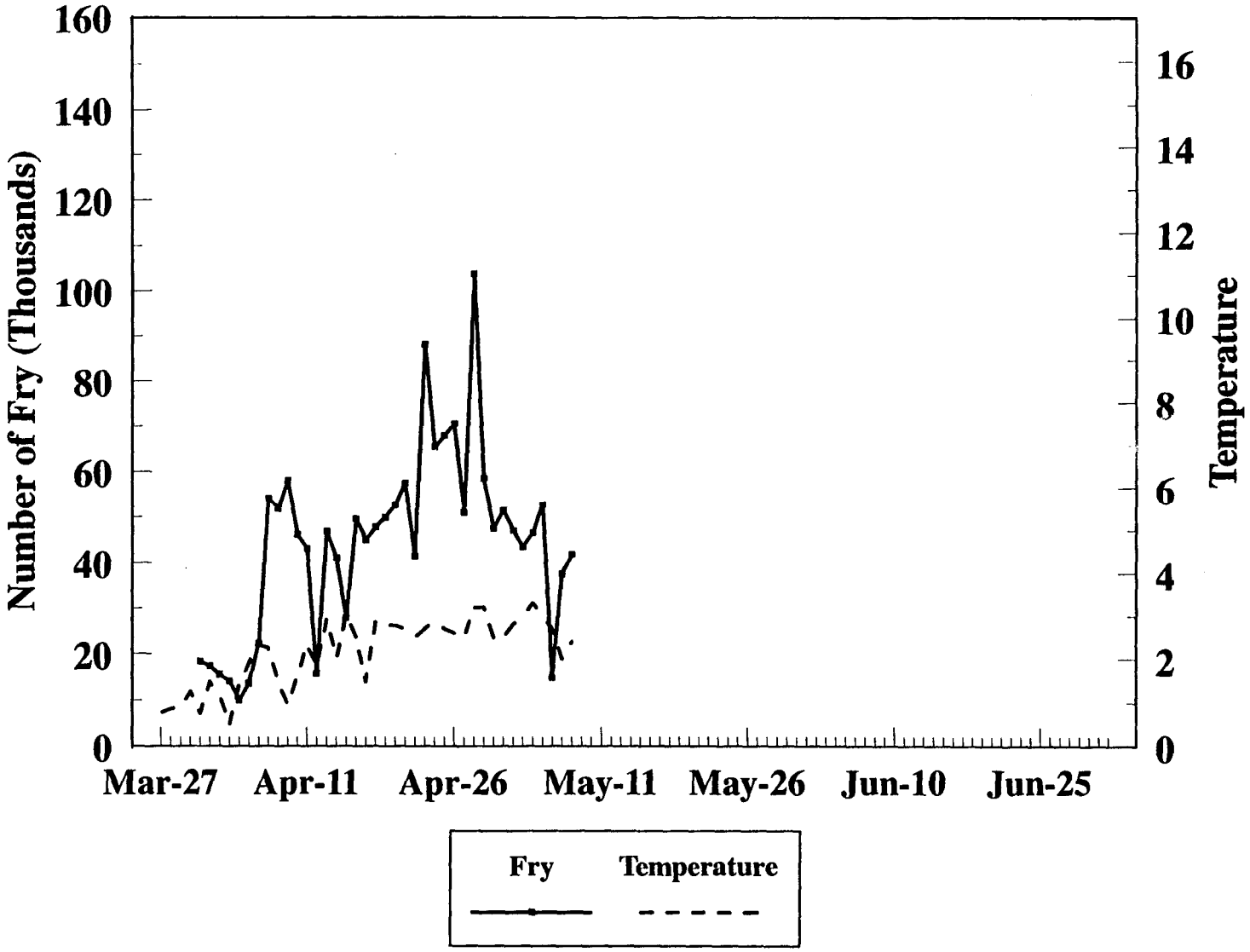

Figure 10. Water temperature and daily estimates of the 1993 kokanee fry migration in the North Fork of the Payette River, Idaho. Temperature data is from Thurow and King, unpublished data.

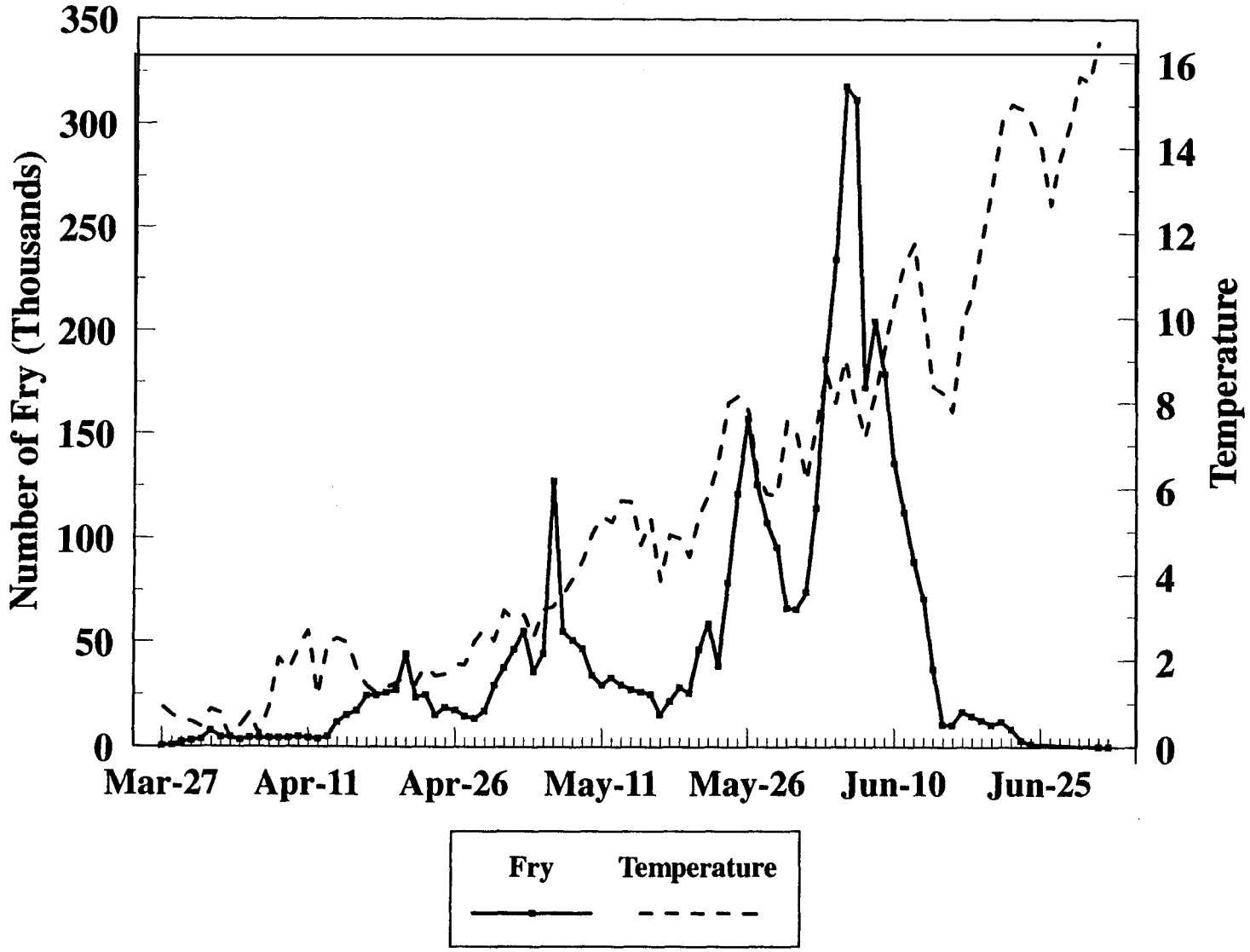

Figure 11. Water temperature and daily estimates of the 1994 kokanee fry migration in the North Fork of the Payette River, Idaho.

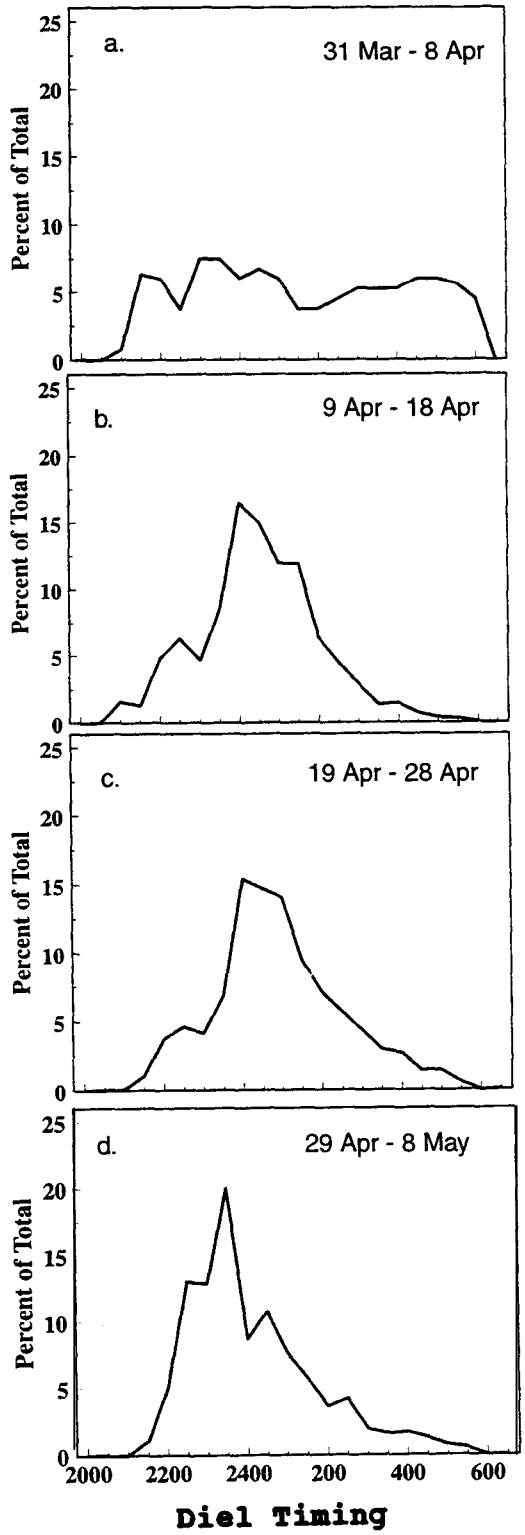

Figure 12. Diel timing of the March to May, 1993, kokanee fry migrations in the North Fork of the Payette River, Idaho.

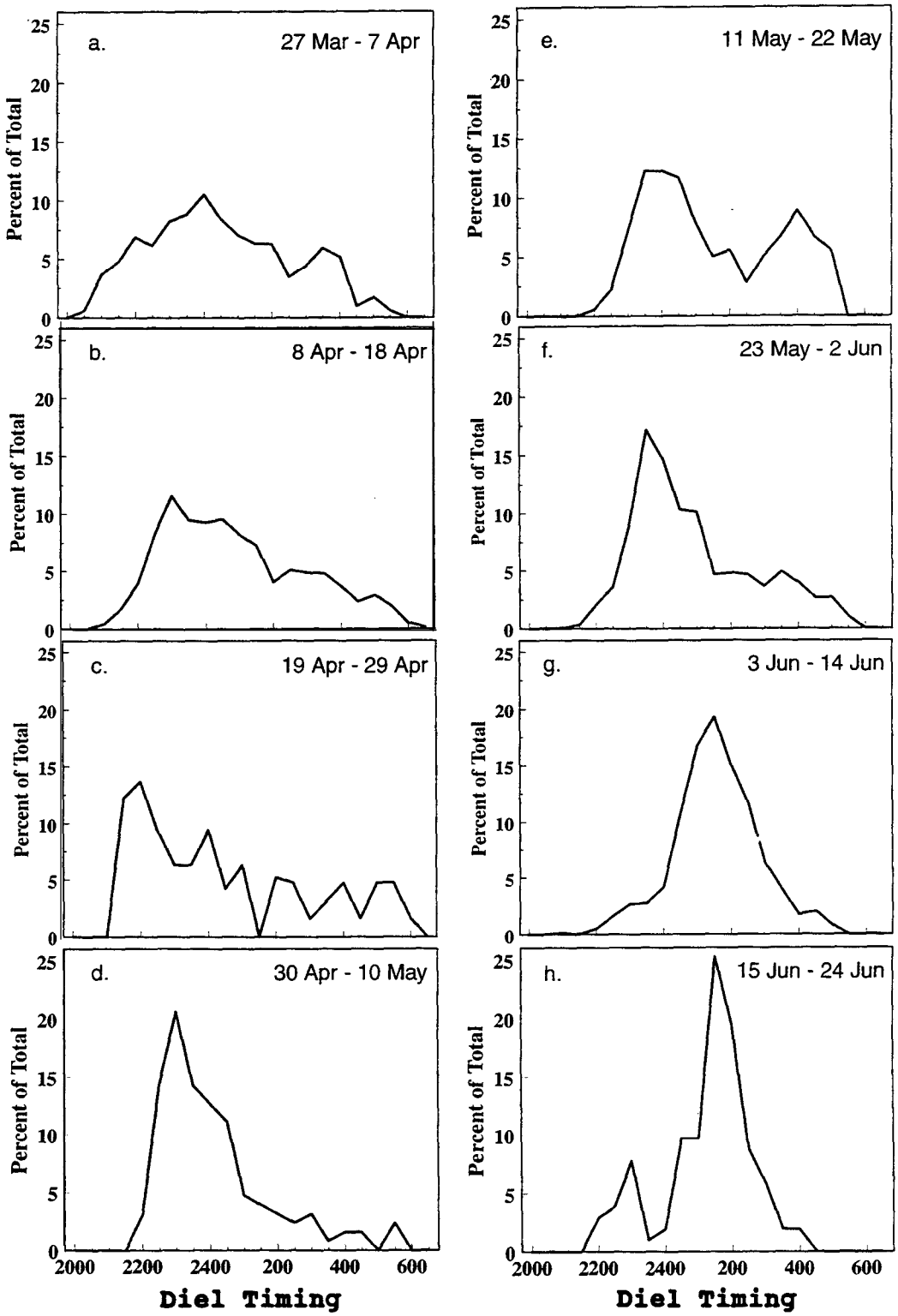

Figure 13. Diel timing of the March through June, 1994, kokanee fry migrations in the North Fork of the Payette River, Idaho.

was accompanied by a smaller peak during May around 0330 hours (Figure 13). During the final stages of the run in June 1994, peak nightly abundance shifted approximately 2 hours to 0130 hours (Figure 13) and the migration during both years became progressively shorter. Fry actually migrated approximately 9 hours per night in early April 1994, 7.5 hours in early May, and 6 hours in late June.

Trap Efficiency

Trap efficiency was negatively related to river stage in 1993 (r=-0.81; Table 9). Catches of marked fry were pooled according to time periods with similar flow conditions. Pooled trap efficiencies were 4.21% (river stage 0-3 cm), 2.70% (river stage 3-10 cm), and 1.21% (river stage >10 cm). Trap efficiency and river stage in 1994 were also negatively related (r=-0.65; Table 10). Pooled trap efficiencies used to expand nightly totals from 27 March to 2 June 1994 were 4.20% (river stage 0-37 cm), 2.03% (river stage 38-72 cm), and 0.697% (river stage > 73 cm). Flow and debris conditions were similar while the trap was operated at site 2 from 2 June to 4 June 1994 (Figure 7). The trap efficiency (1.22%; Table 11) was used to expand nightly totals during this period. To expand nightly totals after 9 June, while the trap was operated at site 3 (Figure 7), we used 0.984% (14 June; Table 11) as trap efficiency. We pooled 1993 data collected at site 1 (Table 9) and 1994 data collected at site 3 (Table 11; Figure 7) for an additional comparison of trap efficiencies and river stage. Pooling the data was justified because the trap positioned at either site fished essentially the same horizontal and vertical portion of the water column. The

Table 9. Relative river stage and number of kokanee fry marked, released, and recaptured for assessing trap efficiency in the North Fork of the Payette River, Idaho, from 4 April to 4 May 1993 at trap site 1.

Date	River Stage (cm)	Number Marked	Number Recaptured	Trap Efficiency %
16 April	0.5	311	14	4.50
12 April	1.7	125	4	3.20
21 April	2.2	586	25	4.27
4 April	4.3	146	7	4.79
23 April	7	225	3	1.33
4 May	22.3	153	0	0
29 April	23.3	340	6	1.76
1 May	26.3	166	2	1.20

Table 10. Relative river stage and number of kokanee fry marked, released, and recaptured for assessing trap efficiency in the North Fork of the Payette River, Idaho, from 4 April to 2 June 1994 at trap site 2.

Date	River stage (cm)	Number marked	Number recaptured	Trap efficiency %
10 April	15	80	3	3.75
13 April	17	79	5	6.33
4 April	20	61	1	1.64
17 April	54	144	0	0.00
29 April	58	115	5	4.35
19 May	85	38	0	0.00
18 May	90	32	1	3.13
24 May	104	183	0	0.00
20 May	104	126	2	1.59
25 May	108	107	0	0.00
2 June	111	783	2	0.255
31 May	112	215	2	0.930
1 June	115	498	6	1.20
26 May	116	157	2	1.27

Table 11. Relative river stage and number of kokanee fry marked, released, and recaptured for assessing trap efficiency in the North Fork of the Payette River, Idaho, after 2 June 1994 at trap site 3.

Date	River Stage (cm)	Number Marked	Number Recaptured	Trap Efficiency %
6 June	116	1414	20	1.41
7 June	116	1087	11	1.01
8 June	121	732	3	0.410
9 June	121	710	14	1.97
14 June	128	508	5	0.984

pooled data also revealed a negative correlation (r=-0.69; Tables 9 and

Recruitment and Bcta-to-Fry Survival

During the sampling period in 1993 (31 March to 8 May), we estimated 1.73 million (95% bound +/- 0.338 x 10^6) kokanee fry entered Payette Lake (Table 12; Figure 8). Since we could not sample the NFPR after 8 May, this number is a partial estimate of total recruitment. The 1994 recruitment (Table 12; Figure 9) was estimated at 4.53 million (95% bound +/- 1.16 x 10^6). From the analysis of temperature units and cumulative fry emigration in 1994 (Figure 12), total recruitment in 1993 was estimated at 2.51 million (1.73 million divided by 68.8%). Kokanee had accumulated 698 thermal units from 31 August 1992 (date of peak adult trap count in 1992) until 8 May 1993. The same number of thermal units were acquired from 7 September 1993 (date of peak adult trap count in 1993) until 5 June 1994. Therefore, 5 June was the reference date for estimating 1993 recruitment. By 5 June 1994, 68.8% of the total 1994 kokanee fry recruitment had occurred. Using total egg depositions for both years, egg-to-fry survival for both year classes was similar (Table 12). Egg-to-fry survival was 18.9% (95% bound +/- 3.7%) and 24.4% (95% bound +/- 6.3%) for the 1992 and 1993 brood years, respectively.

Fry Size, Condition, and Developmental Stage

We used only those data from 1994 that were collected during similar accumulated thermal units as the 1993 sampling period to control for temporal differences for between year comparisons. Kokanee sampled

Table 12. Total egg deposition and egg-to-fry survival for the 1992 and 1993 kokanee broods at Payette Lake, Idaho. Ninety-five percent confidence limits are indicated in parentheses.

	1992	1993
Total egg deposition[a]	13.3×10^6	18.6×10^6
	(0.462×10^6)	(0.712×10^6)
Estimated fry numbers	1.73×10^6	4.53×10^6
	(0.338×10^6)[b]	(1.16×10^6)
Estimated recruitment	2.51×10^6	4.53×10^6
	(0.491×10^6)[c]	(1.16×10^6)
Percent egg-to-fry	18.9	24.4
survival (S)	$(15.7 \leq S \leq 21.8)$	$(18.8 \leq S \leq 29.4)$

[a] Objective 1.
[b] partial estimate of recruitment from 31 March - 8 May 1993.
[c] total recruitment determined from analyses of thermal units and 1994 cumulative fry counts.

from 20 March to 8 May 1993 migrated during accumulated temperature units of 600.8 and 697.5 (ºC; Figure 14). Similar thermal units were encountered during 23 May and 5 June 1994. During these comparable time periods, length of migrant kokanee was significantly larger in 1994 than in 1993 (P=0.0001; Figure 15). Overall, nightly mean length of migrant kokanee fry varied 6.1 mm (range=22.4-28.5) and 6.9 mm (range=20.6-27.5) in 1993 and 1994, respectively. The overall length distributions (all data from 1993 and 1994) revealed kokanee were larger in 1994 with some individuals growing to > 30 mm (Figure 16). Length varied 20.0 mm (range=12.6-33.6 mm) and 19.7 mm (range=17.5-37.2 mm) in 1993 and 1994, respectively. Comparison of condition factor (Figure 15) and stage of development between 1993 and 1994 (Figure 17) were opposite that of length; condition factor and stage of development were significantly higher in 1993 (P=0.0001). Only those near the end of the run in 1994 were similar in developmental stage to those in 1993 (Figure 17). The percent of kokanee at lower developmental stages increased after freshets (11 May 1994).

Within year comparisons of length, condition factor, and developmental stage revealed significant overall differences in all categories for both years (P=0.0001; P=0.003 for 1994 condition factor). Multiple comparison tests revealed which time periods differed within years with respect to length, development, and condition in 1993 (Table 13) and 1994 (Table 14). Mean length in 1993 increased then decreased significantly from late March to early May while condition factor did the opposite. Longer fry from 3 April to 20 April had relatively low weight indicated by the condition; fry from 21 April to 8 May were shorter but relatively heavy. Developmental stage in 1993 increased

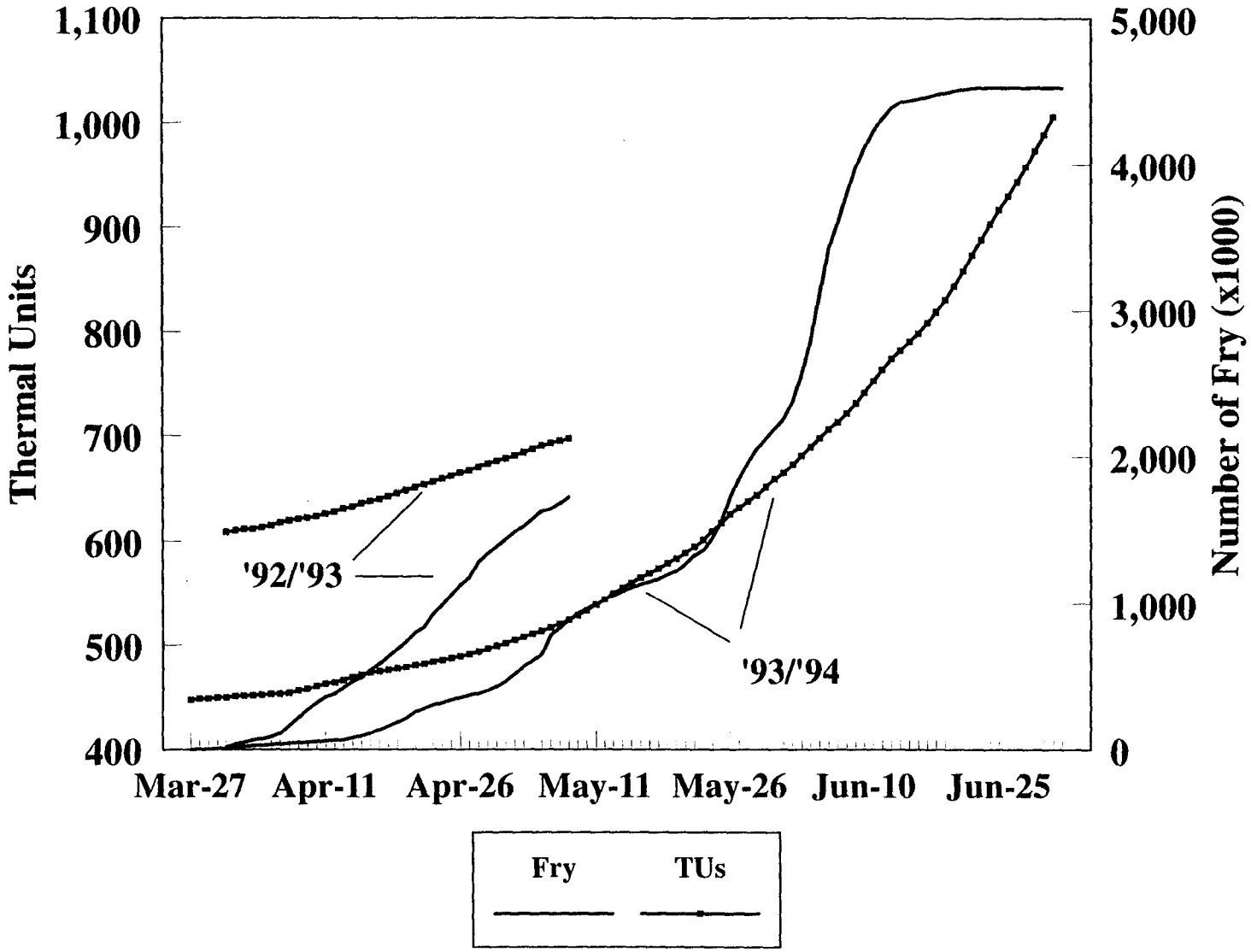

Figure 14. Thermal units accumulated by kokanee during 1992/1993 and 1993/1994 and cumulative estimates of fry migrating in the North Fork of the Payette River, Idaho.

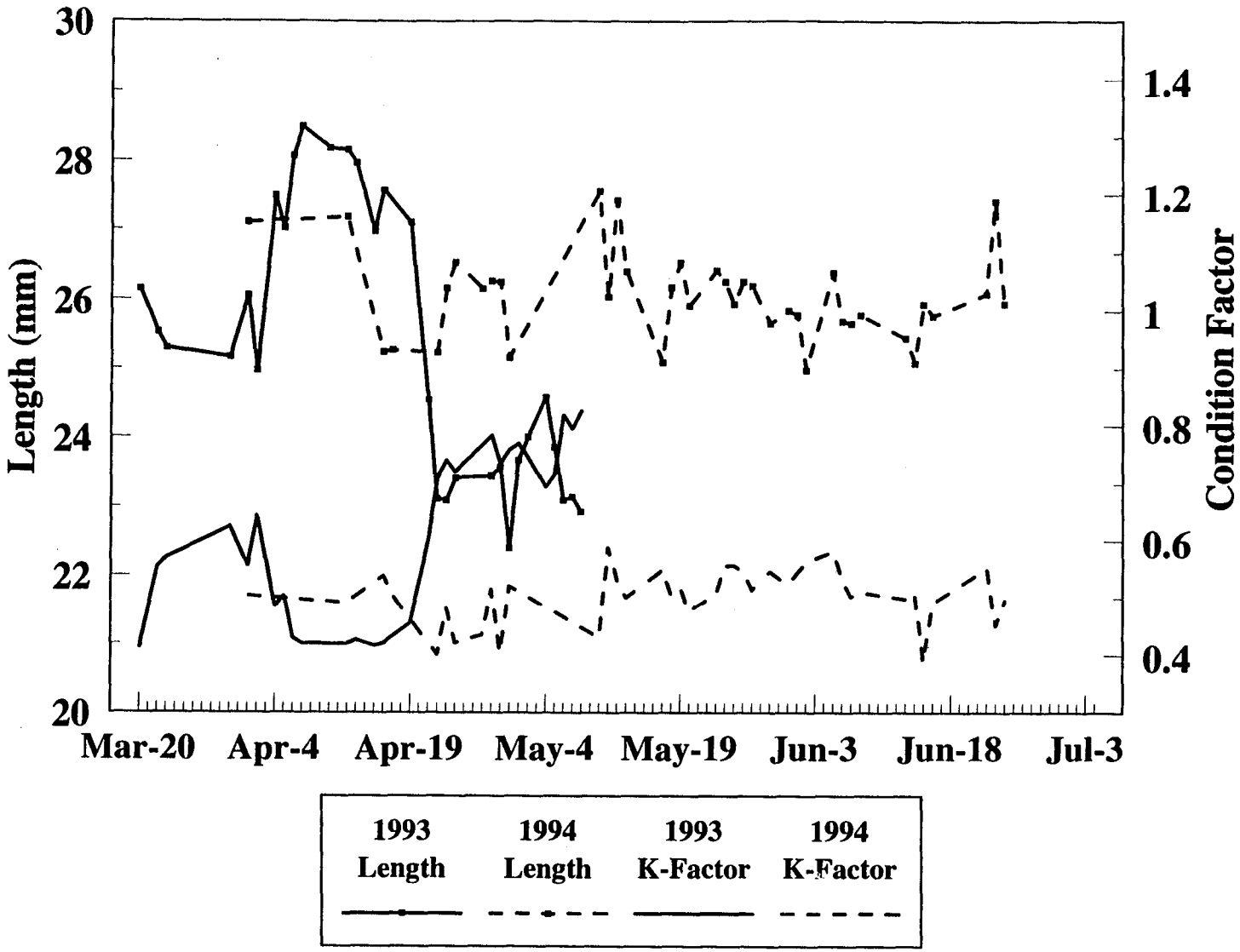

Figure 15. Length and Fulton's condition factor of kokanee fry during the 1993 and 1994 fry migrations in the North Fork of the Payette River, Idaho.

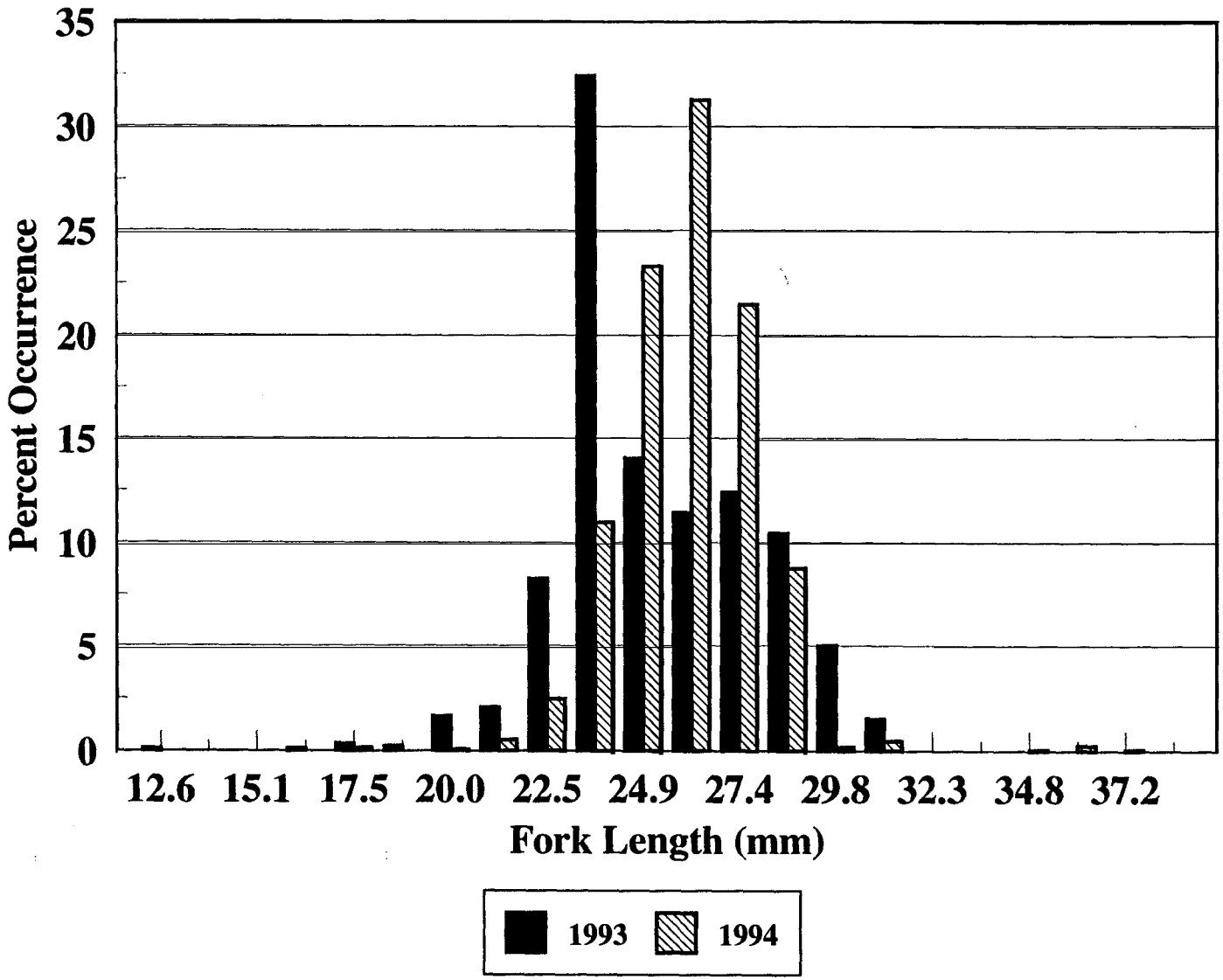

Figure 16. Length distributions of kokanee fry for 1993 and 1994 migrations in the North Fork of the Payette River, Idaho.

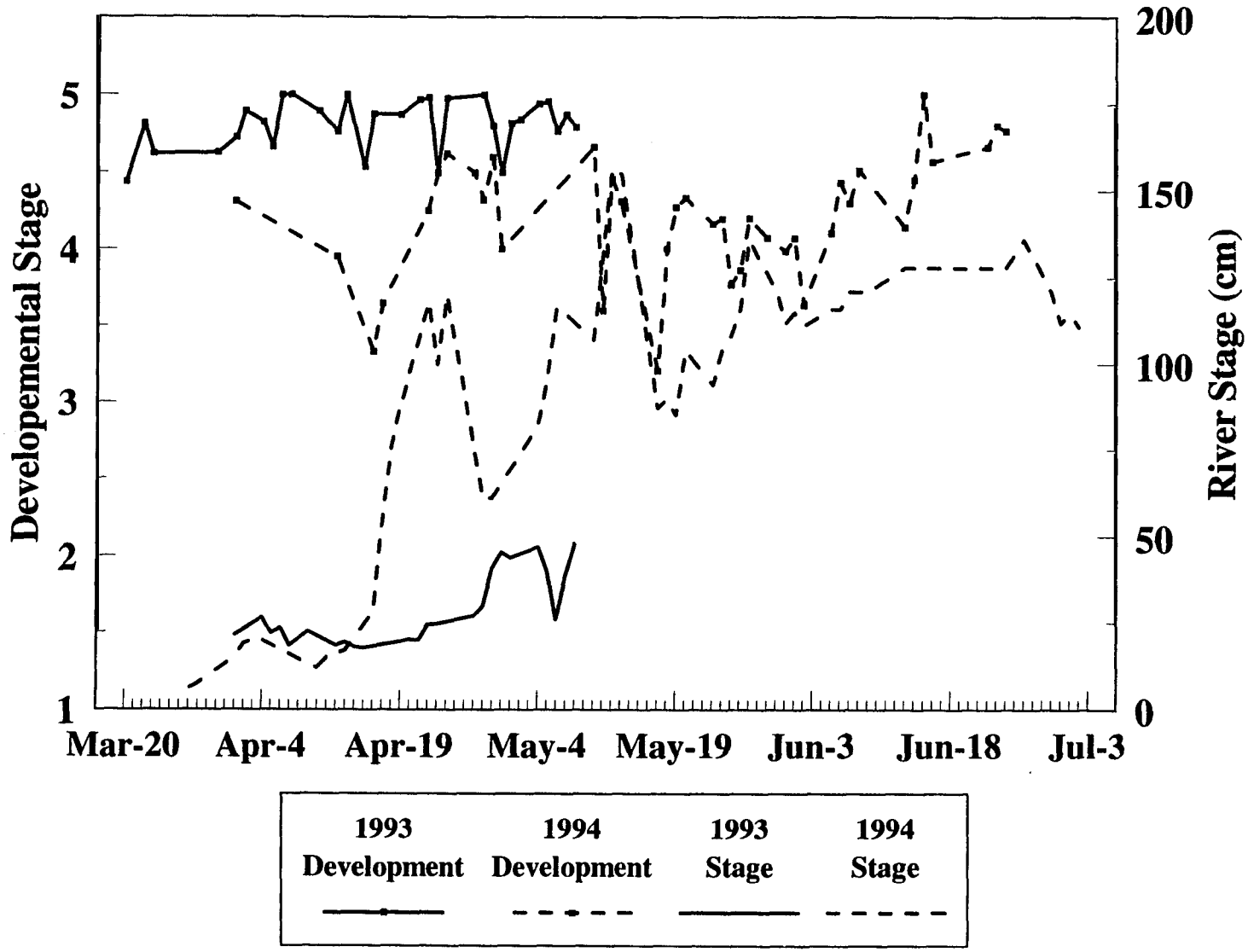

Figure 17. Developmental stage of kokanee fry and river stage during the 1993 and 1994 fry migrations from the North Fork of the Payette River, Idaho.

Table 13. Average length, developmental stage, and condition factor comparisons for 1993 migrant kokanee in the North Fork of the Payette River, Idaho. Within each category, means sharing a common letter are not significantly different (P>0.05).

Period	Mean length (mm)	Developmental stage	Fultons condition factor
20 March - 2 April	25.7 y	4.58 y	0.512 y
3 April - 20 April	27.8 x	4.86 x	0.439 z
21 April - 8 May	23.6 z	4.89 x	0.733 x

Table 14. Average length, developmental stage, and condition factor comparisons for 1994 migrant kokanee in the North Fork of the Payette River, Idaho. Within each category, means sharing a common letter are not significantly different (P>0.05).

Period	Length (mm)	Developmental stage	Fultons condition factor
1 April - 16 April	26.3 x	3.82 z	0.518 xy
17 April - 3 May	25.8 y	4.21 y	0.485 y
4 May - 22 May	26.3 x	4.12 y	0.515 xy
23 May - 30 May	26.1 yx	3.96 yz	0.547 x
31 May - 11 June	25.7 y	4.18 y	0.534 x
12 June - 28 June	25.8 y	4.55 x	0.505 xy

between the first and second periods then stabilized (Table 13). Mean length in 1994, which encompassed the entire fry migration, significantly decreased with the longest fry occurring during early April and the shortest during June (Table 14). Condition factor in 1994 declined early but was generally stable. Developmental stage in 1994 was low early in the run, stabilized during most of the run, and increased significantly during the final period (Table 14).

DISCUSSION

Seasonal and Diurnal Emigration Timing

Barns (1969) hypothesized growth potential and food availability operate as selective forces to govern the time of lake entry by sockeye fry. Brannon (1984) and Miller and Brannon (1982) identified emergence timing of salmonid fry from the redd as the major evolutionary factor that has established sockeye spawning time in a stream. As a result of these selective pressures and that incubation time is determined by the temperature regime of the spawning stream, Brannon (1987) concluded the appropriate spawning time is relatively fixed for each population and is a genetic characteristic of each stock that has been selected to assure an optimum emergence timing. Kokanee have existed in Payette Lake at least since the late 1800s when Everman (1896) reported "large redfish" and "little redfish" spawning in the inlet to Payette Lake. Spawning time for this population, primarily in September, and emergence timing and time of lake entry beginning in late March, has been genetically refined over many generations resulting in the optimum time of lake entry with respect to growth potential and food availability.

Migration of sockeye salmon and kokanee fry toward their nursery lake is primarily nocturnal (Hartman et al. 1962; Acara and Smith 1971; Stober and Hamalainen 1979; and Fraley and Clancey 1988). Hartman et al. (1962) concluded migratory behavior of sockeye salmon fry had important survival value. These authors believed fry migrated during the darkest hours of the night to avoid predation by Dolly Varden *S. malma.* During daylight hours they observed fry hiding behind clumps of grass. We observed similar behavior in fry released at daylight (marked and unmarked). We observed active migration generally between 2130 and 0530 hours during times representing sunset and sunrise, respectively. Other investigators reported similar migration times for kokanee (Acara and Smith 1971; Fraley and Clancey 1988) and sockeye salmon (Hartman et al. 1962; Brannon 1972; and Stober and Hamalainen 1979), and Hartman et al. (1962) and Acara and Smith (1971) also observed shortened times of active migration as the season progressed. They attributed shortened fry movement to progressively longer periods of daylight. We observed, as did McDonald (1960a) and Hartman et al. (1962), later peaks in nightly abundance as the season progressed. Actual timing of the nightly peaks may be a result of the distance of spawning grounds to our trap. Our trap site was sufficiently close to the spawning grounds so fry emerging from gravels would probably reach the trap in the same night. Egg deposition was later in upstream spawning areas, and because temperatures were lower, fry from upstream reaches could have migrated later in the season.

Trap Efficiency

Sampling migrant juvenile salmonids with traps is often difficult as a result of harsh conditions associated with spring runoff, high flows, and large volumes of debris. Traps designed to catch all or most of downstream migrants can be washed out, as we were in 1993, or clogged with debris causing potential harm to fishes and sampling gear. As an alternative, some investigators have chosen to subsample migrating juveniles with traps of reduced size (Seelbach et al. 1985; Tsumura and Hume 1986; McMenemy and Kynard 1988; Dempson and Stansbury 1991). Using smaller traps requires a more accurate estimate of juvenile abundance by a more accurate assessment of trap efficiency. Trap efficiency is applied to the partial count (partial count divided by proportion) to estimate total abundance. In some instances investigators rely on small sample sizes and low numbers of marked individuals to estimate trap efficiency, which can be related to a lack of available fish (Seelbach et al. 1985; Tsumura and Hume 1986; McMenemy and Kynard 1988). Relying on few samples, particularly if they are temporally clustered, may be misleading because trap efficiency can conceivably change with flow, light, temperature, debris, and predation conditions that occur during spring runoff. Acara and Smith (1971) observed horizontal, vertical, and diel shifts in the distribution of migratory kokanee during a single year of recruitment. With such behavioral shifts, trap efficiencies based on few trials may not be adequate for accurately estimating size of juvenile populations.

We observed variable trap efficiencies with a relatively large sample size, 27 trials using 9,121 fry, during this 2 year study that was partially explained by river stage. River stage accounted for 66%,

42%, and 48% of variation in trap efficiency in 1993, 1994, and the pooled data from sites one (1993) and three (1994), respectively. Although probable behavioral changes occurred with time, the most plausible explanation for the observed changes in efficiency was the cross-sectional area being fished was reduced at high flows. The trap-mouth was small relative to the river cross-section. While this area remained constant, high flows increased the river cross-section thus reducing efficiency of the trap (i.e. captured a smaller proportion of marked individuals). Efficiency was more closely related to flow in 1993. The sampling period in 1993 was shorter than 1994 and therefore might not reflect the probable behavioral shifts that occurred over the entire migration period. In 1993, we did not sample during peak river flow which might change behavior and therefore change trap efficiency. Also, other variables, such as sediment discharge, river profile, and light levels, could affect migratory behavior of juvenile salmonids and probably could account for additional variation not accounted for in our sampling.

Utility of the vital stain, Bismarck brown-R, for marking fry was considered enormous for working with small, fragile fish. We were able to mark numerous fry quickly and easily. Other marking alternatives, fin-clipping and fluorescent grit, were considered too severe and time-consuming for the size and fragility of kokanee fry. Many investigators have successfully used this dye to mark kokanee fry and other salmonid juveniles in fish production and behavioral studies (Ward and Verhoeven 1963; Mundie and Traber 1983; Bowles et al. 1987; Fraley and Clancey 1988). We used similar dye concentrations at temperatures within the range of those reported and found negligible mortality and adequate mark

retention. Upon releasing marked fry at sunrise, we observed them to seek cover immediately in the substrate or vegetation along the stream bank that was often preceded by a few seconds of drifting or actively swimming downstream 3 to 4 m. The majority of recaptures were caught during the initial hour or two of sampling during the next dark period, and few were captured as late as 0100 hours approximately 4 hours after active migration had begun. We believe these observations and the lack of daytime captures support the assumption that marked kokanee upon release delayed migration until nighttime.

Recruitment and Egg-to-Fry Survival

The fry trap used in this study was safe and easy to operate, inexpensive (about $500, U.S.), and provided consistent results over 2 years of sampling. Overall trap mortality, often higher in fyke net designs (Conlin and Tutty 1979), was about 7.5% at 1,420 fry. The egg-to-fry survivals we observed in this study were higher than most reported by other investigators for sockeye salmon and kokanee (Table 15). Many factors may be contributing to the high spawning and incubation success in the NFPR. Flow conditions during incubation were identified as a major factor influencing pink and chum *O. keta* salmon survival (McNeil 1966; McNeil 1968). Flows in the NFPR during incubation are relatively stable. The river is normally covered with ice and snow from November until early March. Scouring of spawning beds by rain-on-snow events are uncommon in the region. Although reaches of the river have been negatively impacted by forestry activities in the watershed (U.S. Forest Service 1991), existing spawning areas appear sufficient to produce high survival to the fry stage. However, further

Table 15. Reported kokanee and sockeye salmon Oncorhvnchus nerka egg-to-fry survivals in various locations. All survivals were determined from egg deposition to emigrant fry.

Species	% egg-fry survival	Location	Source	Comments
kokanee	0.50 - 29.1	Lake Stevens, WA	Pfiefer 1978	four streams
kokanee	4.2	Redfish Creek, B.C.	Fleck and Andrusak 1977	
kokanee	5 - 14	Mission spawning channel, B.C.	Shepherd 1990	improved area
kokanee	15.4	Banks Lake, WA	Stober and Tyler 1982	beach spawners
kokanee	41 - 62	Peachland Creek	Shepherd 1990	improved area
sockeye salmon	0.7 - 13.7	Naknek River System, AK	Ellis and McNeil 1979	ten observations
sockeye salmon	1.8 - 25	Hooknose Creek, B.C.	*Anonymous* 1955	seven observations
sockeye salmon	4.5	Cedar River, WA	Stober and Hamalainen 1979	
sockeye salmon	7.8	Williams Creek, B.C.	Anonymous 1955	
sockeye salmon	8.5	Hidden Creek, AR	Hartman et al. 1962	
sockeye salmon	9.3 - 13.8	Scully Creek, B.C.	Anonymous 1955	six observations
sockeye salmon	17.7	Williams Creek, B.C.	Anonymous 1955	improved area

degradation of spawning areas from increased fine sediment loads should be averted to protect existing spawning habitat.

Fry Size, Condition, and Developmental Stage

The 1992 kokanee brood entered the upper reaches of the NFPR about a week earlier than did the 1993 brood and undoubtedly resulted in an earlier egg deposition. The annual difference was apparently due to an unnatural flow increase caused by water releases from upstream reservoirs (Objective 1). Minor shifts in spawning time, which occurred at mean temperatures of 11'C, could alter emergence timing which occurs at 30C. Fry from the 1993 brood were longer but not higher in condition or developmental stage when compared to fry produced from the 1992 brood. We observed as many as 44% of the migrants with significant amounts of yolk left to be absorbed (stages 1 and 2) at times of increasing river stage in 1994. Survival of these fish during the remaining migration to the lake and during the initial lake residence is probably lower than fry in later stages of development. Fry from the 1993 brood accumulated fewer temperature units than did fry from the 1992 brood at similar time periods. When spring flows in 1994 scoured spawning gravels and forced kokanee to migrate, a significant portion of kokanee may not have been developmentally ready. Environmental disturbances that affect the timing of spawning and egg deposition, such as unnatural flow increases, may have negative consequences on year-class strength. We do not know if kokanee survival to and in the lake will be affected by their earlier stage of development. The lack of concealing pigmentation and the presence of a bright orange yolk sac may subject those individuals to higher predation risk. Size and condition

factor of migrant kokanee fry in the NFPR was similar to those reported by Shepherd (1990) for two creeks in British Columbia.

We observed similar length trends observed by others for kokanee (Shepherd 1982; Shepherd 1990) and pink and chum salmon (Barns 1970) over the entire period of outmigration in 1994. Data from 1993 was only collected during the initial part of the run and thus are inconclusive with respect to seasonal trends. Length of migrating fry probably has direct survival importance. Fry vulnerability and length were found to be directly related (Sams 1967; Beall 1972). Since weight of salmonid fry tend to decrease with length over a migration season, condition factors based on length and weight are expected to remain generally constant (Sams 1970). Shepherd (1990) observed this trend at Peachland Creek, British Columbia, however, in the Mission channel weights of kokanee were variable. We observed stable condition factors throughout the kokanee run in 1994 and relatively erratic data for the abbreviated 1993 sampling period.

Developmental stage in kokanee and sockeye salmon generally increases as the season progresses (Clarke and Smith 1972; Stober and Hamalainen 1979; Shepherd 1990). We also observed kokanee in later stages of development near the end of the run in 1994. Accumulated temperature units play a major role in these consistent observations. Also, we observed fry in June 1994 that had obviously reared in the river for varying lengths of time. Some individuals had attained lengths of nearly 38 mm. Fraley and Clancey (1988) made similar observations in the Flathead River system, Montana. Optimum migration and lake conditions may occur at some narrow, optimum time, (first week of June based on 1994 data), and kokanee may delay migration for short

periods, rear in the river, and migrate during an optimum period. Size, condition, and stage of development data should be interpreted with caution since many variables affect migration timing during the approximately 3 month period: spawning time and characteristics (i.e. "wave" spawning), river flow, and temperature regime of the incubation habitat.

Objective 3. To determine* kokanee *survival* to *pre-emergence in relation to substrate size composition.

INTRODUCTION

Intragravel incubation from egg deposition to fry emergence represents a critical time in the salmonid life cycle as mortality is highest and most variable during this early life stage (McNeil 1969). Fisheries investigators have used many devices and techniques to evaluate survival during the egg-to-fry stage. Fry enumeration shortly after emergence has been used to assess total mortality during the critical egg-to-fry stage (Wolf 1950; Acara and Smith 1971; Clarke and Smith 1972; Tagart 1984; Fraley and Clancey 1988). Artificial methods have been used to observe survival at various points during incubation to assess factors influencing incubation and to identify stages of highest mortality. Whitlock-Vibert boxes (MacKenzie and Moring 1988), artificial redds (Gustafson-Marjanen and Moring 1984), plastic cylinders (Scrivener 1988), and nylon bags (Pauwels and Haines 1994) were used to measure survival to hatching and emergence of various salmonids.

Estimating salmonid survival during incubation has become necessary for managing natural populations and determining impacts of watershed management. Silvicultural activities in the Pacific Northwest and other regions of the United States has led to increasing levels of sediments entering streams which often results in degradation of spawning and rearing substrate used by salmonid fishes (Shirazi and Seim 1979). Effects of fines on salmonid spawning success has received much attention (Chapman 1988), and fisheries researchers generally agree excess fine sediments in salmonid spawning areas are a cause of embryo and larval mortality (Iwamoto et al. 1978). Low embryo survival has

been attributed to reduced substrate permeability and/or entrapment of larvae and fry (Cordone and Kelley 1961; Gibbons and Salo 1973; Iwamoto et al. 1978). Reduced permeability restricts water flow to incubating embryos and results in decreased oxygen supply and increased accumulation of toxic metabolites around embryos. Entrapment of embryos and larvae occurs when fines accumulate and prevent emergence of fry. Percent embryo survival has been shown to be positively related to substrate composition for several species of salmonids (Shirazi and Seim 1979).

Fish habitat in the NFPR has been degraded as a result of forest management practices in the watershed, and a decline in kokanee spawning habitat was predicted as a result of timber sales proposed for 1992 (U.S. Forest Service 1991). Kokanee spawn primarily in the sediment depositional zone in the NFPR below the confluence of Fisher Creek, therefore, watershed activities resulting in increased delivery of sediment are expected to directly affect kokanee spawning habitat in the NFPR. We assessed kokanee survival from egg deposition to fry emergence for the 1992 and 1993 kokanee broods in Payette Lake (Objectives 1 and 2). We also examined kokanee survival to the pre-emergent fry stage for the 1991, 1992, and 1993 kokanee broods in Payette Lake in relation to substrate composition in spawning areas. We partitioned mortality for two brood years within the egg-to-fry stage of two periods: mortality from egg deposition to pre-emergent fry and mortality during the final stages of gravel residence, emergence, and emigration in the NFPR to our fry sampling station in the lower NFPR. Collection of substrate composition data enabled us to describe relations with pre-emergent survival, general quality of substrate available to kokanee in the NFPR,

and a framework for future monitoring of principal spawning sites in the NFPR.

METHODS

Density and Survival

Suspected spawning areas of the NFPR, Box Creek, and Fisher Creek were sampled during March 1993 and 1994 to obtain density and survival estimates of kokanee embryos and larvae. Kokanee embryos and sac fry were captured in a kick screen placed downstream from each sampled area. A hydraulic sampler similar to that described by McNeil (1964) and Magee and Heiser (1971) was used to remove embryos and alevins from a 0.2 m^2 area of gravel. The sampler consisted of a fire pump, 4-cm hose, and a metal pipe wand equipped with a venturi process to mix air with water flowing through the wand. The air-water mixture lifted embryos and sac fry into the current and ultimately into a kick screen. Each area was sampled for 60 seconds. A third person assisted by sweeping low velocity sample areas with a canoe paddle toward the kick screen. Standard window screening was used in 1992 to construct the kick screen (1 m wide x 0.75 m high) and 3.2-mm nylon mesh screening was used in 1993 to minimize fine sediment accumulation. An 8-mm lead line was doubled and sewn into the bottom of the kick screen to keep the netting from rising off the substrate in high velocity areas. All kokanee embryos and alevins were collected from the screen, preserved in a 10% formaldehyde solution, and labeled by stratum and sample number. The samples were later sorted in the laboratory and the contents were tallied under the following categories: # live embryos; # dead embryos; # alevins; # fry; and # embryo fragments.

We distributed sampling effort throughout the NFPR using a stratified random design with proportional allocation (Scheaffer et al. 1990), as spawning areas were sampled in proportion to their size. Area (m^2) of spawning within strata and total area of spawning (Objective 4) was used to allocate effort within strata.

Live embryos, alevins, and fry were sampled then divided by the total living and dead specimens to determine survival to pre-emergence in each sample. Egg fragments were not included in the survival estimates as that generally over estimates survival if dead embryos and sac fry decomposed (McNeil 1964). The number of dead embryos that decomposed during the incubation period were estimated to control bias from embryo decomposition. We planted dead embryos in 14 and 30 numbered Whitlock-Vibert boxes in 1992 and 1993, respectively. Embryos were planted on 19 December 1992 and 23 September 1993 during the actual time of normal kokanee egg deposition in the NFPR. Boxes were filled with gravel substrate and 75 to 100 dead embryos. Artificial redds were constructed by excavating pits in gravel reaches of the NFPR and cleaning gravel in an area that approximated natural kokanee redds. Each box was wrapped in window screening, attached to 0.5-m long rebar with cable ties, and buried in the pits. During March 1993 and 1994, we retrieved the boxes and counted the number of embryos that remained. To adjust survival estimates, we divided observed numbers of dead eggs by the proportion of embryos in the boxes that remained intact. The predicted number of dead eggs were used in our survival estimates.

We evaluated the efficiency of the hydraulic sampling method by conducting several depletion trials in 1993 and 1994 while collecting samples in the NFPR. The specific questions we examined concerned the

proportion of specimens recovered during the initial 60 seconds sampling run and whether the method differed in its ability to recover embryos and alevins during the first sampling run. If embryos, particularly dead ones, were sampled differently than alevins, our survival estimates could be biased. Samples chosen for depletion trials were done systematically from each day's list of samples. Each area chosen for depletion was sampled multiple times (60 s/run) until captures of embryos and alevins were near zero. Captures of embryos and alevins on the first trial were expressed as proportions of the total catch.

Substrate Composition

Gravel substrates in principal kokanee spawning areas in the NFPR were studied to determine the relationship with survival to pre-emergence and the general quality of incubation gravels. Substrates were collected in March 1993 while collecting data on pre-emergent survival. Substrate cores were retrieved immediately adjacent of sites sampled for survival so we could determine the relationship between pre-emergent survival and substrate composition. Data were analyzed with simple linear regression; survival percentages were transformed by arc-sine square root for statistical analysis. Additional substrate cores were collected in July in heavily used kokanee spawning areas prior to the spawning run in 1993.

We used an excavated-core sampler (McNeil and Ahnell 1964) to collect substrate samples. The sampler was forced into the substrate and substrate in the cylindrical core was extracted by hand. The core measured approximately 15 cm x 20 cm. Substrates were packed in 2.3-kg plastic containers, marked for location, and transported to the

laboratory. All samples were oven-dryed at 103°C for 4 days and sorted with a mechanical shaker for 60 seconds through a series of standard U.S.G.S. sieves. Sediment on each sieve was weighed to determine relative weight in each size class. We used the quantile graphical method suggested by Shirazi and Seim (1979) to analyze substrate size distribution. Sediment weight data were plotted on log-probability paper, and statistics of the size distribution (diameters of various percentiles) were taken directly from the plot. Specific data points taken from each plot included diameters at percentiles 5, 16, 25, 50, 75, 84, and 95. We calculated several measures of substrate size distribution from these data and geometric mean particle size (Platte et al. 1979), Fredle index (Lotspeich and Everest 1981), and a modified Fredle index (Beschta 1982). Geometric means (GM) were computed as: GM = $(D_{84}D_{16})^{1/2}$; where D_{84} is the particle size of which 84% of the substrate is smaller, and D_{16} is the particle size of which 16% of the substrate is smaller. The Fredle index (FI) incorporated factors that combine gravel permeability and pore size: FI = $Dg/(D_{75}/D_{25})^{1/2}$; where D_g is the geometric mean particle size and D_{75} and D_{25} are diameters of grains at the 75th and 25th percentiles of cumulative gravel sample weight. Beschta (1982) suggested the Fredle index be improved by using the standard deviation of the geometric mean rather than the sorting coefficient $(D_{75}/D_{25})^{1/2}$. Other statistics computed from sediment weight data include the proportions of substrate particles less than a given size ("percent fines"). Percent weight less than 6.35 mm, 3.35 mm, 0.833 mm, and 0.25 mm were calculated.

RESULTS

Density and Survival

A total of 112 and 106 samples were collected from the NFPR and tributaries with the hydraulic sampler during March 1993 and 1994. Embryos and/or alevins or fry were found in 95 samples in both years. Mean density (No./m^2) of all embryos and alevins was 537 (SD=605; n=112) and density of live embryos, alevins, and fry was 406 (SD=545; n=112) in 1993. Mean density (No./m^2) of all embryos and alevins was 547 (SD=554; n=106) and density of live embryos, alevins, and fry was 414 (SD=478; n=106) in 1994. Mean egg to pre-emergent fry survival in 1993 was 64.5% (SD=37.0%; n=95) using adjusted dead egg numbers; survival using unadjusted dead egg numbers was 66.6% (SD=37.1%; n=95). Mean survival in 1994 was 70.2% (SD=34.0%; n=95) using adjusted dead egg numbers; survival using unadjusted dead egg numbers was 72.4% (SD=33.6%; n=95). Survival data were not distributed normally, but severely skewed, as individual survival ratios tended to be either low or high in both years (Figure 18).

Egg decomposition in Whitlock-Vibert boxes was related to duration of time in gravel substrate. Fourteen boxes were recovered in March 1993 after 87 days exposure and egg loss was 12.3% (range=0-23.0%). Twenty-seven boxes were recovered in March 1994 after 172 days exposure and egg loss was 21.6% (range=2.0-90.0%) which was accepted as indicative of embryo decomposition in the NFPR during normal duration of kokanee incubation. Observed dead embryo values were divided by 0.784 to estimate dead embryo numbers.

Depletion trials indicated a large proportion of each sample were retained within the first minute of sampling and there was little

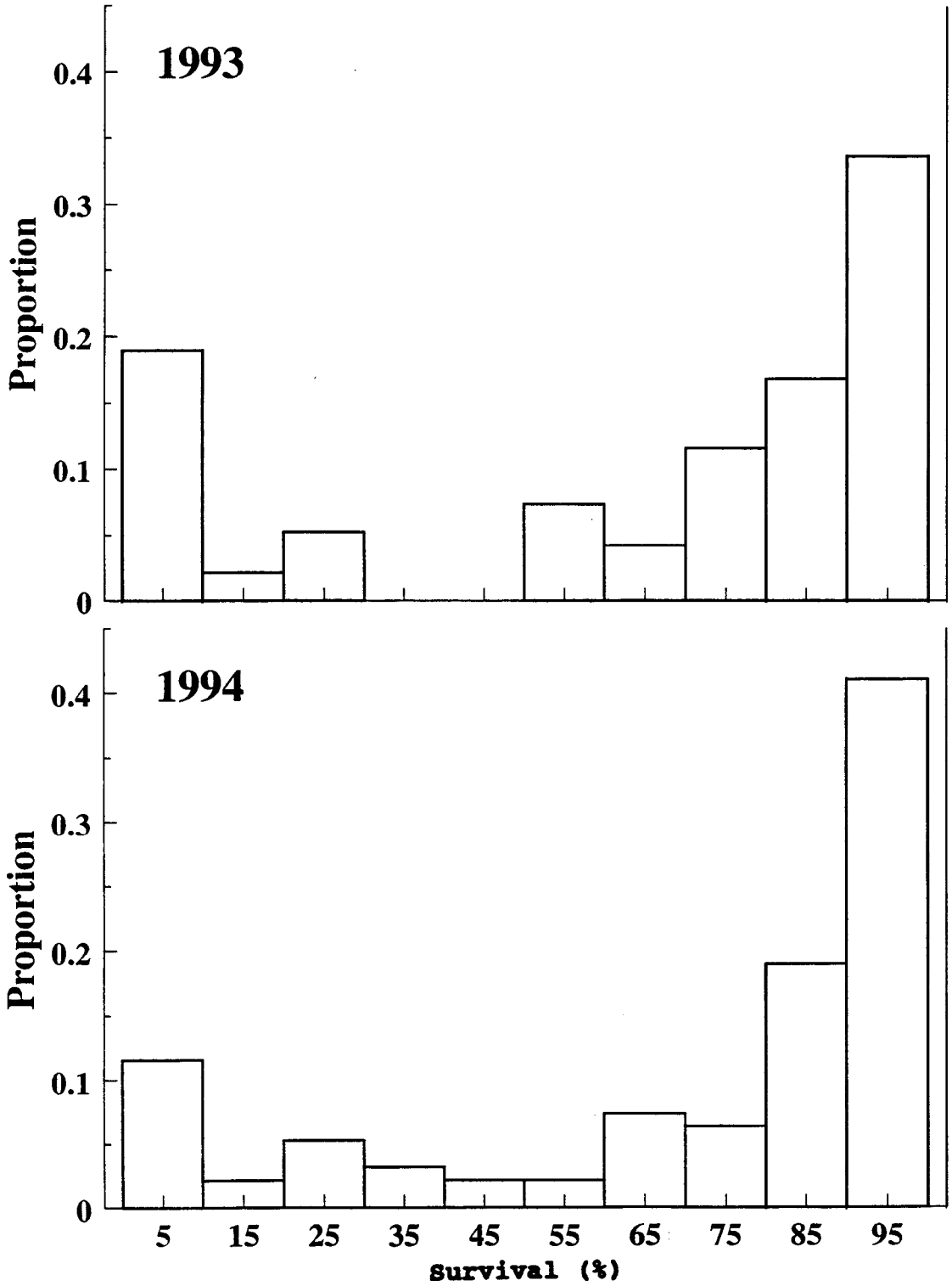

Figure 18. Histograms of survival to pre-emergence as determined from hydraulic sampling in the North Fork of the Payette River, Idaho. in 1993 and 1994.

difference between capture of embryos and sac fry on the first run. Seven and 14 depletion trials were conducted in 1993 and 1994, respectively. Seventy-seven percent of embryos (dead and alive, range=27-100%) and 82.0% of sac fry (range=12-100%) were captured during the first 60 seconds sampling run. Captures averaged 91.5% and 97.6% for embryos and sac fry after the second run. Nearly 100% capture was achieved after the fourth run with the exception of two samples in 1994 when total capture was achieved after five runs.

Substrate Composition

Significant regression equations were determined between transformed survivals (S_t) and the Fredle index and modified Fredle index; variation explained by regression models were low (<24%). Survival data from Area 6 (Appendix Table 1) and the Fredle index revealed the best relationship (r^2=0.24; n=19; P=0.03; S_t=-0.20(FI) + 1.54). Survival data from Area 6 were similarly related to the modified Fredle index (r^2=0.21; n=19; P=0.04; S_t=-0.09(FIm) + 1.14). A significant relation was detected in the entire data set (Appendix Table 1) with the modified Fredle index, but the variation in survival explained by the model was smaller than that for Area 6 (r^2=0.11; n=42; P=0.03; S_t=-0.09(FIm) + 1.11). Relationships between S_t and the geometric mean particle diameter were nearly significant at a = 0.05 for Area 6 data (r^2=0.17; P=0.08; n=19) and all data (r^2=0.07; P=0.08; n=42). Relationships with percent fines were not significant and generally low (usually <1.0% of variation in S_t).

Geometric mean (GM) in principal kokanee spawning areas ranged from 4.8 to 13.5 mm, 1.8 to 6.7 for Fredle index (FI), and 0.6 to 4.5

for the modified Fredle index (FIm; Table 16). Substrates in kokanee spawning areas differed in composition as reflected by size distribution statistics and percent fines. Location A (Table 16; Figure 19) had the highest GM, FI, and FIm and lowest percent fines than any spawning area studied. Statistics for Location C (Figure 20) were slightly lower than Location A, and those for Location D (Figure 20) were significantly lower than Location A (Table 16). Locations A, C, and D were in main channel reaches of the NFPR and were among the most heavily used kokanee spawning areas. These sites were also the first sites selected by kokanee at the initiation of spawning runs in 1992 and 1993. Locations B and E (Figures 19 and 21) were spring habitat that were located in off-channel areas with low velocities (Objective 4) and were also used extensively by spawning kokanee. These spring areas had gravel compositions that differed substantially from main channel areas (Table 16). Geometric mean, FI, and FI_m were consistently lower in Locations B and E; value ranges generally overlapped with those in Location D and overlapped infrequently with Locations A and C. Percent fines in Locations B and E were also higher than in other locations as samples contained as much as 41% and 23% of sample weights < 0.833 mm (Table 16). As much as 59% and 41% of sample weights in Locations B and E were comprised of sediments < 6.35 mm while the range of maximums were 18 to 34% for all other locations.

DISCUSSION

Density and Survival

Our survival estimates for 1992 (Frost and Bennett 1994) and 1993 were similar indicating similar incubation conditions during these years

Table 16. Gravel statistics of five kokanee spawning areas that were highly utilized in 1992 and 1993 in the NFPR. Figures detailing locations are indicated in column one. Ranges of statistics are indicated in parentheses. Locations A and E were in spring habitat.

Location (Figure #)	n	Geometric Mean	Fredle Index (FI)	Modified FI	%<3.35 mm	%<0.833 mm
A (2)	10	13.5	6.7	4.5	14.0	5.4
		(9.6-18.2)	(4.5-10.7)	(2.7-8.2)	(8.1-17.7)	(2.8-7.5)
B (2)	10	4.7	1.4	0.6	34.1	23.1
		(2.6-5.8)	(0.5-2.8)	(0.3-1.1)	(24.3 59.2)	(13.7-41.3)
C (3)	10	9.8	3.9	2.4	21.8	8.0
		(5.8-17.7)	(1.7-9.9)	(1.1-6.0)	(12.3-30.4)	(3.5-12.3)
D (3)	10	5.6	2.3	1.4	26.6	11.4
		(4.2-8.4)	(1.6-4.1)	(1.0-2.7)	(19.3-33.8)	(8.0-14.4)
E (4)	19	4.8	1.8	1.0	31.3	16.1
		(3.2-7.0)	(0.9-4.4)	(0.6-1.6)	(23.2-41.2)	(10.2-22.5)

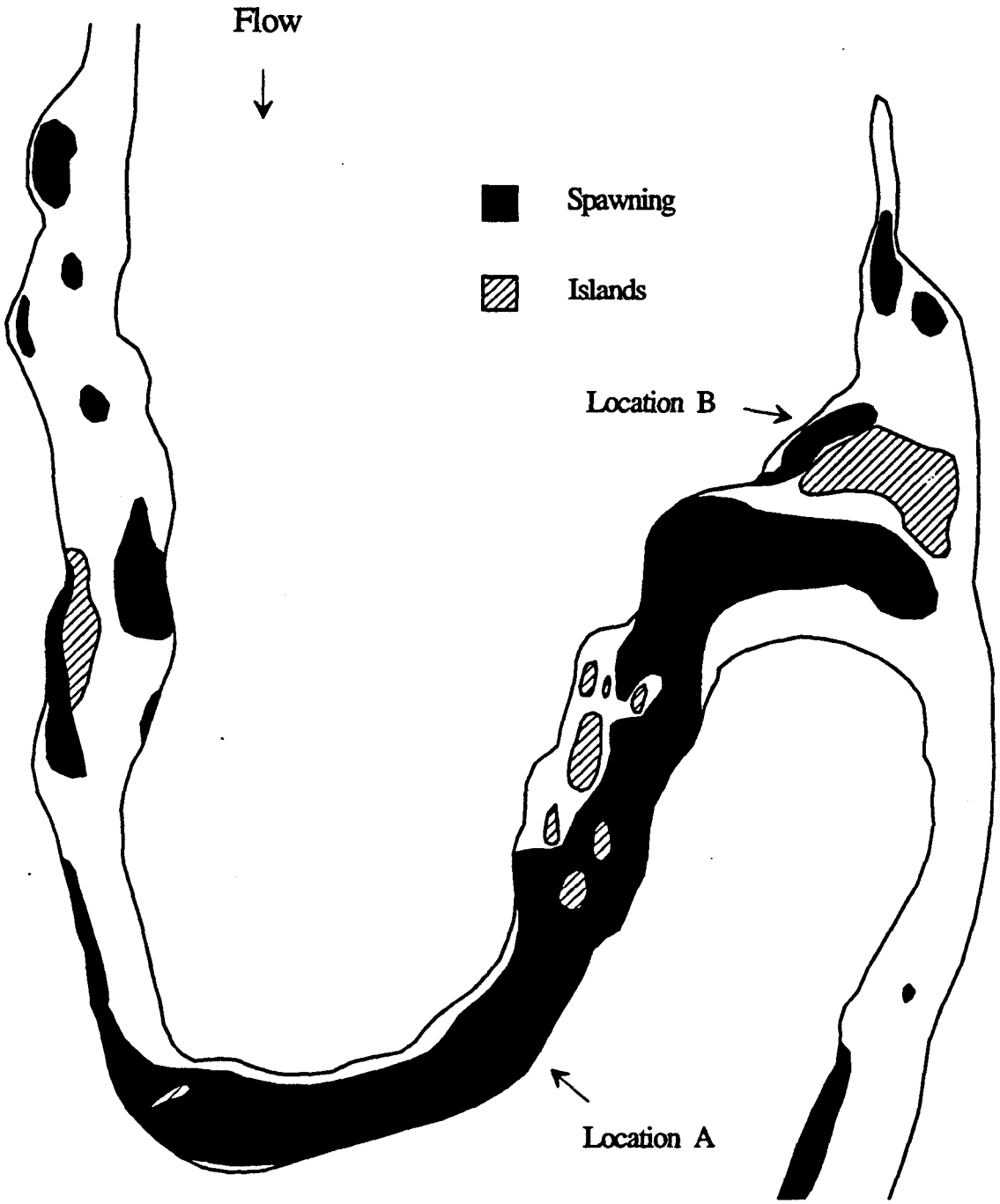

Figure 19. Substrate sampling sites in spawning Locations A and B of the North Fork of the Payette River, Idaho. Location B was classified as spring habitat.

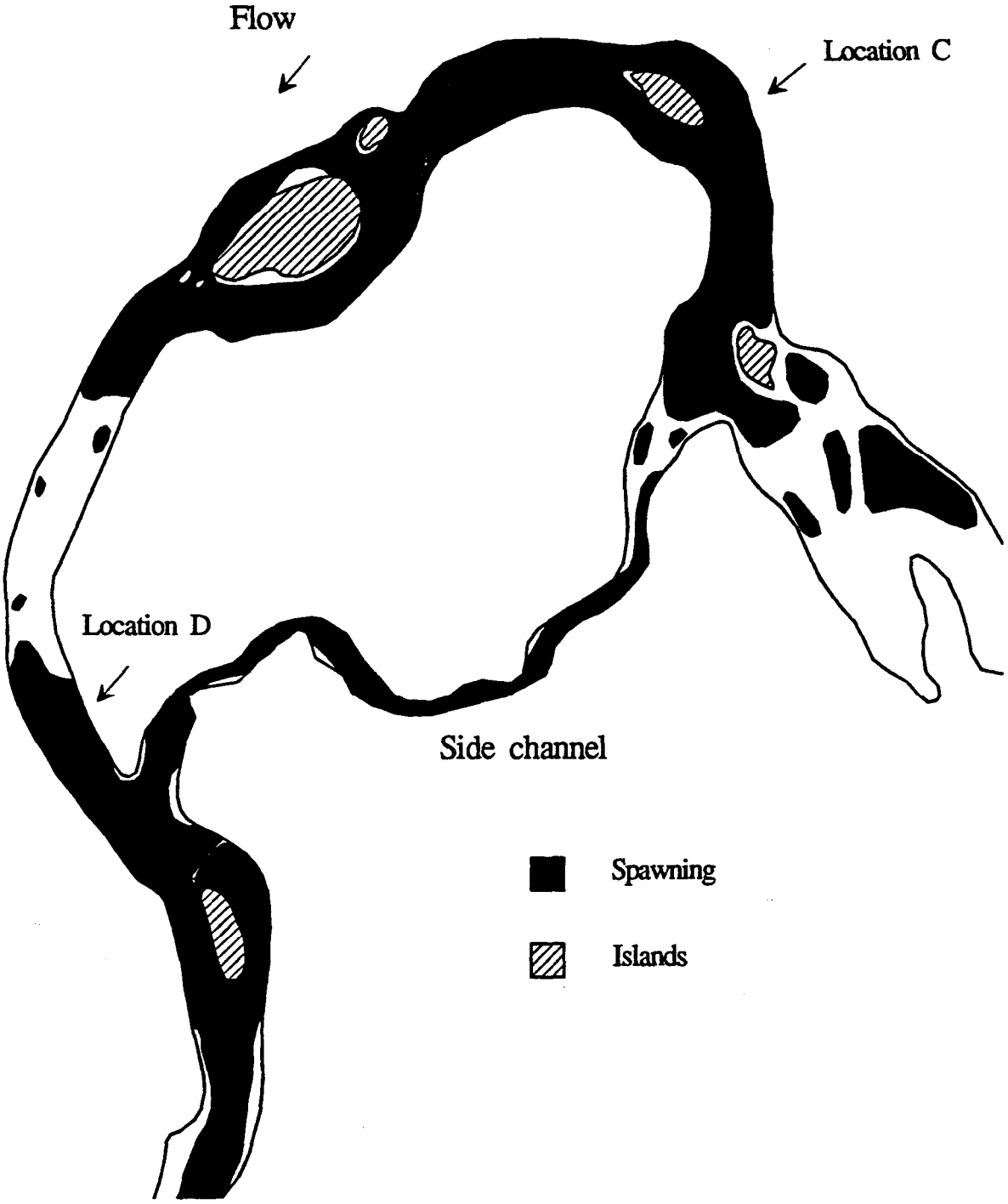

Figure 20. Substrate sampling sites in spawning Locations C and D of the North Fork of the Payette River, Idaho..

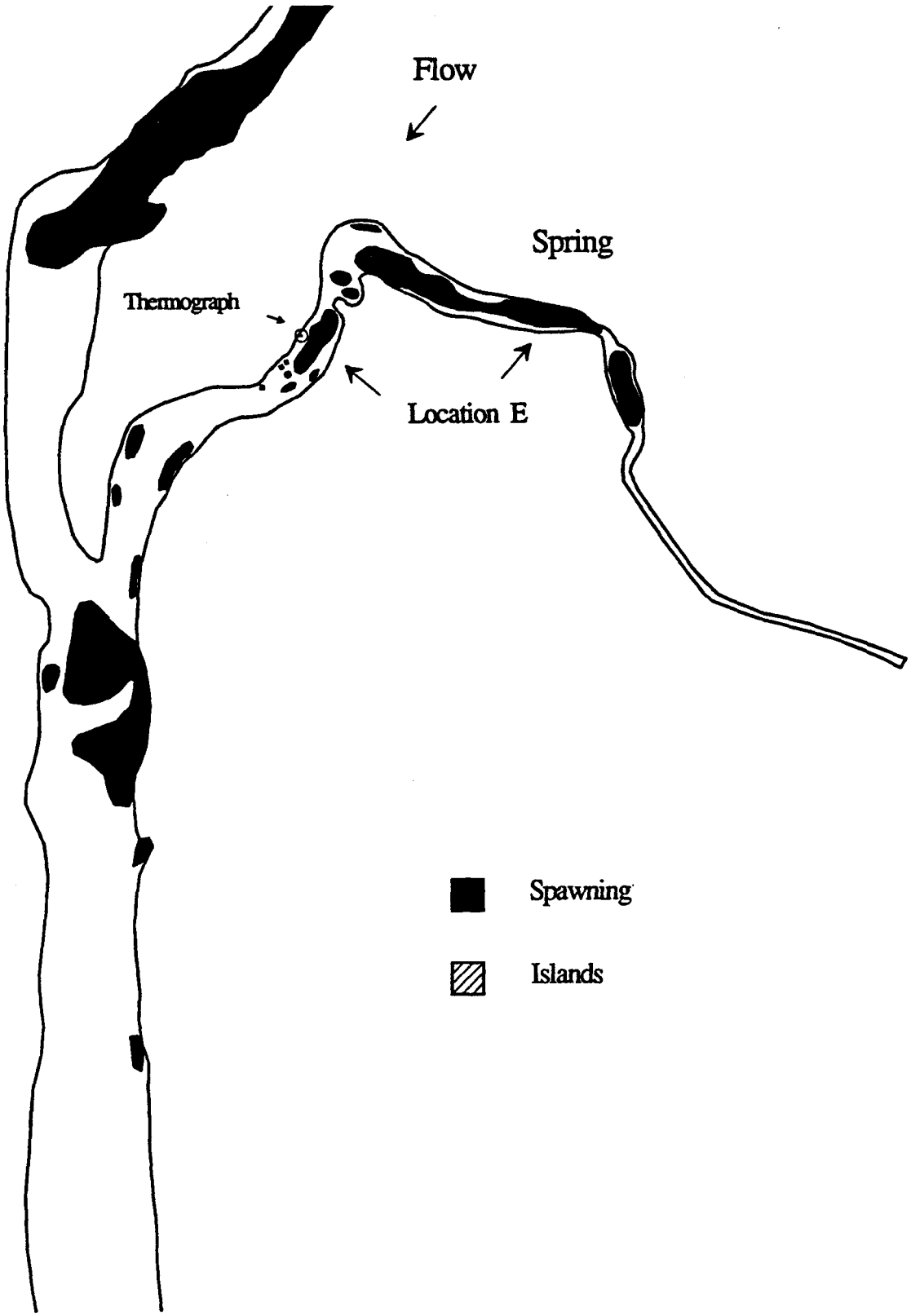

Figure 21. Substrate sampling sites in spawning Location E of the North Fork of the Payette River, Idaho. Location E was classified as spring habitat.

in the NFPR. Survival in 1994 was higher than in 1993 and 1992 which may have been due to differences in accumulated thermal units. Kokanee embryos had gained fewer thermal units at the time of sampling in 1994 than in 1993 as reflected by the proportion of live embryos in our samples. Samples contained 52.4% live eyed eggs of the total live specimens in 1994, while only 5.8% of live specimens were live eggs in 1993. Due to these differences, we observed mortality in 1993 associated with the advanced eyed and sac fry stages that was not observed in 1994. Therefore, survivals were probably comparable among the years sampled.

Densities of eggs and alevins were different between 1992 and years 1993 and 1994. Mean density of eggs and alevins in 1992 was 76/m^2 (Frost and Bennett 1994) far less than 1993 (537/m^2) and 1994 (547/m^2) estimates. Sampling was difficult in 1992 because we sampled later (April) when flows were high. We knew little of where adults had spawned the previous fall and most spawning areas were too deep to sample. Furthermore, some alevins probably had developed into fry and emerged prior to our sampling. During March 1993 a small percentage of alevins had nearly absorbed all of their yolk indicating emergence. Kokanee embryo/alevin densities in 1994 were slightly higher than those in 1993, although highly variable. Increased embryo/alevin densities in 1994 were expected due to a much higher escapement in 1993 than in 1992 (Objective 1) that resulted in higher spawner densities on the spawning grounds. Embryo densities, however, did not increase substantially between 1993 and 1994 suggesting incubation gravels became saturated at escapement levels near that of 1992 and additional spawners caused redd superimposition. Overall densities throughout the NFPR and tributaries

were variable as a result of variable spawner densities in the areas sampled. Densities ranged from 0.0 to 2,575/m^2 in 1993 and 0.0 to 2,615/m^2 in 1994.

Our egg decomposition and depletion experiments validated our method of estimating kokanee survival to pre-emergence. Our hydraulic sampling method is a type of redd excavation technique previously used by McNeil (1962, 1964). Excavation of natural redds has also been used by other investigators to estimate salmonid survival (Hatch 1957; Ball and Cope 1961; Warner 1963; Jordan and Beland 1981). The major criticism of these methods (MacKenzie and Moring 1988; Pauwels and Haines 1994) was the bias introduced by decomposition of eggs and larvae during incubation (McDonald 1960b; McNeil 1964; Harris 1973). We observed embryo decomposition in the NFPR and used corrected embryo counts to adjust survival. Similar decomposition rates were observed by Briggs (1953) in Prairie Creek, California. Loss of coho salmon embryos placed in containers in the streambed averaged 9% after 60 days and 13% after 90 days.

Recovery of embryos and sac fry in our study was high during the initial 60 seconds with the hydraulic sampler. McNeil (1964) collected a mean of 93.0 and 93.1% of naturally spawned and artificially buried pink salmon eggs with two persons sampling the same sampling unit with a hydraulic sampler. McNeil (1964) found an additional bias of the hydraulic sampling method if females failed to deposit eggs. We observed egg retention during 1992 and 1993 in a large sample of female kokanee (Objective 2) and found that retention was minimal compared to PED and therefore did not bias our survival estimates.

Significant kokanee embryo and larval mortalities occurred during our hydraulic sampling in March and emigrant fry sampling (Objective 2) in late March 1993 and 1994. Sixty-five percent and 70.2% of kokanee survived to the pre-emergent stage in 1993 and 1994, respectively. Survival from egg deposition had dropped to 18.9 and 24.4% in 1993 and 1994, respectively, by the time of emigration to Payette Lake. MacKenzie and Moring (1988) estimated survival of Atlantic salmon Salmo salar during the intragravel period and their observations corroborate our findings. They observed highest mortality after hatching as survival dropped from 74% at hatching to 13% at the pre-emergent stage. Our sampling in 1994 coincided with their pre-emergent stage as 94.2% of living kokanee had hatched, while in 1993 only 47.6% of kokanee had hatched. While pre-emergent survival in 1993 was lower than survival at hatching in 1994, the magnitude was not as great as that observed by MacKenzie and Moring (1988) for Atlantic salmon. Possibly, kokanee still had an extended period of gravel residence at the time of sampling in 1993, 15 March, as peak fry emigration from the NFPR usually occurs in early June. Additional mortality must have occurred during this time.

Mortality between our sampling may have occurred during the final stages of incubation, during emergence from gravels, and/or during emigration to Payette Lake. This high mortality may have been due to various physical and biological factors in the stream environment. Mortality may have been caused by excess fine substrate in gravels (Coble 1961; Phillips et al. 1975; Hausle and Coble 1976; Peterson and Metcalfe 1981; Harshbarger and Porter 1982; Irving and Bjornn 1984; Sowden and Power 1985). Low embryo survival has been attributed to

reduced substrate permeability and/or entrapment of larvae and fry (Cordone and Kelley 1961; Gibbons and Salo 1973; Iwamoto et al. 1978). Reduced permeability restricts water flow to incubating embryos and results in decreased oxygen supply and increased accumulation of toxic metabolites around embryos. Entrapment of embryos and larvae occurs when fines accumulate and prevent emergence of fry. Also, mortality from predation during downstream emigration may have occurred in the NFPR. Shepherd (1990) observed kokanee fry in stomachs of rainbow trout during downstream migration in the Mission spawning channel, British Columbia. Rainbow trout are also present in the NPPR during the period of kokanee outmigration and were observed actively feeding near the fry sampling area.

Substrate Composition

Many investigators have described a positive relationship between salmonid egg-to-fry survival and substrate characteristics (Shirazi and Seim 1979; Tappel and Bjornn 1983; Tagart 1984; Young et al. 1991). We did not expect the negative relationship between kokanee survival and substrate composition (Fredle index; r^2=0.24). We are unsure of why higher survivals were associated with smaller gravel compositions. Irving and Bjornn (1984) concluded kokanee and rainbow and cutthroat trout tolerated gravels with more fine particles than chinook salmon studied by Tappel and Bjornn (1983), which probably related to larger size of emergent fry in chinook. However, these observations do not indicate whether kokanee survival would be higher in larger substrate. Most studies relate survival to emergence (STE), rather than to pre-emergence, with substrate characteristics. Measuring survival prior to

emergence does not account for significant mortality which occurs in the later stages of incubation (MacKenzie and Moring 1988) and during emergence (Hausle and Coble 1976; Witzel and MacCrimmon 1981), but can identify stages of highest mortality (MacKenzie and Moring 1988). We do know if significant mortality occurred from the later stages of incubation until fry emigration in the NPFR in 1993 and 1994, however, we believe STE and substrate composition would be positively related. Evaluating STE in relation to substrate quality in the NFPR would be difficult due to runoff conditions at the time of emergence; for this reason, as well as the ability to control environmental variables, laboratory experiments have been used to determine relationships of STE to substrate composition (Tappel and Bjornn 1983; Irving and Bjornn 1984; Young et al. 1991).

Two major approaches have been employed to describe substrates important to fishes (Young et al. 1991). First, the percentage of substrate less than a given size is measured by weight or volume and is commonly referred to as percent fines (Hausle and Coble 1976; Stowell et al. 1983; Witzel and MacCrimmon 1981; Reiser and White 1988; McNeil and Ahnell 1964). Various reference particle diameters have been used (Young et al. 1991) complicating comparison of results, and substrates have been described based on measures of central tendency of the entire particle distribution. Such measures include the geometric mean (Platts et al. 1979), Fredle index (Lotspeich and Everest 1981), modified Fredle index (Beschta 1982), and the arithmetic mean particle size (Crisp and Carling 1989). Use of percent fines to predict STE has been criticized because salmonid survival depends on the entire size distribution of substrate not a portion of it (Platte et al. 1979; Tappel and Bjornn

1983; Young et al. 1991). Young et al. (1991) found that percent fines performed poorly compared to measures of central tendency in predicting STE, and our results corroborate these findings even though we observed survival during only a portion of the kokanee incubation period. Geometric mean particle diameter (GM) is the most accepted method of describing substrate compositions. Young et al. (1991) found that GM accounted for the highest proportion of variation in STE in laboratory experiments with Colorado River cutthroat trout. Platts et al. (1979) suggested the GM be used as the statistic to describe the textural composition of gravel. However, other investigators have argued use of the Fredle index or its modified versions (Lotspeich and Everest 1981; Beschta 1982) as the best measure of spawning substrates. The Fredle index combines the GM with an estimate of the dispersion of particles around the central value, and therefore this index reflects permeability and pore size of the sample. These two factors influence survival because they regulate intragravel water velocity and oxygen supply to salmonid embryos and control intragravel movement of alevins (Lotspeich and Everest 1981). This reasoning may explain why the Fredle index and its modified version was the best predictor of kokanee survival to pre-emergence in the NFPR. However, the GM might have been the best predictor of kokanee STE in the same study area.

Kokanee spawning in the NFPR used a wide range of substrate compositions similar to those reported for other salmonids (Bjornn and Reiser 1991). Areas of upwelling groundwater containing high percentages of fine sediments were extensively used. Burgner (1991) reported sockeye salmon using a wider variety of habitats than any other species of Pacific salmonid as adults use spring-fed ponds more than

other species. Lorenz and Eiler (1989) observed sockeye salmon spawning in areas with upwelling groundwater, and sockeye salmon redds with upwelling had 38% more fine material than did spawning sites without upwelling. Upwelling groundwater in spawning areas probably reduces the importance of substrate characteristics on STE because survivals may be higher in areas of upwelling than in other spawning areas (Semko 1954; Foerster 1968).

Objective 4. To quantify kokanee spawning distribution in relation to available habitat and to analyze use of spawning habitat in relation to availability.

INTRODUCTION

Fishery researchers measure aquatic habitat attributes for many different objectives and such studies play an important role in fisheries management (Orth 1983). Knowledge of habitat attributes enables prediction of impacts from habitat alterations (Stalnaker and Arnette 1976; Stalnaker 1979; U.S. Fish and Wildlife Service 1980a, 1980b, 1981; U.S. Forest Service 1982; Bovee 1982), fish standing stocks (Jenkins 1976; Aggus and Lewis 1977; Binns and Eiserman 1979), probable limiting factors for a population, and probability of success for a species introduction (Orth 1983). Habitat characteristics can be compared to a species' habitat preferences to determine appropriate habitat improvement strategies. For example, dam operation and reservoir design have been modified to improve fish habitat (Jenkins 1970; Groen and Schroeder 1978; Benson 1973, 1980). Habitat measurements are also used to classify fishery habitats (Platts 1980). Classifying aquatic habitats allows generalization of research and management results (Orth 1983). The diversity of species and their relative abundance is largely determined by habitat, therefore, knowledge of aquatic habitat used by fishes is important for management.

We determined kokanee spawning distribution in the North Fork of the Payette River in relation to available habitat. A general description of spawning distribution was available from earlier work (Grander et al. 1990), but precise spawning locations and associated habitat attributes have not been identified. Also, available spawning

habitat in the system has not been examined. The IDF&G tentatively identified quantity and quality of spawning habitat in the NFPR as a potential limiting factor for the population (D. Anderson, Idaho Fish and Game, McCall, Idaho, personal communication). We examined kokanee use of spawning habitat in relation to availability in the NFPR.

Bjornn and Reiser (1991) summarized water depth, velocity, and substrate criteria for anadromous and other salmonids. Kokanee, because of their small size, are at the extreme low end of usable water depths and velocities whereas chinook salmon, a species that attains much larger size, use depths and velocities at the higher extreme. Spawning criteria for water depth and velocities for kokanee range from 6 to 36 cm and 12 to 73 cm/s, respectively (Table 17), although Delisle (1962) concluded kokanee avoid water velocities > 66 cm/s. Parsons and Hubert (1988) constructed habitat use curves for water depth and velocity for two tributaries of Flaming Gorge Reservoir, Wyoming, used by kokanee for spawning. Their study streams differed from ours and, therefore, may not be applicable to populations spawning in habitats similar to ours. Our study site was located in Idaho batholith geology and observations of spawning were at river flows of 10 to 15 m^3/s, whereas, Parsons and Hubert's study sites were 1.6 (Sheep Creek) and 24 m^3/s (Green River). Investigations of habitat selection by fishes need to consider habitat availability in addition to use (Mathur et al. 1985; Orth and Maughan 1986). Parsons and Hubert (1988) also constructed habitat selection curves that consider both use and availability. Use and selection curves are used in the instream flow incremental method (IFIM; Bovee 1982). Habitat availability was different between their streams and availability may differ from ours as well which may reveal new

Table 17. Water depth and velocity measured in kokanee spawning areas. None of the investigators reported use of substrate for spawning.

Source	Depth (cm)	Velocity (cm/s)	How and where developed	Remarks
Delisle 1962	-	0 - 66	California	1 stream, n=10
Thompson 1972	12 - 18	24 - 64	90-95% Cl; Oregon, wide range of streams	n=106 redds
Smith 1973	≥6	15 - 73	Tolerance interval; Oregon	n=106 redds Velocity at 0.4 ft above bed
Hunter 1973	9 - 36	12 - 41	Middle 80% of range; WA; flow 2-30 ft^3/s	n=177 redds; velocity at 0.4 ft above bed
Parsons and Hubert 1988	18 - 37	67 - 73	Use curves; WY, UT; 2 streams	n=433 redds

habitat relationships for kokanee. Spawning habitat use by sockeye salmon has been documented (Foerster 1968; Lorenz and Eiler 1989; Burgner 1991), but application to kokanee is questionable. Also, habits of beach-spawning kokanee have been documented (Hassemer and Rieman 1981; Gipson and Hubert 1992), but their application to river-spawning populations is limited due to habitat differences.

METHODS

We examined spawning distribution and habitat use and availability over the entire distribution of kokanee spawning activity in the NFPR observed in this study (Frost and Bennett 1994) and in the past (Grunder et al. 1990). We observed kokanee spawning immediately below the bridge on Eastside Drive upstream to 0.45 km above the confluence of Fisher Creek encompassing 7.2 km of river and tributaries. Spawning also occurred in side-channel spring areas and Box and Fisher creeks (Figure 1). Our habitat analysis consisted of assessing use-availability of five habitat types and intensive sampling of microhabitat characteristics: water depth, water velocity, and substrate size. We identified habitat types that were actively selected, avoided, or used in proportion to availability and intensively sampled spawning areas as well as areas not used for spawning to further describe and compare habitat types with respect to water depth, velocity, and substrate composition.

We used Arc/Info, a geographic information system (GIS), to map all aspects of habitat use and availability and organize the data in database format. The design for the use-availability analysis was to map all habitat types and spawning areas over the entire kokanee

distribution in the NFPR and to overlay each map coverage to identify use and intensity of use in particular habitat types. First, habitat availability was determined and mapped as a single coverage. Second, observed spawning distribution was identified with respect to spatial distribution and intensity and mapped as a single coverage. Third, we constructed an overlay coverage of spawning distribution and habitat to identify habitat kokanee used. Areas not used for spawning were also analyzed and compiled for statistical comparisons. Microhabitat variables, water depth and velocity and substrate, were observed over the range of flows encountered during spawning to identify habitat availability and whether kokanee exhibit preferences for different levels of each variable.

We initially attempted to use 1:24,000 scale, U.S.G.S. topographic maps on which to build the spawning and habitat maps. The clarity and accuracy of those maps were inadequate for the high level of detail required in our objective. We combined aerial photography and digital scanning with global positioning systems (GPS) to produce a quality, accurate basemap on which to build the coverages. We first scanned 22.9 cm x 22.9 cm aerial photographs, taken by the U.S. Forest Service and created image files in tag image file format (TIFF). Real-world coordinates were attached to the images by a registration procedure in GIS (REGISTER command). The registration process required coordinates of several points easily identified on the ground and photo-image. Bridges and road and tributary intersections were used as reference points. A GPS unit was used to determine coordinate locations of each reference point. Coordinates were expressed in universe transverse mercator (UTM) units. We separated the NFPR study area into 10 areas to

adequately illustrate detail of spawning distribution and habitat use (Figure 22).

Habitat Availability and Use

Habitat Availability

We conducted a complete habitat survey of the kokanee spawning distribution in the NFPR and tributaries during 1992 and 1993. River habitat was classified according to the scheme described by Bisson et al. (1982; Table 18) for riffles, glides, and pools. In addition, we also classified habitat for spring and slough. Individual habitat units were mapped in relation to transects that were established perpendicular to streamflow and marked with flagging and stakes on both stream banks to identify precise locations for later sampling. Transects were also established for collection of microhabitat data. Habitat units not located near transects were mapped by measuring the distance along the centerline of the river to the nearest transect. Stream-width data collected at transects at a flow of 10.9 m^3/s were used to construct the river model. Individual habitat units were digitized in GIS to create a coverage of available habitat for the entire spawning distribution in the NFPR. Area (m^2) of each habitat type and the total area available to kokanee were calculated with the GIS database. Habitat information was compiled during 1992 and 1993.

Spawning Distribution and Habitat Use

We conducted several foot surveys during spawning to determine kokanee escapement (Objective 1). The surveys were also used to determine distribution and intensity of spawning use. Foot surveys were

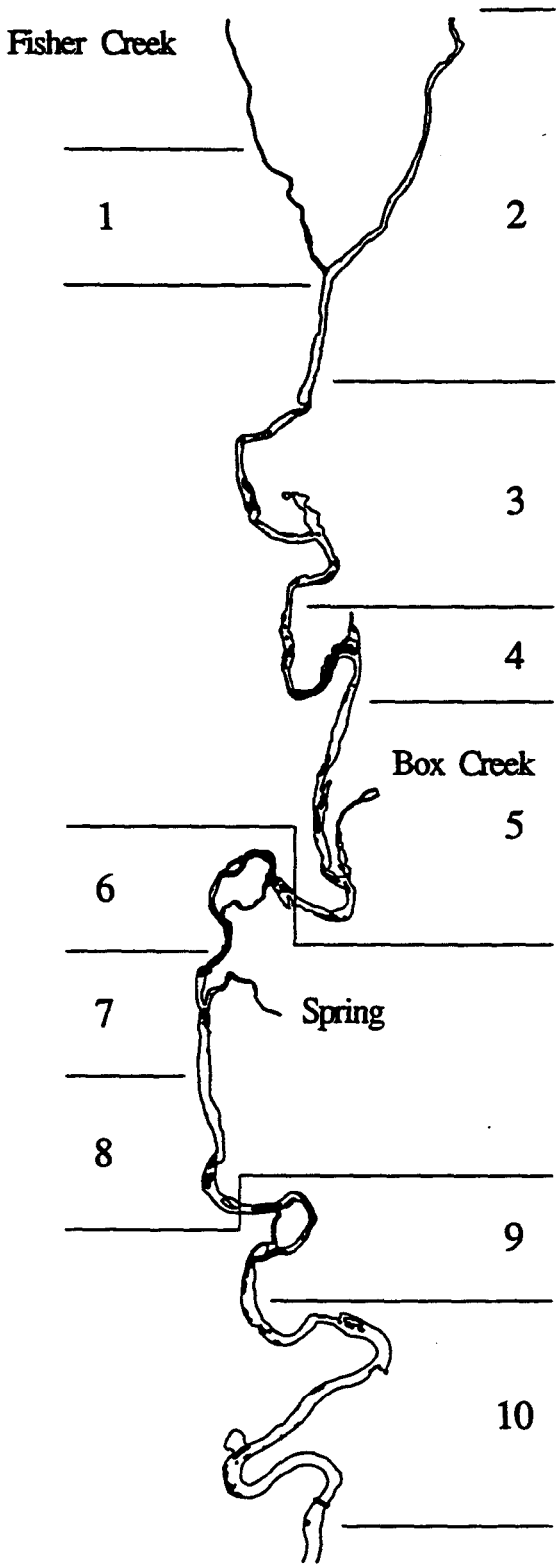

Figure 22. Ten areas of the North Fork of the Payette River, Idaho, used to depict kokanee spawning distribution and available spawning habitat.

Table 18. Habitat classification scheme used to classify aquatic habitat in the North Fork of the Payette River, Idaho. Criteria for pools, glides, and riffles (Orth 1983).

Habitat	Description
pools	deeper habitats with slower current velocities
glides	moderately shallow stream channels with laminar flow, lacking pronounced turbulence
riffles	shallow, turbulent stream segments with higher gradients than pools or glides
sloughs	backwater channels with high silt and sand; water velocities near 0 cm/s
springs	areas of upwelling ground water; temperatures buffered by upwelling; higher % fines,low velocities

conducted by a single observer who walked upstream along a predesignated route and counted spawning kokanee from the stream bank. Counts were conducted every 3 to 4 days throughout the spawning run. The same observer made all counts in 1993 to eliminate between-observer bias. Numbers of kokanee were recorded by stream location and counts were assigned to individual habitat units within each spawning area. A single count of spawners was used for this analysis (29 September 1993), which represented the highest abundance of spawning kokanee in the NFPR during 1993. We chose to use a single count to avoid violating the requirement of independent observations in statistical analyses; temporally spaced observations of the same animals using habitat resources are not totally independent (Alldredge and Ratti 1992). Spawning directly behind the adult weir (Objective 1) was not included in the analysis, because spawning there was partially induced by the physical obstruction of the weir. Spawning distribution data from 1993 was used in our analysis.

Transects established for collection of microhabitat data were visited twice weekly to map all kokanee spawning areas in the NFPR. Points of spawning along each transect were recorded and digitized in GIS to create a spawning distribution coverage. Spawning in areas with no transects or low transect density was hand-drawn from measurements taken with a meter tape, and the exact location of spawning was determined by measurement to the nearest transect.

Statistical Analysis

Habitat use and availability data were analyzed with the Neu method (Alldredge and Ratti 1992), first described by Neu et al. (1974)

for analysis of resource selection data. Habitat resources are considered categorical variables with the Neu method rather than continuous variables. Basic assumptions of the procedure (Alldredge and Ratti 1992) were observations are independent random samples; availability data and animal locations are determined without error. Our analysis compared the observed occurrence of kokanee with that expected for each habitat category. Expected usage was calculated using the proportion (p_i) of each habitat category (i) and the total number of individuals (N) observed (pi x N). The hypothesis tested with the Neu method was each habitat category was used in exact proportion to its availability within the study area. The alternate hypothesis was at least one habitat category was used disproportionately to its availability. The observed counts in each habitat were compared to those expected with the Chi-square goodness-of-fit test. If a significant difference were detected, Bonferroni z-statistics (Miller 1981) were used to construct confidence intervals on the observed use to detect which habitats were used significantly more or less than expected. Experiment error rate (a = 0.05) was controlled by apportioning the significance level over the number of confidence intervals constructed (i.e. the number of habitat types).

Microhabitat Availability and Use

Microhabitat data were collected in the NFPR to provide information on kokanee preference of selected habitat variables. Data on water depth, velocity, and substrate size were collected at transects established perpendicular to streamflow. Transects were established prior to spawning to avoid disturbing spawning fish, and locations of

all transects were marked with flagging tape and stakes on both stream banks so the precise location of each transect could be determined on multiple visits. During 1992 and 1993, 157 and 127 transects were distributed in randomly selected reaches throughout the NFPR and tributaries used by kokanee. All transects during both years were spaced 5 to 30 m apart and exact transect locations were determined to represent linear (downstream) habitat variability. For example, as habitat features changed in a downstream direction, as indicated by transition from pool to riffle habitat, transects were established in deep, slow-moving sections (pool); intermediate sections (transition); and shallow, fast-moving sections (riffle). Overall, the transect methodology was used to fully represent the range and distribution of habitat available to kokanee in the NFPR and tributaries.

Water depth, velocity, and substrate, identified as important for salmonids spawning in streams (Bjornn and Reiser 1991), were observed throughout the kokanee spawning distribution in the NFPR during 1992 and 1993. Water depth, velocity, substrate were measured along each transect at 1-m intervals. Velocity (cm/s) was measured at 6/10 depth with a Marsh-McBirney (model 201D) portable water velocity meter and depth wand. Substrate at each 1-m point was classified according to a seven class scale ranging from silt to boulder: silt (<0.5 mm), fine sand (>0.5-3 mm), coarse sand (>3-6 mm), small gravel (>6-26 mm), large gravel (>26-50 mm), cobble (>50-150 mm), and boulder (>150 mm). A substrate reference collection was developed with substrate collected at study sites in the NFPR and used to aid classification at all times during data collection. The substrate was oven-dried for 72 hours at 103•C and shaken through a series of sieves corresponding to our

classification scheme. Data collection was conducted at flows that normally occur during spawning (4.6-31.1 m^3/s). Data were collected during the spawning run in 1992 and prior to spawning in 1993 at flows predicted for peak spawning. Flows were monitored daily during data collection and during spawning to ensure flows and habitat were similar between sampling periods.

All transects were revisited to collect information on microhabitat use at the time of spawning. Spawning was observed at flows similar to those during data collection on available habitat. Exact locations of spawning (redds) along each transect were recorded and matched with points observed during data collection on available habitat. Points along each transect where kokanee were not spawning were also recorded.

Habitat use curves were constructed for water depth and velocity and substrate size. Use curves, which are species-specific and developed from empirical data describe the likelihood that a given habitat feature will be used by fish at a particular life stage (Bovee and Cochnauer 1977). We chose to develop use curves as the method of analysis so results could be compared to Parsons and Hubert's (1988) evaluation of kokanee spawning habitat use in Flaming Gorge Reservoir. We did not construct habitat selection curves as Moyle and Baltz (1985) suggested, because Parsons and Hubert's (1988) findings did not support their development for spawning kokanees. Bovee (1982) concluded there is a need for a large, accessible library of use curves for application under various stream conditions; therefore, our results will likely add to the available information on spawning behavior of kokanee and provide alternatives to curves now available. Furthermore, Moyle and Baltz

(1985) stated flow studies should use curves developed at the site or a similar site. Use curves were constructed for water depth, water velocity, and substrate size category by frequency histogram analysis according to Bovee and Cochnauer (1977). Differences between microhabitat availability and use distributions were assessed with a Chi-square goodness-of-fit test.

Microhabitat by Habitat Type

Habitat type at each transect was recorded. Each point (1-m interval) was categorized as pool, glide, riffle, spring, or slough as part of the habitat availability and use analysis in the previous section. We report statistics of available and used water depths and velocities and substrate size by habitat type to further describe the habitat relationships in the habitat availability and use analysis. If our habitat classification scheme were accurate (Table 18), we expected water depths to be highest in pools, intermediate in glides, and lowest in riffles. We expected water velocities to be lowest in pools, intermediate in glides, and highest in riffles. We expected pools to have mostly fine sediment and riffles coarse sediment. Slough habitat was not sampled for microhabitat data.

RESULTS

Habitat Availability and Use

Habitat Availability

Pool habitat was the most abundant habitat type available to kokanee in the NFPR during 1993 followed by glide, riffle, slough, and spring (Table 19; Figures 23-32). Total area of all habitat types was

Table 19. Available aquatic habitat by area and total for the entire kokanee spawning distribution in the North Fork of the Payette River, Idaho. Totals for each habitat type were used to calculate expected usage in the use-availability analysis. Units are m'.

Area #	Pool	Glide	Riffle	Slough	Spring	Total
1	0	349.8	679.8	0	0	1,209.6
2	307.9	991.8	11,664.0	0	0	12,963.7
3	5,241.0	8,493.4	4,180.0	3,008.0	0	20,922.4
4	3,807.7	5,367.7	2,112.6	1,058.1	699.5	13,045.6
5	2,758.5	12,222.4	5,273.8	0	0	20,254.7
6	1,312.4	5,233.5	2,771.4	505.7	340.3	10,163.3
7	1,215.6	5,231.8	885.9	95.9	1867.2	9,296.4
8	1,215.4	7,933.2	755.5	0	0	9,904.1
9	2,959.4	5,891.2	0	0	0	8,850.6
10	43,138.1	1,843.2	0	1,990.3	0	46,971.2
Total	61,956	53,558	28,323	6,658	2,907	153,402

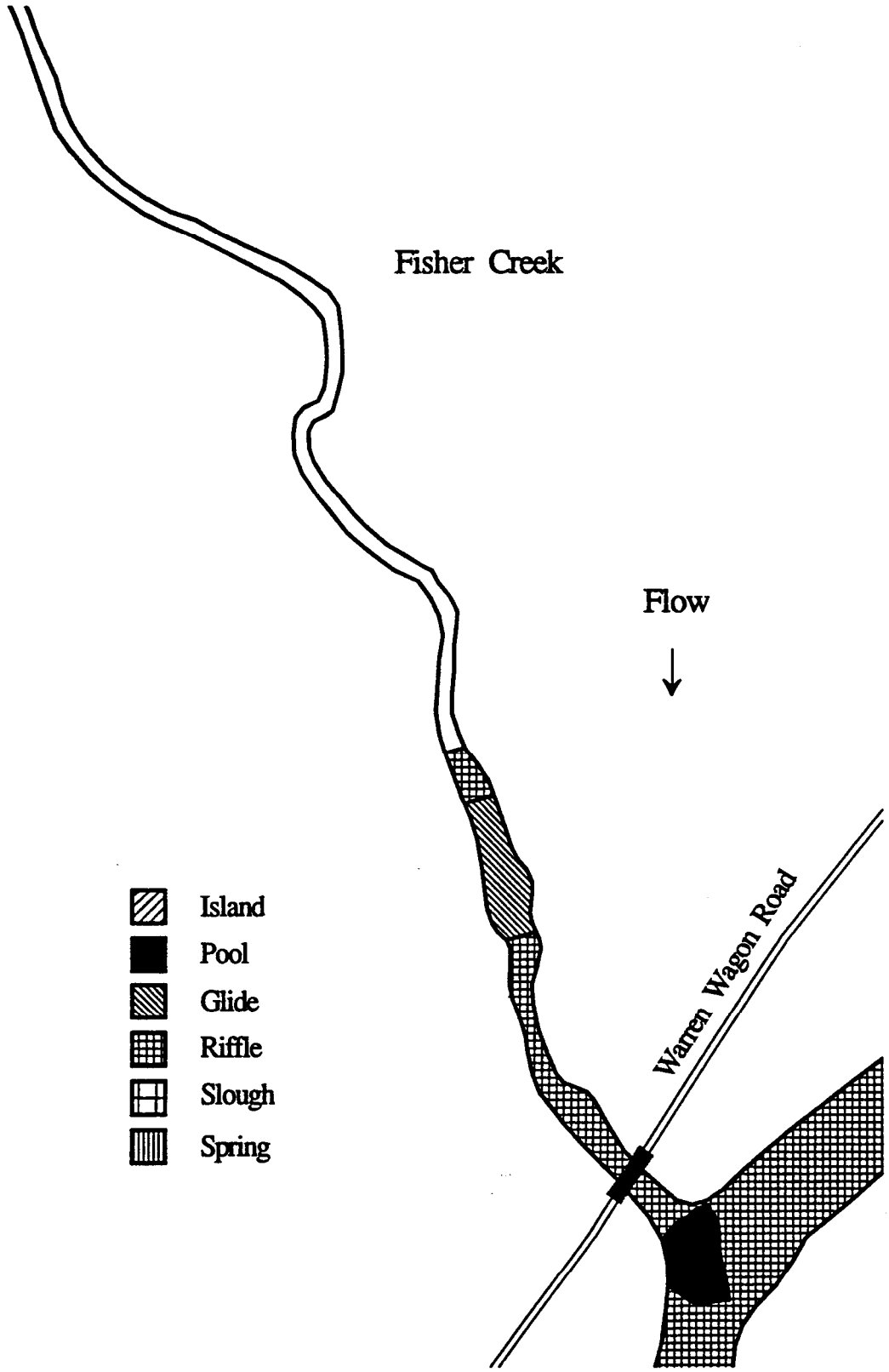

Figure 23. Available aquatic habitat in Area 1, Fisher Creek, of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 16.5 m.

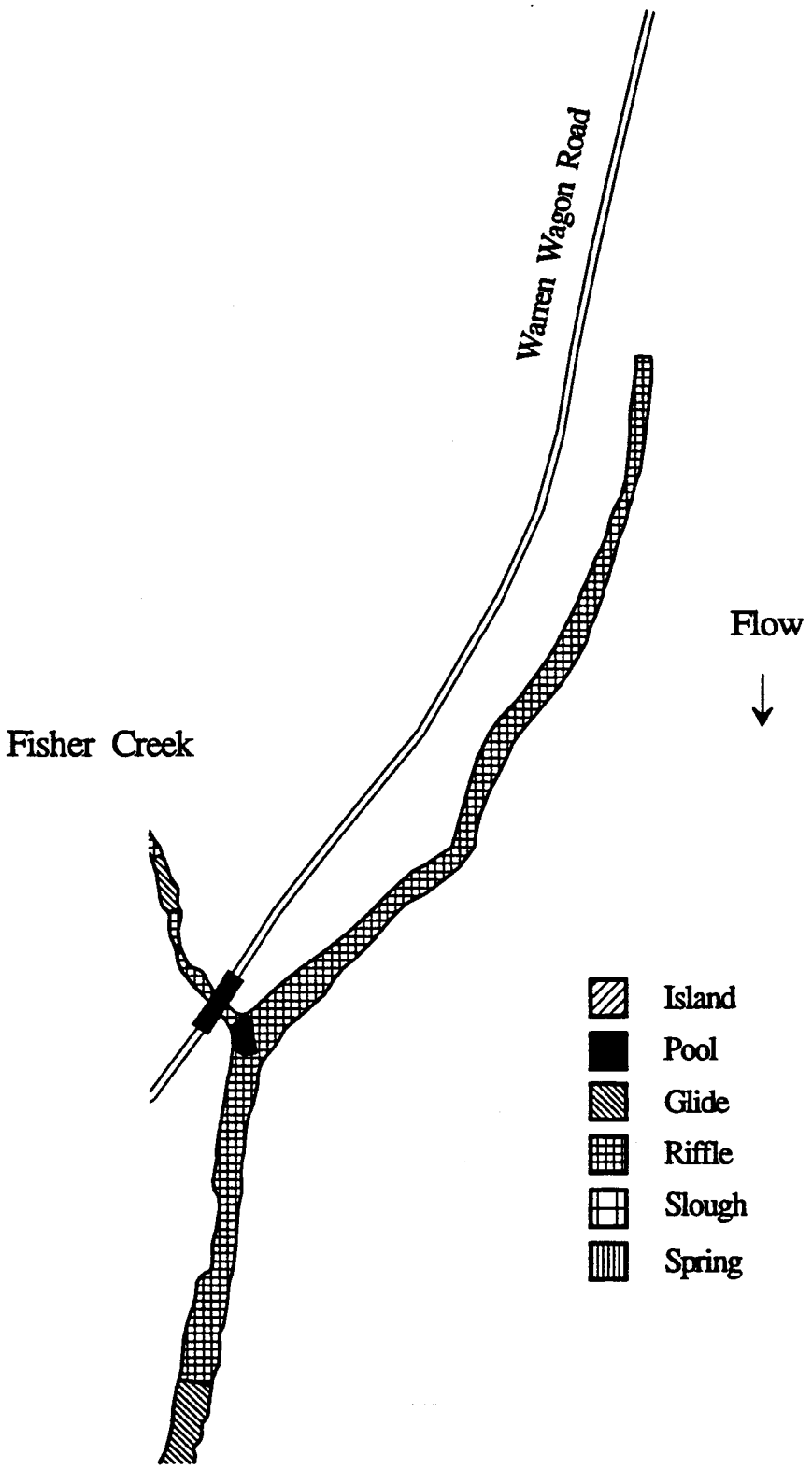

Figure 24. Available aquatic habitat in Area 2 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 46 m.

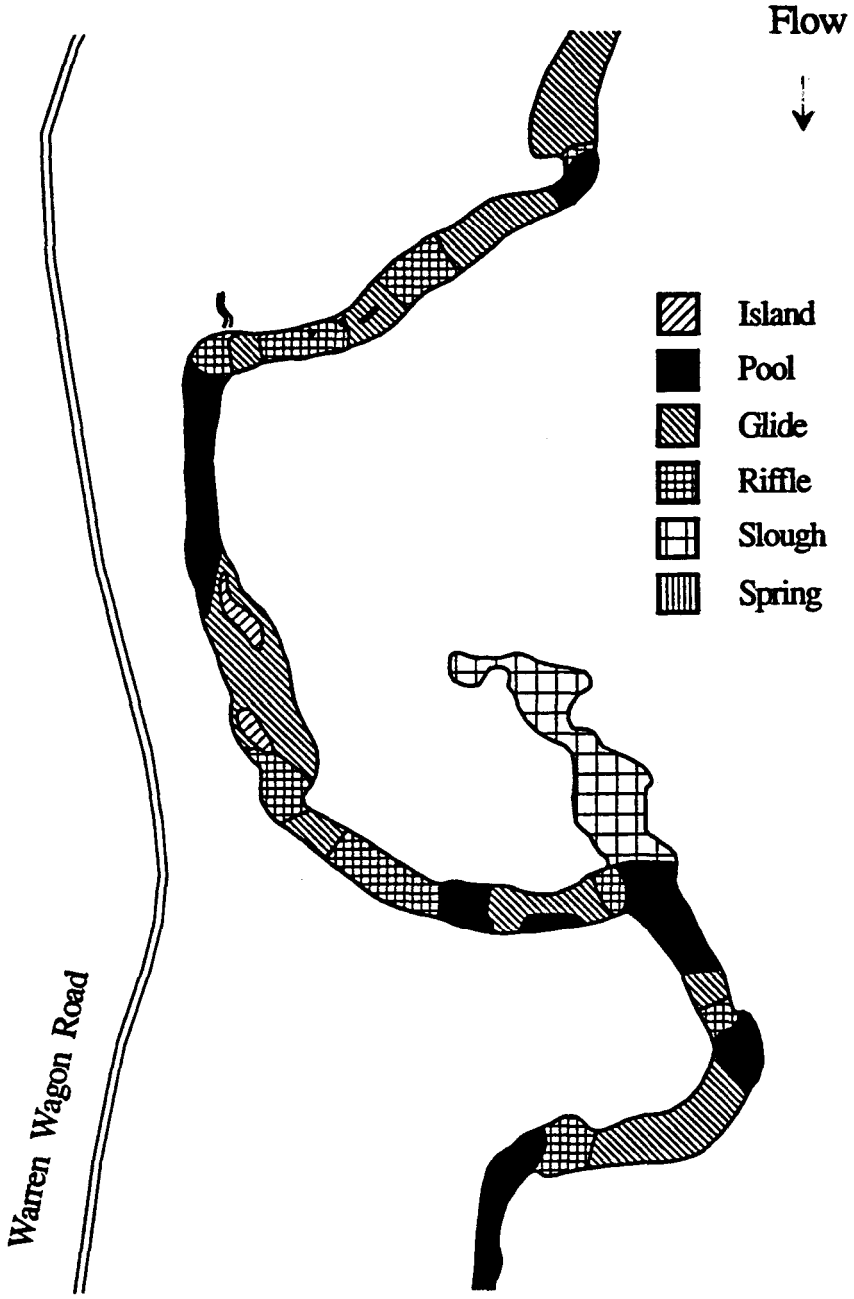

Figure 25. Available aquatic habitat in Area 3 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 35 m.

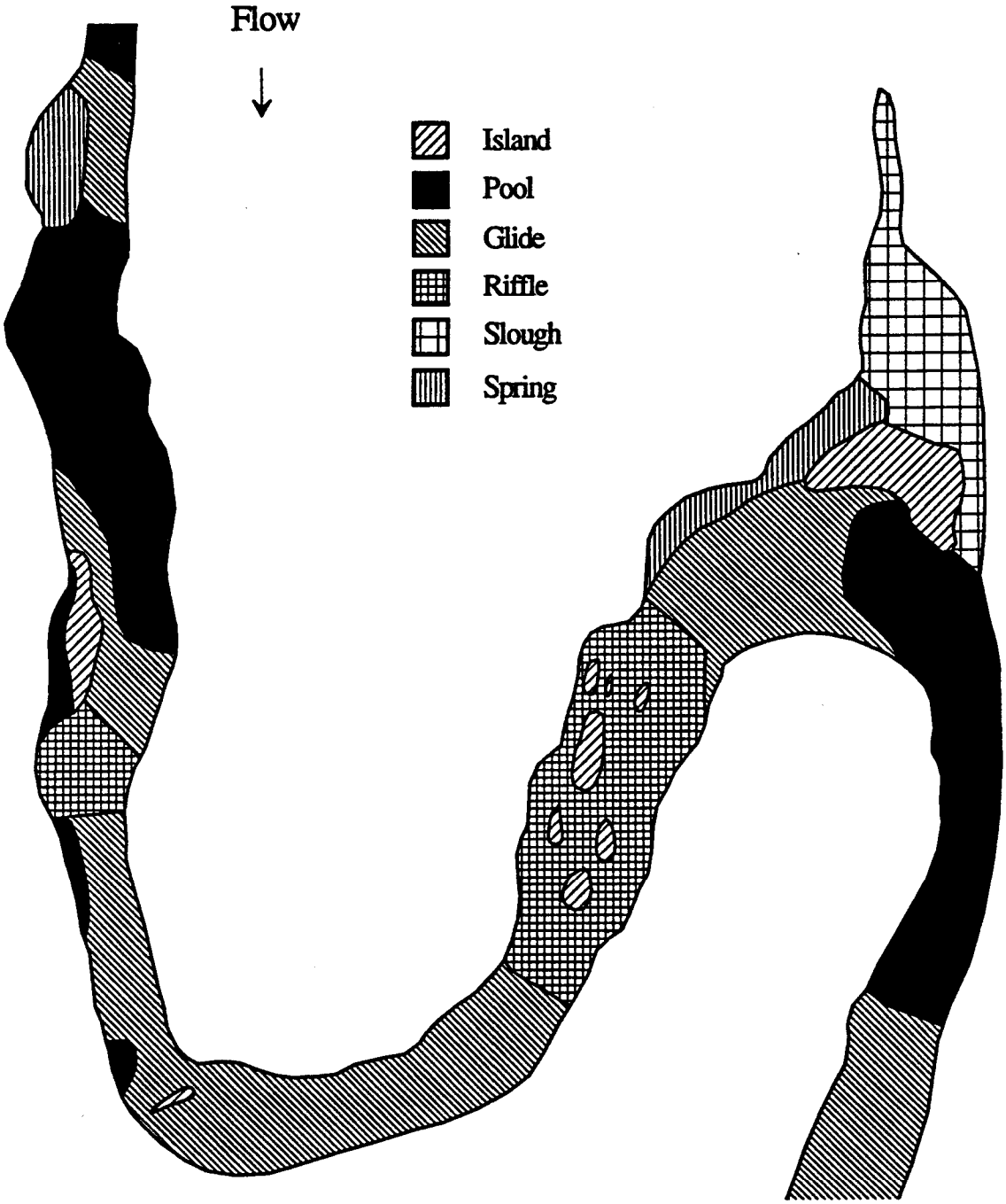

Figure 26. Available aquatic habitat in Area 4 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 14 m.

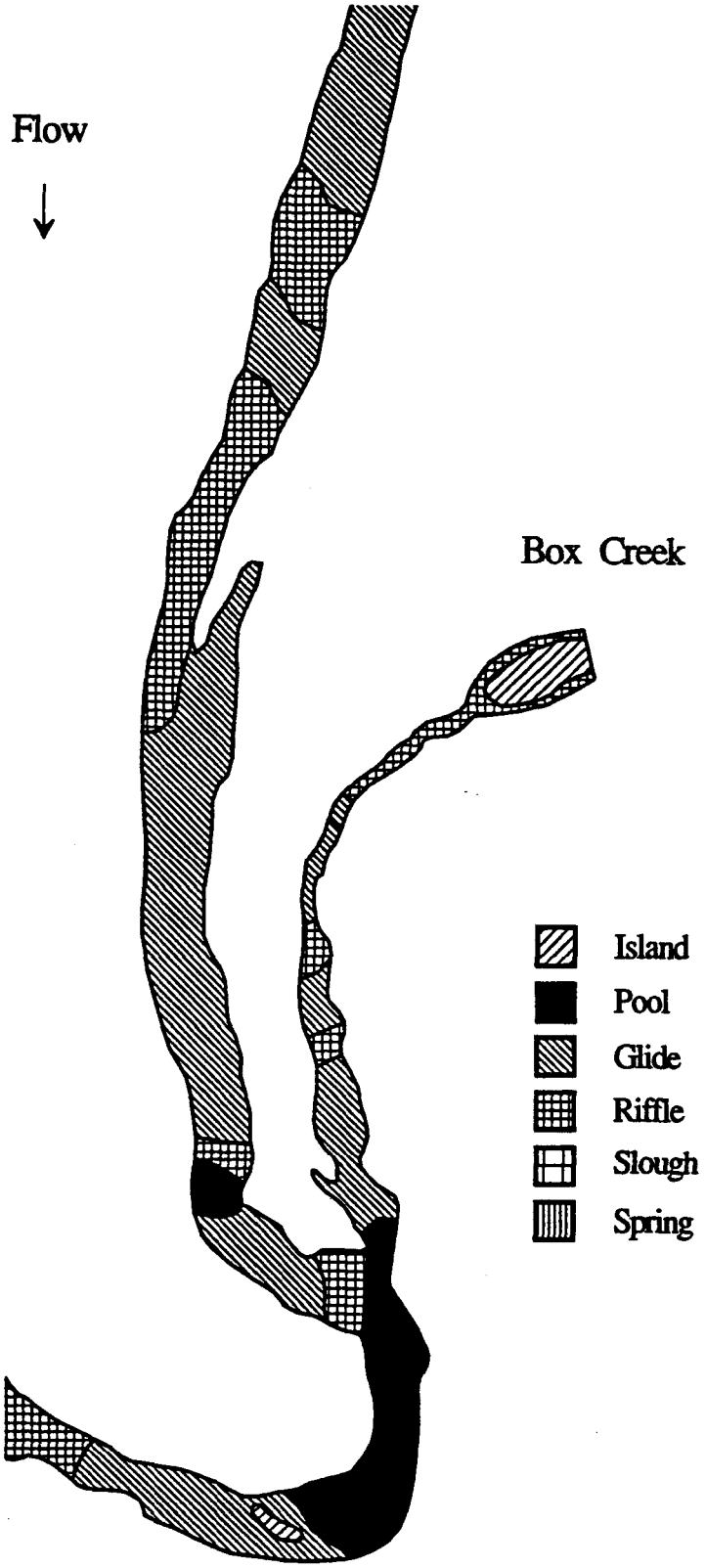

Figure 27. Available aquatic habitat in Area 5 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 27 m.

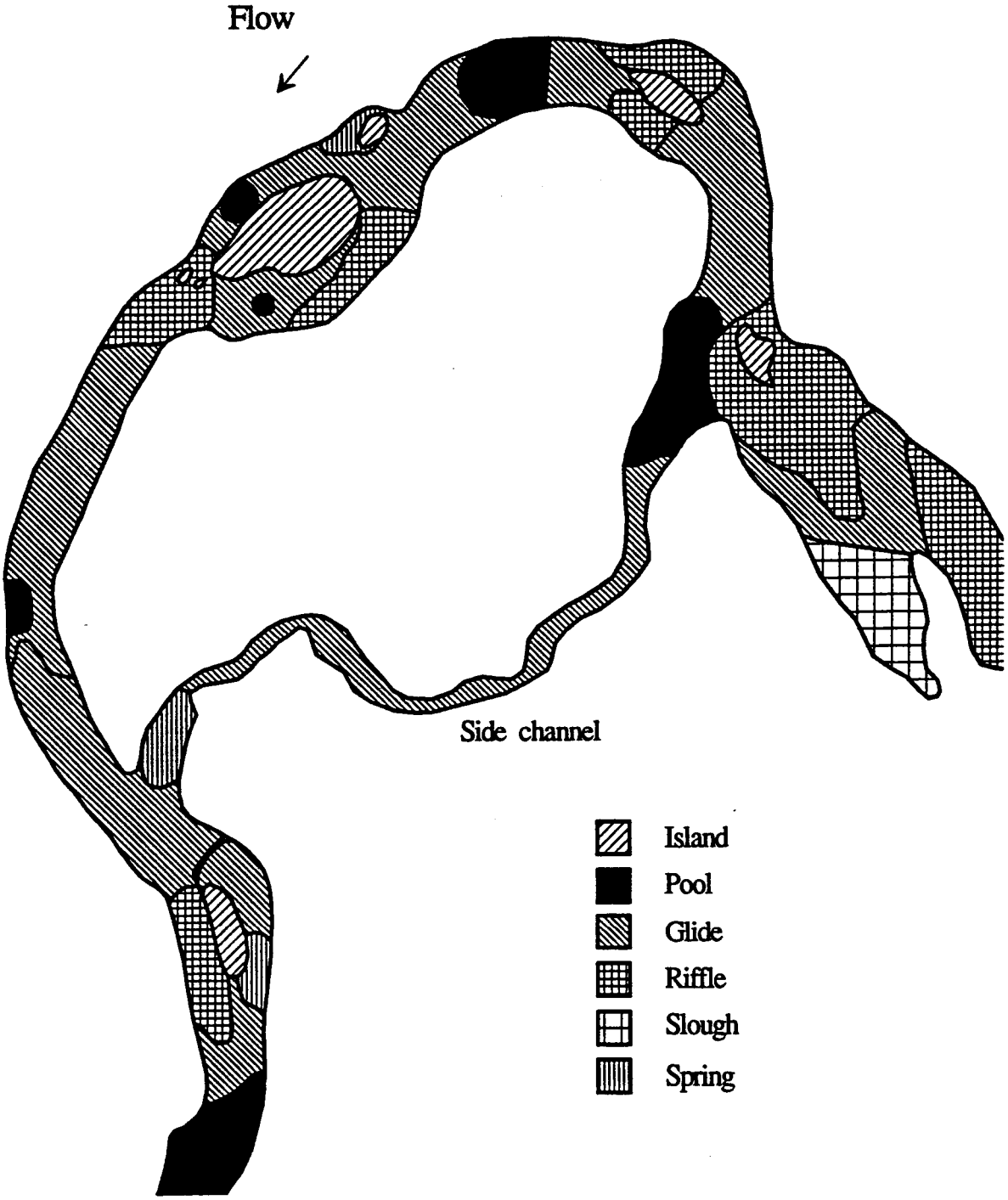

Figure 28. Available aquatic habitat in Area 6 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 14 m.

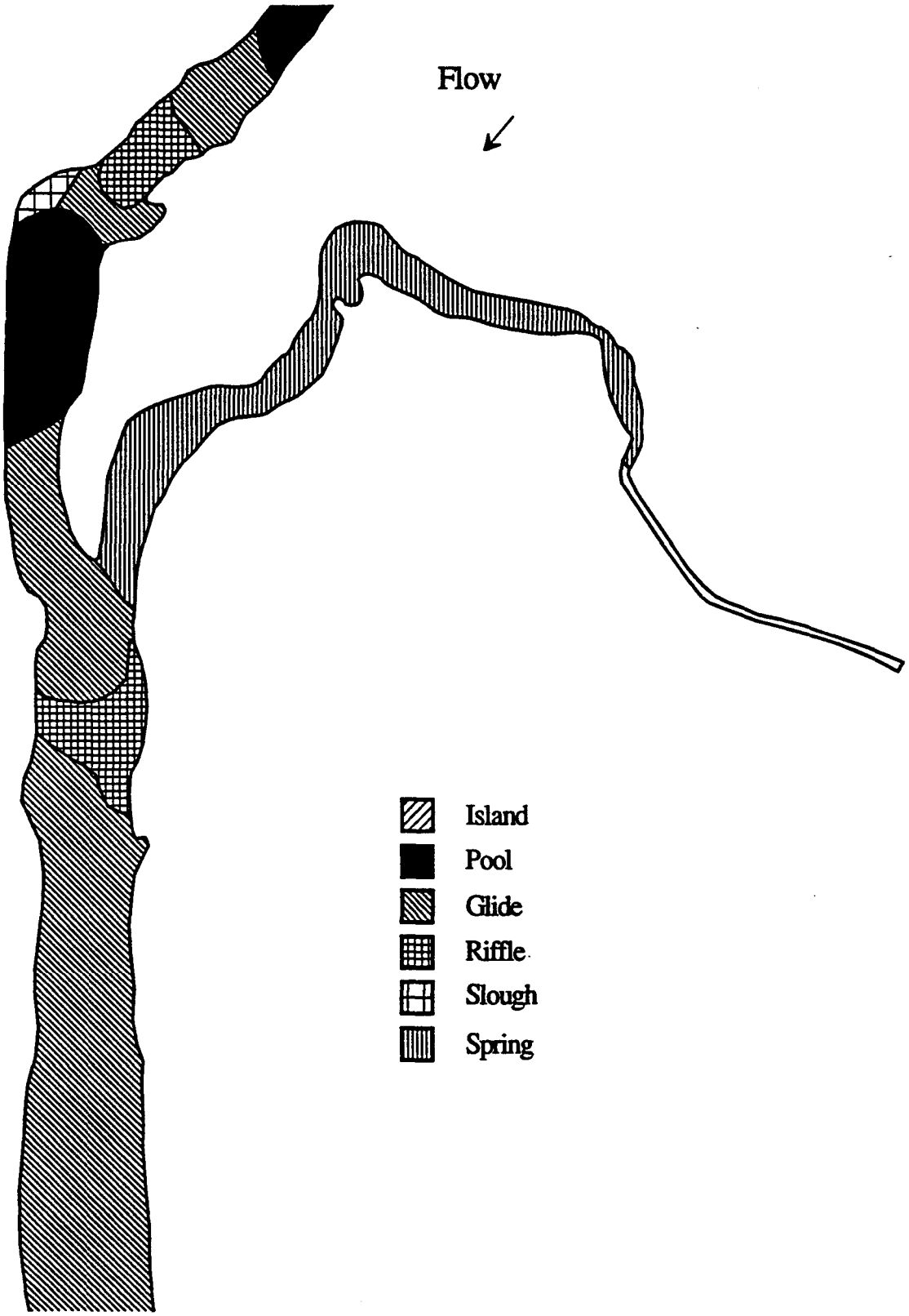

Figure 29. Available aquatic habitat in Area 7 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 15 m.

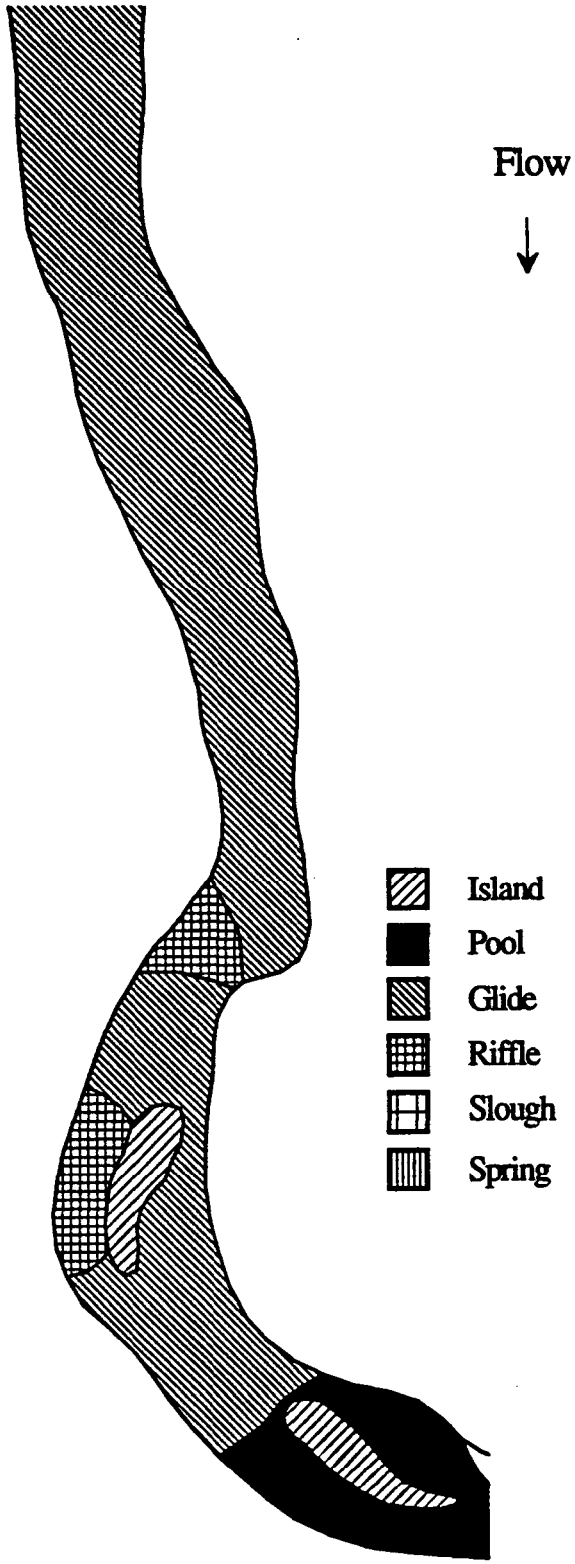

Figure 30. Available aquatic habitat in Area 8 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 16 m.

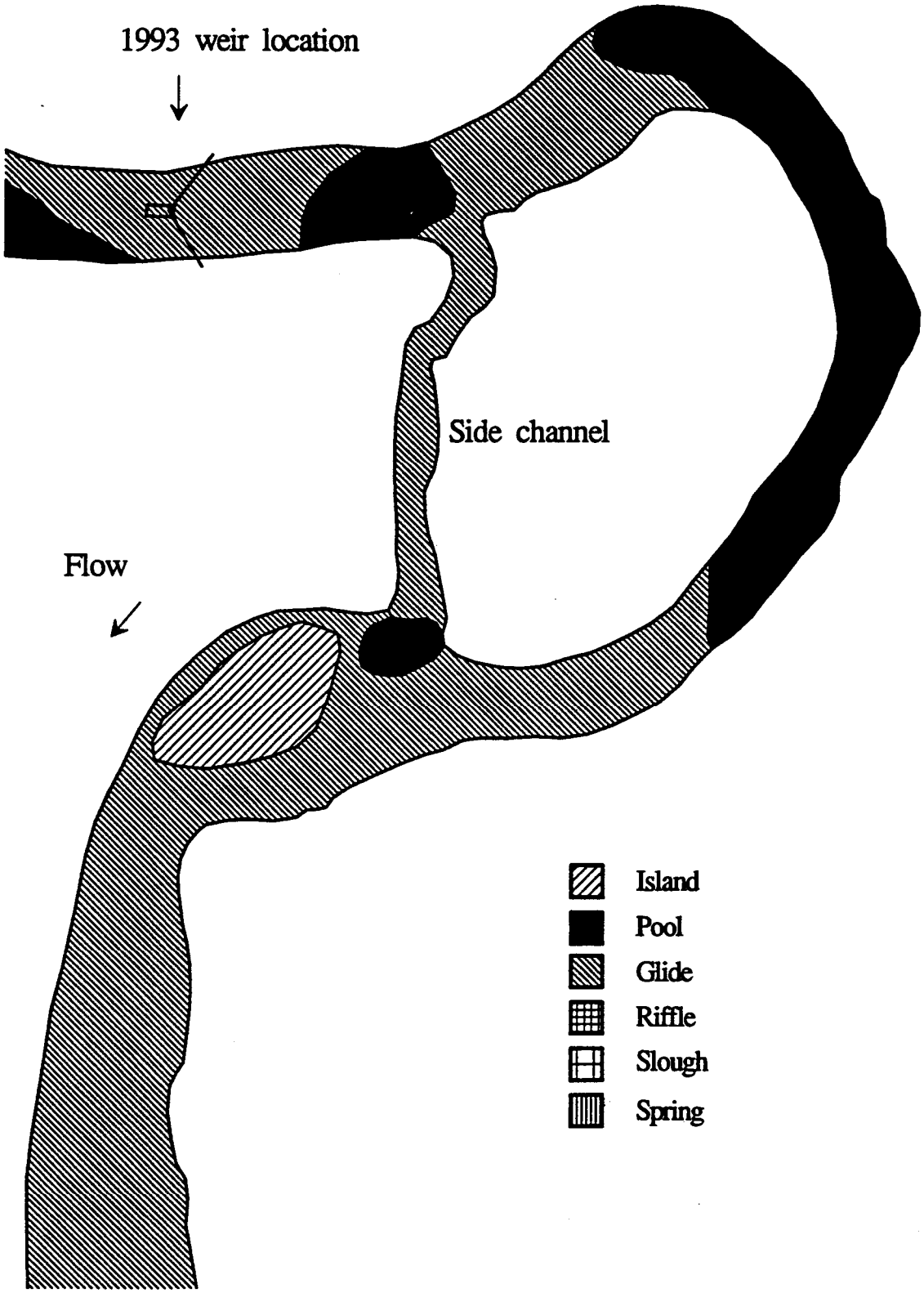

Figure 31. Available aquatic habitat in Area 9 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 15 m.

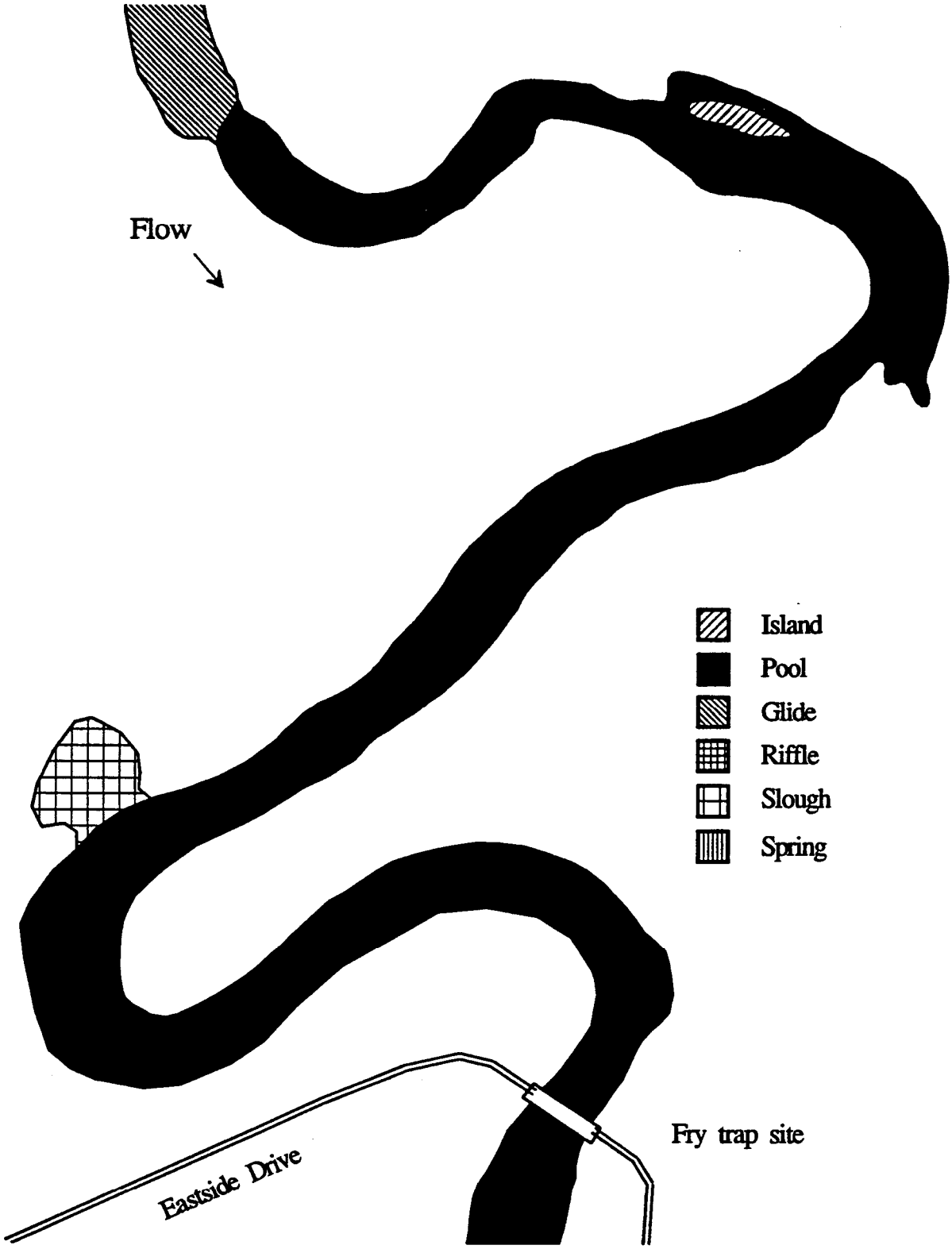

Figure 32. Available aquatic habitat in Area 10 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 28 m.

153,402 m^2. Riffles were most abundant in the upstream limits of kokanee spawning distribution. For example, in Fisher Creek (Area 1, Figure 23) 56.2% of the 1,209.6 m^2 available was classified as riffle (Table 18). In Area 2 (Figure 24), which mostly consisted of the NFPR above the confluence of Fisher Creek, 90.0% of the 12,963.7 m^2 available habitat was classified as riffle. Glide and pool habitat increased in abundance in a downstream direction while abundance of riffle habitat decreased. Areas 5 through 9 (Figures 27-31) were dominated by glide habitat as 51.5 to 80.1% of total area was classified as glide (Table 19). Pool habitat was most abundant in Area 10 (Figure 32), the downstream limit of spawning activity, as 91.8% of available habitat was classified as pool. Availability of slough habitat was relatively low (4.3% of total area) and limited to middle and downstream sections of kokanee spawning distribution (Table 19). Sloughs were associated with historic river channels and oxbows formed on large meanders (Figures 25, 26, 28, 29, 32). Springs were the least abundant habitat type (1.9% of total area) and occurred only in the middle areas of kokanee spawning distribution (Table 19; Figures 26, 28, 29). Large springs (Figures 26 and 29) were associated with historic river channels. Islands, consisting of coarse substrate, were present in the NFPR and were associated with riffle habitat in braided reaches (Figures 25, 26, 28, 30).

Spawning Distribution and Habitat Use

Spawning in the NFPR in 1993 was not uniformly distributed among areas (Table 20; Figures 33 - 42). Spawning activity was distinctly clustered in short reaches (Figures 36, 38, 41) and most spawning (67.9%

Table 20. Spawning distribution by area and total for the 1993 kokanee spawning run in the North Fork of the Payette River, Idaho.

Area #	Number of kokanee	Percent of total
1	43	0.14
2	112	0.36
3	2,467	8.0
4	4,235	13.8
5	2,817	9.2
6	10,341	33.7
7	3,451	11.2
8	196	0.64
9	6,617	21.5
10	432	1.4
Total	30,711	100

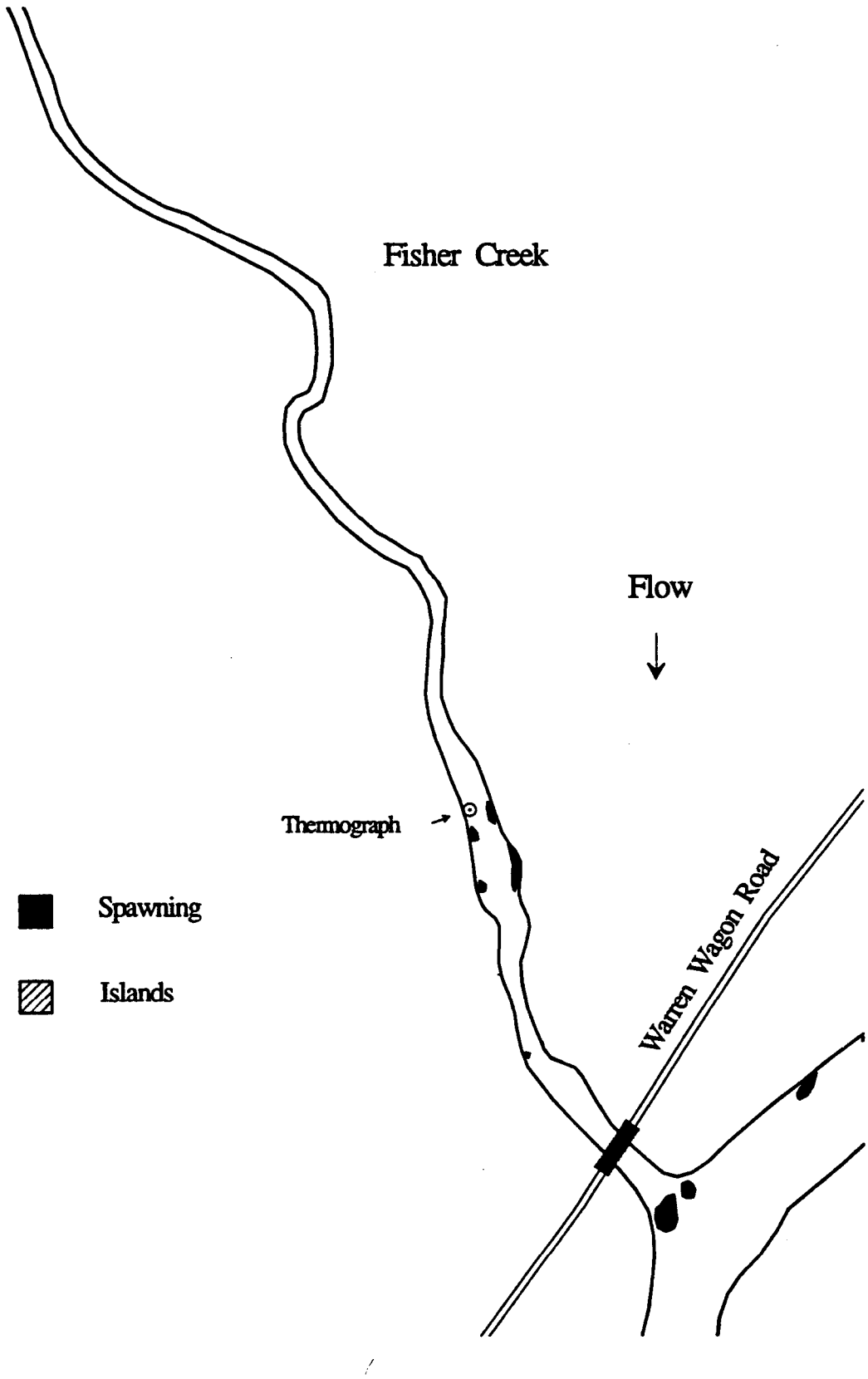

Figure 33. Kokanee spawning distribution in Area 1, Fisher Creek, of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 16 m.

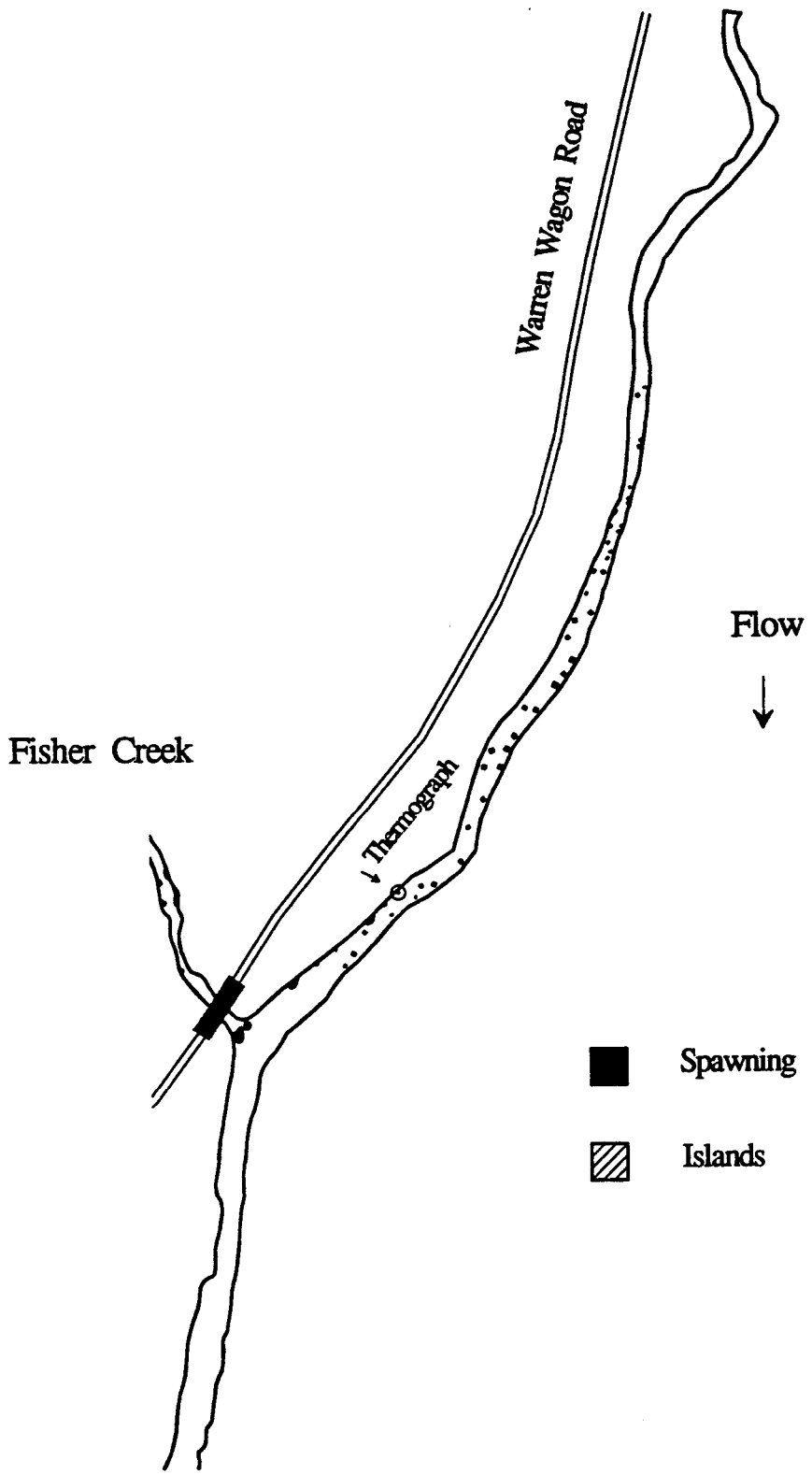

Figure 34. Kokanee spawning distribution in Area 2 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 46 m.

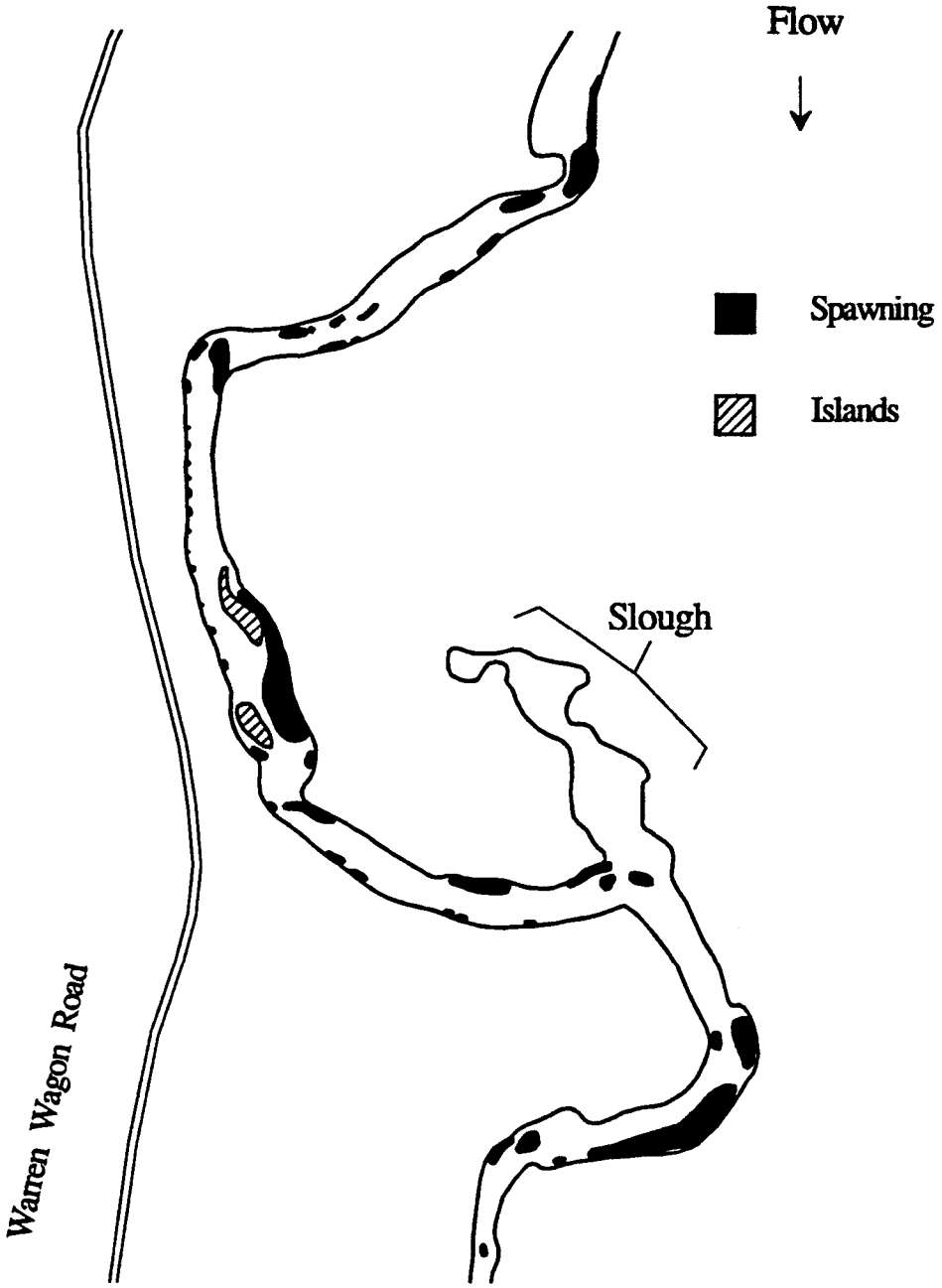

Figure 35. Kokanee spawning distribution in Area 3 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 35 m.

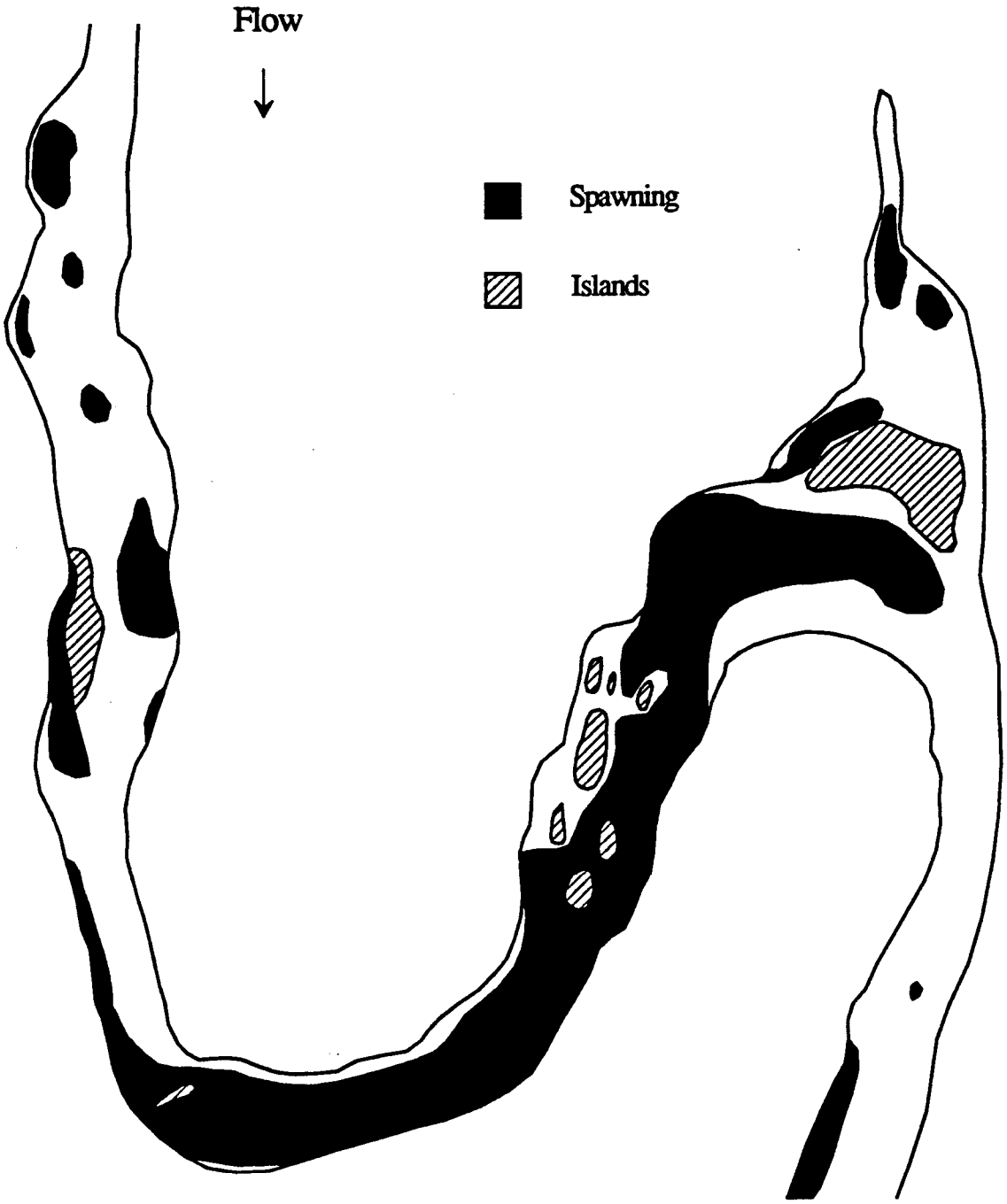

Figure 36. Kokanee spawning distribution in Area 4 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 14 m.

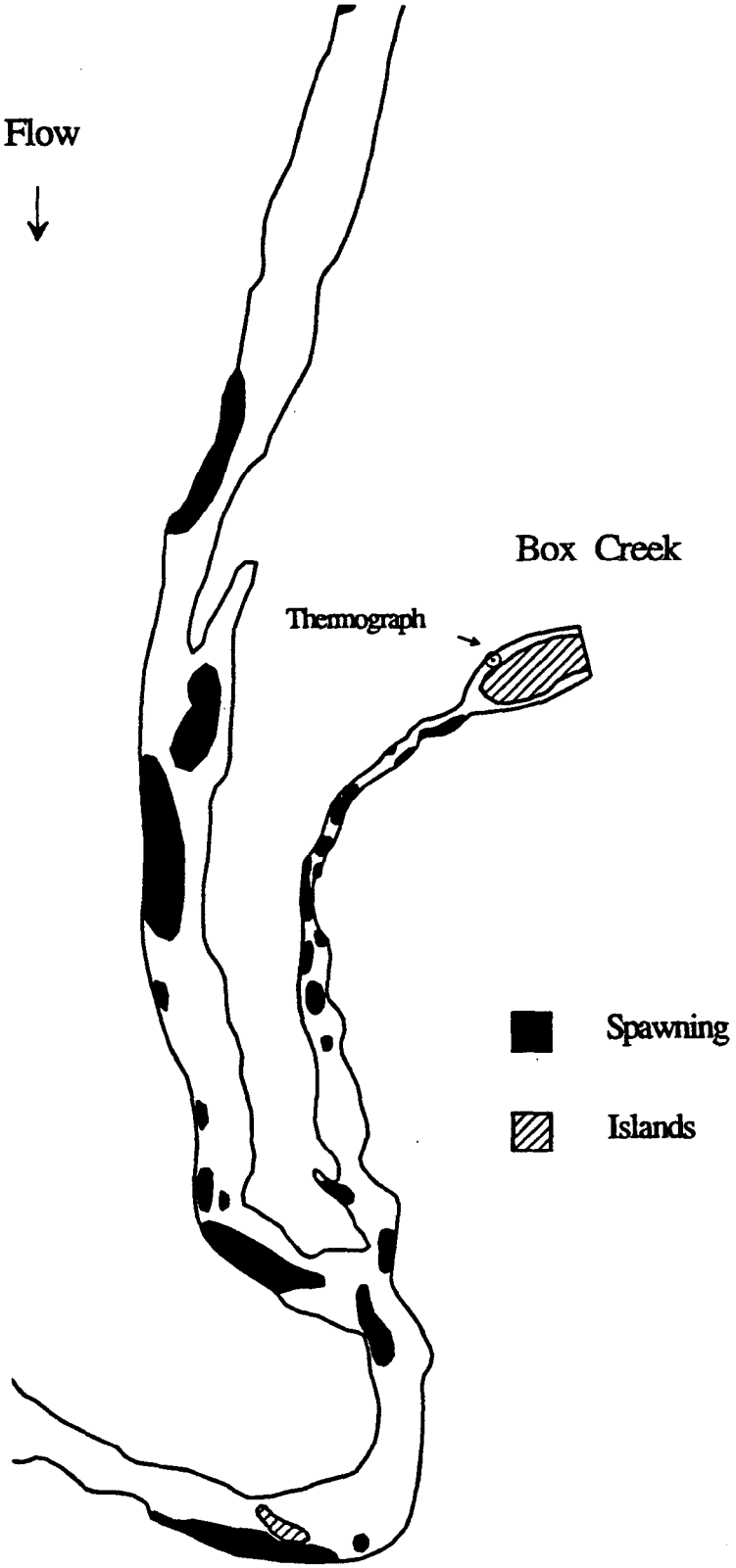

Figure 37. Kokanee spawning distribution in Area 5 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 27 m.

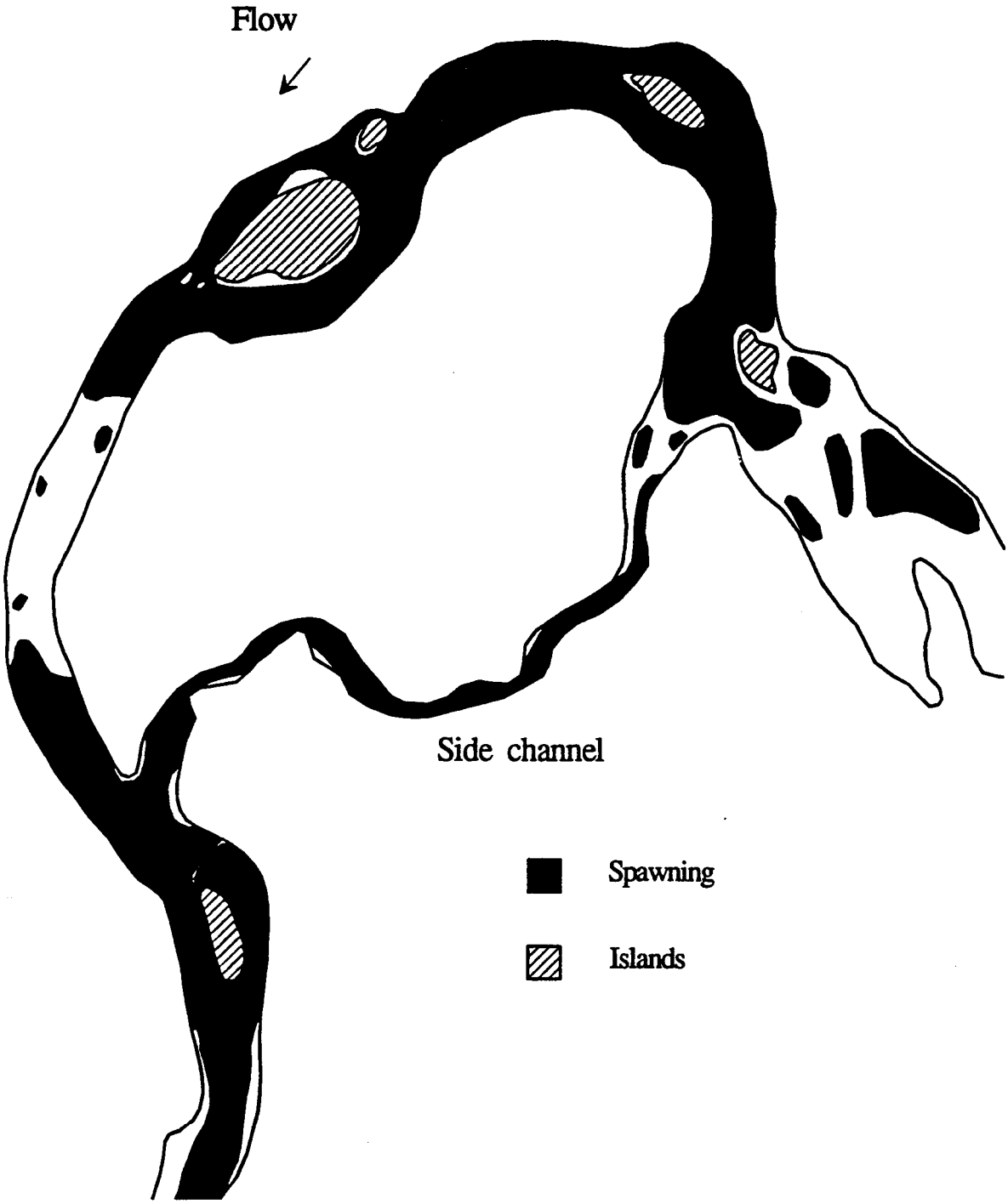

Figure 38. Kokanee spawning distribution in Area 6 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 14 m.

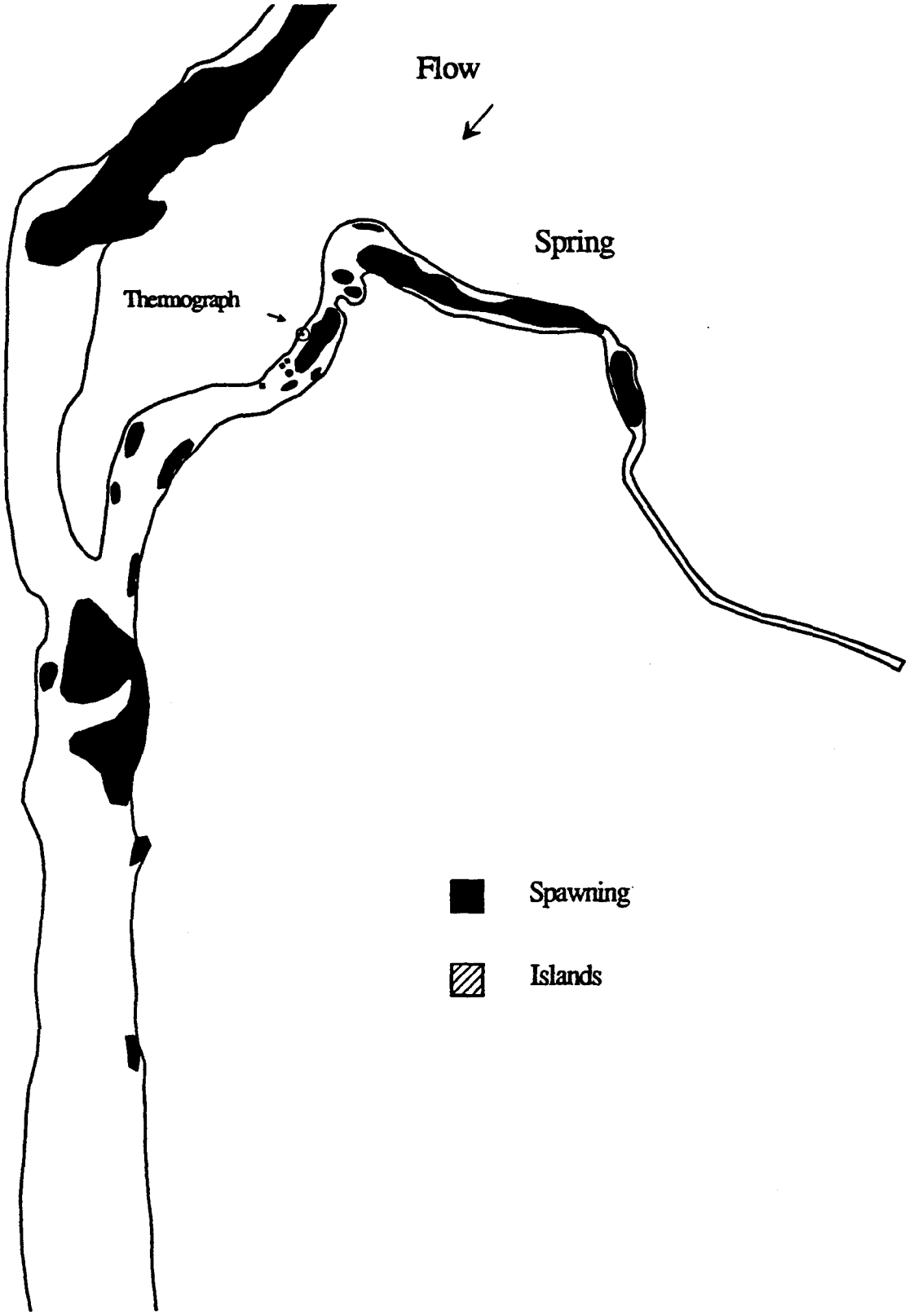

Figure 39. Kokanee spawning distribution in Area 7 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 15 m.

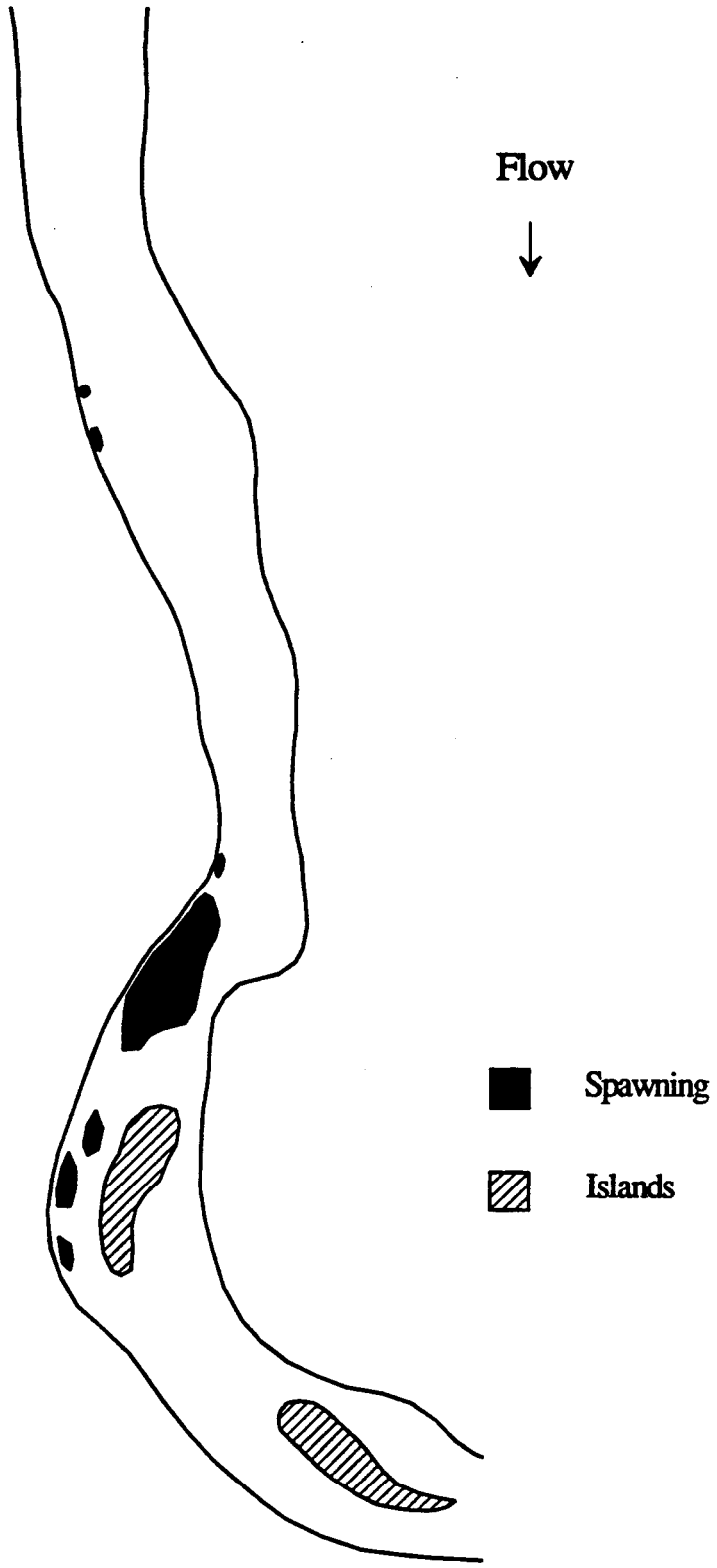

Figure 40. Kokanee spawning distribution in Area 8 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 16 m.

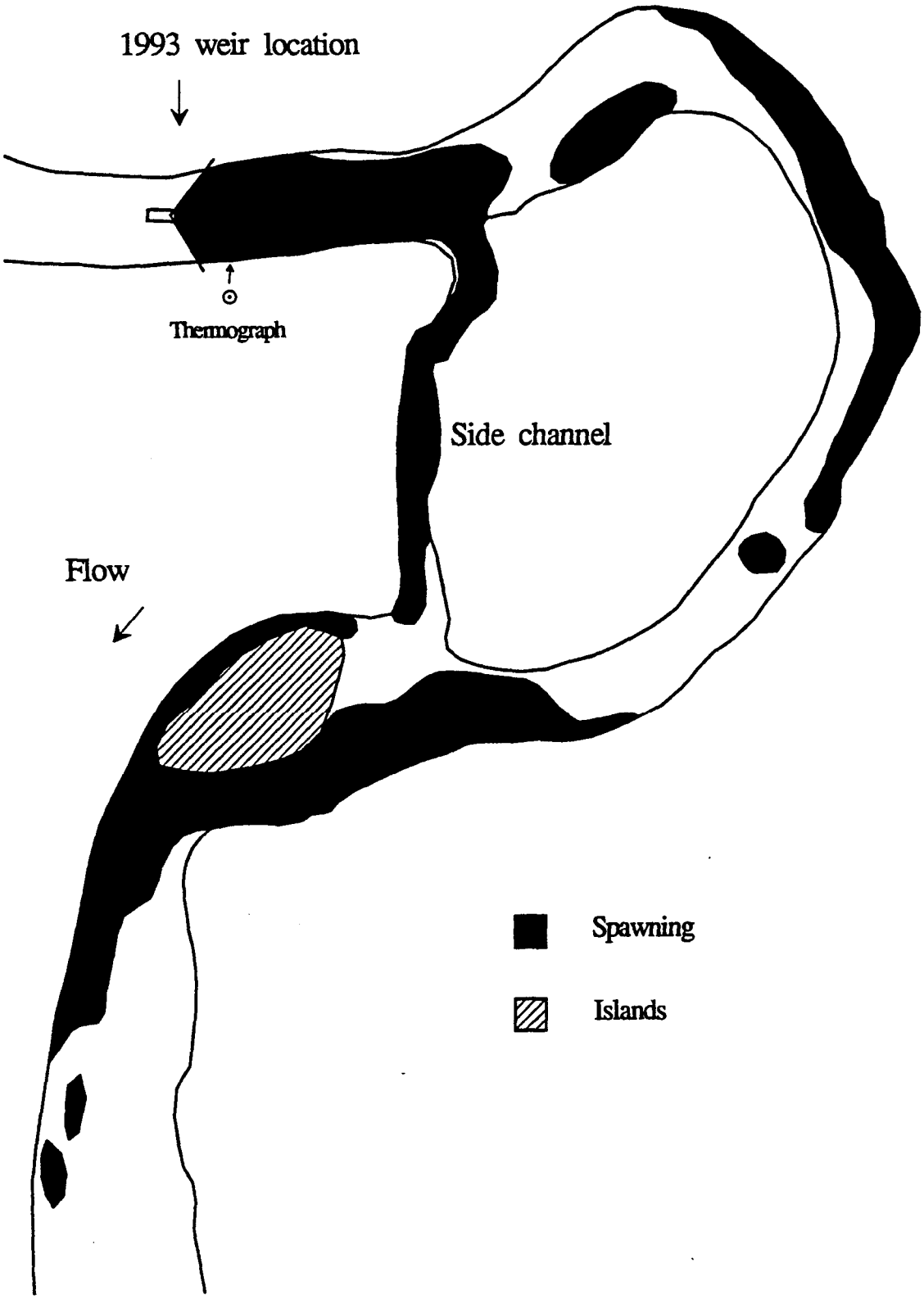

Figure 41. Kokanee spawning distribution in Area 9 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 15 m.

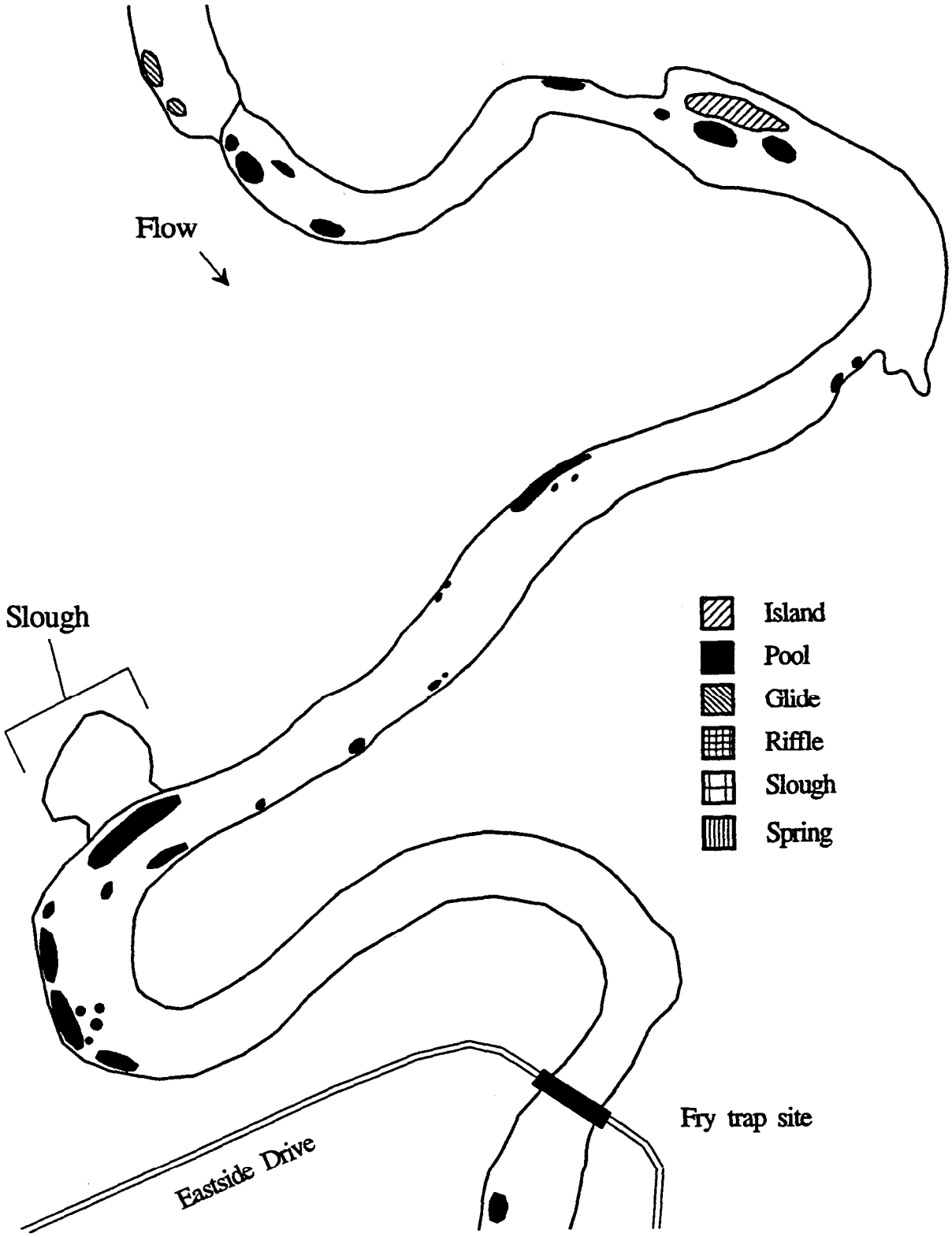

Figure 42. Kokanee spawning distribution in Area 10 of the North Fork of the Payette River, Idaho, in 1993. Scale is 1 cm = 28 m.

of the total count; Table 20), occurred in Areas 4, 5, 6, and 7 (Figures 36-39). Spawning was also high in Area 9, the reach containing the adult weir (Figure 41), as 21.5% of the total spawner count was observed here in 1993. Spawning in the upper Areas, 1 through 3 (Figures 33-35), and Areas 8 (Figure 40) and 10 (Figure 42) was relatively light (Table 20) and usually consisted of spawning groups of < 20 individuals.

Spawning and available-habitat coverage overlays in GIS revealed the habitat types used by kokanee (Figures 43-52) by identifying the areas in common between spawning and available habitat polygons. Percent area used for spawning by habitat type and intensity of use (counts within habitat units) within each area was determined from the GIS database and revealed differential use of habitat types among areas (Table 21). Overall, glides were used most intensively of all habitat types as 51.9% (N=15,939) of all spawning kokanee were counted in glides (Table 21). Riffles (20.0%), pools (19.6%), springs (8.4%), and sloughs (0.1%) were also used by spawning kokanee.

Habitat use for spawning kokanee varied by area in the NFPR. Glide habitat was used most in Area 6 (Figure 48) as 5,444 kokanee used 67.9% of the available glide area (m^2) in this reach, whereas no kokanee were observed using glide habitat in Area 2 (Figure 44; Table 21). Pool habitat, like glide habitat, was used most in Area 6 as 1,480 kokanee used 59.9% of the available pool area (m^2) in this reach, whereas no kokanee were observed using pool habitat in Area 8 (Figure 50). Riffle habitat was also extensively used in Area 6 (Figure 48) as 2,808 kokanee used 61.4% of the available riffle area (m^2). Riffle habitat was used most in Area 7 (Figure 49) as 71.5% of the available riffle area (m^2) was used by 670 kokanee. By contrast, two kokanee were observed using

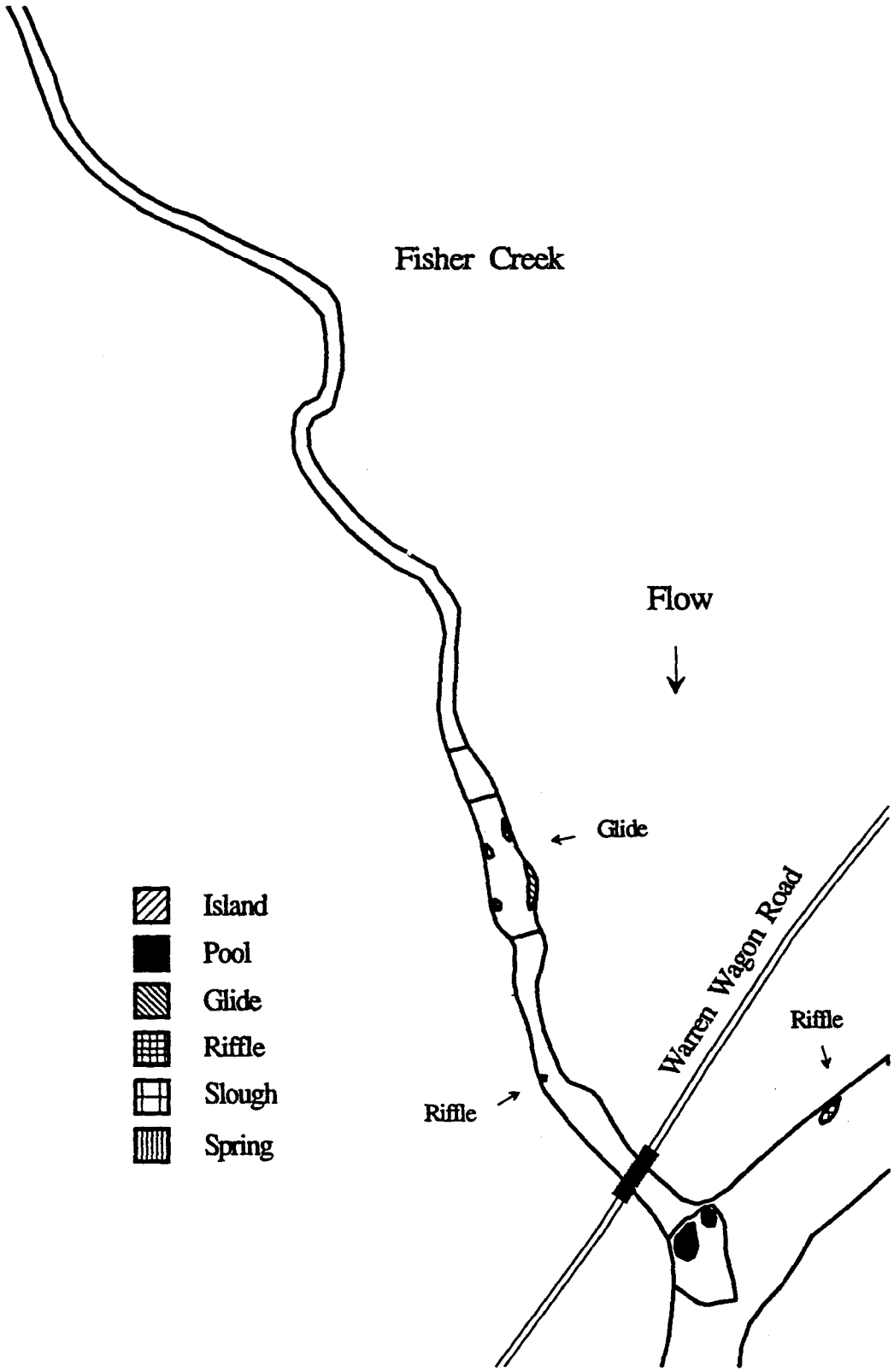

Figure 43. Habitat used by kokanee for spawning in Area 1, Fisher Creek, of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 16 m.

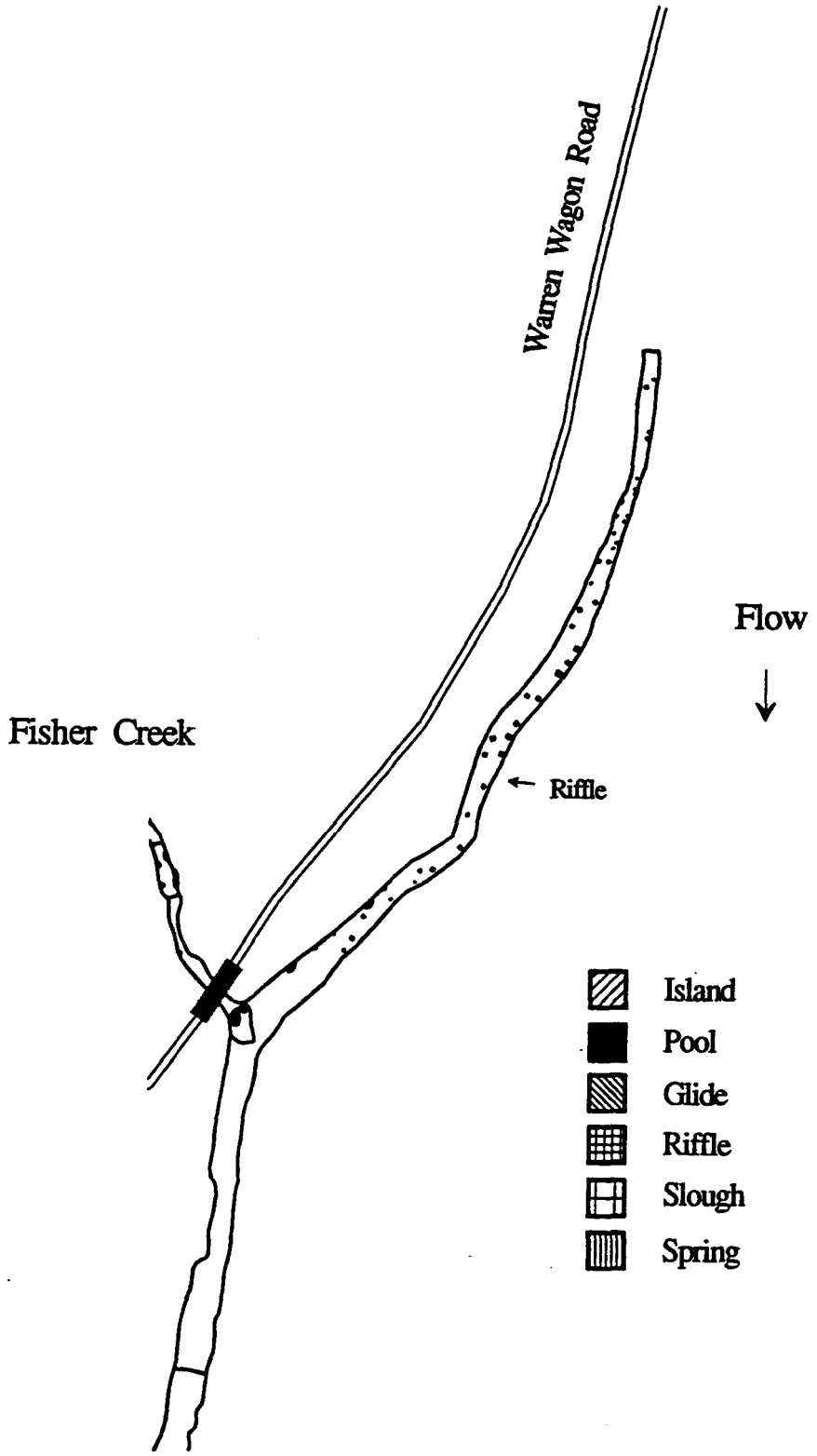

Figure 44. Habitat used by kokanee for spawning in Area 2 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat maps. Scale is 1 cm = 46 m. All spawning above Fisher Creek was in riffles.

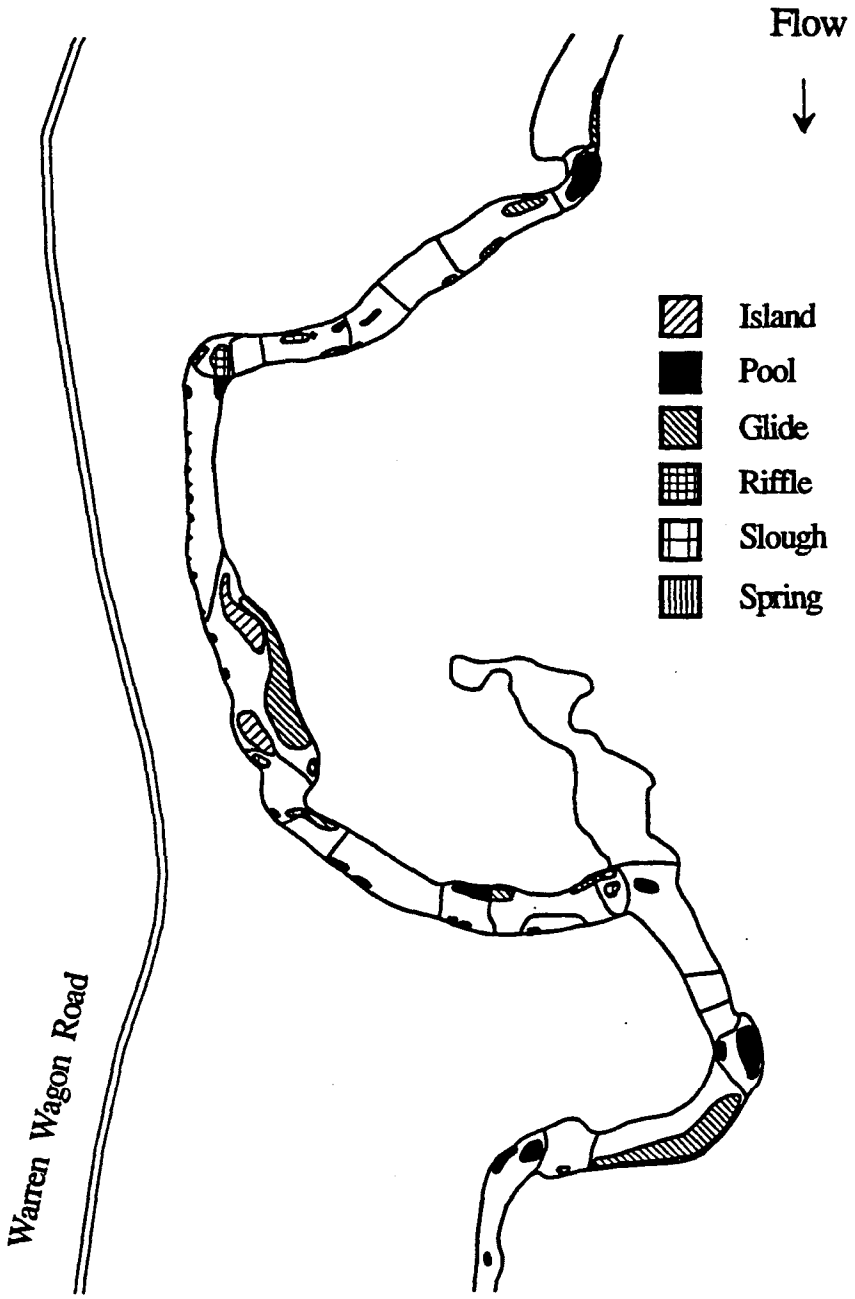

Figure 45. Habitat used by kokanee for spawning in Area 3 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 35 m.

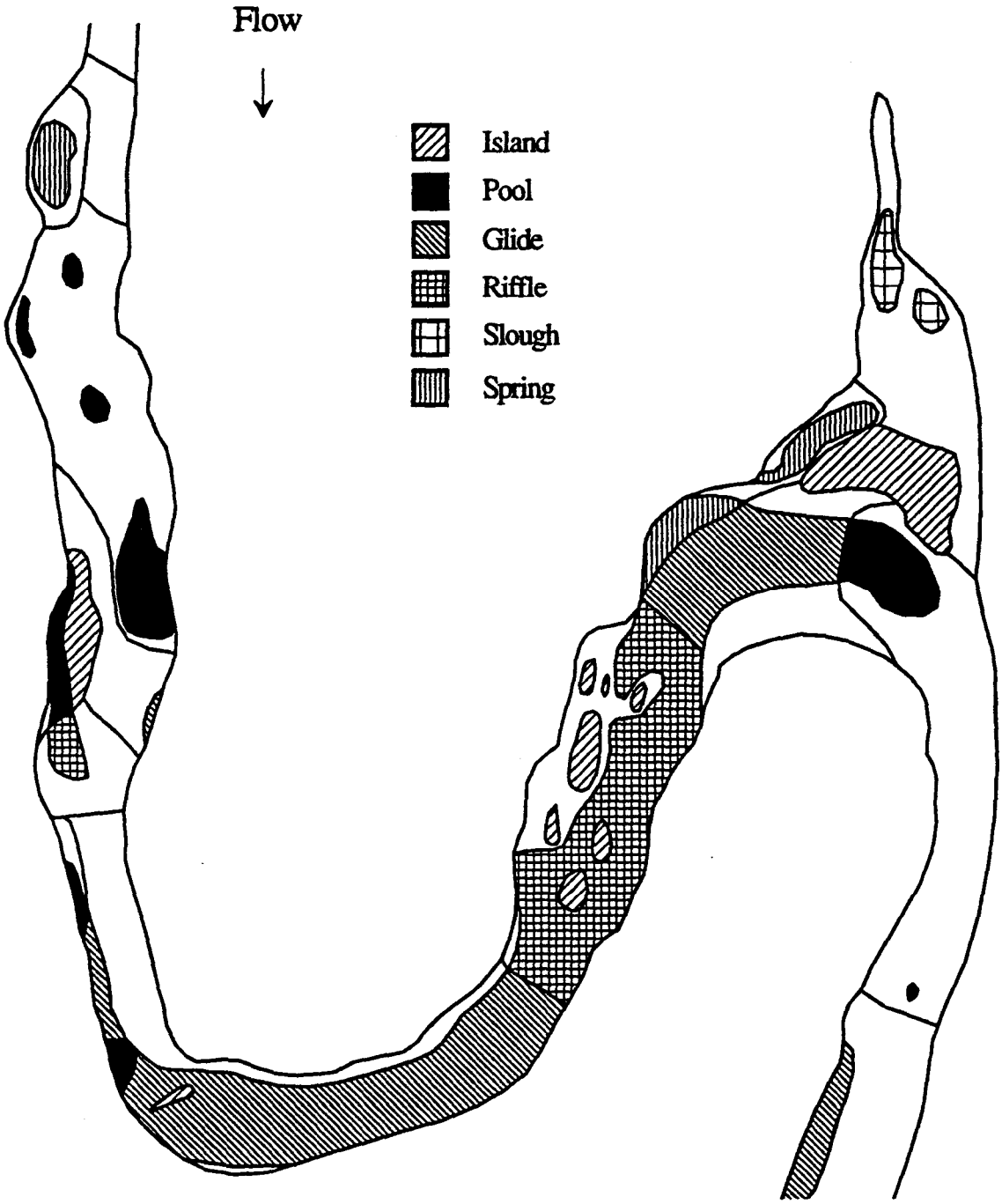

Figure 46. Habitat used by kokanee for spawning in Area 4 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 14 m.

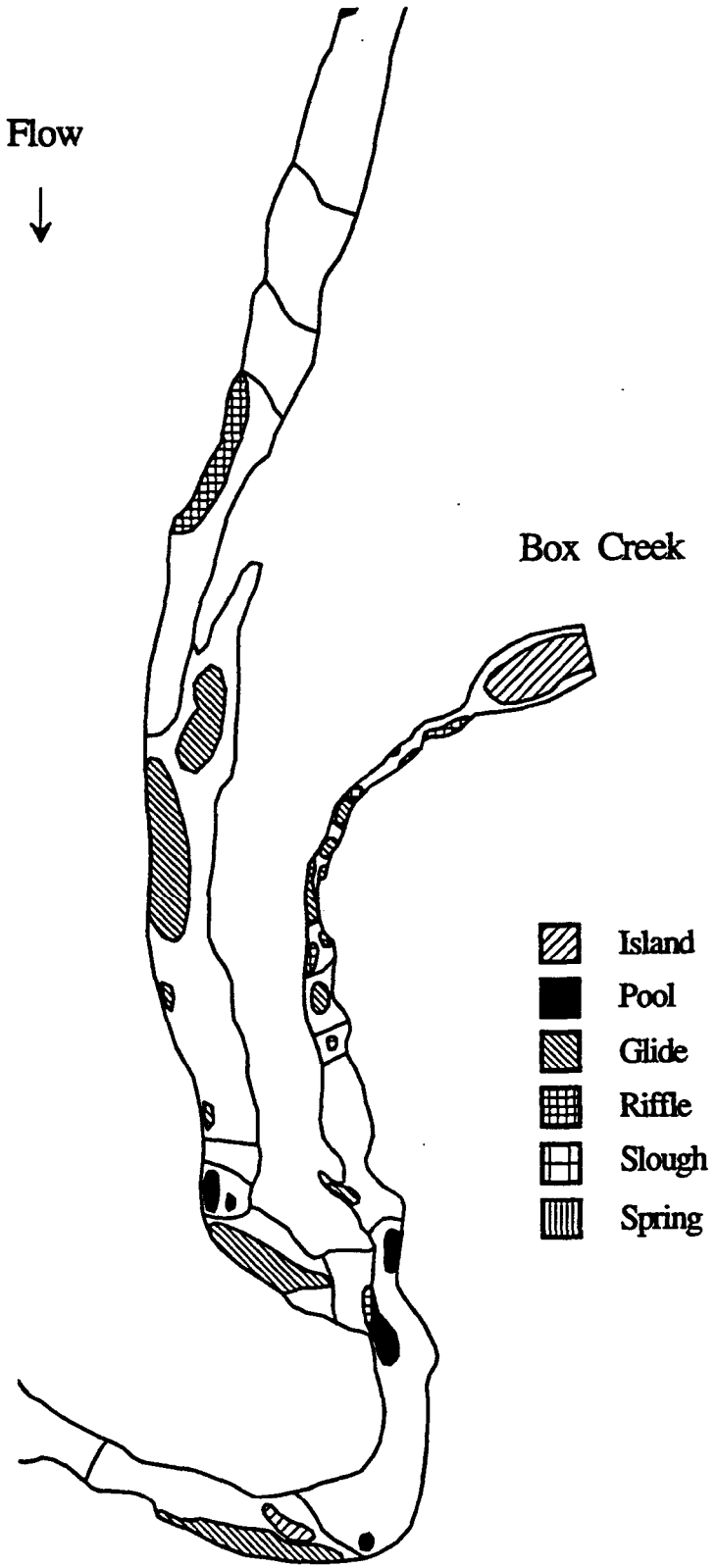

Figure 47. Habitat used by kokanee for spawning in Area 5 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 27 m.

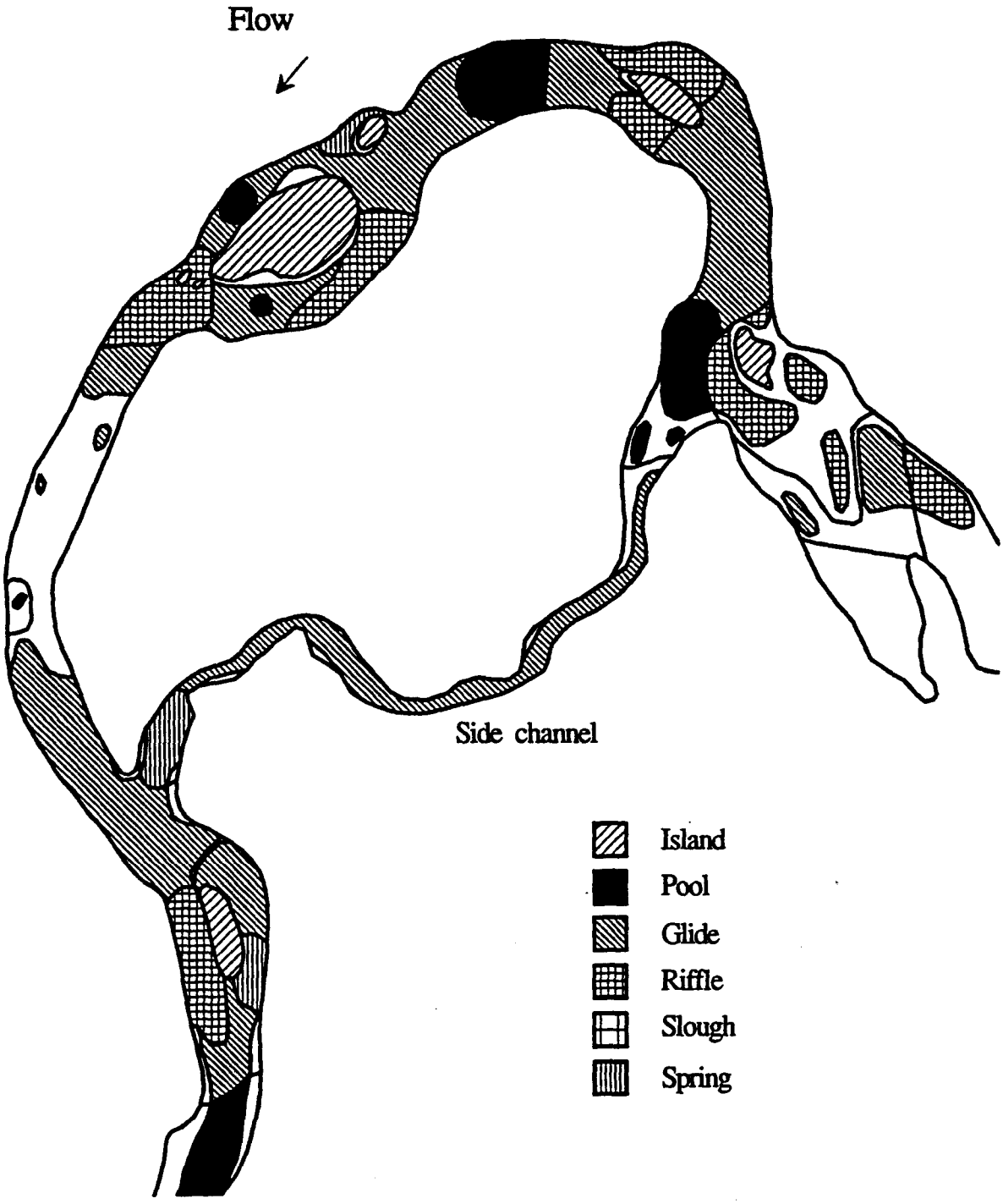

Figure 48. Habitat used by kokanee for spawning in Area 6 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 14 m.

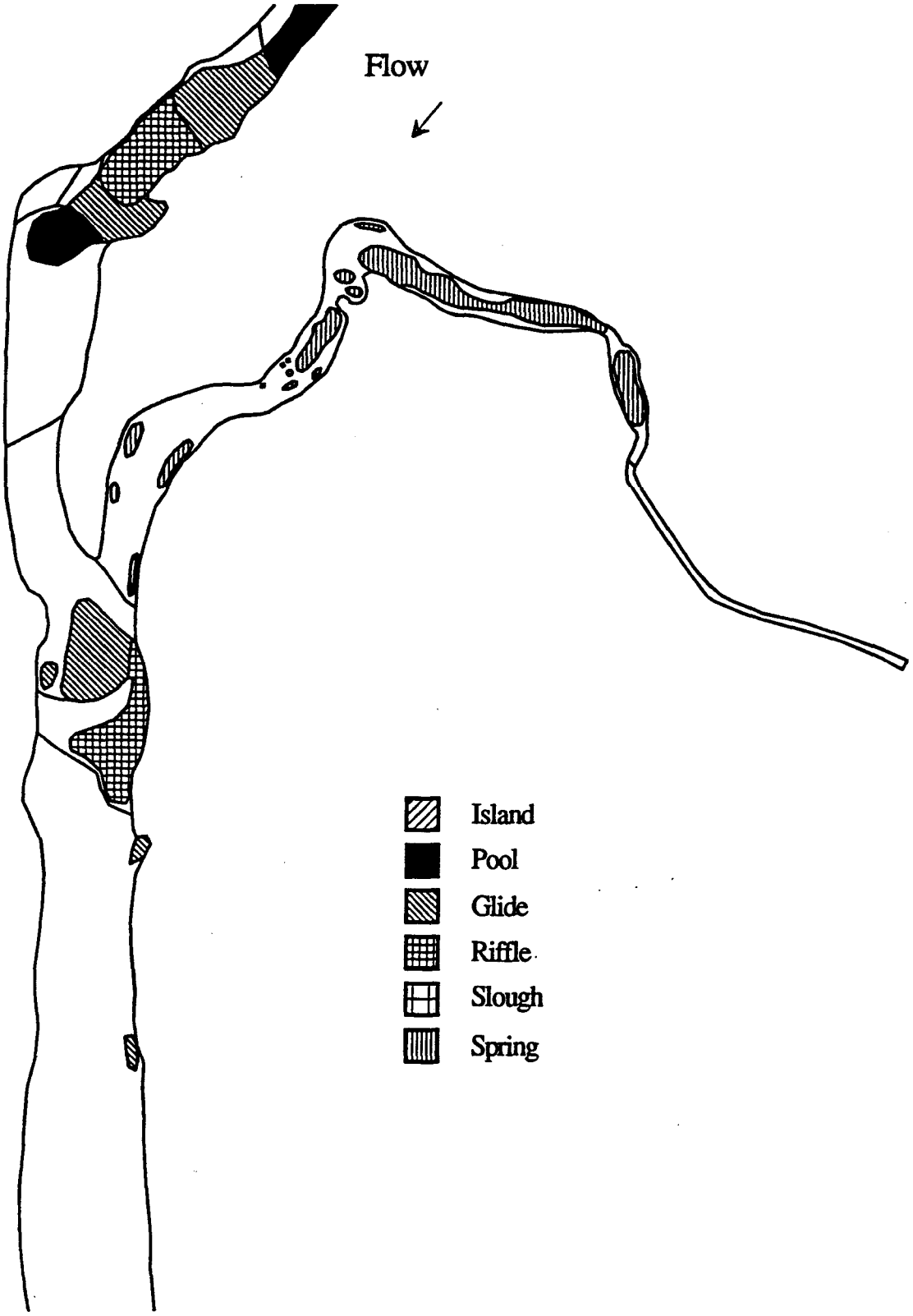

Figure 49. Habitat used by kokanee for spawning in Area 7 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 15 m.

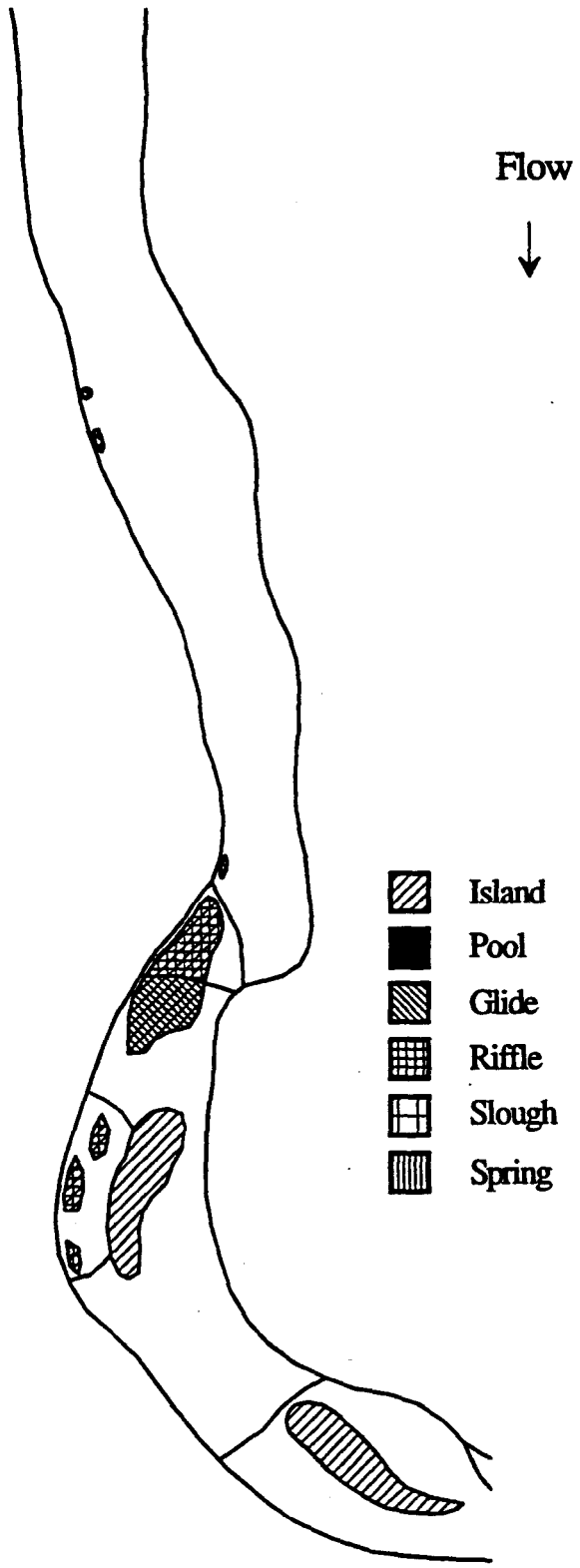

Figure 50. Habitat used by kokanee for spawning in Area 8 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 16 m.

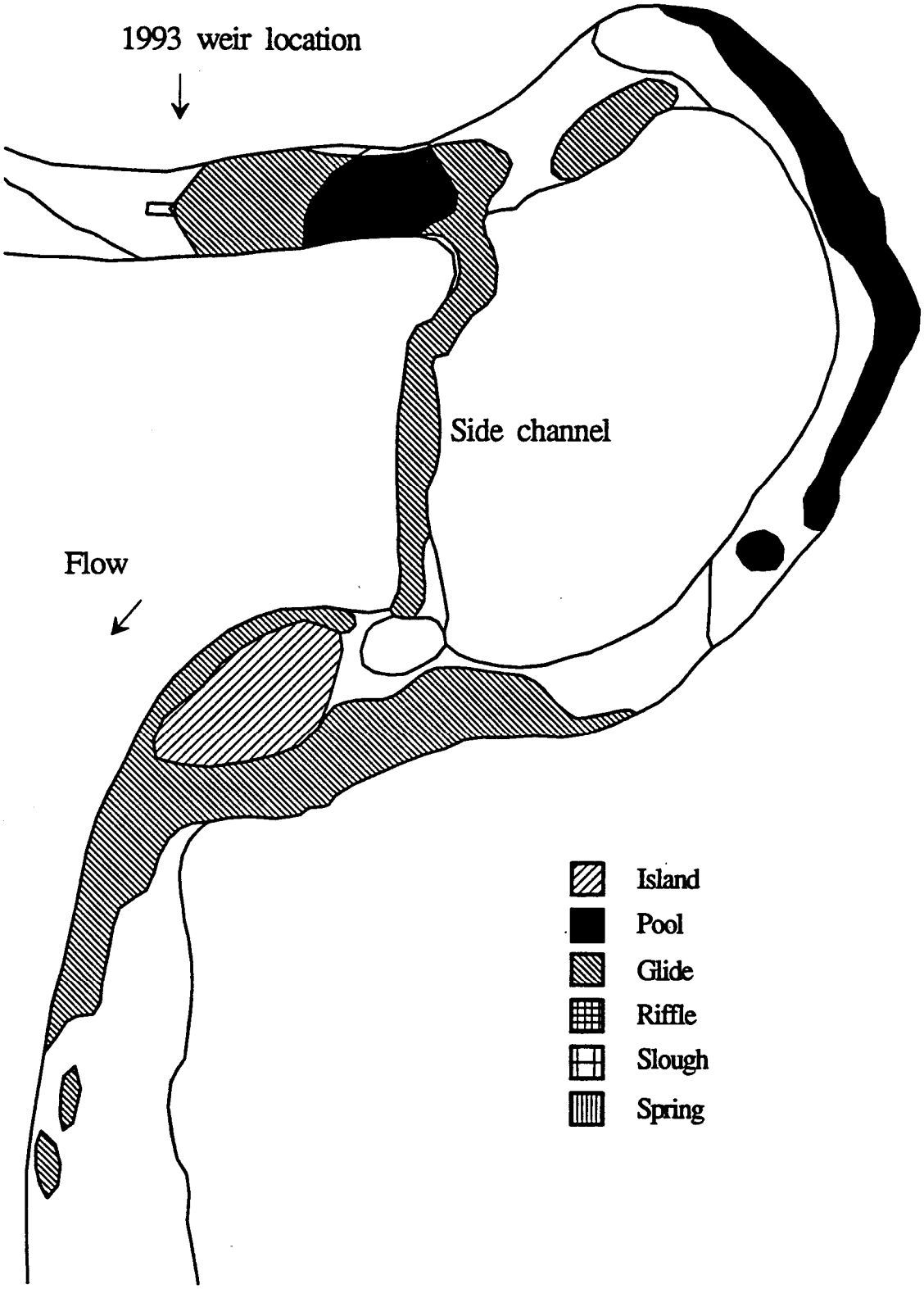

Figure 51. Habitat used by kokanee for spawning in Area 9 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 15 m.

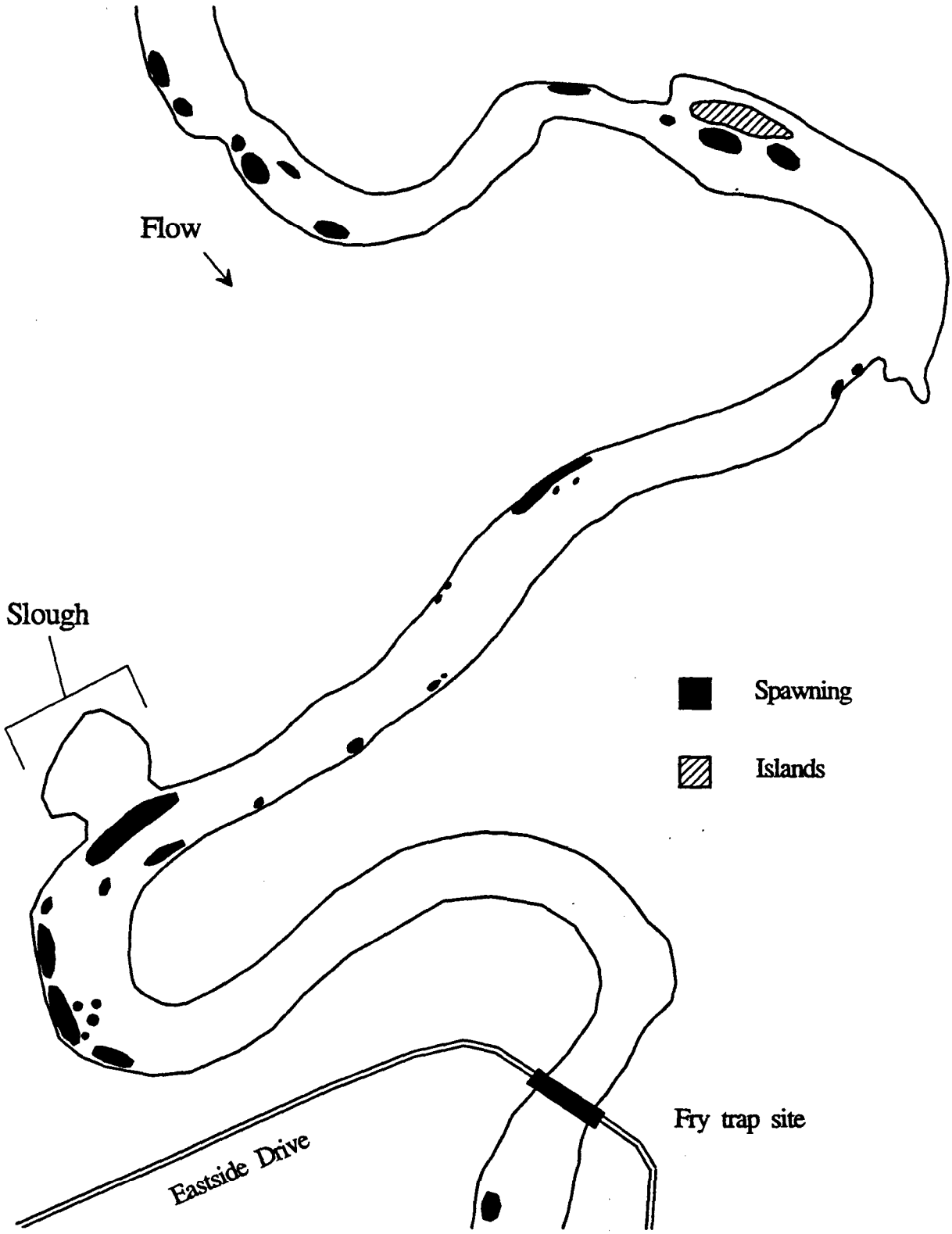

Figure 52. Habitat used by kokanee for spawning in Area 10 of the North Fork of the Payette River, Idaho, in 1993. Shaded polygons indicate area in common between spawning and available habitat coverages. Scale is 1 cm = 28 m.

Table 21. Observed kokanee counts (N) and the percent area available that was used by kokanee for spawning by area, habitat type, and total for the 1993 spawning run in the North Fork of the Payette River, Idaho. Total observed counts were used in the use-availability analysis.

	Pool		Glide		Riffle		Slough		Spring	
Area #	N	%	N	3	N	%	N	%	N	%
1	-	-	41	9.2	2	0.21	-	-	-	-
2	20	16.5	0	0	92	0.94	-	-	-	-
3	840	13.8	1,136	19.2	491	9.5	0	0	-	-
4	482	20.2	1,801	45.3	1,342	6.4	40	12.9	570	57.4
5	397	11.1	1,802	19.6	618	12.3	-	-	-	-
6	1,480	59.9	5,444	67.9	2,808	61.4	0	0	609	91.6
7	580	35.6	805	17.1	670	71.5	0	0	1396	29.2
8	0	0	90	2.8	106	32.3	-	-	-	-
9	1,835	38.7	4,782	45.6	-	-	-	-	-	-
10	394	4.7	38	7.9	-	-	0	0	-	-
Total	6,028		15,939		6,129		40		2,575	

riffle habitat in Area 1 (Figure 43). No riffle habitat was available for use in Areas 9 and 10 (Figures 51 and 52). Slough habitat was used in Area 4 (Figure 46) as 40 kokanee were observed using 12.9% of the slough area (1,058 m^2) available. Spring areas were used extensively regardless of location. Kokanee used from 29.2% in Area 7 (Figure 49) to 91.6% in Area 6 (Figure 48) of available spring habitat (Table 21). A total of 2,575 kokanee, or 8.4% of the total count, used spring habitat for spawning in 1993.

Statistical Analysis

On 29 September 1993, 30,711 kokanee were counted in the NFPR and represented the peak spawning abundance observed during 1993. Habitat use, the distribution of counts across habitat types, differed significantly from that expected based on availability (X^2 = 13,930; $p<0.001$) leading us to reject the null hypothesis that habitat types were used in proportion to availability (Table 22). We determined some habitat types were avoided and others were selected based on availability and observed use. Bonferroni confidence intervals indicated pool and slough habitats were avoided or used less than expected (percent of total area lies above confidence interval). Glide, riffle, and spring habitats were selected or used more than expected (percent of total area lies below confidence interval). We concluded kokanee did not use spawning habitat through a random process but selected and avoided particular habitat types in the NFPR.

Table 22. Habitat use-availability analysis of aquatic habitat within kokanee spawning distribution in the North Fork of the Payette River, Idaho.

Habitat	Kokanee observed	Rokanee expected	χ^2	Percent observed	Area m2	Percent of total area	Bonferroni confidence interval 95%
Pool	6,028	12,404	3,277	0.196	61,956	40.4	19.0≤p≤20.2*
Glide	15,939	10,722	2,538	0.519	53,558	34.9	51.2≤p≤52.6*
Riffle	6,129	5,670	37	0.200	28,323	18.5	19.4≤p≤20.5*
Slough	40	1,333	1,254	0.00130	6,658	4.33	0.077≤p≤C.18*
Spring	2,575	582	6,824	0.0838	2,907	1.90	8.0≤p≤8.8*
Total	30,711	30,711	13,930		153,402		

* = significance ascribed if expected use (Percent of total area) does not lie within confidence interval.

Microhabitat Availability and Use

Microhabitat features were measured at 284 transects during 1992 and 1993. Sampling was conducted over the 7.2 km-reach that encompassed all kokanee spawning. Mean stream width over the sampled reach was 22.0 m (range=4.5-58.6 m). The mean depth throughout the kokanee spawning distribution was 39 cm (range=1-262 cm; n=2,836) and mean velocity was 24 cm/s (range=0-293 cm/s; n=2,819). Microhabitat use by spawning kokanee was evaluated along all transects. Mean depth at spawning locations was 41 cm (range=3-159 cm; n=1,051) and mean velocity was 28 cm/s (range=0-130; n=1,051).

Water depth availability and use distributions were different (X^2 = 72.9; $p<0.001$) indicating depths for spawning were being selected by kokanee (Figure 53). The habitat use curve for water depth showed the highest probability of spawning occurred at a depth of 30 to 42 cm (Figure 53). Water depths in the range of 18 to 30 cm were also highly used. The greatest occurrence of available water depth ranged from 12 to 24 cm.

Water velocity availability and use distributions were different (X^2=153.5; $p<0.001$) indicating velocities for spawning were selected by kokanee (Figure 54). The habitat use curve for water velocity showed the greatest probability of spawning occurred at velocities of 0 to 6 cm/s which was also the most frequently available velocity range (Figure 54).

Substrate availability and use distributions were different (X^2=1,338.9; $p<0.001$) indicating substrates for spawning were being selected by kokanee (Figure 55). The habitat use curve for substrate size revealed the most frequently used substrate was large gravel which

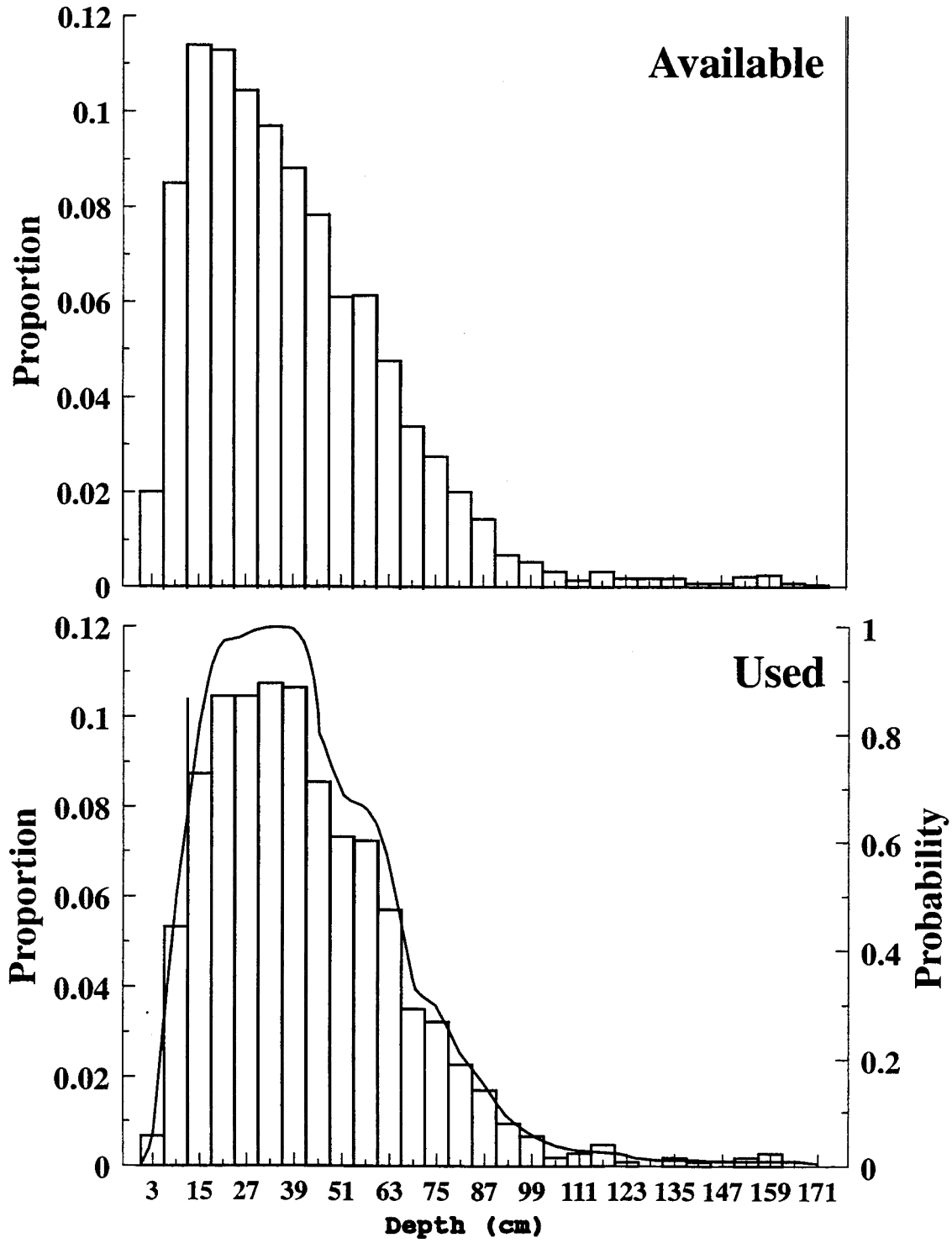

Figure 53. Frequency histograms of available water depth in the North Fork of the Payette River, Idaho, and water depths used by kokanee for spawning in 1992 and 1993. Also shown is the probability curve derived from use data.

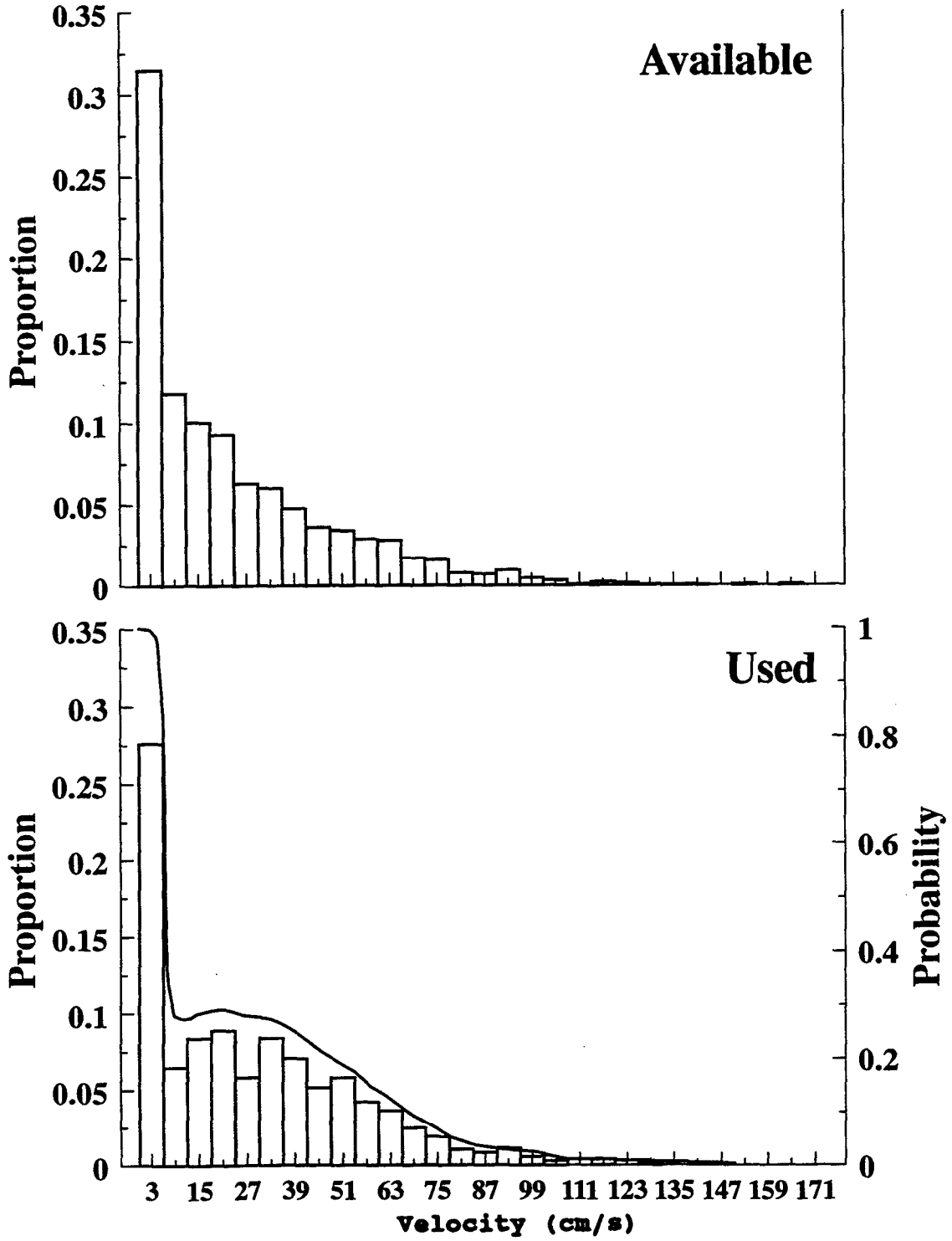

Figure 54. Frequency histograms of available water velocity in the North Fork of the Payette River, Idaho, and velocities used by kokanee for spawning in 1992 and 1993. Also shown is the probability curve derived from use data.

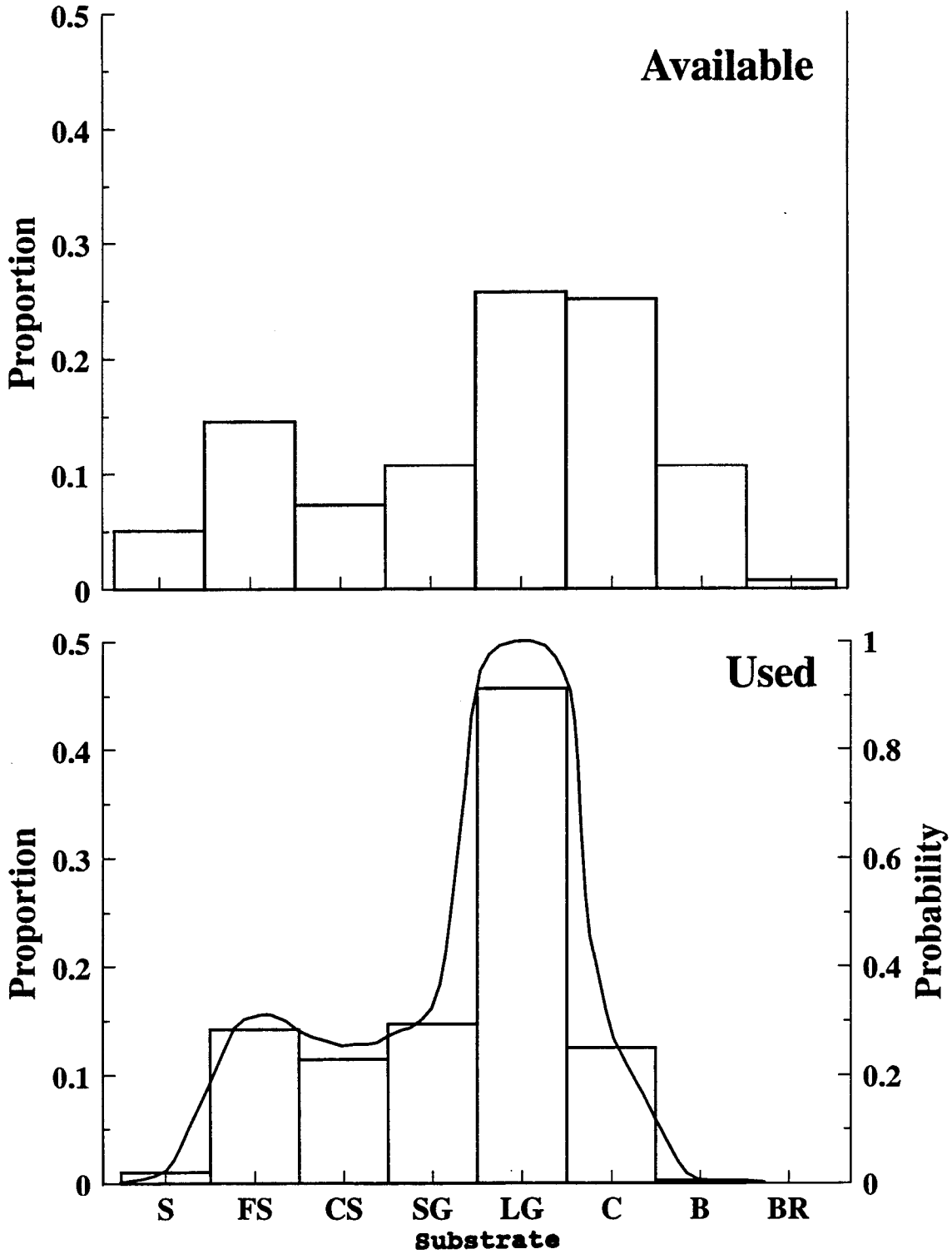

Figure 55. Frequency histograms of available substrate in the North Fork of the Payette River, Idaho, and substrate used by kokanee for spawning in 1992 and 1993. Probability curve is shown for use data. S=silt (<0.5 mm); FS=fine sand (>0.5-3 mm); CS=coarse sand (>3-6 mm); SG=small gravel (>6-26 mm); LG=large gravel (>26-50 mm); C=cobble (>50-150 mm); B=boulder (>150 mm); BR=bedrock.

was the most available (>26-50 mm). Cobble (>50-150 mm) substrate was nearly as abundant as large gravel but was used less. Bedrock was the least abundant substrate available and was not used by kokanee for spawning.

Microhabitat by Habitat Type

Available water depths and depths used for spawning varied by habitat type in the NFPR (Table 23). As expected, pools had the highest average depth (63 cm) and riffles had the lowest (28 cm). Mean depth in springs (46 cm) was higher than that in glides (36 cm) or riffles. Depths used for spawning in the various habitats showed the same pattern as availability. Depths used for spawning in pools was highest (66 cm) and depths used in riffles was lowest (29 cm). Range in observations for available and used water depths was wide and overlapped for all habitat types.

Available water velocities and velocities used for spawning varied by habitat type in the NFPR (Table 24). Springs had the lowest average velocity (3 cm/s) and riffles had the highest (43 cm/s). Average velocities used for spawning were higher than average velocities available in pools and glides. For example, velocities used for spawning in pools averaged 16 cm while the average available velocity in pools was 8 cm/s. Velocities used for spawning in glides averaged 29 cm/s and the average available velocity in glides was 22 cm/s. Average velocities used for spawning were similar to those velocities available in riffles and springs (Table 24).

Available substrate by habitat type revealed differences between pools, glides, riffles, and springs, and availability dictated kokanee.

Table 23. Available and used water depths in four habitat types throughout the kokanee spawning distribution in the North Fork of the Payette River, Idaho during 1992 and 1993.

	Available			Used		
Habitat type	Mean (cm	Range (cm)	N	Mean (cm)	Range (cm)	N
pool	63	1-262	425	66	7-159	118
glide	36	2-101	1,539	40	3-101	579
riffle	28	2-183	692	29	3-79	250
spring	46	4-162	180	51	6-159	105

Table 24. Water velocities available and used by kokanee for spawning in four habitat types throughout the kokanee spawning distribution in the North Fork of the Payette River, Idaho during 1992 and 1993.

	Available			Used		
Habitat type	Mean (cm/s)	Range (cm/s)	N	Mean (cm/s)	Range (cm/s	N
pool	8	0-79	425	16	0-79	118
glide	22	0-130	1,529	29	0-130	579
riffle	43	0-293	686	43	0-119	249
spring	3	0-55	179	3	0-55	105

use of substrate for spawning. The most common substrate available and used for spawning in pools was fine sand (Figure 56). Silt substrate was also common in pools but spawning was never observed in silt. Large gravel was the most common substrate available in glides and was heavily used by spawning kokanee as 54.4% of spawning locations in glides were located in large gravel (Figure 57). Cobble substrate was also relatively common in glides but was not used as frequently. Riffle substrate was, in general, more coarse than that in all other habitat types. The most common substrate in riffles was cobble; boulder and bedrock were more frequently observed in riffles than in any other habitat type (Figure 58). Large gravel substrate was most frequently used in riffles, as 51.4% of spawning locations in riffles were located in large gravel. The most common substrate available and used for spawning in springs was fine sand (Figure 59). Substrate available in springs generally was smaller than that in all other habitat types. Cobble substrate was present in low abundance and boulder and bedrock was not observed in springs. Silt substrate was relatively abundant in springs as it was in pools, and little spawning was observed in substrate dominated by silt.

DISCUSSION

Habitat Use-Availability

Habitat Availability

Available spawning habitat in the North Fork of the Payette River varied among areas. Total habitat area was > 153,000 m^2 of that > 40% was pool and < 19% was riffle. Riffle habitat was present in proportionally higher abundance in upstream areas and pool habitat was

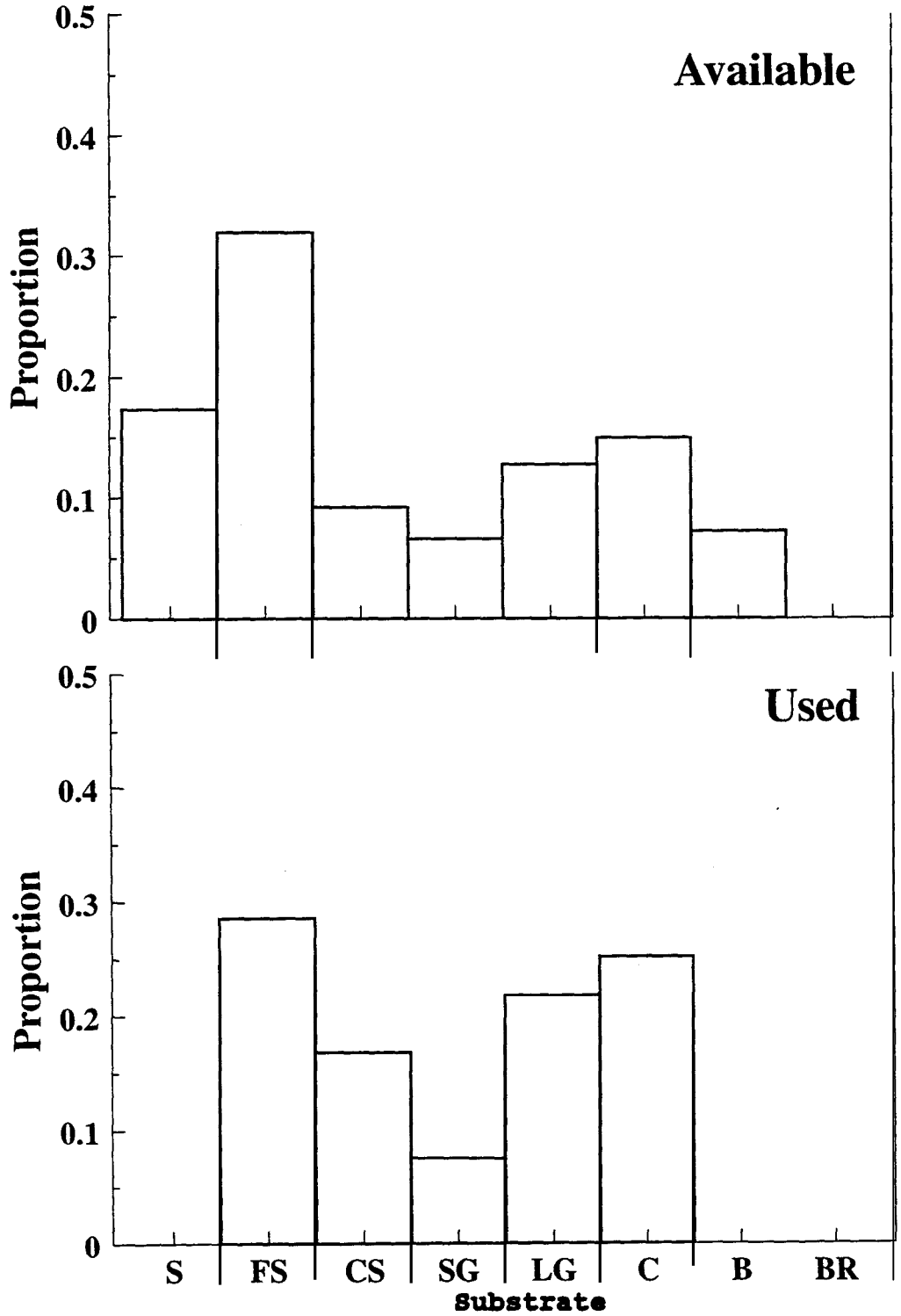

Figure 56. Frequency histograms of available substrate in pools in the North Fork of the Payette River, Idaho, and substrate used by kokanee for spawning in 1992 and 1993. Probability curve is shown for use data. S=silt (<0.5 mm); FS=fine sand (>0.5-3 mm); CS=coarse sand (>3-6 mm); SG=small gravel (>6-26 mm); LG=large gravel (>26-50 mm); C=cobble (>50-150 mm); B=boulder (>150 mm); BR=bedrock.

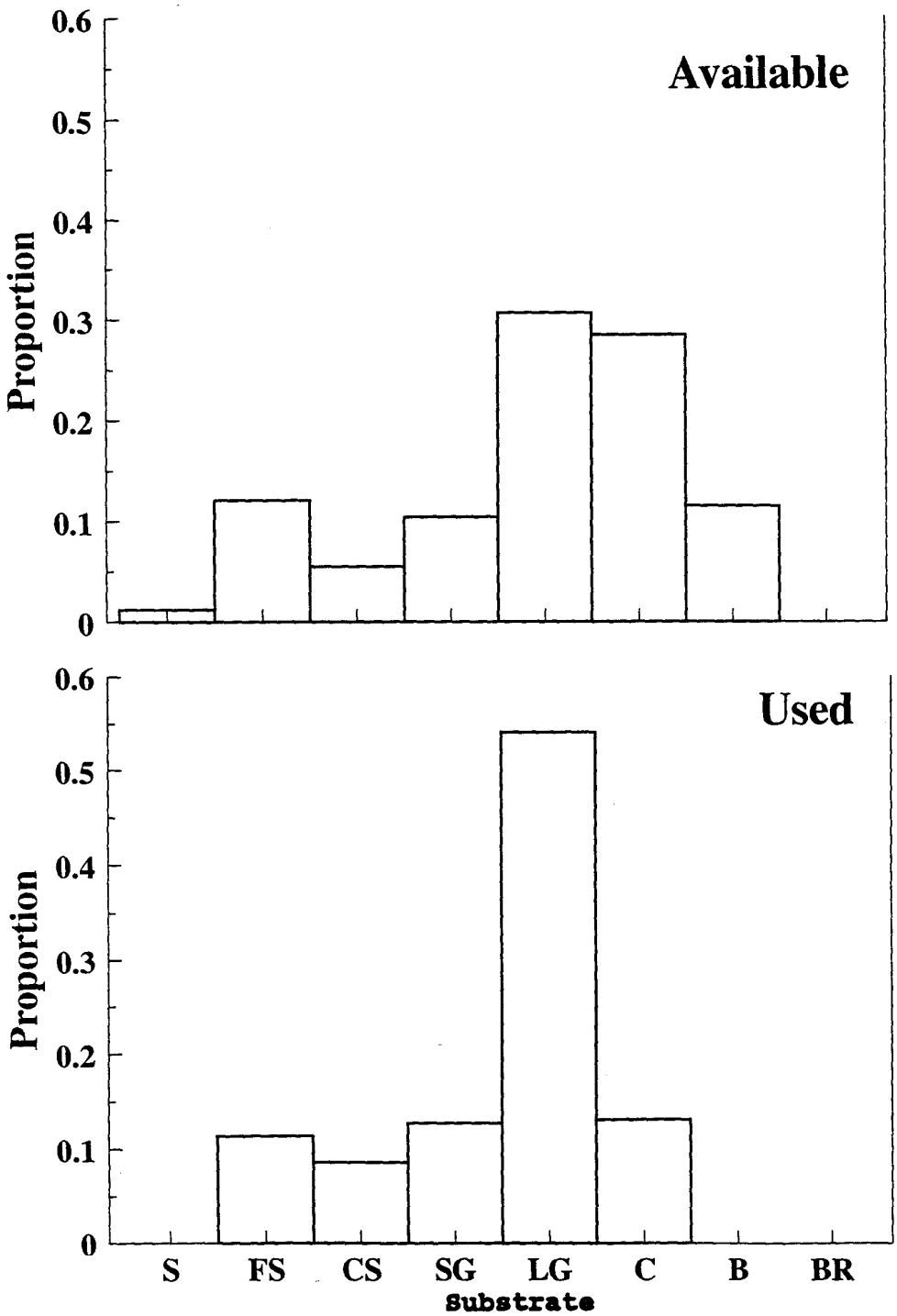

Figure 57. Frequency histograms of available substrate in glides in the North Fork of the Payette River, Idaho, and substrate used by kokanee for spawning in 1992 and 1993. Probability curve is shown for use data. S=silt (<0.5 mm); FS=fine sand (>0.5-3 mm); CS=coarse sand (>3-6 mm); SG=small gravel (>6-26 mm); LG=large gravel (>26-50 mm); C=cobble (>50-150 mm); B=boulder (>150 mm); BR=bedrock.

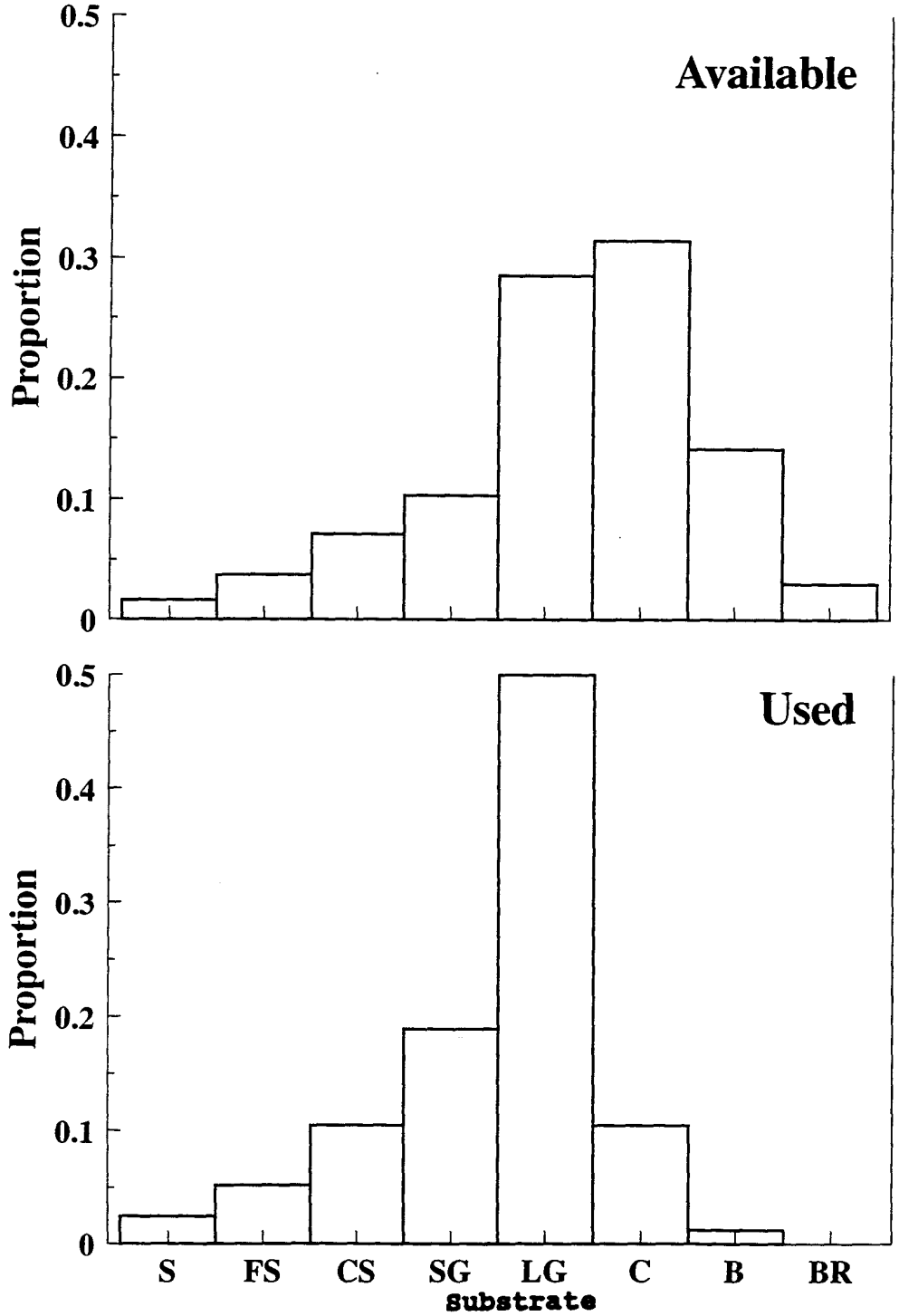

Figure 58. Frequency histograms of available substrate in riffles in the North Fork of the Payette River, Idaho, and substrate used by kokanee for spawning in 1992 and 1993. Probability curve is shown for use data. S=silt (<0.5 mm); FS=fine sand (>0.5-3 mm); CS=coarse sand (>3-6 mm); SG=small gravel (>6-26 mm); LG=large gravel (>26-50 mm); C=cobble (>50-150 mm); B=boulder (>150 mm); BR=bedrock.

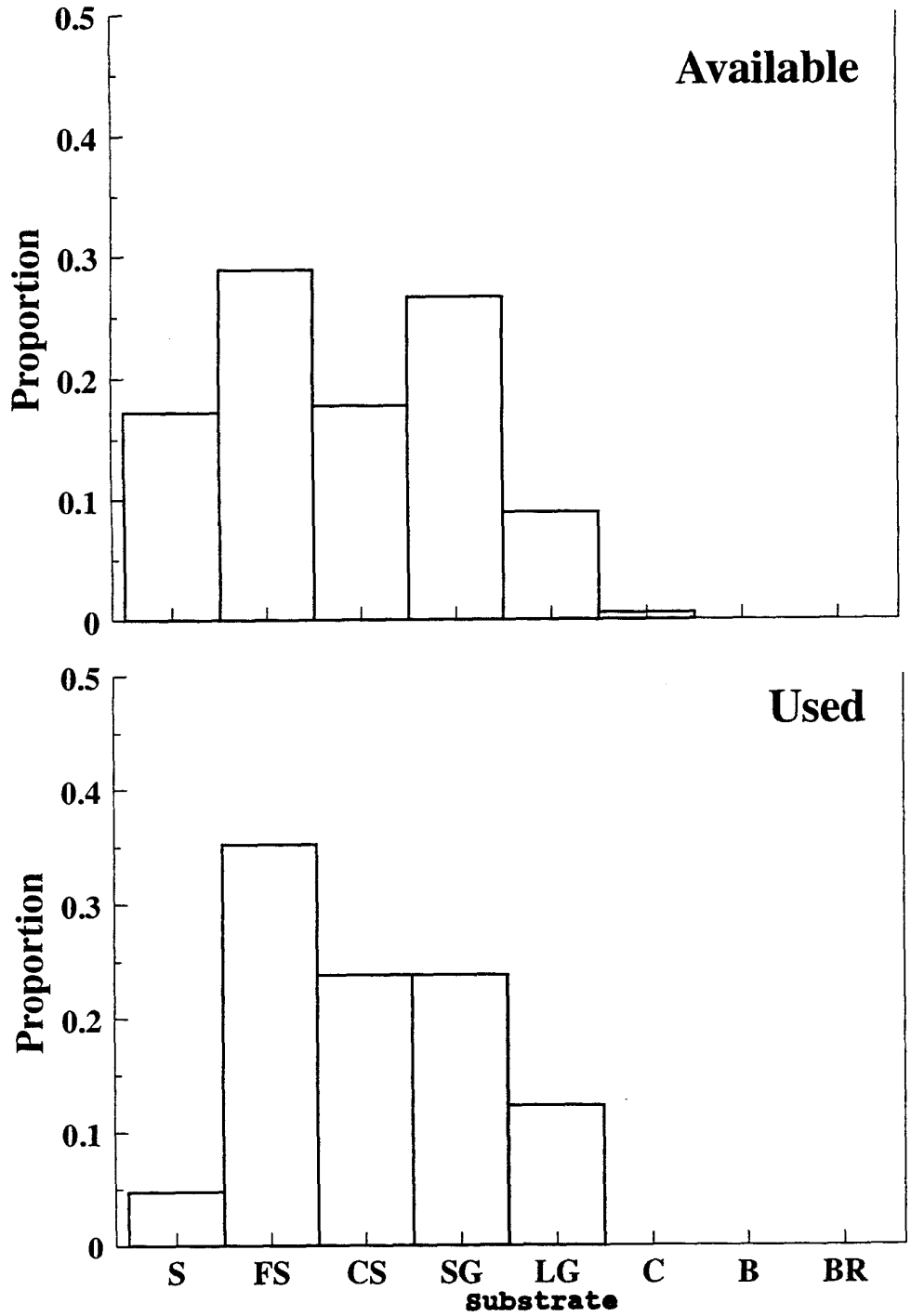

Figure 59. Frequency histograms of available substrate in springs in the North Fork of the Payette River, Idaho, and substrate used by kokanee for spawning in 1992 and 1993. Probability curve is shown for use data. S=silt (<0.5 mm); FS=fine sand (>0.5-3 mm); CS=coarse sand (>3-6 mm); SG=small gravel (>6-26 mm); LG=large gravel (>26-50 mm); C=cobble (>50-150 mm); B=boulder (>150 mm); BR=bedrock.

present in highest abundance downstream. Spring habitat was present in three areas, generally near the middle of the river from upstream to downstream. Use of GIS facilitated development of area maps and distinct delineation of habitat types in the different areas of the NFPR.

Spawning Distribution and Habitat Use

Spawning in the NFPR was not uniformly distributed among areas. Although riffle habitat was most abundant in upstream areas, < 1% of all spawning occurred in 1993 upstream of Area 3. Spawning observed in Areas 6 and 9 accounted for > 55% of all spawning. Spawning in these areas occurred almost everywhere, although the presence of the weir in Area 9 may have contributed to the high use. Steelhead will reportedly spawn in less desirable locations during the latter part of the run (G. Mendel, Washington Department of Fish and Wildlife, Olympia, Washington, personal communication). Area 6 had about 7% of the total available habitat and accounted for > 33% of all spawning. Based on our classification of habitats, glides were used in highest proportion (67.9%) for spawning in Area 6. Pool habitat was also used extensively in Area 6 and kokanee spawned in about 60% of the available pool area. Riffle habitat was also used for spawning in Area 6 (61.4%) and used most extensively in Area 7 (71.5%), although comparatively low levels of spawning occurred in Area 7.

Differences in spawning habitat use among areas in the NFPR were interesting. This differential use suggests other habitat features or interactions of habitat features may affect spawning location other than those measured. For example, the substrate class used for spawning

varied among habitat types. Large gravel was the most common substrate class selected in glides and riffles, although fine sand was the most common substrate class used in pools. Selection of large gravel and cobble was prevalent in pools, however, the proportion used was higher than that available.

Statistical Analysis

Application of the Neu method (Neu et al. 1974) requires basic assumptions for valid analysis of resource selection (Alldredge and Ratti 1992). First, observations of individuals must be random and independent; a restriction that was met in our analysis. Violations of random observations occur most often in studies using small numbers of radio-tagged animals. Violations of independent observations also occur in radio-tagging studies where individuals are observed multiple times, because such observations, even when separated in time, are not completely independent (Alldredge and Ratti 1992). We counted all spawning kokanee observed within the NFPR on a single day which represented the highest abundance of kokanee during the 1993 run. Therefore, randomness of observations was not an issue. Because multiple counts of the same individuals were not used in cur analysis (individuals were only considered once), we concluded our observations met the independence assumption.

The Neu method requires that habitat availability is measured without error, thus we believe the use of GIS was invaluable. The two-dimensional river model created from aerial photographs, GPS, and field data characterized the river with a high degree of accuracy. Our availability data was a true reflection of habitat available to kokanee

for spawning. Categorical description of habitat is inherently biased due to the nature of aquatic, riverine habitat. Delineation of different habitat types, particularly between pool, glide, and riffle, is difficult because transitions between habitat types are gradual. However, use of consistent methods in separating habitat types by a single observer reduced variability and observer error.

A potential source of error in our methodology might have occurred with misidentifying locations of spawning kokanee (i.e. assigning fish to the wrong habitat type). We limited this error by allowing the same person to conduct all counts during 1993. That person became familiar with transect locations, spawning areas used by kokanee, and a coding system for describing exact locations between transects. A predesignated route was mapped and used for all counts (Objective 1). The route was chosen so the highest, most unobstructed views of the river could be achieved at most points facilitating counting and observing fish. We believe these measures provided accurate counts throughout the kokanee distribution in the NFPR. Study site characteristics probably reduced error of differential efficiency in counting between habitat types. Water depth, water clarity, degree of shading, and instream cover differences might reduce the observer's ability to count fish in pool vs. riffle areas. However, in this study, visibility in pools did not seem to be affected as water clarity was high during most counts and water depths, even in the deepest pools, did not limit the observer's visibility of kokanee spawning in pools.

Microhabitat Availability and Use

Spawning habitat used by kokanee in the NFPR was similar to that previously reported with respect to water depth. We identified a depth range of 30 to 42 cm as optimum for kokanee spawning. Smith (1973) described kokanee spawning sites in three Oregon streams as having minimum water depths of 6 cm. Thompson (1972) reported kokanee redds were placed in 9 to 46 cm of water in several Oregon streams. Parsons and Hubert (1988) reported optimum ranges of 18 to 24 cm for a small (1.6 m^3/s; mean wetted width, 8.4 m) creek and 24 to 37 cm for a large (24 m^3/s; mean wetted width 68 m) river. We also observed high use of depths 18 to 24 cm. Parsons and Hubert (1988) observed kokanee spawning in deeper, higher-velocity water than others and our results corroborate their observation for water depth.

We observed drastically different use of water velocities than that reported by Parsons and Hubert (1988) and other investigators. We observed highest use in velocities 0 to 6 cm/s, while Parsons and Hubert (1988) reported optimum velocities of 67 to 73 cm/s. The difference was probably related to the different availability of water velocities among study sites. Velocities of 0 to 6 cm/s were relatively rare in their study sites, while this range dominated the frequency distribution for the NFPR comprising nearly 32% of all observations. Frequency of 67 to 73 cm/s velocities in the NFPR was relatively rare as < 2% of all observations were observed in this range. Smith (1973) observed kokanee spawning in three Oregon streams and reported redds as having velocities of 15 to 73 cm/s. Thompson (1972) observed mean spawning velocities of 24 to 64 cm/s. Delisle (1962) stated that kokanee would not spawn in velocities > 64 cm/s. Hunter (1973) recommended velocities of 12 to 41

cm/s for spawning kokanee. Other than differences in availability, we can not attribute kokanee spawning at lower velocities than other investigators have reported.

All of the study sites from which data on kokanee spawning have been reported are smaller than the NFPR with the exception of Parsons and Hubert's (1988) Green River study site in Wyoming. Bovee (1986) recommended that study streams for determining habitat preferences of fishes be selected with caution. The ideal situation is a stream containing all conceivable combinations of depth, velocity, substrate, and cover, and thus displays a high degree of habitat diversity. Study sites including the NFPR may not be adequately diverse to determine optimum current velocities. Water depth preferences of spawning kokanee are better understood. The NFPR, as well as the Green River site of Parsons and Hubert (1988), had a wide range of depths from which kokanee could use for spawning, and similar optimum ranges were observed at both sites. Moyle and Baltz (1985) recommended individual instream flow studies should use curves developed on the site or at similar sites. Furthermore, Bovee (1986) stated that because of habitat differences, criteria developed in small streams may not be directly applicable in large streams. Bovee (1982) concluded there is a need for a large, accessible library of curves for application under various stream conditions, a point corroborated by Parsons and Hubert's (1988) comparison of depth curves with Hunter (1973). We believe our data on kokanee spawning offer alternatives to currently available curves and permits application of the IFIM over a wider range of stream conditions than was previously available.

We found no reports of kokanee use and preference of spawning substrate, but Bell (1986) reported anadromous salmon and trout spawning substrate should range from 1.3 to 10.2 cm in diameter. Bjornn and Reiser (1991) summarized spawning substrate size criteria for several salmonids. They stated that use of substrate for spawning is mostly dependent on fish size; larger fish are capable of using larger substrate than are smaller fish. Substrate criteria for the five species of anadromous Pacific salmonids were 1.3 to 10.2 cm, while ranges for rainbow (range=0.6-5.2 cm) and brown (range=0.6-7.6 cm) trout were smaller. Our results for kokanee use of spawning substrate were consistent with that expected based on fish size, as the range of substrates (range=2.6-5.0 cm; large gravel) we observed was within that for similar trout species.

Microhabitat by Habitat Type

The results of microhabitat analysis supported our classification used to partition habitat types for determining habitat availability and use. For example, pools had the highest average depth, the lowest average velocity relative to glides and riffles, and the largest amount of fine sand. Riffles had the lowest average depth, highest average velocity, and the most coarse substrate. Springs were a unique habitat type characterized by significant water upwelling, low velocities, and large amounts of fine sediment. Range in values for habitat variables within habitat types was large and all habitat types overlapped with respect to water depth, velocity, and substrate size. Our classification scheme categorized areas of the NFPR to general habitat conditions and microhabitat data revealed a wide range of conditions.

For example, areas classified as pools contained some shallow, high velocity habitat on the periphery. By random chance, our transect method revealed these features were variable after overlapping.

Spawning habitat relationships of the anadromous form of sockeye salmon have been documented well (Ricker 1966; Foerster 1968; Lorenz and Eiler 1989; Burgner 1991). Applicability of relationships to the smaller, nonanadromous kokanee is questionable due to size differences. However, we observed between habitat characteristics used for spawning by sockeye and kokanee in the NFPR. Burgner (1991) stated that among Pacific salmon, sockeye salmon exhibit an adaptation to a wide variety of spawning habitats. Spring fed areas adjacent to the main channel and side channels are used more extensively by sockeye than by other species (Foerster 1968; Burgner 1991). These habitat types were extensively used by kokanee in the NFPR. Also, composition of spawning substrates differ widely in sockeye salmon spawning areas within the same population (Ricker 1966; Lorenz and Eiler 1989), particularly when spawning areas are associated with spring areas. Lorenz and Eiler (1989) believed presence of upwelling groundwater may have been the most important factor determining redd sites. In spawning areas without upwelling, sockeye salmon spawned in reaches with narrow ranges of velocity, temperature, and substrate composition. Use of substrate and water velocities in the NFPR was also highly variable due to the use of spring upwelling areas. Although upwelling groundwater can be low in dissolved oxygen levels and high in dissolved minerals, factors that can adversely affect salmonid egg-to-fry survival, studies indicate sockeye, and presumably kokanee, are well-adapted for successful incubation in such conditions. Sockeye can incubate at lower (3 mg/l) levels of

oxygen than other salmonids (Semko 1954), and egg-to-fry survival rates can be higher (range=15-75%; Semko 1954) in spawning areas containing groundwater than in other spawning areas (<20% survival; Anonymous 1955). Kokanee spawning in spring areas of the NFPR probably results in egg-to-fry survival as high or higher than survival in nonspring habitats.

Objective 5. To assess the effects of flow alterations on kokanee survival to pre-emergence and the availability of spawning habitat in areas of intensive spawning use.

INTRODUCTION

Flows in the NFPR are controlled by three small reservoirs upstream from kokanee spawning areas. The amount of area available for spawning probably changes with flow fluctuations and effects of variable flows on kokanee incubation success is unknown. The major concern in the NFPR is the relative change in area available for spawning and how much spawning area is dewatered as a result of flow fluctuations. Streamflow regulates the amount of spawning habitat available to salmonids in streams. As discharge increases, the area of usable habitat increases followed by a decline in usable area at higher flows as velocities become excessive for spawning (Hooper 1973). Kokanee incubation success is also a concern in the NFPR if the amount of dewatered spawning area is significant. Kokanee year-class strength and flow conditions were negatively related in the South Fork of the Flathead River, Montana, during an 18-year period (Fraley et al. 1986). During low flow years, redd-dewatering caused high winter incubation mortality. Intragravel freezing of salmonid embryos has been related to reduced flows over redds (Neave 1953; McNeil 1966, 1969; Bakkala 1970; Reiser and Wesche 1977). Exposure to severe conditions was a potential source of kokanee embryo mortality in the NFPR. We investigated changes in available spawning habitat in two principal kokanee spawning areas in the NFPR during 1993.

METHODS

During 1992 and 1993 a staff gauge was maintained in the NFPR throughout the sampling period of July to October. Readings from the gauge were taken daily to determine the relative flow elevation. We measured discharge in the NFPR with the midsection method (Orth 1983) nine times over the observed range of flows to develop a rating curve between river stage and flow. Data were analyzed using linear regression techniques. A predictive equation was developed to construct the hydrograph for sampling periods during 1992 and 1993.

Five separate surveys were made during 1993 at 51 transects in two principal kokanee spawning areas to determine changes in area of spawning at different flows. Transects established for Objective 4 were used to determine areas at different flows. Areas were determined with the GIS database (Objective 4). During each survey, two observers walked to each transect and measured total wetted stream width with a meter tape. We plotted total area of wetted stream against flow to determine a relationship between the amount of spawning habitat available and flow. The two kokanee spawning areas selected for this analysis were located in Areas 4 and 6 (Figure 22) and represented principal kokanee spawning sites (Figures 60 and 61). The chosen areas were used so intensively, kokanee were observed constructing redds in shallow water in the extreme margins of wetted area. Water velocities did not appear to be excessive for kokanee spawning at any location.

During March 1993, we estimated incubation success in spawning areas of the NFPR that had been dewatered in 1992. During October 1992, we marked areas so we could locate these dewatered areas in March 1993. We were unable to sample dewatered areas for survival in 1994 due to

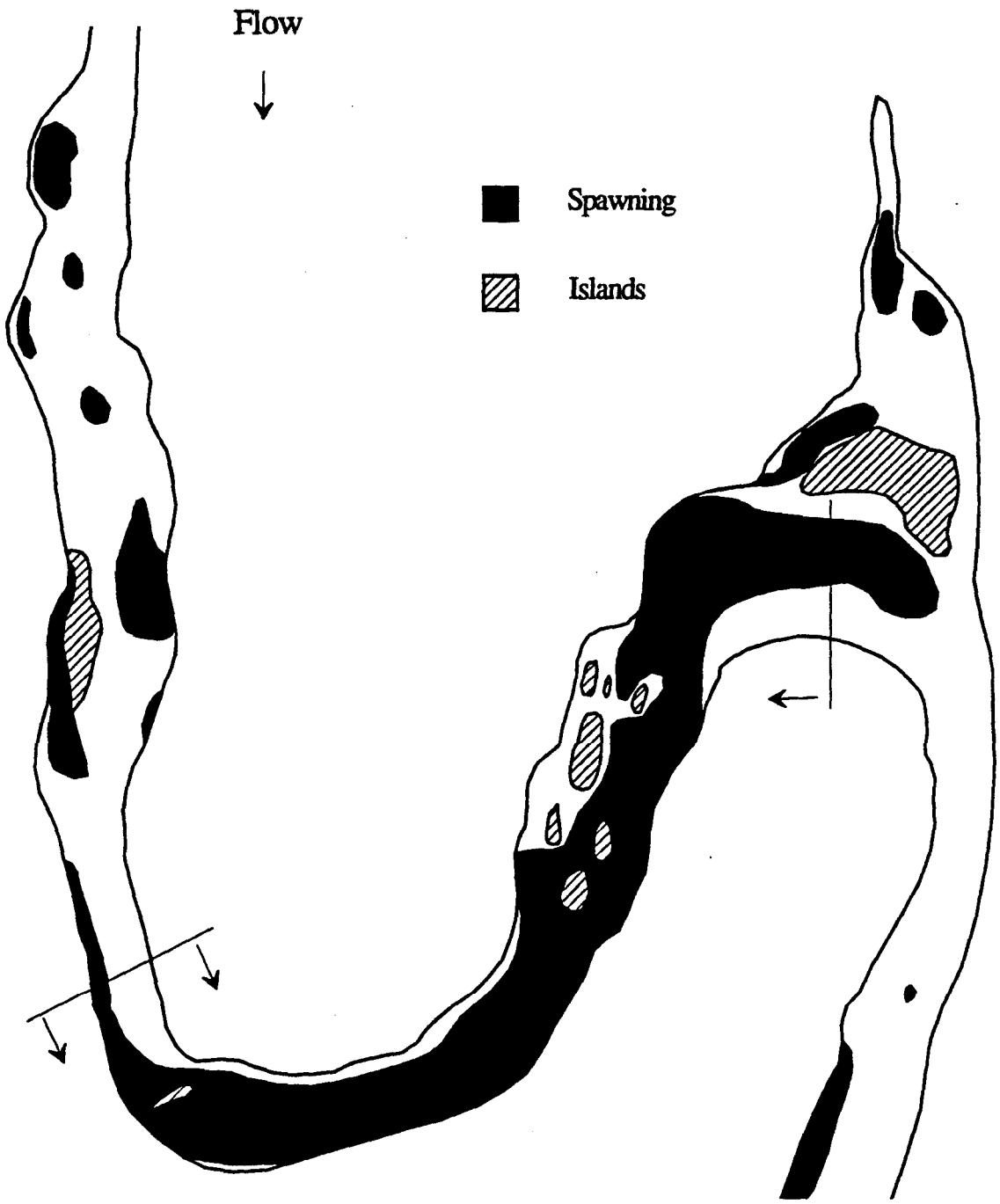

Figure 60. Boundary of the study site in Area 4 of the North Fork of the Payette River, Idaho used to determine relationship between spawning habitat availability and river flow (m^3/s).

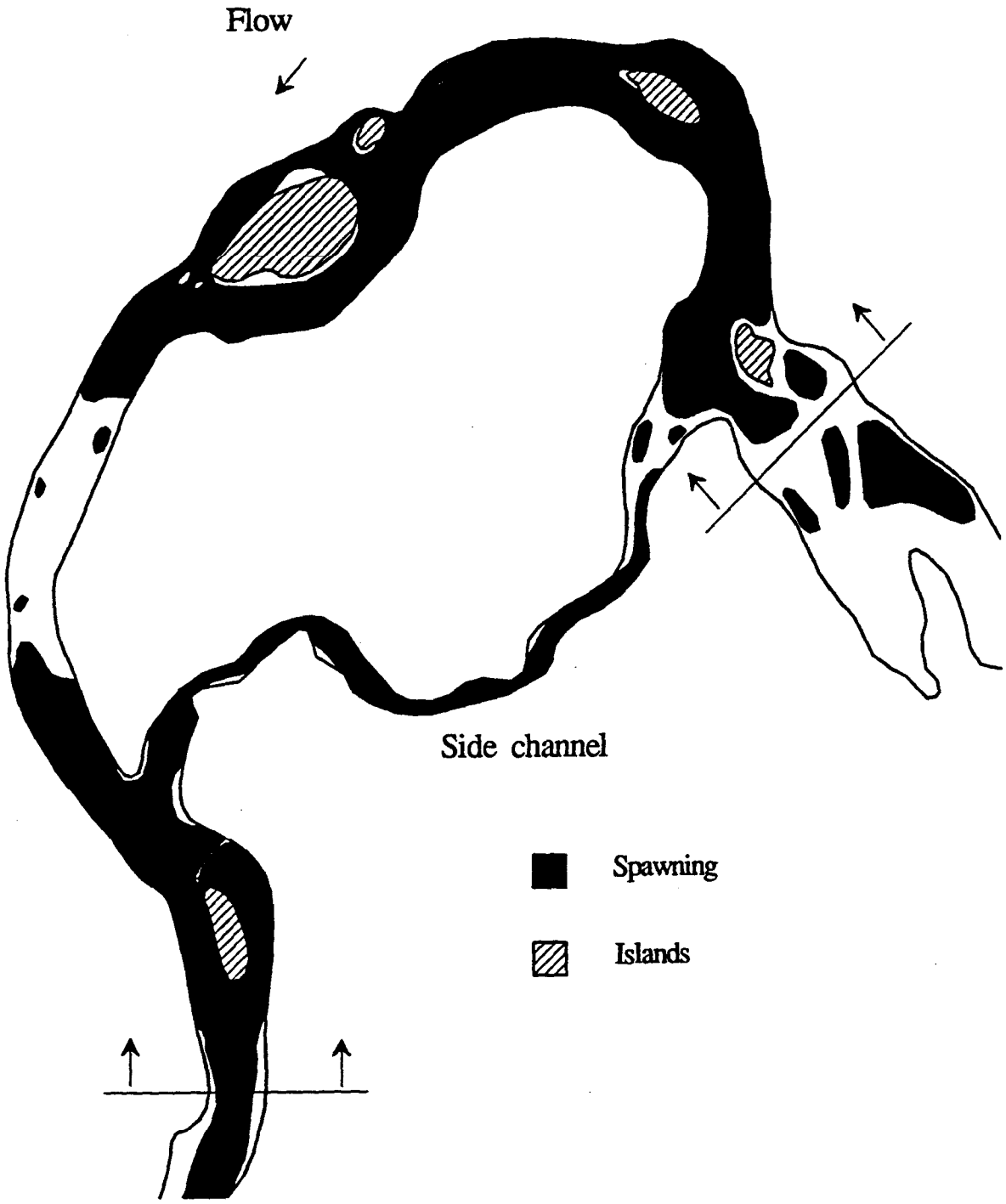

Figure 61. Boundary of the study site in Area 6 of the North Fork of the Payette River, Idaho used to determine relationship between spawning habitat availability and river flow (m^3/s).

extensive ice and snow cover in the marked areas. We estimated incubation success in dewatered areas to the pre-emergent stage using the hydraulic sampling method (Objective 3).

RESULTS

The predictive equation between river stage and flow in the NFPR was log(Y)=2.99 log(X)-3.85 where Y is discharge (m^3/s) and X is river stage (cm). We used the equation to construct a hydrograph for sampling periods in 1992 and 1993 (Figure 62). Flows in the NFPR were lower in fall 1992 than 1993. During kokanee migration in 1992 and 1993, peak flow was 29 and 41 m^3/s, respectively. Base-flow was similar at about 4 m^3/s for both years.

Survival to pre-emergence in dewatered redds was 66.1% (SD=44.8%; n=5) compared to survival in areas of the NFPR not dewatered at 64.5% (SD=37.0%; n=95).

Habitat available to kokanee in two principal spawning areas in the NFPR increased rapidly between baseflow and approximately 10 m^3/s (Figure 63). The amount of available area increased slightly at discharges > 12 m^3/s. Differences in area of spawning habitat was 1,790 m^2 and 1,690 m^2 in Area 4 (Figure 60) and Area 6 (Figure 61), respectively, between base and peak flows. These values were 26 and 24% of maximum spawning area available in Areas 4 and 6, respectively.

DISCUSSION

Overall flows were lower in 1992 due to a lower than normal snowpack in winter 1991/1992 and low summer precipitation. The snowpack was higher in 1993 than 1992 and summer precipitation continued until

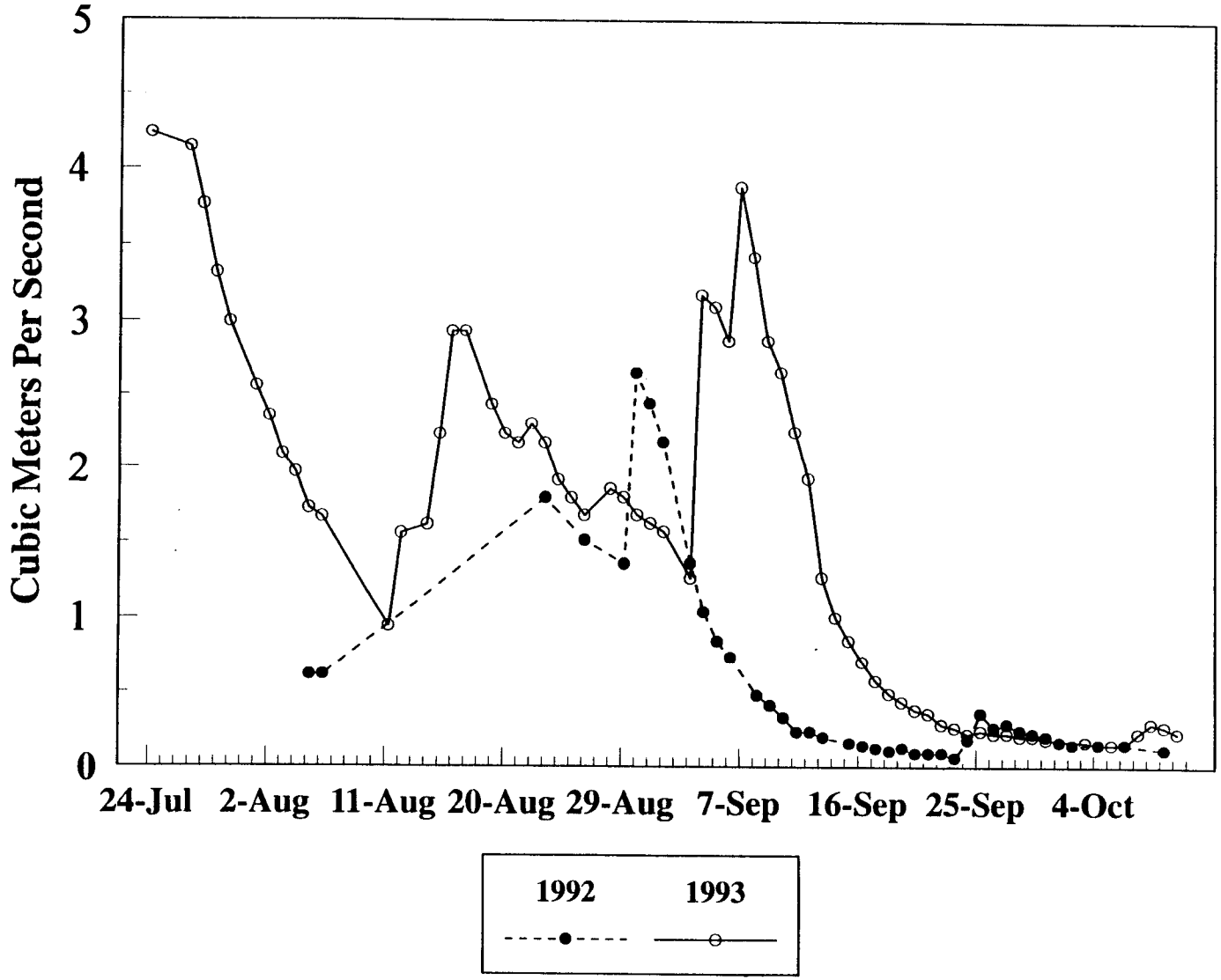

Figure 62. Estimated flows (m^3/s) during the 1992 and 1993 sampling seasons in the North Fork of the Payette River, Idaho.

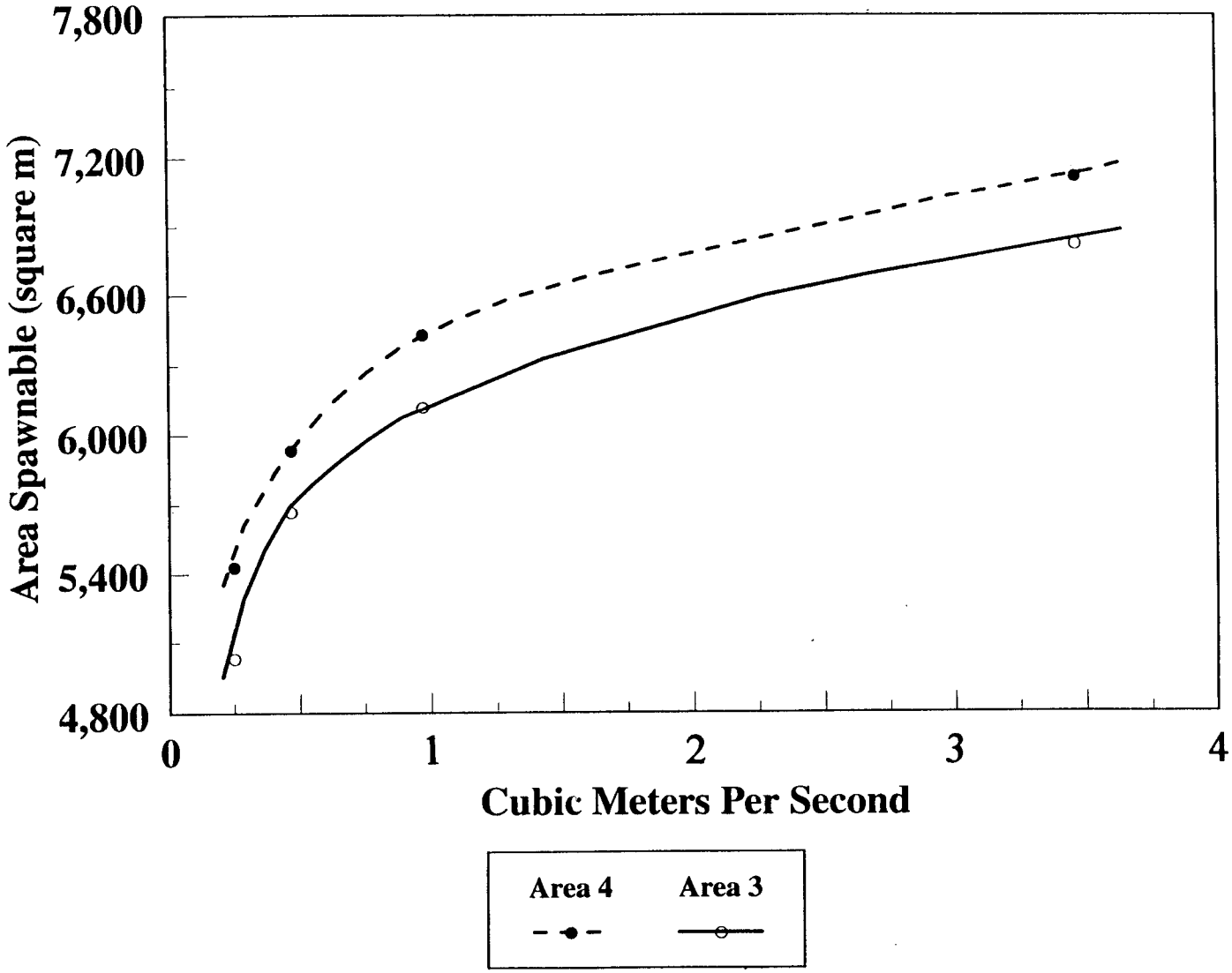

Figure 63. Amount of spawnable area (m^2) in relation to river flow in two principal kokanee spawning areas in the North Fork of the Payette River, Idaho.

the end of July. The increase in flow in mid-August 1993 was a result of a rainy period and release of water from Granite Lake in upstream Fisher Creek. Water was released from Upper Payette Lake during kokanee migration on 4 September and 7 September 1993 (H. Bivons, Lake Reservoir Irrigation District, McCall, Idaho, personal communication) as compared to 30 August 1992, about a week earlier than in 1993. Water releases from these lakes show as distinct peaks on the hydrograph.

Upstream reservoirs range in volume from 39.5 to 79.3 m^3 and affect flows for a short period in the NFPR usually during the kokanee spawning migration. Flows recede to base-flow within about 2 weeks when the reservoirs are evacuated. Base flow was similar during both years which is surprising considering the differences in snowpack and summer precipitation.

Survival in dewatered redds was similar to survival in areas that were watered throughout the incubation period. Survival estimates from dewatered areas were more variable and some dewatered areas could not be sampled with the hydraulic sampler because they remained dewatered. When redds were uncovered by hand, however, we found living alevins and fry in many redds that remained moist but dewatered. Based on our data, kokanee are able to survive dewatering in the NFPR. Fraley et al. (1986) found dam operations caused high incubation mortality by dewatering spawning areas, however, abnormal flow fluctuations in the NFPR like those observed in 1992 and 1993 may not be adversely affecting kokanee fry production. Subsurface flow, periodic rain events, and early snow cover probably helped alleviate embryo/alevin mortality with surface dewatering.

The kokanee spawning migration into the NFPR was stimulated by the unnatural flow increases associated with evacuation of upstream reservoirs. Numbers of kokanee counted in the adult trap increased rapidly during and after peak flows. Spawning and egg deposition, therefore, occurs during decreasing flows and decreasing availability of spawning habitat. We did not observe significant numbers of redds being dewatered in the NFPR. While egg deposition and decreasing flows occur closely in time, spawning site selection and egg deposition generally follows peak flows that lessens dewatering of redds. Flows recede rather quickly to levels where availability of spawning habitat changes little.

We believe current upstream dam operations do not negatively affect availability of spawning habitat or kokanee spawning success in the NFPR. Numbers of dewatered redds were uncommon and those sampled revealed kokanee embryos were tolerant of surface dewatering. Chapman et al. (1986) used egg retention in female chinook salmon to evaluate potential effects of operating Priest Rapids Dam on spawning success in the Columbia River, Washington. Flows varied daily and portions of the spawning area were exposed for several hours each day. Egg retention was low and investigators concluded spawning success was high. Egg retention in kokanee from the NFPR during 1992 and 1993 (Objective 1) also was low and we concluded spawning success was high during both years.

Objective 6. To describe the potential for rehabilitating kokanee spawning habitat in the North Fork of the Payette River with the objective of increasing fry production.

INTRODUCTION

Habitat rehabilitation projects are conducted to enhance a fish population. The initial step of habitat rehabilitation is to identify the factor(s) limiting a population. Once identified, a rehabilitation project aims to alleviate the limiting factor and allow the population to increase. The condition of spawning habitat is often identified as a limiting factor for salmonids (Shepherd 1990). Idaho Fish and Game biologists identified the quantity and quality of spawning habitat in the NFPR as a probable limiting factor for the population. Fish habitat in the NFPR has been degraded by an accumulation of fine sediment as a result of forest management practices in the watershed (U.S. Forest Service 1991). During this phase of the study, we operated under the assumption that spawning habitat was a limiting factor and explored ways to create additional kokanee spawning habitat to increase fry production.

METHODS

Substrate Scarification

We observed high survival to pre-emergence in most kokanee spawning areas during 1993 in the NFPR (Objective 3). Therefore, we focused primarily on creating additional spawning habitat in stream reaches currently not being used for spawning. Six sites were selected in the main channel of the NFPR. Five sites were located in reaches unsuitable for kokanee spawning; one test plot (plot 3) was located in

an area used by kokanee in 1992, although survival to pre-emergence was generally low (50.1%).

A local contractor was hired to scarify the armored layer by repeatedly raking the top 20 cm with the bucket of a four-wheel-drive backhoe. Time required to treat each plot was approximately 10 to 15 minutes. Each plot ranged in size from 55.5 to 80.4 m^2 and was marked with rebar and flagging tape. Use of each plot was determined throughout the 1993 spawning run by counting spawners during foot surveys (Objective 1).

Survival to pre-emergence (Objective 3) in 1993 and 1994 at plot 3 was compared to determine if treatment of poor quality sites might increase survival. Survivals were transformed by aresine-square root and compared with a t-test.

All stream reaches in the NFPR that could potentially become spawning habitat with the prescribed treatment were identified and total area of potential habitat was determined with GIS. Criteria considered to qualify an area as potential habitat were accessibility to heavy machinery, water depths less than maximum tolerated by machinery (approximately 50 cm), armored substrate of size usable by kokanee (6-50 mm), and area not used by adult kokanee for spawning in 1992.

Boulder Placement

We investigated the use of individual boulders placed in midchannel as a means of "naturally" creating spawning habitat for kokanee. Several natural examples existed in the NFPR in high gradient reaches above the confluence of Fisher Creek, but the occurrence of large boulders is more accessible, downstream reaches was low. Also,

partially submerged root wad obstructions provided limited suitable spawning habitat in the NFPR. Obstructions in streams provide salmonid spawning habitat by causing scour around and downstream of each object during high flows followed by deposition of substrate suitable for spawning.

We attempted to mimic these conditions with boulders to encourage deposition of spawning gravels. Addition of large boulders to bedrock substrate in a coastal Oregon stream increased gravels by 27% (House and Boehne 1985). We placed six large (40-80 cm dia) boulders in selected reaches of the NFPR during August 1991. Kokanee use of each boulder was evaluated during the spawning run in September 1994, the time of first possible use after one spring of high flow conditions necessary to scour and deposit substrate behind each structure.

Potential Fry Production

We calculated the potential fry production that could result from the proposed habitat rehabilitation at all identified sites. Expected intensity of use was determined from the observed use of habitat plots during the spawning run in 1993. Expected egg deposition was calculated from female fecundity and sex ratio data of the 1993 run (Objective 1). Survival of embryos to pre-emergence was assessed in March 1994 with a hydraulic sampler (Objective 3). Because plots 1, 2, and 4 in Area 5 differed from plots 5 and 6 in Area 8, calculations of potential fry production were made separately for each area. Sites in Area 8 consisted of small substrate with high fine material. We estimated potential fry production from boulders by assuming each boulder will

provide a maximum of three redds based on observations at naturally positioned boulders in the NFPR.

RESULTS

Substrate Scarification

Habitat plots of treated substrate and potential habitat areas were located in Area 5 (Figure 64) and Area 8 (Figure 65). Dominant substrate within habitat plots consisted of small gravel (>6-26 mm), large gravel (>26-50 mm), and cobble (>50-150 mm; Table 25). Kokanee used each treated plot in 1993 and use in each reach was exclusive to the treated plot. Use by adult kokanee occurred throughout the spawning run. Peak counts were observed on 20 September at plots 1 through 4 and 29 September at plots 5 and 6.

Survival of embryos naturally deposited in 1992 at site 3 (Figure 64) was 50.1% (n=3) while survival of embryos naturally deposited in 1993 after treatment was 99.0% (n=3). Survival between years was not significantly different (P=0.120).

Boulder Placement

Boulders were placed in river reaches in Area 2 (Figure 66) and Area 5 (Figure 64). Five of the boulders provided spawning habitat for kokanee during the 1994 spawning run after one spring of high flow. Boulders 1, 3, 4, and 6 had at least one kokanee pair (one redd) spawning on the downstream side in a substrate mixture of coarse sand (>3-6 mm) and small gravel (>6-26 mm). Boulder 5 had two redds on the downstream side of similar sized substrate. Boulder 2, the smallest

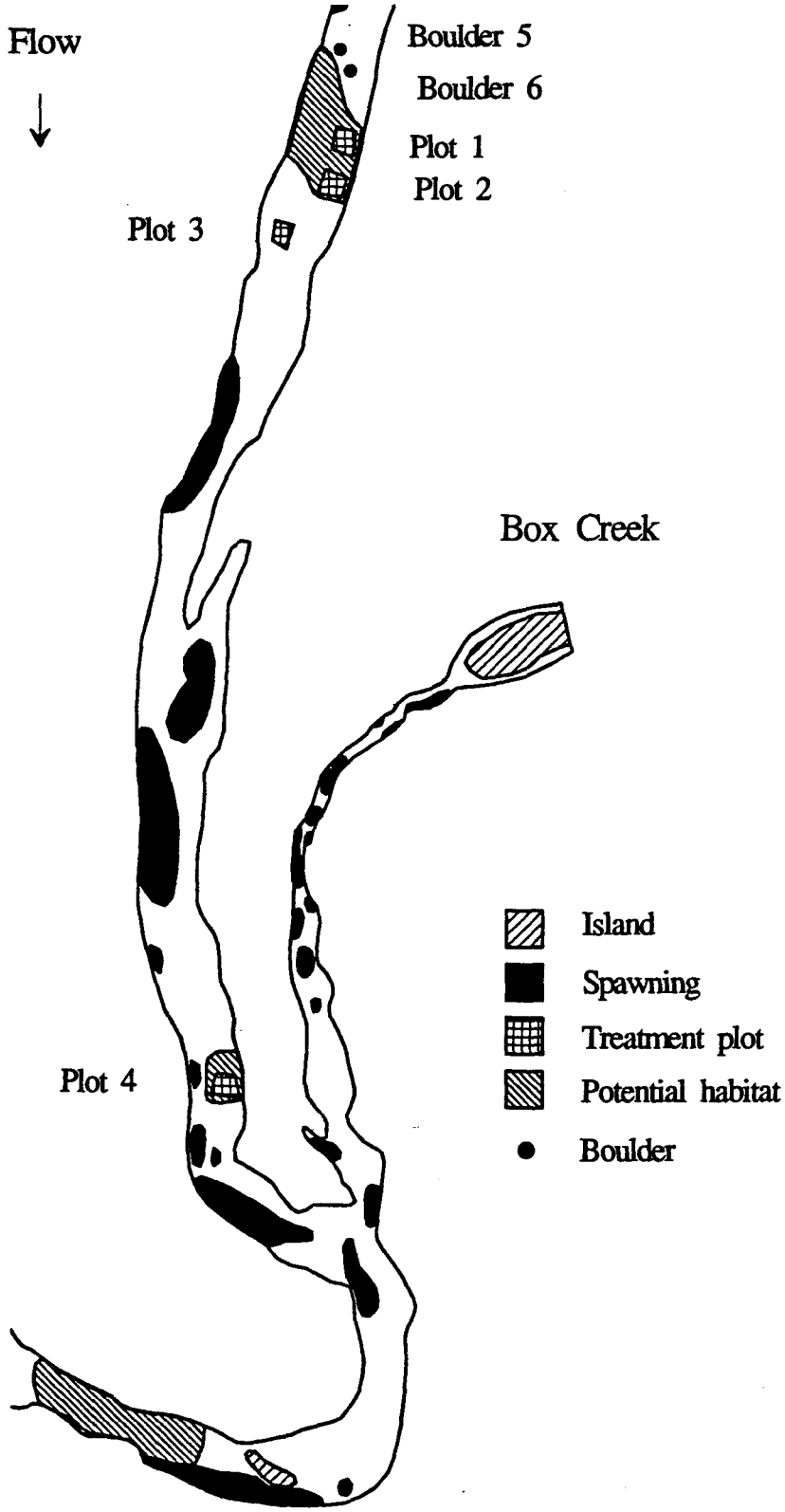

Figure 64. Habitat rehabilitation treatment plots, potential habitat, and location of experimental boulders 5 and 6 in Area 5 of the North Fork of the Payette River, Idaho.

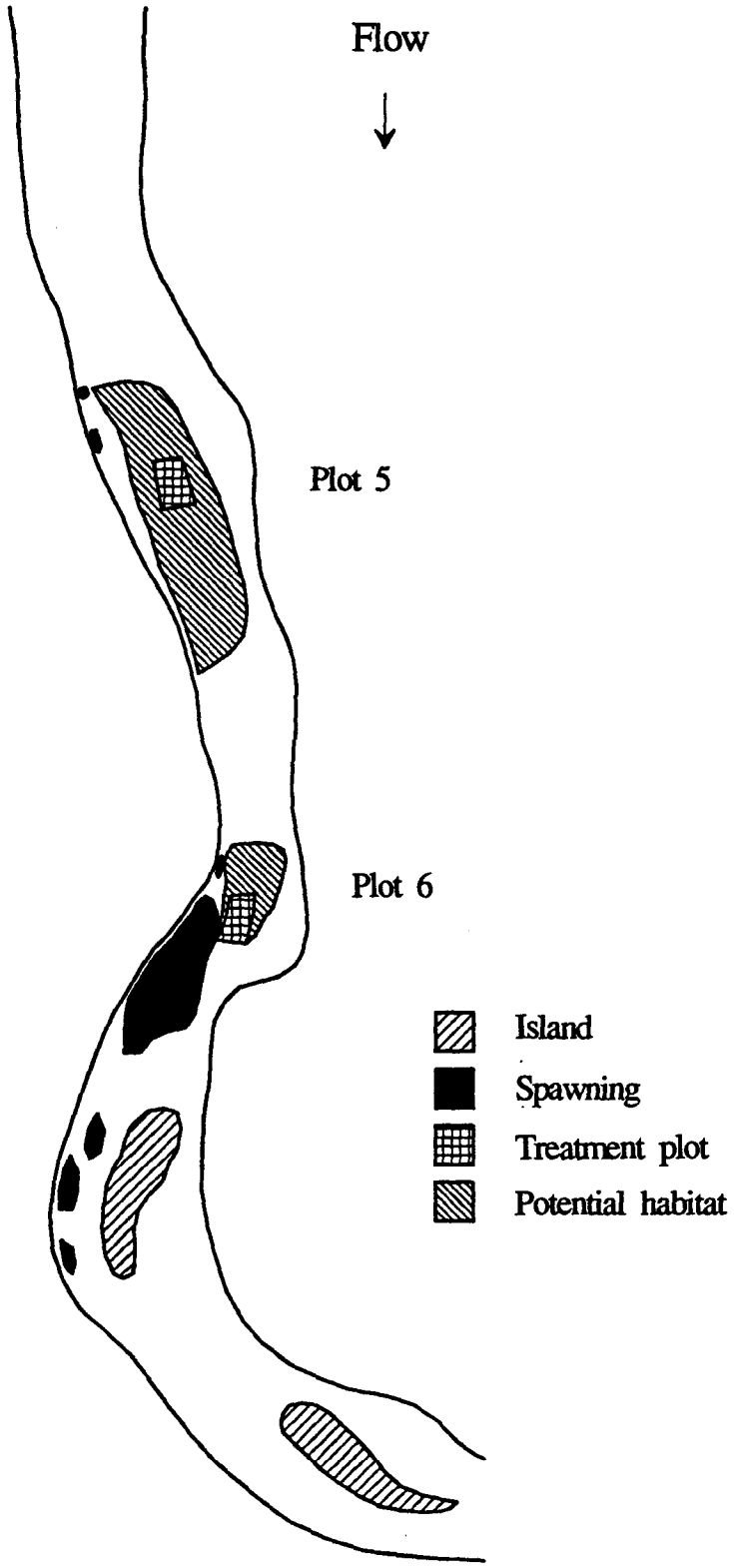

Figure 65. Habitat rehabilitation treatment plots and potential habitat in Area 8 of the North Fork of the Payette River, Idaho.

Table 25. Area (m^2), dominant substrate, and peak spawner count in 1993 for treated habitat plots in the North Fork of the Payette River, Idaho.

Plot #	Area m^2	Dominant Substrate	Number of Spawners
1	72.3	cobble	28 (20 Sept)
2	80.4	cobble	64 (20 Sept)
3	55.5	cobble	33 (20 Sept)
4	73.6	cobble	13 (20 Sept)
5	76.3	large gravel	24 (29 Sept)
6	64.8	small gravel	9 (29 Sept)

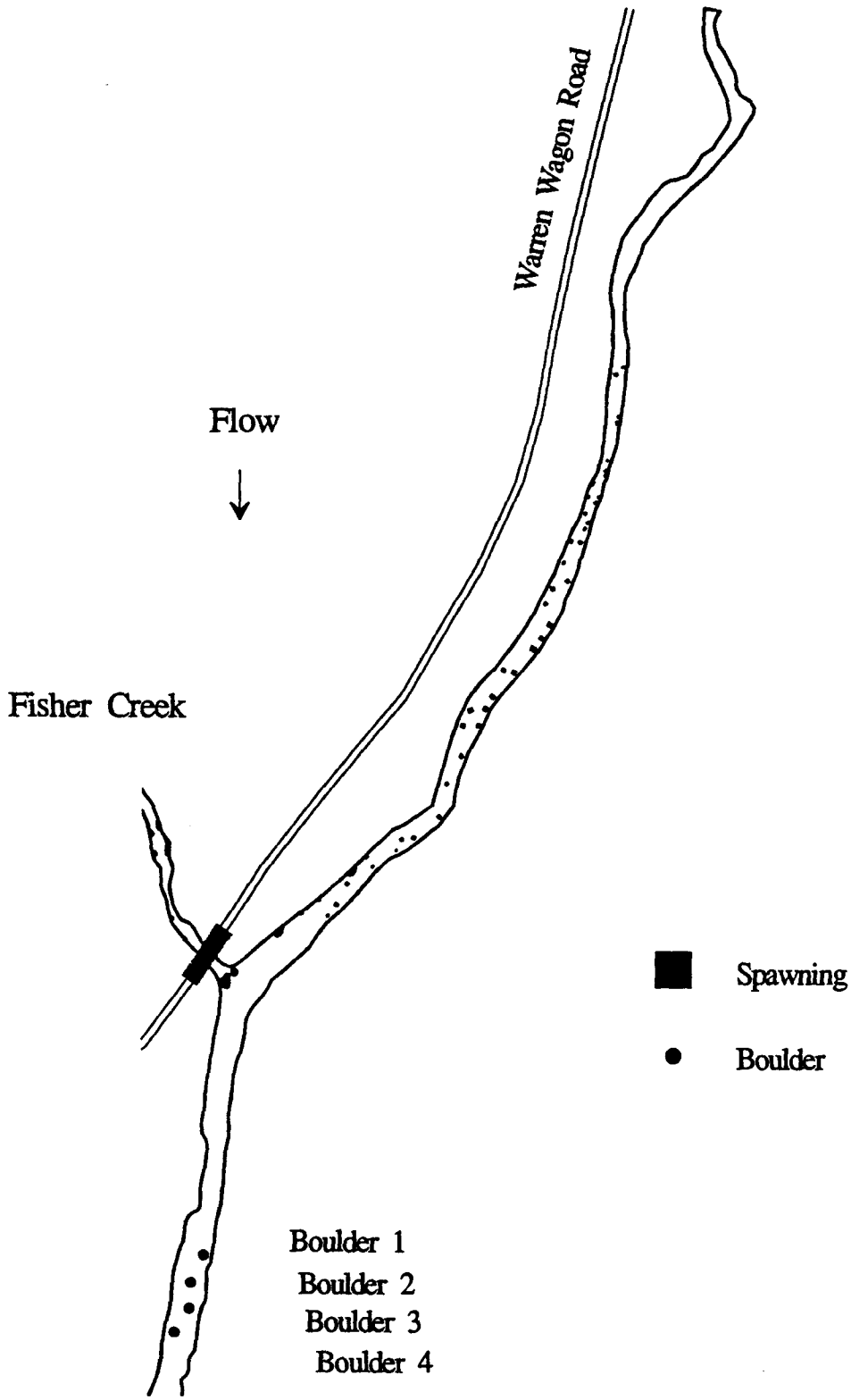

Figure 66. Location of experimental boulders 1 - 4 in Area 2 of the North Fork of the Payette River, Idaho.

(ca. 40 cm dia) and the only structure not used, accumulated small amounts of coarse sand.

Potential Fry Production

We observed successful incubation in all plots of scarified substrate and survival was generally high. Overall survival averaged 84.8% (0-100%) and was highest at plots located in Area 8 (100%; Table 26). Estimated fry production from substrate scarification was 338,420 kokanee. Most of the anticipated production (74%) would come from sites in Area 5 the location of most favorable for rehabilitation (64.5%; Figure 64).

Expected fry production from placement of 30 boulders was minor compared to that anticipated from substrate scarification. Assuming survival at 64.5% (1993 data, Objective 3), we estimated 36,300 fry would be expected at maximum use of all boulders.

DISCUSSION

Substrate Scarification

Any effort to rehabilitate or enhance spawning habitat with the objective of increasing fish production should be preceded by an inventory of existing spawning and incubation conditions and limiting factors (House and Boehne 1985). Our analyses of egg-to-fry survival (Objectives 1 and 2), pre-emergent survival (Objective 3), and spawning distribution and habitat use (Objective 4) suggest additional spawning habitat and fry production in the NFPR is not necessary at the present time. Therefore, we recommend delaying the described treatments until needed for enhanced recruitment. Periodic monitoring of habitat

Table 26. Estimated fry production expected as a result of spawning habitat rehabilitation (substrate scarification) in the North Fork of the Payette River, Idaho.

	Area 5	Area 8
	Plots 1, 2, and 4	Plots 5 and 6
Plot Area (m^2)	226.3	141.1
Total Area (m^2)	2,261.8	1,242.8
Expected Density ($\#/m^2$)[a]	0.464	0.234
Survival %[b]	80.7 (n=16)	100 (n=3)
Expected Fry Production[c]	251,900	86,600
Total	338,500	

[a] peak spawner counts summed and multiplied by 1.73 (expansion factor, Objective 1) to estimate total use.
[b] to preemergence as determined with hydraulic sampler (Objective 3).
c calculated using male to female ratio 1.1:1 and mean fecundity 625 ova.

quality, pre-emergent survival, or fry production in the NFPR would provide data that suggest when spawning habitat improvement should be done. Protection of aquatic riverine habitat from additional sedimentation in the NFPR is the best alternative for avoiding future habitat quality problems.

We identified a successful method of creating spawning habitat by scarifying substrate previously unsuitable for kokanee spawning in the NFPR. We are unaware of studies or practices using such a method for creating salmonid spawning habitat. Our data also indicate possible increased recruitment from treating sites currently used for spawning where incubation success is low. However, during this study such sites were relatively rare in the NPFR (Objective 3).

We initially predicted annual treatment would be necessary to remove armoring and fines. However, a cursory assessment during the spawning run in 1994 indicated that use of plots 1 through 4 was at least as high as in 1993. Use of plots 5 and 6 in Area 8 was less, as only one redd was observed at plot 6 and two redds were observed at plot 5. Differences between areas were probably determined by substrate and channel characteristics. Dominant substrata of plots 5 and 6 were smaller than those in plots of Area 5. Potential spawning habitat in Area 8 is directly downstream of a long, straight reach of fine and coarse sand, a condition that likely resulted in substrate movement during high flows and refilling of interstitial spaces at treated sites. These factors will dictate the need for annual treatment of potential habitat in Area 8.

Additional benefits of our method of substrate treatment were low cost and ease of operation. Other alternatives for rehabilitating and

creating salmonid spawning habitat have been successful, but are somewhat expensive and difficult to maintain. House and Boehne (1985) constructed gabion weirs and installed log sills and boulder groupings to enhance fish habitat in East Fork Lobster Creek, Oregon. Numbers coho salmon and steelhead spawning increased substantially with numbers of rearing young. House and Boehne (1985) reported four to six person crews and anticipated costs of $1,200 (U.S.) per gabion structure. Spawning channels have been used successfully to produce sockeye salmon fry in British Columbia (McDonald and Hume 1984), however, project costs are usually high (West and Mason 1987). Total cost of substrate scarification and boulder placement was $460 (U.S.) in 1993, and projected cost for completing all proposed treatment was estimated $2,667 (U.S.), or about the same cost of two gabions.

Boulder Placement

House and Boehne (1985) used boulder groupings as part of the successful rehabilitation and enhancement of salmonid habitat in East Fork Lobster Creek, Oregon. They used large boulders (>60 cm) individually as well as in clusters and in conjunction with gabions and log sills. All but one boulder remained in place. All six boulders we placed in the NFPR remained after one spring flow period, although peak flows in 1994 in the NFPR were lower than normal due to below normal snowpack. During years of normal or above normal runoff, boulders may not remain stationary, however, high flows are necessary to encourage gravel recruitment around each structure. We recommend using boulders ≥ 60 cm.

Based on our observations in the NFPR, maximum spawning use associated with each boulder is three redds. An alternative to boulders might be large woody debris in the form of root wads. We observed root wads that provided excellent spawning habitat for kokanee. Roots were firmly anchored in the substrate and the structures encouraged deposition of spawning gravels and provided substantial cover in shallow water. These structures provided substantially more area for spawning than boulders, as we counted up to 30 redds directly behind one root wad structure. However, only four root wads were located within the kokanee spawning distribution in the NFPR. Their use in the future, in addition to boulders, could be considered.

Potential Fry Production

Cost-benefit analysis of rehabilitation efforts should be an important part of preproject planning. We calculated expected benefits, in terms of fry production, of a well-defined plan for creating kokanee spawning habitat in the NFPR. Our results were based on observed use of habitat plots by adult kokanee and observed survival to the pre-emergent fry stage at all treatment areas. Kokanee escapements into the NFPR in 1992 and 1993 were considerably higher than recent years (Objective 1), and fry production from those broods were probably higher (Objective 2). In light of this, the total potential benefit of our proposed habitat rehabilitation remained somewhat significant. Total potential fry production expected from substrate scarification and use of boulders was 15.0% and 8.3% of fry recruitment in 1993 and 1994, respectively. Benefit of substrate scarification outweighed that of boulder placement as potential fry production due to substrate treatment alone was 13.5%

and 7.5% of fry recruitment from the 1992 and 1993 kokanee broods, respectively.

Actual overall benefits of rehabilitation could be higher especially during years of high spawner escapements in the form of reduced egg mortality, if the spawners using the treated areas would have contributed to redd superimposition in areas of high spawner densities. We did observe some signs of redd superimposition particularly in 1994 when escapement was high. Significant accumulations of eggs were located in slack-water areas that were probably dislodged by the second "wave" of spawners using areas saturated by spawners only 2 weeks earlier. The actual benefit of habitat rehabilitation may be higher than calculated, if each female kokanee in the second "wave" of spawners destroyed an entire redd of a previous spawner.

Our methods of creating and improving spawning habitat in the NFPR might be improved and the benefits of treatment could be increased with identification of more potential sites. Additional sites could become available for substrate treatment if access problems for heavy machinery were overcome. We identified sites as potential habitat only if banks were stable or if access by stream crossings and subsequent travel by streambed was suitable and not likely to cause significant damage. Additionally, spawner densities might be increased substantially at the sites we identified for substrate treatment by removing channel armoring, boulder and cobble substrate (>50 mm), to encourage natural recruitment of gravel as House and Boehne (1986) suggested. We feel such actions would increase densities, particularly in Area 5 reaches, because at most plots use was restricted to patches of gravel while

significant area was still dominated by unsuitable cobble substrate. Natural gravel recruitment would probably fill the void of displaced armoring material.

GENERAL DISCUSSION

The principal justification for conducting this project was that recruitment to Payette Lake was limiting the sports fishery. Our findings indicate the last 2 years had high levels of kokanee escapement, successful spawning, incubation and downstream fry migration to the lake. Habitat conditions in the North Fork of the Payette River are better than hypothesized. Survival to the emigrant fry stage for the 1992 and 1993 brood years was higher than most systems reported in the literature for kokanee and sockeye salmon populations in the Western United States, Canada, and Alaska. Egg retention in females, one indicator of spawning success, was low even at high escapements (>30,000 spawners) in the North Fork of the Payette River.

Stocking of hatchery reared kokanee fry in Payette Lake has not improved the kokanee sport fishery in Payette Lake. We collected small numbers of hatchery-reared adult kokanee in a trap during 1993. The low returns suggest discontinuing hatchery stocking of kokanee in Payette lake.

The emigration period of kokanee fry from the North Fork of the Paytette River to Payette Lake occurs from late March through June. Peak seasonal migration occurred during the normal peak discharge (early June) in the North Forth of the Payette River.

Temperature differences between years affect the timing of migration and the degree of development of the fry. Thermal units accumulated by the 1992 cohort was higher than the 1993 brood, primarily a result of later spawning in 1993. Kokanee alevins and sac fry may not have been developmentally ready to migrate as flows increased in April and May 1994. Percentage of sac fry migrating in 1994 was nearly 50% of

some nightly catches. Assuming alevins migrate into the lake, survival of alevin kokanee may be lower during initial lake residence than fry with near complete absorption of their yolk sac. We are unsure of why spawning time differed between years, but variable timing may have significant consequences for fry survival.

Habitat in a few principal spawning areas of the North Fork of the Payette River was generally similar to that described in the literature for sockeye salmon. Sockeye salmon show the widest range of adaptations to spawning habitat among Pacific salmonids as spawning adults will use beach shoals, headwater rivers, rivers between lakes, spring-fed ponds and creeks, side channels, and lake outlet rivers. Substrate used for spawning in these habitats is also variable. Habitat used by kokanee in the North Fork of the Payette River demonstrated similar diversity; spawning was observed in main channel areas, steep gradient headwater reaches, side channels, and springs with upwelling ground water. About the only difference in habitat that we observed in the North Fork of the Payette River was kokanee spawning in lower velocity areas.

Although silvicultural activities have been extensive in the North Fork of the Payette River watershed, kokanee embryo and fry survival based on our 2 year study seems adequate to populate Payette Lake. As indicated, sockeye salmon exhibit the widest range of habitat conditions of all Pacific salmon. The relatively high survival we observed could reflect the species adaptations to smaller substrates. The mechanism is unclear, but mass cleaning in small areas by large concentrations of spawners could be producing high quality habitat followed by stable flows in the North Fork of the Payette River during incubation with little deposition of fines. Rain-on-snow events are potentially

dangerous to incubating salmonid embryos and larvae but are uncommon in the region. We believe the availability of a small number of high quality spawning sites in the North Fork of the Payette River is adequate to produce kokanee fry at the level necessary to fully seed available habitat in Payette Lake. However, further degradation of spawning habitat by land-use activities in the watershed could occur and adversely affect kokanee production to the lake.

Another concern in the North Fork Payette drainage was fluctuating flows from the three small upstream reservoirs. Reservoir evacuation in August and September increased flows duing kokanee spawning. Water releases did not strand significant numbers of redds and survival in dewatered and fully innundated redds was similar. Operation of reservoirs in 1992 and 1993 did not significantly impact kokanee and, therefore, we recommend future operation not depart from that observed in these years. In particular, reservoir evacuation should occur over an extended period of time and not be limited to short releases of large amounts of water and should be completed by the end of the first week in September.

We were successful in creating kokanee spawning habitat in the North Fork of the Payette River using substrate scarification and boulder placement in areas unsuitable for spawning. Potential fry production estimates indicate significant numbers of fry could be produced from improved habitat. At current levels of survival and seeding to the lake, additional spawning habitat is currently not necessary in the North Fork of the Payette River.

SUMMARY

1. Kokanee spawning escapements were significantly higher in 1992 and 1993 than in the previous 4 years. Estimated escapement was 31,920 and 59,310 in 1992 and 1993, respectively. Potential egg deposition was 13.3 million (95% bound +/- 0.462 x 10^6) and 18.6 million (95% bound +/- 0.712 x 10^6) in 1992 and 1993, respectively.

2. Egg retention in kokanee, an accepted indicator of spawning success in the literature, was low during both years (n=377). A majority of females observed in all age classes in both years contained zero unvoided eggs; in 1992 and 1993, 94% and 97% of females, respectively, retained 20 eggs or less.

3. Age 4 kokanee dominated the 1992 and 1993 kokanee spawning runs into the North Fork of the Payette River. Spawners of similar age and sex were smaller in 1993 than in 1992 coinciding with the larger run in 1993, possibly an indication of higher lake densities.

4. Mean egg to pre-emergent fry survival in 1993 was 66.6% (SD=37.1%; n=95) compared to 72.4% (SD=33.6%; n=95) in 1994. Kokanee fry recruitment to Payette Lake was estimated at 2.51 million (95% bound +/- 0.491 x 10^6) and 4.53 million (95% bound +/- 1.16 x 10^6) for the 1992 and 1993 brood years, respectively. Egg-to-fry survival was 18.9% (95% bound +/- 3.2%) for the 1992 cohorts and 24.4% (95% bound +/- 6.3%) for the 1993 brood years.

5. Kokanee spawning distribution in the North Fork of the Payette River encompassed the total river area of 153,402 m^2. Pool habitat was the most abundant (40.4%) followed by glide (34.9%), riffle (18.5%), slough (4.33%), and spring (1.90%). Riffles were the most abundant habitat in upstream reaches, glides were most abundant in mid-section, and pools were most abundant at the downstream limits of kokanee spawning distribution.

6. Sixty-eight percent of spawning kokanee were counted in Areas 4, 5, 6, and 7, midsection reaches of the study area. Habitat use by spawning fish differed significantly from that expected based on availability (X^2=13,930; $p<0.001$). Glide, riffle, and spring habitats were selected while pools and slough habitat were not based on availability.

7. Mean depth at spawning locations was 41 cm (range=3-159 cm; n=1,051) and mean velocity was 28 cm/s (range=0-130; n=1,051). The highest probability of spawning occurred at depths of 30 to 42 cm, velocities of 0 to 6 cm/s, and in substrate dominated by large gravel (>26-50 mm). Spawning habitat criteria determined for kokanee in this study were similar to that previously reported for water depths but velocity was lower.

8. Kokanee selected spawning sites in the North Fork of the Payette River that differed widely in substrate composition, similar to observations for sockeye salmon. Average geometric mean particle diameter ranged from 4.8 to 13.5 mm in spawning locations while average percent fines in spawning locations ranged from 14.0 to 34.1% (by

weight) for particles < 3.35 mm and 5.4 to 23.1% for particles < 0.833 mm.

9. Flow fluctuations in the North Fork of the Payette River as a result of upstream reservoir evacuations occurred for short time periods and were timed with initial kokanee migration and spawning activity. Altered flows did not result in a significant number of dewatered redds. Survival to pre-emergence in dewatered redds (mean=66.1%; SD=44.8%; n=5) was similar to that in areas not dewatered (mean=66.6%; SD=37.1%; n=95). The timing of water releases and relatively small volume probably serve to limit negative impacts to kokanee reproduction and incubation success in the North Fork of the Payette River.

10. Substrate scarification and placement of large (40-80 cm dia) boulders had the potential to increase recruitment by 338,500 fry, or about 15% of the 1992 kokanee cohort. Embryo survival and fry recruitment is deemed adequate to fully seed Payette Lake.

REFERENCES

Acara, A.H. and H.D. Smith. 1971. A technique for enumerating kokanee salmon (Oncorhvncus nerka) fry emigrating through streams, with an appendix for processing catch data by IBM 360 Fortran IV computer programs. Journal of the Fisheries Research Board of Canada 28:573-585.

Aggus, L.R., and S.A. Lewis. 1977. Environmental conditions and standing crop of fishes in predator-stocking-evaluation reservoirs. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 30:131-140.

Alldredge, J.R., and J.T. Ratti. 1992. Further comparison of some statistical techniques for analysis of resource selection. Journal of Wildlife Management 56(1):1-9.

Anderson, R.O. and S.J. Gutreuter. 1983. Length, weight, and associated structural indices. Pages 283-300 in L.A. Nielsen, and D.L. Johnson, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Anonymous. 1955. Fisheries Research Board of Canada, Annual Report, Halifax, Nova Scotia.

Bakkala, R.G. 1970. Synopsis of biological data on the chum salmon, Oncorhvnchus keta (Walbaum) 1792. FAO Species Synopsis 41, Circular 315. Washington, D.C. 89p.

Ball, O.P., and O.B. Cope. 1961. Mortality studies on cutthroat trout in Yellowstone Lake. U.S. Fish and Wildlife Service Research Report 55.

Barns, R.A. 1967. Differences in performance of naturally and artificially propagated sockeye salmon migrant fry, as measured with swimming and predation tests. Journal of the Fisheries Research Board of Canada 24(5):1117-1152.

Barns, R.A. 1969. Adaptations in sockeye salmon associated with incubation in stream gravels Pages 71-87 in T.G. Northcote, editor. Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries. University of British Columbia, Vancouver, B.C.

Barns, R.A. 1970. Evaluation of a revised hatchery method tested on pink and chum salmon fry. Journal of the Fisheries Research Board of Canada 27:1429-1452.

Beall, E.P. 1972. The use of predator-prey tests to assess the quality of chum salmon Oncorhvnchus keta fry. Master's thesis. University Washington, Seattle.

Bell, M.C. 1986. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Corps of Engineers, Office of the Chief of Engineers, Fish Passage Development and Evaluation Program, Portland, Oregon.

Benson, N.G. 1973. Evaluating the effects of discharge rates, water levels, and peaking on fish populations in Missouri River main stem impoundments. Geophysical Monographs Series 17:683-689.

Benson, N.G. 1980. Effects of post-impoundment shore modifications on fish populations in Missouri River reservoirs. United States Fish and Wildlife Service Research Report 80, Washington, D.C.

Beschta, R.L. 1982. Comment on "Stream system evaluation with emphasis on spawning habitat for salmonids" by M.A. Shirazi and W.R. Seim. Water Resources Research 18:1292-1295.

Binns, N.A., and F.M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Transactions of the American Fisheries Society 108:215-228.

Bisson, P.A., J.L. Nielsen, R.A. Palmason, and L.E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. Pages 62-73 in N.B. Armantrout, editor. Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information, Western Division, American Fisheries Society, Portland, Oregon.

Bjornn, T.C., D.R. Craddock, and D.R. Corley. 1968. Migration and survival of Redfish Lake, Idaho, sockeye salmon, Oncorhvnchus nerka. Transactions of the American Fisheries Society 97:360-373.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 47-82 in W.R. Meehan, editor. Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Boisclair, D., and W.C. Leggett. 1989. Among-population variability of fish growth: III influence of fish community. Canadian Journal of Fisheries and Aquatic Sciences 46:1539-1550.

Borisov, V.M. 1978. The selective effect of fishing on the population structure of species with a long life cycle. Journal of Ichthyology 18:896-904.

Bovee, R.D., and T. Cochnauer. 1977. Development and evaluation of weighted criteria, probability-of-use curves for instream flow assessments: fisheries. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-77/63.

Bovee, R.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-82/26.

Bovee, R. D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. U.S. Fish and Wildlife Service Biological. Report 86(7).

Bowler, B. 1981. Lake and reservoir investigations. Kokanee lake systems inventory. Job Performance Report, Project F-73-R-3, Idaho Department of Fish and Game, Boise.

Bowles, E.C., V.L. Ellis, D. Hatch, and D. Irving. 1987. Kokanee stock status and contribution of Cabinet Gorge Hatchery, Lake Pend Oreille, Idaho. Annual Progress Report, Project No. 85-339, Division of Fish and Wildlife, Bonneville Power Administration, Portland, Oregon.

Brannon, E.L. 1972. Mechanisms controlling migration of sockeye salmon. International Pacific Salmon Fisheries Commission Bulletin XXI, Vancouver, B.C.

Brannon, E.L. 1984. Influence of stock origin on salmon migratory behavior. Pages 103-112 in J.D. McCleave, G.P. Arnold, J.J. Dodson, and W.H Neill, editors. Mechanisms of migration in fisheries. Plenum Press, New York, NY.

Brannon, E.L. 1987. Mechanisms stabilizing salmonid fry emergence timing. Pages 120-124 in D. Smith, L. Margolis, and C.C. Wood, editors. Sockeye salmon (Oncorhvnchus nerka) population biology and future management. Canadian Special Publication of Fisheries and Aquatic Sciences 96.

Briggs, J.C. 1953. The behavior and reproduction of salmonid fishes in a small coastal stream. California Department of Fish and Game, Fish Bulletin 94.

Brocksen, R.W., G.E. Davis, and C.E. Warren. 1970. Analysis of trophic processes on the basis of density-dependent functions. Pages 468-498 in J.H. Steole, editor. Marine Food Chains. Oliver and Boyd, Edinburg.

Burgner, R.L. 1991. Life history of sockeye salmon Oncorhvnchus nerka. Pages 3-117 in C. Groot and L. Margolis, editors. Pacific Salmon Life Histories. UBC Press, Vancouver, B.C.

Chapman, D.W., D.E. Weitkamp, T.L. Welsh, M.B. Dell, and T.H. Schadt. 1986. Effects of river flow on the distribution of chinook salmon redds. Transactions of the American Fisheries Society 115:537-547.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117:1-21.

Clarke, W.C., and H.D. Smith. 1972. Observations on the migration of sockeye salmon fry (Oncorhynchus nerka) in the Lower Babine River. Fisheries Research Board of Canada 29:151-159.

Coble, D.W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Transactions of the American Fisheries Society 90:469-474.

Conlin, K., and B.O. Tutty. 1979. Juvenile salmonid field trapping manual. Canada Fisheries and Marine Service Manuscript Report 1530, Department of Fisheries and Oceans, Vancouver, B.C.

Cordone, A.J., and D.E. Kelley. 1961. The influence of inorganic sediments on the aquatic life of streams. California Fish and Game 47:189-228.

Cousens, N.B.F., G.A. Thomas, C.G. Swann, and M.C. Healey. 1982. A review of salmon escapement estimation techniques. Canadian Technical Report of Fisheries and Aquatic Sciences 1108.

Craddock, D.R. 1959. A modified fyke net for the live capture of seaward migrating salmon. The Progressive Fish Culturist 21:45-46.

Crisp, D.T., and P.A. Carling. 1989. Observations on siting, dimensions and structure of salmonid redds. Journal of Fish Biology 34:119-134.

Davis, R.D., J.L. Congleton, and R.W. Tyler. 1980. Modified fyke net for the capture and retention of salmon smolts in large rivers. The Progressive Fish Culturist 42(4):235-237.

Delisle, G.E. 1962. Water velocities tolerated by spawning kokanee salmon. California Fish and Game 48:77-78.

Dempson, J.B., and D.E. Stansbury. 1991. Using partial counting fences and a two-sample stratified design for mark-recapture estimation of an Atlantic salmon smolt population. North American Journal of Fisheries Management 11:27-37.

Ellis, R.J., and W.J. McNeil. 1979. Possible management procedures for increasing production of sockeye salmon smolts in the Naknek River System, Bristol Bay, Alaska. National Oceanic and Atmospheric Administration, National Marine Fisheries Service SSRT-733.

Everman, B.C. 1896. Salmon investigations in Idaho. Bulletin of the United States Fish Commission 15:253-289.

Fleck, J.L., and H. Andrusak. 1977. Adult enumeration and fry production at Redfish Creek, British Columbia. Fisheries Technical Circular No. 28.

Foerster, R.E. 1968. The sockeye salmon Oncorhvnchus nerka. Fisheries Research Board of Canada Bulletin 162.

Fraley, J.J., and S.L. McMullin. 1983. Effects of the operation of Hungry Horse Dam on the kokanee fishery in the Flathead River system. Annual report to the Bonneville Power Administration, Montana Department of Fish, Wildlife and Parks, Kalispell.

Fraley, J.J. 1986. Effects of hydroelectric operations on the kokanee population in the Flathead River System, Montana. North American Journal of Fisheries Management 6:560-568.

Fraley, J.J., S.L. McMullin, and P.J. Graham. 1986. Effects of hydroelectric operations on the kokanee population in the Flathead River System, Montana. North American Journal of Fisheries Management 6:560-568.

Fraley, J.J., and P.T. Clancey. 1988. Downstream migration of stained kokanee fry in the Flathead River system, Montana. Northwest Science 62(3):111-117.

Frost, F.O., and D.H. Bennett. 1994. Determination of kokanee incubation success, potential egg deposition, and fry production from the North Fork of the Payette River, Idaho. Annual Report, Idaho Department of Fish and Game, Boise.

Gibbons, D.R., and E.O. Salo. 1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada. U.S. Forest Service Technical Report PNW-10, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Gilbert, C.H. 1914. Contributions to the life-history of the sockeye salmon. Papers 1-10. Annual Report, British Columbia Fisheries Department, 1913-1924.

Gipson, R.D., and W.A. Hubert. 1992. Habitat selection by shoreline-spawning kokanee in Flaming Gorge Reservoir, Wyoming-Utah. Western Division American Fisheries Society. Program Abstracts, FR 37(4).

Goodlad, J.C., T.W. Gjernes, and E.L. Brannon. 1974. Factors affecting sockeye salmon Oncorhvnchus nerka growth in four lakes of the Fraser River system. Journal of the Fisheries Research Board of Canada 31:871-892.

Groen, C.L., and T.A. Schroeder. 1978. Effects of water level management on walleye and other coolwater fishes in Kansas reservoirs. American Fisheries Society Special Publication 11:278-283.

Grunder, S.A., J.D. Linman, and D.R. Anderson. 1990. Federal Aid in Fish Restoration. Regional Fishery Management Investigations, Job Performance Report, Project F-71-R-13, Idaho Department of Fish and Game, Boise.

Grunder, S.A., and D.R. Anderson. 1991. Federal Aid in Fish Restoration. Regional Fishery Management Investigations, Job Performance Report, Project F-71-R- 14, Idaho Department of Fish and Game, Boise.

Gustafson-Marjanen, R.I., and J.R. Moring. 1984. Construction of artificial redds for evaluating survival of Atlantic salmon eggs and alevins. North American Journal of Fisheries Management 4:455-456.

Hamilton, R., and J.W. Buell. 1976. Effects of modified hydrology on Campbell River salmonids. Canada Fisheries and Marine Science, Technical Report PAC/T-76-20, Vancouver, Canada.

Handford, P., G. Bell, and T. Reimchen. 1977. A gill-net fishery considered as an experiment in artificial selection. Journal of the Fisheries Research Board of Canada 34:954-961.

Harris, G.S. 1973. A simple egg box planting technique for estimating the survival of eggs deposited in stream gravel. Journal of Fish Biology 5:85-88.

Harshbarger, T.J., and P.E. Porter. 1982. Embryo survival and fry emergence from two methods of planting brown trout eggs. North American Journal of Fisheries Management 2:84-89.

Hartman, W.L., C.W. Strickland, and D.T. Hoopes. 1962. Survival and behavior of sockeye salmon fry migrating into Brooks Lake, Alaska. *Transactions* of the American Fisheries Society 91:133-139.

Hartman, W.L., and R.L. Burgner. 1972. Limnology and fish ecology of sockeye salmon nursery lakes of the world. Journal of the Fisheries Research Board of Canada 29:699-715.

Hassemer, P.F., and B.E. Rieman. 1981. Observations of deep-spawning kokanee on artificially created spawning habitat. North American Journal of Fisheries *Management* 1:173-176.

Hatch, R.W. 1957. Success of natural *spawning* of rainbow trout in the Finger Lakes region of New York. New York Fish and Game Journal 4:69-87.

Hausle, D.A., and D.W. Coble. 1976. Influence of sand in redds on survival and emergence of brook trout (Salvelinus fontinalis). Transactions of the American Fisheries Society 105:57-63.

Hooper, D.R. 1973. Evaluation of the effects of flows on trout stream ecology. Pacific Gas and Electric Company, Department of Engineering Research, Emeryville, California.

House, R.A., and P.L. Boehne. 1985. Evaluation of instream enhancement structures for salmonid spawning and rearing in a coastal Oregon stream. North American Journal of Fisheries Management 5:283-295.

House, R.A., and P.L. Boehne. 1986. Effects of instream structures on salmonid habitat and populations in Tobe Creek, Oregon. North American Journal of Fisheries Management 6:38-46.

Hunter, J.W. 1973. A discussion of game fish in the state of Washington as related to water requirements. Washington State Department of Game, Spokane.

Idaho Department of Fish and Game. 1991. Fisheries Management Plan, 1991-1995. Boise, Idaho.

Irving, J.S., and T.C. Bjornn. 1984. Effects of substrate size composition on survival of kokanee salmon and cutthroat and rainbow trout. Idaho Cooperative Fisheries Research Unit, Technical Report 84-6, University of Idaho, Moscow.

Iwamoto, R.N., E.O. Salo, M.A. Madej, and R.L. McComas. 1978. Sediment and water quality: a review of the literature including a suggested approach for water quality criteria. U.S. Environmental Protection Agency, EPA 910/9-78-048, Seattle, Washington.

Janssen, P.J., and D.O. Anderson. 1994. Federal Aid in Fish Restoration. Regional fisheries management investigations, Job Performance Report, Project F-71-R-16, Idaho Department of Fish and Game, Boise.

Jenkins, R.M. 1970. The influence of engineering design and operation and other environmental factors on reservoir fishery resources. Water Resources Bulletin 6:110-119.

Jenkins, R.M. 1976. Prediction of fish production in Oklahoma reservoirs on the basis of environmental variables. Annals of the Oklahoma Academy of Science 5:11-20.

Jordan, R.M., and K.F. Beland. 1981. Atlantic salmon spawning survey and evaluation of natural spawning success. Atlantic Sea-Run Salmon Commission, Final Performance Report AFS-20-R, Bangor, Maine.

Koski, R.V. 1966. The survival of coho salmon (Oncorhynchus kisutch) from egg deposition to emergence in three Oregon coastal streams. Master's thesis. Oregon State University, Corvallis.

Koski, R.V. 1972. Effects of sediment on fish resources. Fisheries Research Institute, University of Washington, Seattle.

Koski, R.V. 1975. The survival and fitness of two stocks of chum salmon (Oncorhvnchus keta) from egg deposition to emergence in a controlled stream environment at Big Beef Creek. Doctoral dissertation. University of Washington, Seattle.

Kyle, G.B., J.P. Koenings, and B.M. Barrett. 1988. Density-dependent trophic level responses to an introduced run of sockeye salmon Oncorhvnchus nerka at Frazer Lake, Kodiak Island, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 45:856-867.

Lorenz, J.M., and J.H. Eiler. 1989. Spawning habitat and redd characteristics of sockeye salmon in the glacial Taku River, British Columbia and Alaska. Transactions of the American Fisheries Society. 118:495-502.

Lorz, H.W., and T.G. Northcote. 1965. Factors affecting stream location, and timing and intensity of entry by spawning kokanee Oncorhvnchus nerka into an inlet of Nicola Lake, British Columbia. Journal of the Fisheries Research Board of Canada 22(3):665-687.

Lotspeich, F.B., and F.H. Everest. 1981. A new method for reporting and interpreting textural composition of spawning gravel. U.S. Forest Service Research Note PNW-139.

MacKenzie, C., and J.R. Moring. 1988. Estimating survival of Atlantic salmon during the intergravel period. North American Journal of Fisheries Management 8:45-49.

Magee, J.R., and D. Heiser. 1971. An improved hydraulic egg and fry sampler. Washington Department of Fisheries Report, Olympia, Washington.

Manzer, J.I., and I. Miki. 1986. Fecundity and egg retention of some sockeye salmon Oncorhvnchus nerka stocks in British Columbia. Canadian Journal Fisheries and Aquatic Sciences 43:1643-1655.

Mason, J.C. 1969. Hypoxial stress prior to emergence and competition among coho salmon fry. Journal of the Fisheries Research Board of Canada 26:63-91.

Mathisen, O.A. 1955. Studies on the spawning biology of the red salmon, Oncorhvnchus nerka (Walbaum) in Bristol Bay, Alaska, with special reference to the effect of altered sex ratios. Doctoral dissertation. University of Washington, Seattle.

Mathisen, O.A. 1962. The effect of altered sex ratios on the spawning of red salmon. Pages 137-247 in T. S. Y. Koo, editors. Studies of Alaska red salmon. University of Washington Press, Seattle.

Mathur, D., W.H. Bason, E.J. Purdy, Jr., and C.A. Silver. 1985. A critique of the instream flow incremental methodology. Canadian Journal of Fisheries and Aquatic Sciences 42:825-830.

McDonald, J. 1960a. The behavior of Pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. Journal of the Fisheries Research Board of Canada 17:655-676.

McDonald, J.G. 1960b. A possible source of error in assessing the survival of Pacific salmon eggs by redd sampling. Canadian Fish Culturist 26:27-30.

McDonald, J., and J.M. Hume. 1984. Babine Lake sockeye salmon (Oncorhvnchus nerka) enhancement program: testing some major assumptions. Canadian Journal of Fisheries and Aquatic Sciences 41:70-92.

McMenemy, J.R., and B. Kynard. 1988. Use of inclined-plane traps to study movement and survival of Atlantic salmon smolts in the Connecticut River. North American Journal of Fisheries Management 8:481-488.

McNeil, W. J. 1962. Mortality of pink and chum salmon eggs and larvae in Southeast Alaska streams. Doctoral dissertation. University of Washington, Seattle.

McNeil, W. J. 1964. A method of measuring mortality of pink salmon eggs and larvae. U.S. Fish and Wildlife Service, Fisheries Bulletin 63:575-588.

McNeil, W.J., and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish and Wildlife Service Special Scientific Report-Fisheries 469.

McNeil, W.J. 1966. Effects of the spawning bed environment on reproduction of pink and chum salmon. U.S. Fish and Wildlife Service, Fisheries Bulletin 64:495-523.

McNeil, W.J. 1968. Migration and distribution of pink salmon spawners in Sashin Creek in 1965 and survival of their progeny. U.S. Fish and Wildlife Service, Fisheries Bulletin 66:575-586.

McNeil, W.J. 1969. Survival of pink and chum salmon eggs and alevins. Pages in T.G. Northcote editor. Symposium on salmon and trout in streams. H.R. MacMillan lectures in fisheries. Institute of Fisheries, University of British Columbia.

Meehan, W.R., and D.B. Siniff. 1962. A study of the downstream migrations of anadromous fishes in the Taku River, Alaska. Alaska Department of Fish and Game, F-005-R.

Miller, R.G. 1981. Simultaneous statistical inference. Second edition. Springer-Verlag, New York, New York.

Miller, R.J., and E.L. Brannon. 1982. The origin and development of life history patterns in Pacific salmonids. Pages 269-309 in E.L. Brannon, and E.O. Salo editors. Proceedings Salmon and Trout Migratory Behavior Symposium. University of Washington, Seattle.

Milner, A., and L. Smith. 1985. Fyke nets used in a southeastern Alaskan stream for sampling salmon fry and smolts. North American Journal of Fisheries Management 5:502-506.

Moyle, P.B., and D.M. Baltz. 1985. Microhabitat use by an assemblage of California stream fishes: developing criteria for instream flow determinations. Transactions of the American Fisheries Society 114:695-704.

Mundie, J.H., and R.E. Traber. 1983. Movements of coho salmon (Oncorhvnchus kisutch) fingerlings in a stream following marking with vital stain. Canadian Journal Fisheries and Aquatic Sciences 40(8):1318-1319.

Murray, C.B. 1980. Some effects of temperature on zygote and alevin survival, rate of development and size at hatching and emergence of Pacific salmon and rainbow trout. Master's thesis. University of British Columbia, Vancouver.

Neave, F. 1953. Principles affecting the size of pink and chum salmon populations in British Columbia. Journal of the Fisheries Research Board of Canada 9(9):450-491.

Neu, C.W., C.R. Byers, and J.M. Peek. 1974. A technique for analysis of utilization-availability data. Journal of Wildlife Management 38:541-545.

Orth, D.J. 1983. Aquatic habitat measurements. Pages 61-84 in L.A. Nielsen, and D.L. Johnson, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Orth, D.J., and O.E. Maughan. 1986. In defense of the instream flow incremental methodology. Canadian Journal of Fisheries and Aquatic Sciences 43:1092-1093.

Parsons, B.G.M., and W.A. Hubert. 1988. Influence of habitat availability on spawning site selection by kokanees in streams. North American Journal of Fisheries Management 8:426-431.

Pauwels, S.J., and T.A. Haines. 1994. Survival, hatching, and emergence success of Atlantic salmon eggs planted in three Maine streams. North American Journal of Fisheries Management 14:125-130.

Peterson, R.H., and J.L. Metcalfe. 1981. Emergence of Atlantic salmon fry from gravels of varying composition: a laboratory study. Canadian Technical Report of Fisheries and Aquatic Sciences 1020.

Pfeifer, R.L. 1978. Evaluation of the natural reproduction of kokanee Oncorhvnchus nerka Walbaum in Lake Stevens, Washington, as related to the lake limnology and basin hydrology. Master's thesis. University of Washington, Seattle.

Phillips, R.W., and K.V. Koski. 1969. A fry trap method for estimating salmonid survival from egg deposition to fry emergence. Journal of the Fisheries Research Board of Canada 6:133-141.

Phillips, R.W., R.L. Lantz, E.W. Claire, and J.R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Transactions of the American Fisheries Society 104:461-466.

Platte, W.S., M.A. Shirazi, and D.H. Lewis. 1979. Sediment particle sizes used by salmon for spawning, and methods for evaluation. U.S. Environmental Protection Agency, EPA-600/3-79-043, Corvallis Environmental Research Laboratory, Corvallis, Oregon.

Platte, W.S. 1980. A plea for fishery habitat classification. Fisheries 5(1):2-6.

Porter, T.R. 1973. Fry emergence trap and holding box. Progressive Fish Culturist 35:104-06.

Quimby, A.J., and N.C. Dudiak. 1983. An intertidal salmon fry trap. North American Journal of Fisheries Management 3:212-215.

Reiser, D.W., and T.A. Wesche. 1977. Determination of physical and hydraulic preferences of brown and brook trout in the selection of spawning locations. Water Resources 64. Water Resources Research Institute, University of Wyoming.

Reiser, D.W., and T.C. Bjornn. 1979. Habitat requirements of anadromous salmonids. Influence of Forest and Rangeland Management on Anadromous Fish Habitat in the Western United States and Canada. US Forest Service General Technical Report PNW-96:1-54, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Reiser, D.W., and R.G. White. 1988. Effects of two sediment size-classes on survival of steelhead chinook salmon eggs. North American Journal of Fisheries Management 8:432-437.

Rieman, B.E., and D.L. Meyers. 1990. Status and analysis of salmonid fisheries: kokanee population dynamics. Federal Aid in Fish Restoration, Job Performance Report, Project F-73-R-12, Idaho Department of Fish and Game, Boise.

Rieman, B.E., and D.L. Meyers. 1992. Influence of fish density and relative productivity on growth of kokanee in ten oligotrophic lakes and reservoirs in Idaho. Transactions of the American Fisheries Society 121:178-191.

Ricker, W.E. 1940. On the origin of kokanee, a freshwater type of sockeye salmon. Proceedings and Transactions. Royal Society of Canada 3 34(5):121-135.

Ricker, W.E. 1966. Sockeye salmon in British Columbia. International North Pacific Fisheries Commission Bulletin 18:59-70.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 119.

Ricker, W.E. 1981. Changes in the average size and average age of Pacific salmon. Canadian Journal of Fisheries and Aquatic Sciences 38:1636-1656.

SAS Institute. 1988. SAS procedures guide for personal computers, version 6.03 edition. SAS Institute, Cary, North Carolina.

Schaffer, W.M., and P.F. Elson. 1975. The adaptive significance of variations in life history among local populations of Atlantic salmon in North America. Ecology 56:577-590.

Scheaffer, R.L., W. Mendenhall, and L. Ott. 1990. Elementary survey sampling. PWS-Kent Publishing Company, Boston.

Scott, W.B., and E.J. Crossman. 1973. Freshwater Fishes of Canada. Fisheries Research Board of Canada, Bulletin 184.

Scrivener, J.C. 1988. Two devices to assess incubation survival and emergence of salmonid fry in an estuary streambed. North American Journal of Fisheries Management 8:248-258.

Seelbach, P.W., R.N. Lockwood, and G.R. Alexander. 1985. A modified inclined-screen trap for catching salmonid smolts in large rivers. North American Journal of Fisheries Management 5:494-498.

Semko, R.S. 1954. The stocks of West Kamchatka salmon and their commercial utilization. Izvestiia TINRO 41:3-109. Translation from Russian: Fisheries Research Board of Canada, Translation Series 288, Ottawa; also U.S. Fish and Wildlife Service, Translation Series 30, Seattle, Washington.

Shearer, W.M. 1972. a study of the Atlantic salmon population of the North Esk 1961-1970. Master's thesis. University of Ediburgh, Scotland.

Shepherd, B.G. 1982. Biological reconnaissance of Mathers and Pallant Creeks, Queen Charlotte Islands, December 1977 to December 1978. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1648.

Shepherd, B.G. 1990. Kokanee fry production assessment of Mission Spawning Channel and Peachland Creek, 1990. Technical Report, Ministry of Environment, Penticton, B.C.

Shirazi, M.A., and W.R. Seim. 1979. A stream systems evaluation: an emphasis on spawning habitat for salmonids. US Environmental Protection Agency, EPA-600/3-79-109, Corvallis, Oregon.

Skud, B.E. 1958. Relation of adult pink salmon size to time of migration and fresh-water survival. Copeia 1958(3):170-176.

Smith, A.R. 1973. Development and application of spawning velocity and depth criteria for Oregon salmonids. Transactions of the American Fisheries Society 102:312-316.

Sowden, T.R., and G. Power. 1985. Prediction of rainbow trout embryo survival in relation to groundwater seepage and particle size of spawning substrates. Transactions of the American Fisheries Society 114:804-812.

Stalnaker, C.B., and J.L Arnette, editors. 1976. Methodologies for the determination of stream resource flow requirements: as assessment. US Fish and Wildlife Service, Washington, D.C.

Stalnaker, C.B. 1979. The use of habitat structure preferenda for establishing flow regimes necessary for maintenance of fish habitat. Pages 321-337 in J.V. Ward and J.A. Stanford, editors. The ecology *of* regulated streams. Plenum Press, New York, New York.

Stober, Q.J., and A.H. Hamalainen. 1979. Cedar river sockeye salmon fry emigration. Final Report, Washington State Department of Fisheries, Olympia.

Stober, Q.J., and R.W. Tyler. 1982. Rule curves for irrigation drawdown and kokanee salmon Oncorhynchus nerka egg to fry survival. Fisheries Research 1:195-218.

Stowell, R.A., A. Espinosa, T.C. Bjornn, W.S. Platts, D.C. Burns, and J.S. Irving. 1983. A guide for predicting salmonid response to sediment yields in Idaho Batholith watersheds. U.S. Forest Service Report, Region 1/Region 4, Ogden, Utah.

Tagart, J.V. 1984. Coho salmon survival from egg deposition to fry emergence. Pages 173-181 in J.M. Walton, and D.B. Houston, editors. Proceedings of the Olympic Wild Fish Conference. Peninsula College, Port Angeles, Washington.

Tappel, P.D., and T.C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. North American Journal of Fisheries Management 3:123-135.

Thompson, R.E. 1972. Determining stream flows for fish life. Pages 31-50 in Proceedings of the instream flow requirement workshop. Pacific Northwest River Basins Commission, Portland, Oregon.

Trippel, E.A., and F.W. H. Beamish. 1989. Lake trout growth potential predicted from cisco population structure and conductivity. Canadian Journal of Fisheries and Aquatic Sciences 46:1531-1538.

Tsumura, K., and J.M.B. Hume. 1986. Two variations of a salmonid smolt trap for small rivers. North American Journal of Fisheries Management 6:272-276.

United States Fish and Wildlife Service. 1980a. Habitat as a basis for environmental assessment. Division of Ecological Services, ESM 101, Washington, D.C.

United States Fish and Wildlife Service. 1980b. Habitat evaluation procedures (HEP). Division of Ecological Services, ESM 102, Washington, D.C.

United States Fish an. Wildlife Service. 1981. Standards for the development of abitat suitability index models. Division of Ecological Serv.ces, ESM 103, Washington, D.C.

United States Forest -ervice. 1982. Aquatic habitat survey handbook (FSH 2609.23) f.r the General Aquatic Wildlife System (G.A.W.S.). Untied States D-partment of Agriculture, Forest Service, Region 4, Ogden, Utah.

United States Forest Service. 1991. Final Environmental Impact Statement for he Accelerated Engelmann Spruce Harvest for Brush Creek, Hendric's Creek, and Copet Creek Salvage Timber Sales. Fisheries Sect'on, pp. III/IV10-22•. Payette National Forest, McCall, Idaho.

Ward, F.J., and L.A. Verhoeven. 1963. Two biological stains as markers for sockeye sa mon fry. Transactions of the American Fisheries Society 62:379 383.

Warner, R. 1963. Natural spawning success of land-locked salmon (Salmo salar). Transactions of the American Fisheries Society 92:161-164.

West, C.J., and J.C. Mason. 1987. Evaluation of sockeye salmon (Oncorhynchus __nerka) production from the Sabine Lake Development Project. Pages 176-190 in H.D. Smith, L. Margolis, and C.C. Wood, editors. Socke e salmon (Oncorhynchus nerka) population biology and future management. Canadian Special Publication of Fisheries and Aquatic Scences 96.

Wickett, W.P. 1954. The oxygen supply to salmon eggs in spawning beds. Journal of the Fisheries Research Board of Canada 11:933-953.

Witzel, L.D., and H.R. MacCrimmon. 1981. Role of gravel substrate on ova survival nd alevin emergence of rainbow trout, Salmo gairderi, Canadian Journal of Zoology 59:629-636.

Wolf, P. 1950. A trap for the capture of fish and other organisms moving downst.eam. Transactions of the American Fisheries Society 80:41-45.

Wydoski, R.S., and D.H. Bennett. 1981. Forage species in lakes and reservoirs of the western United States. Transactions of the American Fishrries Society 110:764-771.

Young, M.R., W.A. H Bert, and T.W. Wesche. 1991. Selection of measures of substrate •omposition to estimate survival to emergence of salmonids and to detect changes in stream substrates. North American Jour al of Fisheries Management 11(3):339-346.

Appendix Table 1. Statistics for gravel samples collected in kokanee spawning areas in the North Fork of the Payette River, Idaho. (See Figure 1 for Area location). GM=Geometric Mean; FI=Fredle index; FI_m=modified Fredle index. Survival (S) data was to pre-emergent stage observed in 1993.

Sample	Area	GM	FI	FI	<6.35 mm (%)	<3.35 mm (%)	<0.833 mm (%)	<0.25 mm (%)	S
1	5	4.6	1.3	0.8	41.4	31.1	16.8	1.2	0
2	5	5.2	1.5	0.9	43.5	33.3	15.0	1.1	-
3	6	6.2	1.8	1.1	43.0	32.0	11.5	0.3	89.7
4	6	20.2	7.5	14.0	34.9	24.9	11.0	0.9	0
5	6	5.6	1.2	0.8	46.0	38.3	20.1	1.3	100
6	6	9.8	3.2	2.0	29.4	21.8	7.3	0.5	88.5
7	6	10.1	4.7	3.3	27.9	16.8	8.5	1.3	1.0
8	6	6.2	2.2	1.4	40.6	29.2	9.1	1.1	-
9	6	6.4	2.6	1.8	36.9	25.2	7.6	1.1	62.5
10	6	9.6	3.6	2.3	30.9	21.1	7.9	0.7	0
11	6	4.8	1.6	0.9	46.6	33.4	13.8	0.9	0
12	6	8.2	3.2	2.1	34.3	22.4	7.5	0.4	95.3
13	6	8.1	3.0	2.1	32.7	22.9	6.3	1.2	50.0
14	6	9.1	2.7	1.5	30.8	23.4	9.6	0.6	84.6
15	6	8.3	3.5	2.4	31.8	20.1	3.0	1.5	98.0
16	6	8.2	3.2	2.0	32.5	22.8	7.7	0.7	58.1
17	6	6.7	2.5	1.2	31.7	23.8	12.1	1.5	98.9
18	6	7.4	2.5	1.6	31.6	24.4	9.5	0.9	14.7
19	6	6.0	1.9	1.1	40.5	28.3	12.8	1.0	83.7
20	6	7.6	2.5	1.6	35.6	25.2	8.2	0.7	1.0

Appendix Table 1 (continued). Statistics for gravel samples collected in kokanee spawning areas in the North Fork of the Payette, Idaho. (See Figure 1 for Area location). GM=Geometric Mean; FI=Fredle index; FI_m=modified Fredle index. Survival (S) data was to pre-emergent stage observed in 1993.

Sample #	Area	GM	FI	FIm	<6.35 mm (%)	<3.35 mm (%)	<0.833 mm (%)	<0.25 mm (%)	S
21	6	8.0	2.8	1.5	30.7	23.1	10.6	1.2	92.9
23	9	5.7	2.3	1.2	33.6	24.9	13.0	0.8	38.1
24	9	6.6	2.8	1.7	33.8	23.4	11.3	0.9	78.3
25	9	5.4	2.5	1.4	36.3	24.1	12.0	1.2	93.4
26	9	7.2	3.1	1.8	34.9	22.8	10.8	0.6	65.2
27	5	7.0	2.2	1.2	38.2	26.3	9.0	0.5	84.6
28	5	9.5	3.2	1.8	32.5	22.3	8.3	0.5	58.1
29	5	8.0	3.1	1.8	31.2	21.9	9.5	0.6	82.8
30	5	6.4	2.2	1.2	34.1	24.9	13.3	2.1	95.3
31	4	9.7	3.8	2.0	26.0	19.4	9.9	1.6	9.7
32	5	11.0	4.0	2.3	28.1	19.9	6.4	0.5	80.2
33	5	12.4	4.2	2.6	25.8	19.0	7.5	1.2	87.4
34	5	6.4	1.5	0.8	41.9	32.0	16.8	1.1	4.1
35	5	14.1	5.0	3.4	23.4	16.0	6.1	0.5	0
36	5	2.4	0.9	0.2	36.3	24.9	6.8	0.5	1.0
37	4	10.3	4.0	2.6	28.7	19.3	5.1	0.3	87.2
38	3	8.0	1.9	1.1	32.8	25.5	13.0	0.9	95.4
39	1	8.2	2.4	1.3	38.9	28.0	11.4	0.7	82.1
40	4	9.4	3.1	1.8	29.0	22.1	9.8	1.2	86.8
41	3	9.1	3.0	1.7	31.9	22.8	9.6	0.8	0
42	4	8.9	3.3	1.9	29.4	22.0	7.2	0.5	98.0

Appendix Table 1 (continued). Statistics for gravel samples collected in kokanee spawning areas in the North Fork of the Payette River, Idaho. (See Figure 1 for Area location). GM=Geometric Mean; FI=Fredle index; FI_m=modified Fredle index. Survival (S) data was to pre-emergent stage observed in 1993.

Sample #	Area	GM	FI	FI	<6.35 mm (%)	<3.35 mm (%)	<0.833 mm (%)	<0.25 mm (%)	S
43	3	12.9	4.4	2.9	24.9	17.8	3.8	0.2	92.7
44	4	8.2	2.3	1.3	38.6	28.1	10.2	1.0	79.8
45	6	7.1	2.8	1.8	35.5	24.9	9.1	0.2	-
46	6	14.0	7.5	5.1	18.5	11.4	3.3	0.2	-
47	6	5.8	2.6	1.8	37.8	25.3	9.0	0.4	-
48	6	3.4	1.2	0.7	52.0	36.4	18.6	1.2	-
49	6	9.7	5.0	3.1	23.8	16.7	5.5	0.3	-
50	6	4.8	1.8	1.0	37.4	28.3	13.5	1.1	-
51	6	6.5	2.6	1.7	35.0	24.7	9.3	0.5	-
52	6	5.4	2.1	1.3	35.4	26.7	11.1	0.6	-
53	6	7.2	3.1	2.1	31.4	22.6	7.4	0.5	-
54	6	4.9	1.7	1.1	39.2	30.6	12.4	0.5	-
55	6	8.0	3.4	2.3	30.4	21.4	6.2	0.5	-

Submitted by:

David H. Bennett
Frank O. Frost

IDAHO DEPARTMENT OF FISH AND GAME

Steven M. Huffaker, Chief
Bureau of Fisheries

Al Van Vooren
Fish Research Manager