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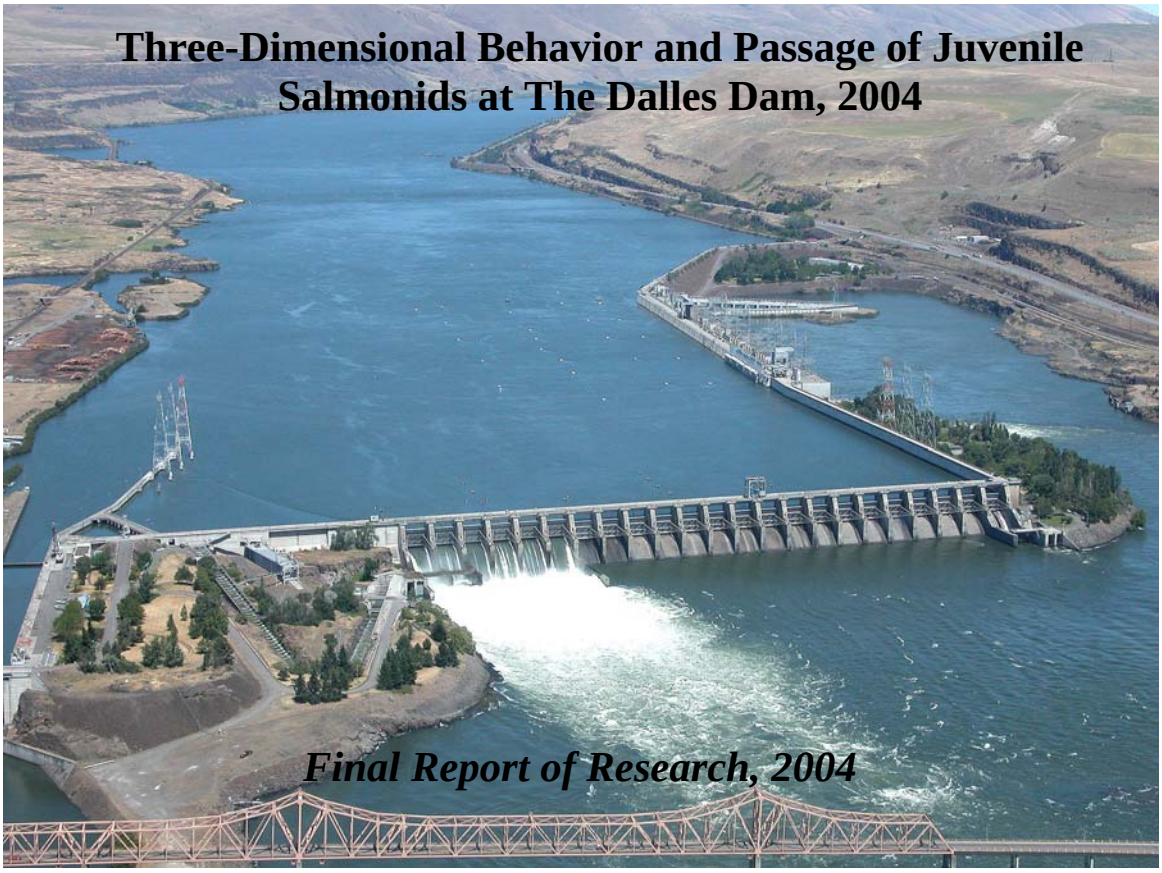

Three-Dimensional Behavior and Passage of Juvenile Salmonids at The Dalles Dam, 2004

Final Report of Research, 2004

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Table of Contents

Table of Contents ..... i-ii

Acknowledgments iii

Suggested Citation Format iii

List of Figures ..... v-xiv

List of Tables ..... xv-xvi

List of Appendix Figures ..... xvii-xviii

Executive Summary ..... xix-xxii

Chapter One

Introduction 3

Methods 5

- Study Area 5
- Three-dimensional Acoustic Tracking Systems 5
- Hydrophone Arrays 6
- Data Analysis 11
- Three-dimensional System Accuracy 11
- Tagging, Handling, and Release Procedures 13
- Approach Path 14
- Approach Velocity and Residence Time 14
- Ice and Trash Sluiceway and Spillway Passage Efficiency 15
- Behavioral Guidance Structure Feasibility 17

Results 17

- Dam Operations 17
- Three-dimensional System Accuracy 21
- Fish Release, Travel Times, and Detection Rates 21
- Approach Path 30
- Approach Velocity and Residence 38
- Ice and Trash Sluiceway and Spillway Passage Efficiency 50
- Behavioral Guidance Structure Feasibility 52
- Computational Fluid Dynamics Model Data 71

Discussion 71

References 77

Chapter Two

Introduction 83

- Background 83

Objectives 85

Methods.....85

Study Area 85
Fish Tagging and Releases.....87
Acoustic Telemetry Systems.....88
Operations.....88
Data Processing.....90
Data Analysis.....91

Results.....95

Fish Passage Efficiency 95
Powerhouse Distribution.....95
Spillway Distribution.....99
Spillbay Passage Effectiveness.....114
Individual Spillbay Distribution 114
Hourly Distributions 129
Acoustic Telemetry Compared to 2003 Mobile Hydroacoustics.....129

Discussion.....141

Powerhouse Passage Distribution.....141
Spillway Passage Distribution 142
Distribution at Spillbays 143
Passage Timing.....143
Acoustic Telemetry Compared to 2003 Mobile Hydroacoustics.....145
Guidance Structure.....146

References.....147

Appendix Figures.....151

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List of Figures

Chapter 1

Figure 1-1. Locations of hydrophones at The Dalles Dam during 2004 7

Figure 1-2. Bathymetry of The Dalles Dam forebay showing the location of Big Eddy, Grave Island, and Louise Island.....8

Figure 1-3. Precision of global positioning systems (A) Trimble Pro XR and (B) Trimble Geo XT used during 2004 to monitor hydrophones mounted to floating structures in the forebay of The Dalles Dam. Data represents positions recorded at a fixed location on the dam. The listed specifications for Pro XR and Geo XT in horizontal estimates are ± 0.050 and ± 1.0 m, respectively 10

Figure 1-4. (A) Drogue equipped with a real-time kinematic global positioning system antenna and acoustic transmitter set at 4.212 m below the surface. (B) The Dalles Dam forebay showing tracks of drogues drifted through the hydrophone arrays 12

Figure 1-5. The 275 m line at the end of main turbine unit 22 represents the location of a BGS with a 30 degree angle from the face of the dam. The box on the end of the BGS is a 40 x 40 m volume that extends from the surface to the bottom of the river and is used in part to recalculate the modified spill passage efficiency of those fish that came in contact with the BGS and were deemed to be diverted into this volume.....18

Figure 1-6. Mean daily discharge and passage indices. (A) Mean daily discharge at John Day Dam and The Dalles Dam and daily hatchery steelhead, yearling Chinook salmon, and sockeye salmon passage indices at John Day Dam during spring, 29 April to 7 June 2004. (B) Mean daily discharge at John Day Dam and The Dalles Dam and daily subyearling Chinook salmon passage index at John Day Dam during summer, 22 June to 26 July 2004. Passage indices were acquired from the Fish Passage Center (*www.fpc.org*) in October 2004 22

Figure 1-7. Time of first detection for (A) hatchery steelhead, (B) yearling Chinook salmon, (C) subyearling Chinook salmon, and (D) sockeye salmon during spring and summer 2004 at The Dalles Dam.....24

Figure 1-8. Time of last detection for (A) hatchery steelhead, (B) yearling Chinook salmon, (C) subyearling Chinook salmon, and (D) sockeye salmon during spring and summer 2004 at The Dalles Dam.....25

Figure 1-9. Travel times of (A) hatchery steelhead, (B) yearling Chinook salmon, (C) subyearling Chinook salmon, and (D) sockeye salmon from release to first 3D detection during spring and summer 2004 at The Dalles Dam 26

Figure 1-10. Forebay residence times of (A) hatchery steelhead, (B) yearling Chinook salmon, (C) subyearling Chinook salmon, and (D) sockeye salmon during spring and summer 2004 at The Dalles Dam.....29

Figure 1-11. Horizontal distributions of acoustically-tagged hatchery steelhead entering the forebay of The Dalles Dam during nighttime, 2100 to 0529 hours, from 29 April to 7 June 2004. Fish approach paths were constructed by dividing the forebay into 19 vertical planes parallel to the spillway and 60 vertical planes perpendicular to the powerhouse that were spaced 20 m apart. Each plane was divided into 20 m wide bins represented by the black squares. The size of the squares represents the number of fish swimming through a specific bin as a percent of the total number of fish crossing the specific plane. The deepest regions of the forebay are represented in dark blue by the bathymetry map in the background.....31

Figure 1-12. Horizontal distributions of acoustically-tagged hatchery steelhead entering the forebay of The Dalles Dam during daytime, 0530 to 2059 hours, from 29 April to 7 June 2004. Fish approach paths were constructed by dividing the forebay into 19 vertical planes parallel to the spillway and 60 vertical planes perpendicular to the powerhouse that were spaced 20 m apart. Each plane was divided into 20 m wide bins represented by the black squares. The size of the squares represents the number of fish swimming through a specific bin as a percent of the total number of fish crossing the specific plane. The deepest regions of the forebay are represented in dark blue by the bathymetry map in the background.....32

Figure 1-13. Horizontal distributions of acoustically-tagged yearling Chinook salmon entering the forebay of The Dalles Dam during nighttime, 2100 to 0529 hours, from 29 April to 7 June 2004. Fish approach paths were constructed by dividing the forebay into 19 vertical planes parallel to the spillway and 60 vertical planes perpendicular to the powerhouse that were spaced 20 m apart. Each plane was divided into 20 m wide bins represented by the black squares. The size of the squares represents the number of fish swimming through a specific bin as a percent of the total number of fish crossing the specific plane. The deepest regions of the forebay are represented in dark blue by the bathymetry map in the background.....34

Figure 1-14. Horizontal distributions of acoustically-tagged yearling Chinook salmon entering the forebay of The Dalles Dam during daytime, 0530 to 2059 hours, from 29 April to 7 June 2004. Fish approach paths were constructed by dividing the forebay into 19 vertical planes parallel to the spillway and 60 vertical planes perpendicular to the powerhouse that were spaced 20 m apart. Each plane was divided into 20 m wide bins represented by the black squares. The size of the squares represents the number of fish swimming through a specific bin as a percent of the total number of fish crossing the specific plane. The deepest regions of the forebay are represented in dark blue by the bathymetry map in the background.....35

Figure 1-15. Horizontal distributions of acoustically-tagged subyearling Chinook salmon entering the forebay of The Dalles Dam during nighttime, 2100 to 0529 hours, from 22 June to 26 July 2004. Fish approach paths were constructed by dividing the forebay into 19 vertical planes parallel to the spillway and 60 vertical planes perpendicular to the powerhouse that were spaced 20 m apart. Each plane was divided into 20 m wide bins represented by the black squares. The size of the squares represents the number of fish swimming through a specific bin as a percent of the total number of fish crossing the specific plane. The deepest regions of the forebay are represented in dark blue by the bathymetry map in the background.....36

Figure 1-16. Horizontal distributions of acoustically-tagged subyearling Chinook salmon entering the forebay of The Dalles Dam during daytime, 0530 to 2059 hours, from 22 June to 26 July 2004. Fish approach paths were constructed by dividing the forebay into 19 vertical planes parallel to the spillway and 60 vertical planes perpendicular to the powerhouse that were spaced 20 m apart. Each plane was divided into 20 m wide bins represented by the black squares. The size of the squares represents the number of fish swimming through a specific bin as a percent of the total number of fish crossing the specific plane. The deepest regions of the forebay are represented in dark blue by the bathymetry map in the background.....37

Figure 1-17. Plan views of median fish elevation for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during 2004 at The Dalles Dam 39

Figure 1-18. Vertical distributions of yearling Chinook salmon entering the forebay of The Dalles Dam in 2004 during daytime, 0530 to 2059 hours, for (A) fish more than 180 m from the non-overflow wall or powerhouse, and (B) fish within 180 m of the non-overflow wall or powerhouse.....40

Figure 1-19. Vertical distributions of subyearling Chinook salmon entering the forebay of The Dalles Dam in 2004 during daytime, 0530 to 2059 hours, for (A) fish more than 180 m from the non-overflow wall or powerhouse, and (B) fish within 180 m of the non-overflow wall or powerhouse.....41

Figure 1-20. Vertical distributions of yearling Chinook salmon entering the forebay of The Dalles Dam in 2004 during nighttime, 2100 to 0529 hours, for (A) fish more than 180 m from the non-overflow wall or powerhouse, and (B) fish within 180 m of the non-overflow wall or powerhouse.....42

Figure 1-21. Vertical distributions of subyearling Chinook salmon entering the forebay of The Dalles Dam in 2004 during nighttime, 2100 to 0529 hours, for (A) fish more than 180 m from the non-overflow wall or powerhouse, and (B) fish within 180 m of the non-overflow wall or powerhouse.....43

Figure 1-22. Vertical distributions of hatchery steelhead entering the forebay of The Dalles Dam in 2004 during nighttime, 2100 to 0529 hours, for (A) fish more than 180 m from the non-overflow wall or powerhouse, and (B) fish within 180 m of the non-overflow wall or powerhouse.....44

Figure 1-23. Vertical distributions of hatchery steelhead entering the forebay of The Dalles Dam in 2004 during daytime, 0530 to 2059 hours, for (A) fish more than 180 m from the non-overflow wall or powerhouse, and (B) fish within 180 m of the non-overflow wall or powerhouse.....45

Figure 1-24. Plan views of mean approach velocity for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during daytime, 0530 to 2059 hours, during 2004 at The Dalles Dam 46

Figure 1-25. Plan views of mean approach velocity for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during nighttime, 2100 to 0529 hours, during 2004 at The Dalles Dam 47

Figure 1-26. Plan views of median residence time for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during daytime, 0530 to 2059 hours, during 2004 at The Dalles Dam 48

Figure 1-27. Plan views of median residence time for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during nighttime, 2100 to 0529 hours, during 2004 at The Dalles Dam 49

Figure 1-28. The sluiceway passage efficiencies of hatchery steelhead, yearling Chinook salmon, and subyearling Chinook salmon swimming within a specific distance of the sluiceway entrance at main turbine unit 1 while (A) the sluiceway entrance at main turbine unit 18 was closed and while (B) the sluiceway entrance at main turbine unit 18 was open. Passage efficiencies are the number of fish passing through the sluiceway entrance at main turbine unit 1 as a percent of the total fish detected within that distance of the sluiceway entrance.....51

Figure 1-29. Plan views of volumetric sluiceway passage efficiency for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during 2004 at The Dalles Dam. Volumetric passage efficiency was calculated by the number of fish passing through a specific bin and subsequently passing through the sluiceway entrance at main turbine unit 1 as a percentage of the total fish detected in that bin 53

Figure 1-30. Plan views of volumetric spillway passage efficiency for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during 2004 at The Dalles Dam during daytime, 0530 to 2100 hours. Volumetric passage efficiency was calculated by the number of fish passing through a specific bin and subsequently passing through the spillway as a percentage of the total fish detected in that bin 54

Figure 1-31. Plan views of volumetric spillway passage efficiency for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during 2004 at The Dalles Dam during nighttime, 2100 to 0529 hours. Volumetric passage efficiency was calculated by the number of fish passing through a specific bin and subsequently passing through the spillway as a percentage of the total fish detected in that bin 55

Figure 1-32. Length of BGS of (A) 275 m and (B) 150 m at main turbine unit 22. The box on the end of the BGS represents a 40 m x 40 m volume from the surface to the bottom for use in calculations of the BGS modified spill passage efficiency 61

Figure 1-33. Angle of BGS at (A) 45 degrees and (B) 30 degrees at main turbine unit 22. The box on the end of the BGS represents a 40 m x 40 m volume from the surface to the bottom for use in calculations of the BGS modified spill passage efficiency 62

Figure 1-34. Change in spillway passage efficiency for hatchery steelhead with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 25 degree angle relative to the plane of the powerhouse 63

Figure 1-35. Change in spillway passage efficiency for yearling Chinook salmon with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 25 degree angle relative to the plane of the powerhouse.....64

Figure 1-36. Change in spillway passage efficiency for hatchery steelhead with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 30 degree angle relative to the plane of the powerhouse 65

Figure 1-37. Change in spillway passage efficiency for yearling Chinook salmon with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 30 degree angle relative to the plane of the powerhouse.....66

Figure 1-38. Change in spillway passage efficiency for hatchery steelhead with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 35 degree angle relative to the plane of the powerhouse 67

Figure 1-39. Change in spillway passage efficiency for yearling Chinook salmon with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 35 degree angle relative to the plane of the powerhouse.....68

Figure 1-40. Change in spillway passage efficiency for hatchery steelhead with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 40 degree angle relative to the plane of the powerhouse 69

Figure 1-41. Change in spillway passage efficiency for yearling Chinook salmon with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 40 degree angle relative to the plane of the powerhouse.....70

Figure 1-42. Change in spillway passage efficiency (SPE) for (A) hatchery steelhead and (B) yearling Chinook salmon with the behavioral guidance structure (BGS) at a constant 30 degree downstream angle from the plane of the powerhouse and 6 m depth. Color scale and elevation changes represent differences in SPE as a result of variations in BGS anchor location on the dam, the upstream end of main turbine unit 22 to the upstream end of main turbine unit 11, and length of the BGS, 0 m to 275 m in 25 m increments.....72

Chapter 2

Figure 2-1. Bathymetric map of The Dalles Dam forebay. Elevation is shown in meters from deep (purple) to shallow (light blue) 86

Figure 2-2. Shaded areas are showing the minimum extent of 3D coverage area for the acoustic telemetry systems that were deployed at The Dalles Dam, 2004. All exit points at the powerhouse and spillway were monitored in order to determine fish passage.....89

Figure 2-3. Each spillbay was divided into six regions in order to determine the distribution of fish as they passed individual bays. Region 1 was closest to the Washington or north shore, and region 6 was closest to the Oregon or south shore. Fish were counted as passing each region if their last 3D tracked location was within 15 m of the tainter gate.....94

Figure 2-4. Powerhouse at The Dalles Dam showing location and a representative passage graph at numbered fish turbine units (FU), main turbine units (MU) and sluiceway (striped).....97

Figure 2-5. Percent of total discharge for the powerhouse by turbine unit for the spring and summer sampling seasons. Spring data was summarized from April 29 to June 7, and summer data was summarized from June 23 through July 18, 2004 100

Figure 2-6. Number of fish passing the powerhouse by exit for both spring and summer. Indeterminate numbers are those fish that were detected in the powerhouse array, but were not close enough to a specific turbine unit so that we could differentiate a specific exit. The lighter bars at main turbine units 1 and 18 represent the fish passing into the sluiceway entrance above those units 101

Figure 2-7. Number of fish passing the powerhouse by exit for spring samples. Indeterminate numbers are those fish that were detected in the powerhouse array, but were not close enough to a specific turbine unit so that we could differentiate a specific exit. The lighter bars at main turbine units 1 and 18 represent the fish passing into the sluiceway entrance above those units 102

Figure 2-8. Number of fish passing the powerhouse by exit for each species. Indeterminate numbers are those fish that were detected in the powerhouse array, but were not close enough to a specific turbine unit so that we could differentiate a specific exit. The lighter bars at main turbine units 1 and 18 represent the fish passing into the sluiceway entrance above those units 103

Figure 2-9. Number of fish passing the powerhouse by exit for each species and diel period. Indeterminate numbers are those fish that were detected in the powerhouse array, but were not close enough to a specific turbine unit so that we could differentiate a specific exit. The lighter bars at main turbine units 1 and 18 represent the fish passing into the sluiceway entrance above those units 104

Figure 2-10. Number of fish passing the powerhouse by exit for each species and diel period. Indeterminate numbers are those fish that were detected in the powerhouse array, but were not close enough to a specific turbine unit so that we could differentiate a specific exit. The lighter bars at main turbine units 1 and 18 represent the fish passing into the sluiceway entrance above those units 105

Figure 2-11. Spillway at The Dalles Dam showing location and representative passage at numbered spillbays (1-23). Only spillbays 1-10 were operated for our spring and summer seasons, with priority for 40% flow through spillbays 1-6. Y-axis displays the spillbay, X-axis is the percentage of fish passing an individual spillbay for Figures 11 to 19. The dark line downstream of bays 6 and 7 represents a guide-wall installed in spring 2004. 106

Figure 2-12. Spillway at The Dalles Dam showing location and representative spill percentage for the spring and summer seasons at numbered spillbays (1-23). Only spillbays 1-10 were operated for our spring and summer seasons, with priority on spillbays 1-6. Y-axis displays the spillbay, X-axis is the percentage of water passing individual spillbays 107

Figure 2-13. Ratio of fish passage to percent spill (e.g., effectiveness) calculated using the total spill of each spillbay for the season divided into the number of fish passing that exit. Spillbay 10 was opened briefly during the summer season. Spill at spillbay 10 was only 0.02% of total spill for the period of the study 108

Figure 2-14. Percent of fish exiting through the spillway by individual spillbay for both spring and summer samples. Indeterminate numbers included those fish detected in the spillway array but not close enough to a specific exit point to identify an exit location 109

Figure 2-15. Percent of fish exiting through the spillway by individual spillbay for springtime samples. Indeterminate numbers included those fish detected in the spillway array but not close enough to a specific exit point to identify an exit location 110

Figure 2-16. Percent of fish exiting through the spillway by individual spillbay for summer and diel period of subyearling Chinook salmon. Indeterminate numbers included those fish detected in the spillway array but not close enough to a specific exit point to identify an exit location 111

Figure 2-17. Percent of fish exiting through the spillway by individual spillbay for all species. Indeterminate numbers included those fish detected in the spillway array but not close enough to a specific exit point to identify an exit location.....112

Figure 2-18. Percent of fish exiting through the spillway by individual spillbay for species and diel period. Indeterminate numbers included those fish detected in the spillway array but not close enough to a specific exit point to identify an exit location 113

Figure 2-19. Effectiveness of fish passage calculated using the total spill of each spillbay and dividing into the number of fish passing that exit. Graphs are organized by species. The spring spill graph is showing the percentage of spill through individual spillbays throughout the season 115

Figure 2-20. Effectiveness of fish passage calculated using the total spill of each spillbay and dividing into the number of fish passing that exit. The summer spill graph is showing the percentage of spill through individual spillbays throughout the season.....116

Figure 2-21. Percent distribution of fish passing at spillbay 1. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore 117

Figure 2-22. Percent distribution of fish passing at spillbay 2. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore 118

Figure 2-23. Percent distribution of fish passing at spillbay 3. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore 119

Figure 2-24. Percent distribution of all fish passing at spillbay 4. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore ..120

Figure 2-25. Percent distribution of all fish passing at spillbay 5. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore ..121

Figure 2-26. Percent distribution of all fish passing at spillbay 6. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore ..122

Figure 2-27. Percent distribution of fish species passing at spillbay 1. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore. Spillbay 1 included two sockeye salmon passing through regions 3 and 4 123

Figure 2-28. Percent distribution of fish species passing at spillbay 2. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore. Spillbay 2 included four sockeye salmon passing through regions 3, 4 and 5 124

Figure 2-29. Percent distribution of individual fish species passing at spillbay 3. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore. Spillbay 3 included six sockeye salmon passing through regions 2, 3, 4, and 5.....125

Figure 2-30. Percent distribution of individual fish species passing at spillbay 4. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore. Spillbay 4 included three sockeye salmon passing through regions 1, 3, and 6.....126

Figure 2-31. Percent distribution of individual fish species passing at spillbay 5. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore. Spillbay 5 included five sockeye salmon passing through regions 1, 2, 3, and 5.....127

Figure 2-32. Percent distribution of fish by individual species passing at spillbay 6. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore. Spillbay 6 included six sockeye salmon passing through regions 4, 5, and 6.....128

Figure 2-33. Hourly distributions of fish passage. All species are represented in these graphs. Total passage was the sum of all fish that passed through any exit at each of the passage regions 130

Figure 2-34. Hourly distributions of spring fish passage. Yearling Chinook salmon, hatchery steelhead, and sockeye salmon are represented in these graphs (spring samples). Total passage is the sum of all fish that passed through any of the passage regions (turbines, sluiceway, or spillway) 131

Figure 2-35. Hourly distributions of subyearling Chinook salmon passage. Total passage is the sum of all fish that passed through any of the passage regions (turbines, sluiceway, or spillway) 132

Figure 2-36. Hourly distributions of hatchery steelhead passage. Total passage is the sum of all fish that passed through any of the passage regions (turbines, sluiceway, or spillway) 133

Figure 2-37. Hourly distributions of sockeye salmon passage. Total passage is the sum of all fish that passed through any of the passage regions (turbines, sluiceway, or spillway) 134

Figure 2-38. Hourly passage distributions for subyearling Chinook salmon. Sluiceway passage included five subyearling Chinook salmon. Total passage is the sum of all fish that passed through any of the passage regions (turbines, sluiceway, or spillway) 135

Figure 2-39. The density of fish distribution for spring daytime mobile hydroacoustic samples, in 2003. The area shown was the extent of mobile transects. The distribution of fish density was interpolated between grids of 61 x 61 m.....137

Figure 2-40. The relative distribution of yearling Chinook salmon during spring daytime for 3D acoustic telemetry data in 2004 (upper map), and the density of fish distribution for spring daytime mobile hydroacoustic samples in 2003 (lower map). The displayed distribution was within the minimum area that was covered by the 3D hydrophone array. Distributions were interpolated between grids of 61 x 61 m.....138

Figure 2-41. The density of fish for spring nighttime mobile hydroacoustic samples in 2003. The area shown was the extent of mobile transects. Fish density was interpolated between grids of 61 x 61 m.....139

Figure 2-42. The relative distribution of yearling Chinook salmon during spring nighttime for 3D acoustic telemetry data in 2004 (upper map), and the density of fish distribution for spring nighttime mobile hydroacoustic samples in 2003 (lower map). The displayed distribution was within the minimum area that was covered by the 3D hydrophone array. Distributions were interpolated between grids of 61 x 61 m.....140

List of Tables

Table 1-1. Definitions of fish passage metrics used in the 3D acoustic telemetry behavior analysis for data collected at The Dalles Dam 2004.....16

Table 1-2. Spring 2004 treatment schedule for sluiceway entrances at main turbine units 1 and 18 at The Dalles Dam. Treatments were randomized within a two-day block. Open and closed events are for 24 h. Treatments begin and end at 0800 hours for each day. The sluiceway entrance at main turbine unit 1 is open unless otherwise noted.....19

Table 1-3. Summer 2004 treatment schedule for sluiceway entrances at main turbine units 1 and 18 at The Dalles Dam. Treatments were randomized within a two-day block. Open and closed events are for 24 h. Treatments begin and end at 0800 hours for each day. The sluiceway entrance at main turbine unit 1 is open unless otherwise noted.....20

Table 1-4. Number and percent of hatchery steelhead (HST), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOC) that were released, detected, and 3D tracked during spring and summer 2004 at The Dalles Dam 23

Table 1-5. Number and percent of hatchery steelhead (HST), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOC) first and last detected during daytime, 0530 to 2059 hours, and nighttime, 2100 to 0529 hours, during spring and summer 2004 at The Dalles Dam.....23

Table 1-6. Travel times in hours from time of release to time of the first 3D detection of hatchery steelhead (HST), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOC) during spring and summer 2004 at The Dalles Dam 28

Table 1-7. Residence times in hours from time of the first 3D detection to the time of last 3D detection of hatchery steelhead (HST), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOC) during spring and summer 2004 at The Dalles Dam 28

Table 1-8. Change in spillway passage efficiency (SPE) for hatchery steelhead (HST) with differences in the length, angle, and depth of a proposed behavioral guidance structure (BGS) that begins at the upstream corner of main turbine unit 22 and is anchored downstream at an angle relative to the plane of the powerhouse.....56

Table 1-9. Change in spillway passage efficiency (SPE) for yearling Chinook salmon (CH1) with differences in the length, angle, and depth of a proposed behavioral guidance structure (BGS) that begins at the upstream corner of main turbine unit 22 and is anchored downstream at an angle relative to the plane of the powerhouse.....58

Table 2-1. Number of 24-h blocks during which the sluiceway entrances were opened. The sluiceway entrance at main turbine unit 1 was open for the duration of the study period. The sluiceway entrance at main turbine unit 18 was open and closed for 24-h periods.....93

Table 2-2. The fish passage efficiency (FPE), spillway passage efficiency (SPE), and the sluiceway passage efficiency (SLPE) with reference to overall project passage (SLPE Project), and powerhouse passage (SLPE Powerhouse) for all four species.....96

Table 2-3. The fish passage efficiency (FPE), spillway passage efficiency (SPE), and the sluiceway passage efficiency (SLPE) with reference to overall project passage (SLPE Project), and powerhouse passage (SLPE Powerhouse) for all four species combined along with values for individual species efficiencies for both daytime and nighttime.....96

Table 2-4. Ratios of fish passing through the sluiceway calculated as the number of fish passing with the sluiceway entrance at main turbine unit 1 open only, or both sluiceway 1 and sluiceway 18 entrances open and divided by the number of 24-h blocks available for each treatment. The values in parentheses are the N values for each group.....98

List of Appendix Figures

Appendix Figure 1-A.1. Plan view of fish tracks of hatchery steelhead, yearling Chinook salmon, subyearling Chinook salmon, and sockeye salmon approaching The Dalles Dam during daytime, 0530 to 2059 hours, during 2004 at The Dalles Dam. Individual fish have a unique color 152

Appendix Figure 1-A.2. Plan view of fish tracks of hatchery steelhead, yearling Chinook salmon, subyearling Chinook salmon, and sockeye salmon approaching The Dalles Dam during nighttime, 2100 to 0529 hours, during 2004 at The Dalles Dam. Individual fish have a unique color 153

Appendix Figure 1-A.3. Plan view of fish tracks of hatchery steelhead, yearling Chinook salmon, subyearling Chinook salmon, and sockeye salmon passing through the spillway during 2004 at The Dalles Dam. Individual fish have a unique color 154

Appendix Figure 1-A.4. Plan view of fish tracks of hatchery steelhead, yearling Chinook salmon, subyearling Chinook salmon, and sockeye salmon passing through main turbine units 11-22 and the sluiceway entrance at main turbine unit 18 in the powerhouse during 2004 at The Dalles Dam. Individual fish have a unique color.....155

Appendix Figure 1-A.5. Plan view of fish tracks of hatchery steelhead, yearling Chinook salmon, subyearling Chinook salmon, and sockeye salmon exiting through main turbine units 1-10, fish turbine units 1-2, and the sluiceway entrance at main turbine unit 1 in the powerhouse at The Dalles Dam during 2004 field studies. Individual fish have a unique color 156

Appendix Figure 1-B.1. Vertical distributions of hatchery steelhead crossing vertical planes located at 10-m intervals in front of the sluiceway entrance at main turbine unit 1 during daytime, 0530 to 2059 hours. (A) Vertical distributions of hatchery steelhead crossing vertical planes and passing through the sluiceway entrance at main turbine unit 1 during daytime. (B) Vertical distributions of hatchery steelhead crossing vertical planes and not passing through the sluiceway entrance at main turbine unit 1 during daytime 157

Appendix Figure 1-B.2. Vertical distributions of yearling Chinook salmon crossing vertical planes located at 10-m intervals in front of the sluiceway entrance at main turbine unit 1 during daytime, 0530 to 2059 hours. (A) Vertical distributions of yearling Chinook salmon crossing vertical planes and passing through the sluiceway entrance at main turbine unit 1 during daytime. (B) Vertical distributions of yearling Chinook salmon crossing vertical planes and not passing through the sluiceway entrance at main turbine unit 1 during daytime.....158

Appendix Figure 1-B.3. Vertical distributions of subyearling Chinook salmon crossing vertical planes located at 10-m intervals in front of the sluiceway entrance at main turbine unit 1 during daytime, 0530 to 2059 hours. (A) Vertical distributions of subyearling Chinook salmon crossing vertical planes and passing through the sluiceway entrance at main turbine unit 1 during daytime. (B) Vertical distributions of subyearling Chinook salmon crossing vertical planes and not passing through the sluiceway entrance at main turbine unit 1 during daytime.....159

Appendix Figure 1-B.4. Vertical distributions of hatchery steelhead crossing vertical planes located at 10-m intervals in front of the sluiceway entrance at main turbine unit 1 during nighttime, 2100 to 0529 hours. (A) Vertical distributions of hatchery steelhead crossing vertical planes and passing through the sluiceway entrance at main turbine unit 1 during nighttime. (B) Vertical distributions of hatchery steelhead crossing vertical planes and not passing through the sluiceway entrance at main turbine unit 1 during nighttime 160

Appendix Figure 1-B.5. Vertical distributions of yearling Chinook salmon crossing vertical planes located at 10-m intervals in front of the sluiceway entrance at main turbine unit 1 during nighttime, 2100 to 0529 hours. (A) Vertical distributions of yearling Chinook salmon crossing vertical planes and passing through the sluiceway entrance at main turbine unit 1 during nighttime. (B) Vertical distributions of yearling Chinook crossing vertical planes and not passing through the sluiceway entrance at main turbine unit 1 during nighttime.....161

Appendix Figure 1-B.6. Vertical distributions of subyearling Chinook salmon crossing vertical planes located at 10-m intervals in front of the sluiceway entrance at main turbine unit 1 during nighttime, 2100 to 0529 hours. (A) Vertical distributions of subyearling Chinook salmon crossing vertical planes and passing through the sluiceway entrance at main turbine unit 1 during nighttime. (B) Vertical distributions of subyearling Chinook salmon crossing vertical planes and not passing through the sluiceway entrance at main turbine unit 1 during nighttime 162

Executive Summary

In the past ten years, substantial efforts have been made to enhance the downstream passage of juvenile salmonids at main-stem hydroelectric dams on the Columbia and Snake rivers. Much of this effort has focused on optimizing spill conditions, enhancing existing surface bypass routes, and reducing turbine entrainment of downstream migrating salmonids. Because The Dalles Dam does not have a system for screening the turbine intakes, much of the work to improve downstream passage conditions has focused on keeping fish out of the turbines and passing them through the sluiceway or spillway. At the spillway, fish passage efficiency and survival for various spill levels has been studied extensively and some progress has been made. However, The Dalles Dam is unique in its layout and design and poses distinct problems for out-migrating juvenile salmonids. Turbine and spillway routes have shown less than ideal survival in past years, and previous research has provided useful but limited data on juvenile salmonid entry distribution into the forebay. The movement of juvenile salmonids in relation to dam operations within 400 m upstream of the spillway is still poorly understood. The objective of this study was to gather this information and apply it towards the design of behavioral guidance structures (BGS) to divert juvenile salmonids from the turbine units and into the spillway for passage.

From 29 April through 26 July 2004 we tagged fish with ultrasonic transmitters and released 366 juvenile hatchery steelhead, 357 juvenile yearling Chinook salmon, 364 juvenile subyearling Chinook salmon, and 75 juvenile sockeye salmon. We detected 93.7% of the steelhead, 96.4% of the yearling Chinook salmon, 83.5% of the subyearling Chinook salmon, and 90.7% of the sockeye salmon.

Tagged juvenile salmonids had similar approach paths to the powerhouse and the spillway. Juvenile fish approach paths converged over Big Eddy, a deep area of the river, and then either diverged to a direct route to the spillway or a route toward the powerhouse. One group followed the bulk flow into the east end of the powerhouse and continued west along the powerhouse to the spillway. A portion of these fish passed through the powerhouse. The other group did not follow the flow into the powerhouse, but simply continued directly to the spillway. The two approach paths on the north and

south side of Grave Island and subsequent convergence of fish at a mid-river location upstream of the east end of the powerhouse are significant findings for the development of a guidance structure. Furthermore, the subsequent segregation of fish that moved toward the powerhouse or directly toward the spillway is critical information needed to design a guidance structure.

Diel patterns of approach were less distinct for hatchery steelhead than for yearling and subyearling Chinook salmon. In general, most fish traveled in the mid-river area during the nighttime. Steelhead were more likely to approach the spillway during the nighttime compared to daytime when most fish swam toward the powerhouse. Although the percent of fish approaching the powerhouse differed between daytime and nighttime, the approach route for yearling Chinook salmon at the powerhouse were similar during daytime and nighttime.

During the daytime, hatchery steelhead, yearling Chinook salmon, and subyearling Chinook salmon were widely distributed in the water column as they approached the earthen dam. Downstream of the earthen dam the bottom of the river becomes shallow (24 m deep) and is nearly uniform in depth. The vertical distribution of all species shifted toward the surface of the water as forebay depth became shallower. Depth of approach differed by diel period between steelhead and Chinook salmon. Yearling and subyearling Chinook salmon approached deeper during the daytime than at nighttime. Conversely, hatchery steelhead approached deeper during the nighttime than during the daytime.

Observed diel changes in approach paths and vertical distributions of fish will present challenges to the design of an effective fish guidance structure in the forebay. Furthermore, this study was conducted for one season under a wide range of dam operations and relatively low river flows increasing the uncertainty of conclusions we might draw about fish behavior under other operating conditions. Our results indicated that a behavioral guidance structure at the east end of the powerhouse will divert all species that are approaching the powerhouse.

Horizontal approach path distributions showed that many steelhead and Chinook salmon traveled along the powerhouse and passed in front of the main turbine unit 1 sluiceway entrance without entering. Where the thalweg meets the upstream end of the

powerhouse a trench begins that runs the length of the powerhouse. The trench is about 10 m deeper than the surrounding bathymetry and extends about 40 m out from the powerhouse. A large proportion of approach paths followed along the inside edge of this trench, with about 20-25% of all fish approaching within 40 m of the sluiceway entrance at main turbine unit 1. Distributions showed that few fish approached within 20 m of the sluiceway. Hence, sluiceway passage efficiency was low by all measures.

We calculated the spillway passage efficiency of fish detected within a specific bin of water (SPE_v) and subsequently passing through the spillway as a percent of the total number of fish detected within the bin. SPE_v was 100% for steelhead, yearling Chinook salmon, and subyearling Chinook salmon passing through volumes directly upstream of the spillway for both daytime and nighttime. All species had SPE_v greater than 80% further away from the powerhouse near mid-channel during the nighttime. During the daytime hatchery steelhead and yearling Chinook salmon had SPE_v greater than 80% for most bins in the forebay except within 30 m of the powerhouse. Subyearling Chinook salmon had daytime SPE_v greater than 80% for most bins in the forebay including those within 30 m of the powerhouse.

We developed a simple model to estimate changes in overall spillway passage efficiency (SPE) if a behavioral guidance structure (BGS) is installed. We assumed that fish approaching the BGS would be guided along the BGS to the downstream end. We also assumed that fish guided to the volume of water at the end of the BGS would then experience a SPE similar to that estimated for tagged fish in our 2004 field studies. Fish tracks that approached the BGS at elevations below the bottom of the BGS were assumed to continue their trajectories unchanged. Spillway passage efficiency generally increased as the length of the structure was increased. We found that varying the depth of the BGS between 5 m and 8 m resulted in a less than or equal to 1% change in SPE regardless of the length.

The simple BGS/SPE model has demonstrated flexibility to estimate the effect on SPE for any proposed guidance structure at various locations in the forebay. It is possible to add new features as CFD models are created. We have studied the behavior of hatchery steelhead and yearling Chinook salmon at Lower Granite Dam as they approached the BGS. This knowledge has improved predictions of fish response to a

guidance structure at The Dalles Dam. This tool could be used in conjunction with the fish surrogate model being developed by the Corp of Engineers to determine feasibility and design of a behavioral guidance structure.

Overall fish passage efficiency (FPE) for all species was high, with a strong diel component observed. Daytime passage was very high (>90% for all species), primarily due to a large number of fish exiting through the spillway. Nighttime FPE results (67-87%) were much lower than the daytime FPE results for all species, due to higher turbine passage at night and a lower proportion of fish using the spillway and sluiceway at night. The sluiceway was the primary route of passage at the powerhouse compared to turbine units, yielding passage efficiencies for the sluiceway between 44 and 66% during springtime (referenced to powerhouse passage), and 20% for the summertime. All species had higher sluiceway passage during the daytime than during the nighttime. The distribution of juvenile salmonid passage across the powerhouse was even for operating turbine units 3 to 22. Turbine units 1 and 2 had greater passage than all other units. The powerhouse distributions were marked by a shift between daytime and nighttime passages. Most of the turbine passage occurred at night.

The distribution of juvenile salmonids in the spring and summer indicated a preference for spillbay 6, which passed 23.4% of the tagged fish. Spillbays 1 and 4 passed the fewest fish of spillbays 1 to 6. Spillbays 1-6 were operated consistently throughout the season while spillbays 7-10 were not. However, a much greater proportion of fish passed through bays 7-10 than bays 1-6 in comparison to the amounts of water spilled in those bays throughout the spring and summer outmigration period. This suggests a strong preference for fish passage at the southern spillbays.

Chapter One

Three-Dimensional Behavior and Passage of Juvenile Salmonids
at The Dalles Dam, 2004

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Introduction

The Dalles Dam is unique in its design and configuration and poses distinct problems for outmigrating juvenile salmonids. Because there are no turbine screens or smolt bypass system at The Dalles Dam, the only means to pass fish through non-turbine routes is through the spillway and ice and trash sluiceway. Some work has been done to increase passage through these routes, but passage through non-turbine routes [Fish Passage Efficiency (FPE)] is about 80-90% with the remaining 10-20% passing through the turbines. Project survival estimates of 92-96% for fish passing through the spillway, 92-93% for fish passing through the sluiceway, and 81-86% for fish passing through the turbine are among the lowest in the Columbia River Basin (Ploskey et al. 2001a). There is clearly a need to improve survival of juvenile salmonids passing through The Dalles Dam.

Recognizing the need to improve survival at The Dalles Dam, the U.S. Army Corps of Engineers has conducted tests to reduce the number of fish entering the turbines, improve sluiceway fish passage efficiency, and optimize spill conditions. One potential passage enhancement alternative was to occlude the upper half of the turbine intakes to prevent fish from entering the intakes. Steel plates that occluded the upper half of the turbine intakes were evaluated in 2002. Data indicate that these plates did not dramatically reduce turbine entrainment rates (Johnson et al. 2002).

At the spillway, various spill levels have been studied and some progress has been made to optimize spill conditions for passage and tailrace egress (Allen et al. 2000; Allen et al. 2001). In 2004, a training wall was installed in the tailrace between spillbays 6 and 7. The intent of the training wall was to improve tailrace egress conditions and improve survival of fish passing through the spillway. The benefits of the training wall have yet to be determined.

Potential use of the existing sluiceway at The Dalles Dam as a passage alternative was evaluated many years ago (Nichols 1979; Nichols 1980; Nichols and Ransom 1981; Nichols and Ransom 1982). Nichols (1979) found the sluiceway entrances at the west end of the powerhouse had higher yearling Chinook salmon passage rates than did entrances in the middle. Nichols (1980) recommended that the sluiceway be operated 24

h/d because noticeable numbers of smolts used the sluiceway at night, although highest passage was during daylight hours. Based on these and other data, the sluiceway entrance at main turbine unit 1 has been open 24 h/d to pass juvenile salmonids during spring and summer. The sluiceway has been operated like this for the last 20 years. More recent studies indicate that more could be done to optimize the efficiency of the sluiceway as a passage alternative. In 2004, tests were conducted to examine the benefit of operating an additional sluiceway entrance at main turbine unit 18.

Although a substantial amount of data has been collected at The Dalles Dam, there is an absence of critical information that managers need to make improvements at this facility. Information on vertical and horizontal distribution of fish throughout the forebay of The Dalles Dam is limited (Giorgi and Stevenson 1995; Ploskey et al. 2001a). Studies designed to examine forebay approach behavior have been conducted, but sample sizes were small (Holmberg et al. 1997; Sheer et al. 1997). These studies tracked 266 radio-tagged yearling Chinook salmon and 121 subyearling Chinook salmon. Most fish began moving toward the powerhouse, often toward the east end, but a small proportion moved along the north part of the forebay to the spillway. A similar study in 1995 showed subyearling Chinook salmon moved down the north shore or at mid-channel and entered the forebay at the east end of the powerhouse (Sheer et al. 1997). Previous passage efficiency and survival studies conducted at The Dalles Dam using radio telemetry and fixed hydroacoustics were not designed to develop new passage alternatives (Hensleigh et al. 1999; Moursund et al. 2001; Ploskey et al. 2001b; Moursund et al. 2002; Beeman et al. 2003).

One passage alternative being explored is the use of a behavioral guidance structure (BGS) to divert fish away from the turbines and toward the spillway. As this option is investigated, more data is needed on the behavior of the fish in the forebay. Radio telemetry studies have observed a difference in approach distribution for spring and summer migrants. Summer migrants follow closer to the shorelines than spring migrants which follow the channel thalweg. Fixed hydroacoustic studies have observed changes in diel passage distribution and overall passage distribution related to total project operations (Ploskey et al. 2001b). However, the movement of juvenile salmonids in relation to dam operations at distances up to 400 m upstream of the dam is still poorly

understood. The objective of this study was to gather this information and use it to design a BGS to divert juvenile salmonids from the turbine units and into the spillway for passage. In 1998, a BGS was installed in the forebay of Lower Granite Dam. The BGS was a steel wall 330 m long and 17-24 m deep. The purpose of the BGS was to change the horizontal distribution of downstream migrants approaching the powerhouse and guide them toward the surface bypass and collector. Radio telemetry and hydroacoustic techniques showed that about 80% of the fish migrating towards turbines 1-3 were successfully diverted and radio telemetry showed a significant increase in fish passage efficiency when the BGS was in compared to when it was stored in the out position (Adams et al. 2001). Building on this experience, we used a three-dimensional (3D) fish tracking system to examine the movements of acoustic-tagged fish as they approached and passed The Dalles Dam in 2004. These data along with knowledge gained from previous BGS studies at Lower Granite Dam can be used to help determine the appropriate location and size of a BGS for The Dalles Dam.

Methods

Study Area

This study was conducted at The Dalles Dam from 29 April to 7 June during spring and from 23 June to 26 July 2004 during summer. The Dalles Dam is located 309 river kilometers (RKM) upstream from the mouth of the Columbia River. The Dalles Dam is the second to the last dam millions of juvenile salmon encounter during their emigration from the headwater streams within the Columbia River Basin.

Three-dimensional Acoustic Tracking Systems

The acoustic tracking system consisted of acoustic transmitters, hydrophones, and receivers. Five acoustic receivers continuously monitored 76 hydrophones deployed in the forebay. Each hydrophone had a 290° beam width. The acoustic transmitters broadcasted a signal at 307.5 kHz and individual transmitters emitted signals that varied in repetition rate. Different repetition rates allowed us to monitor multiple transmitters

without losing the ability to identify individual acoustic transmitters. Time differential in signal reception was used to determine acoustic transmitter positions. A 3D position was possible if its signal was received on at least four hydrophones as it passed through the array. The algorithm used in 3D fish tracking is similar to the principles used in Global Positioning Systems (GPS: Parkinson and Spilker 1996).

Hydrophone Arrays

We deployed 76 hydrophones to create five nearly contiguous detection zones in the forebay at The Dalles Dam (Figure1-1). The first and largest zone covered a rectangular volume upstream of the powerhouse, adjacent to the earthen portion of the dam. The upstream end of this array (system 1) began near the first bend in the earthen portion of the dam and continued downstream to the adult fish ladder, near powerhouse main turbine unit 22. This array extended from the earthen section of the dam out into the river 200 m. The water depth in this array changed rapidly from 12-93 m and included a deep hole known as Big Eddy and two submerged islands known as Grave Island and Louise Island (Figure 1-2). It was not possible to deploy conventional hydrophone towers on the bottom of the forebay at the designated locations; therefore masts with hydrophones attached were suspended from barges 12.2-18.3 m below the surface.

Three arrays covering the length of the powerhouse were similar to each other in organization. The second hydrophone array (system 2) began at main turbine unit 22 and extended to main turbine unit 13. The next hydrophone array (system 3) began at main turbine unit 11 and continued to main turbine unit 5. The last hydrophone array on the powerhouse (system 4) began at main turbine unit 4 and ended on the non-overflow wall 46 m downstream of fish turbine unit 1. Surface hydrophones were mounted about 2 m below the surface and the bottom hydrophones were mounted about 4 m from the river bottom on a tower. The fifth hydrophone array (system 5) was located upstream of the spillway. This hydrophone array coverage ranged from spillbay 1 to spillbay 16 and extended upstream 134 m. The spillway array consisted of 16 hydrophones.

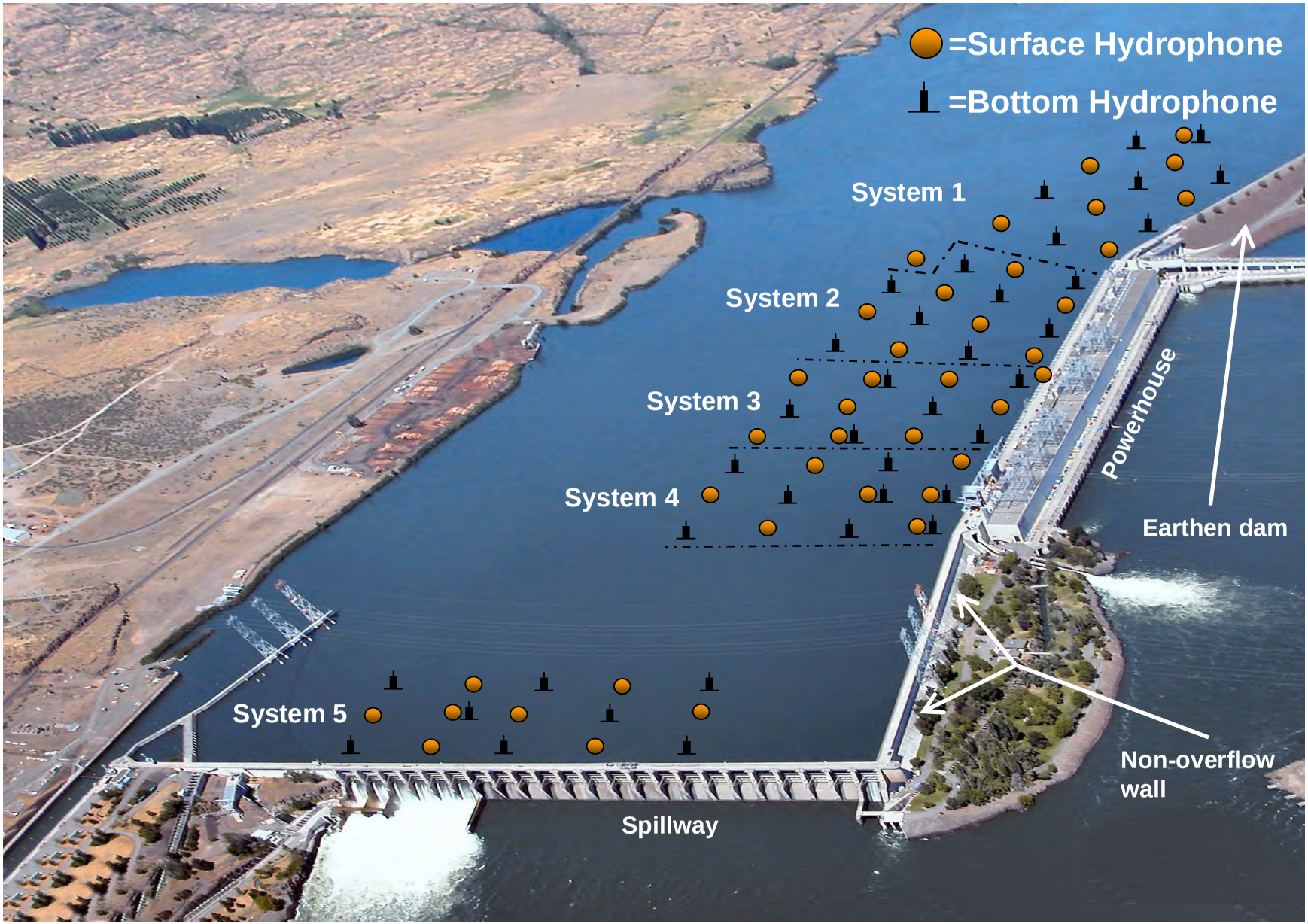

Figure 1-1. Locations of hydrophones at The Dalles Dam during 2004.

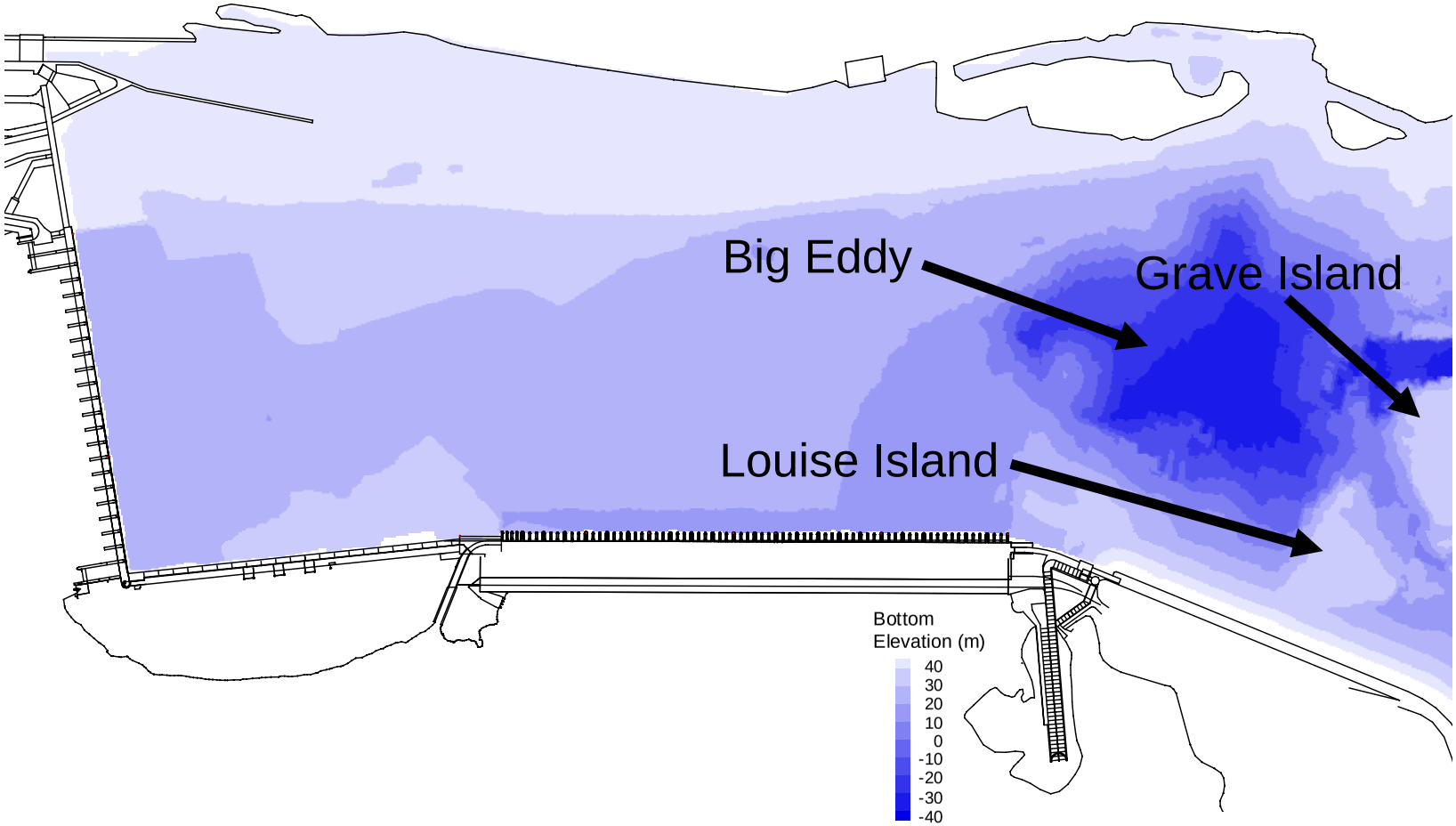

Figure 1-2. Bathymetry of The Dalles Dam forebay showing the location of Big Eddy, Grave Island ,and Louise Island.

The geometry of the hydrophone arrays largely determines the accuracy and precision of 3D position estimates of the acoustic transmitter. Hydrophone geometries with a length, width, and height ratio of 1:1:1 maximize precision and accuracy of 3D position estimates. However, deployment of hydrophone arrays in a 1:1:1 geometry would have been very costly and this level of precision was not required to meet the objectives of this study. The geometry of the arrays deployed in the forebay at The Dalles Dam allowed us to meet study objectives in a cost effective manner. They geometry of the farthest upstream array was 5.8:4.6:1 (106.7 m upstream x 83.8 m across x 18.3 m deep). The geometry of the three arrays in front of the powerhouse was 3.2:3.2:1 (76 m upstream x 76 m across x 24 m deep). The geometry of the array in front of the spillway was 2.7:3:1 (67 m upstream x 73 m across x 24 m deep).

Accurate locations of hydrophone positions were necessary to minimize error in 3D position estimates. The 3D tracking algorithm uses the hydrophone positions, transmitter signals received on the synchronized hydrophones, and speed of sound in water to derive 3D position estimates. A multibeam hydroacoustic system in conjunction with a real time kinematic (RTK) GPS was used to position hydrophones located on the bottom of the forebay to an accuracy of ± 30 cm. We used Trimble RTK, Pro XR, and Geo XT GPS units to continuously record the horizontal position of hydrophones located on floating structures at 5 s intervals and RTK GPS was used to determine hydrophone elevations. The accuracy specifications of the RTK are ± 1.45 cm in the horizontal plane and ± 2.45 cm in the vertical plane. Pro XR and Geo XT GPS units had horizontal accuracy specifications of ± 5.0 and ± 100 cm, respectively (Figure 1-3). We used a Nikon A5 Total Station to position hydrophones that were fixed to dam structures, providing hydrophone position estimates within ± 2.1 cm. The survey methods that we used allowed us to minimize the contribution of hydrophone location error to the overall error in acoustic transmitter position estimates. The coordinate systems used to position the hydrophones within the study volume were Oregon North State Plane zone referenced to the North American Datum, 1927 (NAD27) and National Geodetic Vertical Datum, 1929 (NGVD29).

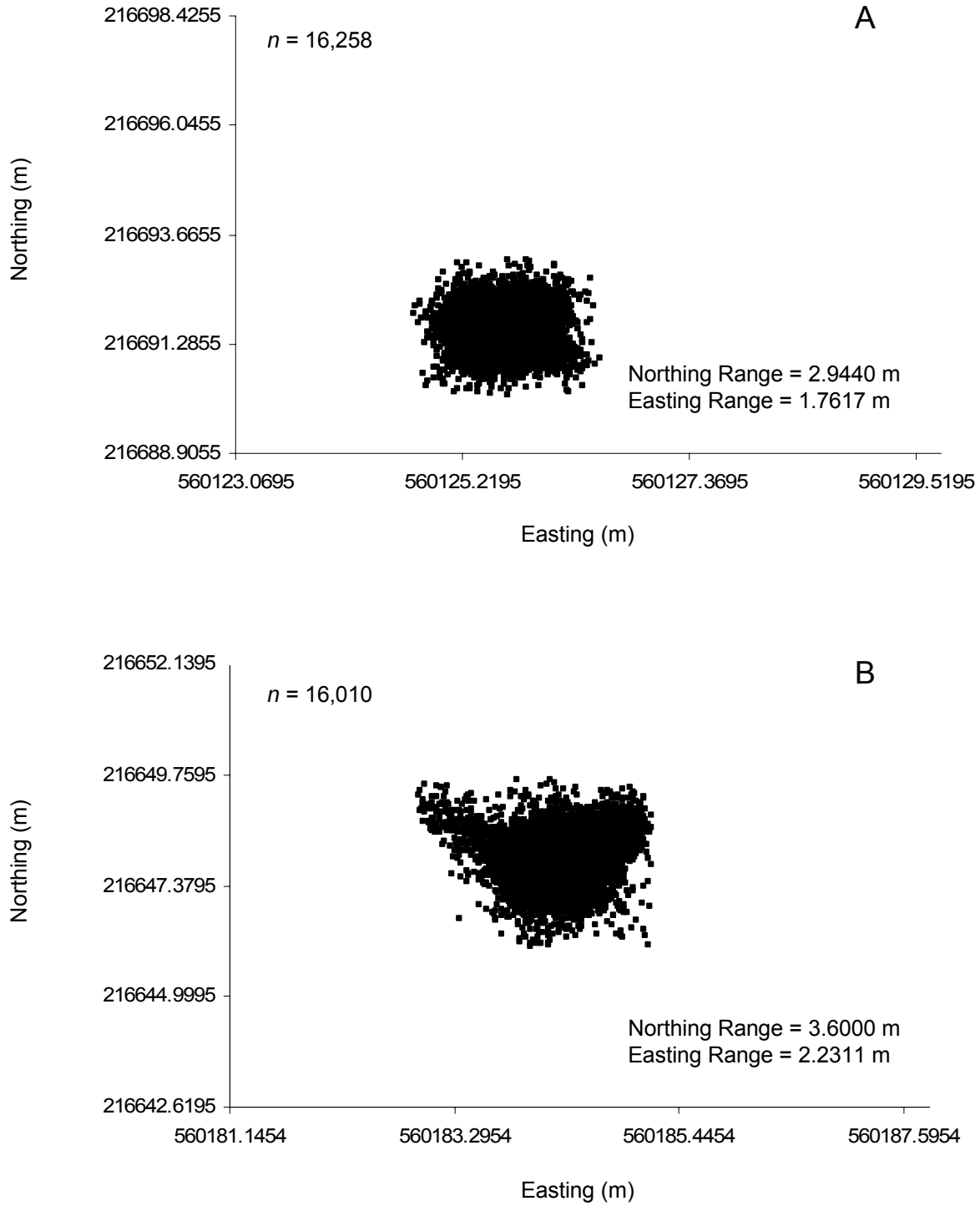

Figure 1-3. Precision of global positioning systems (A) Trimble Pro XR and (B) Trimble Geo XT used during 2004 to monitor hydrophones mounted to floating structures in the forebay of The Dalles Dam. Data represents positions recorded at a fixed location on the dam. The listed specifications for Pro XR and Geo XT in horizontal estimates are ± 0.050 and ± 1.0 m, respectively.

Speed of sound in water was directly measured at three locations within the hydrophone arrays. Sound velocimeters were deployed at main turbine unit 22, main turbine unit 5, and mid-length of the navigation wall. The three sound velocimeters, with "time-of-flight" technology, were used to record the speed of sound in water at 30 s intervals for the entire study period. Speed of sound measurements were averaged hourly and used in the 3D positioning algorithm to generate 3D position estimates.

Data Analysis

Several processing steps were necessary to render the data in a 3D perspective. The first data analysis step was to separate valid transmitter signals from ambient noise in the raw data files using automarking software (Hydroacoustic Technology, Inc., Acoustic Transmitter Software, Seattle, WA). Each transmitter signal recorded from all hydrophones was examined to determine if it was a valid data point. The next step was to incorporate the speed of sound in water and hydrophone position data. In the last step, the software calculated 3D position estimates using a hyperbolic algorithm. The system required detections on at least four hydrophones to calculate a 3D position estimate.

Three-dimensional System Accuracy

We evaluated 3D data accuracy by drifting acoustic transmitters through the hydrophone array and comparing 3D position estimates to RTK GPS position estimates. Two acoustic transmitters were suspended 4.212 m below the water surface with an RTK GPS antenna mounted above them (Figure 1-4). The 3D system accuracy was calculated as:

$$\text{Horizontal Accuracy} = \sqrt{\left(x_{3D} - x_{RTK}\right)^2 + \left(y_{3D} - y_{RTK}\right)^2}$$

$$\text{Vertical Accuracy} = \left|z_{3D} - z_{RTK}\right|$$

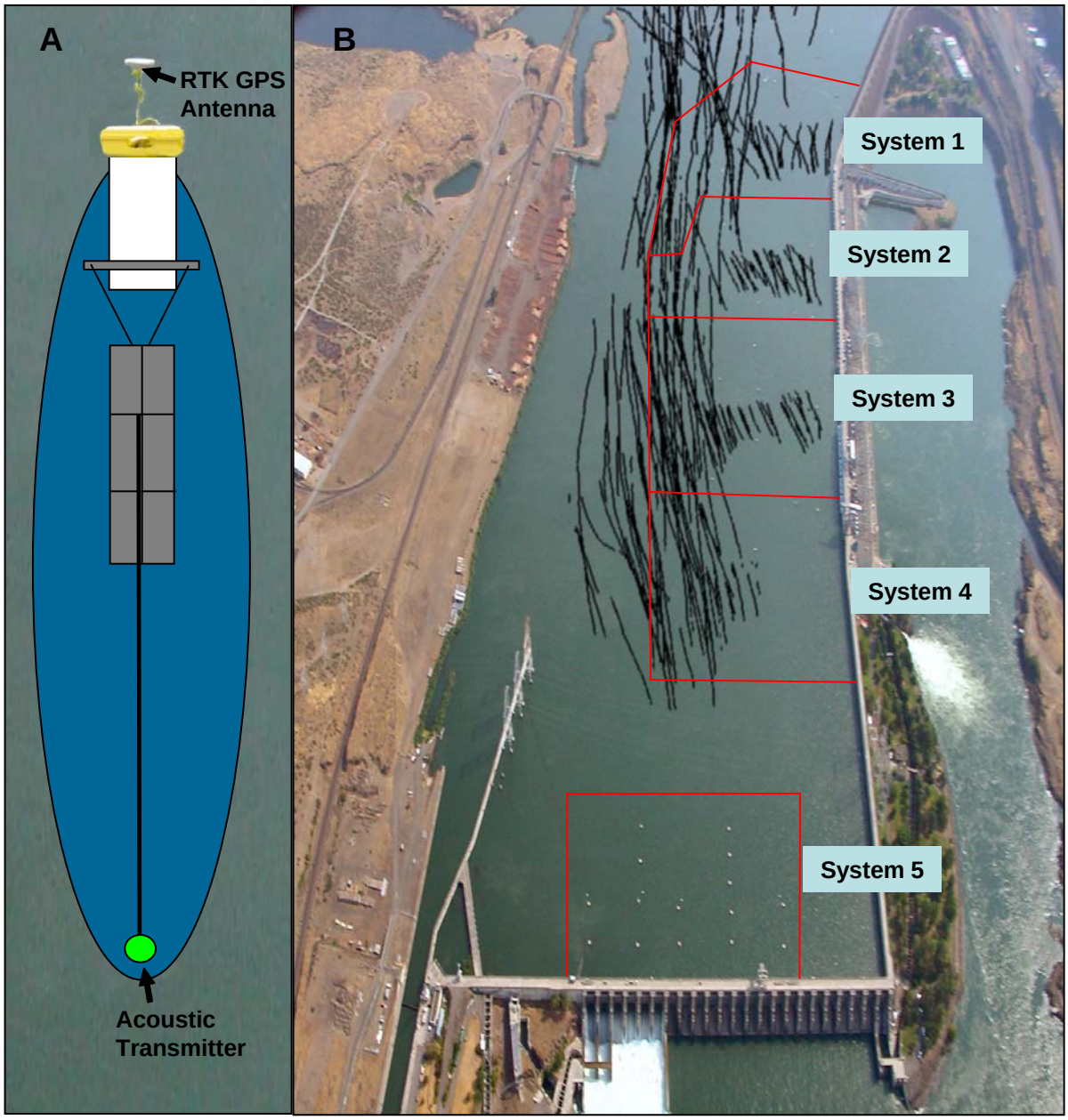

Figure 1-4. (A) Drogue equipped with a real time kinematic global positioning system antenna and acoustic transmitter set at 4.212 m below the surface. (B) The Dalles Dam forebay showing paths of drogues drifted through the hydrophone arrays.

Tagging, Handling, and Release Procedures

We used acoustic transmitters that produced a 307.5 kHz signal with a 3 ms pulse width. Within that frequency, individual transmitters emitted signals that varied in repetition rate, otherwise referred to as pulse rate. The transmitter signal rate was staggered by a minimum of 5 ms between individual transmitters and the rates used during the study ranged from 700 ms to 1,650 ms. We tagged juvenile yearling Chinook salmon (*Oncorhynchus tshawytcha)* and steelhead (*O. mykiss*) using the model 795-E acoustic transmitter. The model 795-E acoustic transmitter has a functional life of 10-12 d after activation. The 795-E acoustic transmitters had exterior dimensions of 20 mm in length and 6 mm in diameter. Average weight of the 795-E acoustic transmitter was 1.5 g and resulted in a maximum transmitter-to-fish weight ratio of 4.75%. We tagged juvenile subyearling Chinook salmon and sockeye salmon (*O. nerka)* using the model 795-M acoustic transmitter. The model 795-M acoustic transmitters had a functional life of 6-8 d after activation. The 795-M acoustic transmitters had exterior dimensions of 15 mm in length and 6 mm in diameter. Average weight of the 795-M acoustic transmitter was 0.75 g and resulted in a maximum transmitter-to-fish weight ratio of 4.8%. The 795-M tag was smaller and allowed us to tag a larger portion of the subyearling Chinook salmon population than the 795-E tag.

We tagged juvenile hatchery steelhead, yearling Chinook salmon, subyearling Chinook salmon, and juvenile sockeye salmon obtained from the smolt monitoring facility at John Day Dam. Fish were collected and placed into perforated holding containers (127 L) inside insulated tanks. The fish were held inside the tanks supplied with flow through river water for at least 24 h prior to tagging. Acoustic transmitters were surgically implanted using procedures described by Adams et al. (1998).

The hatchery steelhead and yearling Chinook salmon implanted with acoustic transmitters were at least 140 mm in fork length and the subyearling Chinook salmon and sockeye salmon implanted with an acoustic transmitters and were at least 120 mm. Immediately after implantation, fish were placed in 5 gallon (18.9 L) perforated buckets supplied with fresh river water and allowed to recover for about 5 min. The perforated bucket containing the fish was then placed in an insulated holding tank with flow through

river water and held for 24 h. Fish were released at mid-channel in the tailrace of John Day Dam at RKM 346 to allow fish to redistribute both horizontally and vertically in the water column before approaching The Dalles Dam. Releases occurred in the morning, between 0600 and 1000 hours and in the evening, between 1800 and 2030 hours to stagger fish arrival time at The Dalles Dam.

Approach Path

Fish approach paths were examined by dividing the forebay into 60 vertical planes perpendicular to the powerhouse and 19 vertical planes parallel to the spillway. The first plane on the spillway was located at the corner of the non-overflow wall and the spillway. The first plane on the powerhouse was located 46 m west of fish turbine unit 1 at the bend in the non-overflow wall. Additional planes were spaced 20 m apart and continued to the upstream end of the earthen dam array. Horizontal approach paths were constructed by dividing each plane into 20 m horizontal bins. We then calculated the number of fish swimming through each bin on their first approach to the dam as a percent of the total fish crossing a specific plane. Vertical approach paths were observed by creating two vertical planes parallel to the powerhouse and extending from the upstream end of the earthen dam to the spillway. Two planes were used to evaluate depth differences of fish less than 180 m and more than 180 m from the powerhouse. Calculations were based on the percent of fish swimming through 1.5 m vertical bins within the planes that extended from the water surface to the bottom of the forebay. Diel comparisons were made by defining daytime as 0530 to 2059 hours, and nighttime as 2100 to 0529 hours.

Approach Velocity and Residence Time

Three-dimensional fish tracks were analyzed for trends in fish approach velocity and residence time. The forebay from the bend in the earthen dam down to the spillway and from the powerhouse out to the range of the 3D position estimates were divided into 20 x 20 m bins that extended from the water surface to the bottom of the forebay. A

mean fish approach velocity was derived for each bin by calculating the mean fish velocity for each fish track segment passing through a bin. We then calculated the grand mean of segment velocities to represent the approach velocity of fish through each bin. Mean residence time for fish in each bin was determined by summing the total residence time of individual fish in each bin and calculating the mean of all fish detected in a bin. Kriging interpolation of cell centered data was then projected for each variable across the forebay as a contour plot to facilitate multi-species comparisons.

Ice and Trash Sluiceway and Spillway Passage Efficiency

We calculated metrics describing ice and trash sluiceway and spillway passage efficiency in several ways (Table 1-1): 1) the number of fish passing through the sluiceway as a percent of the total number of fish detected in the forebay ($SLPE_T$), 2) the number of fish crossing a specific distance from the sluiceway and subsequently passing the sluiceway as a percent of the total number of fish detected within that distance from the sluiceway ($SLPE_D$), 3) the number of fish passing through a specific volumetric bin and subsequently passing the sluiceway as a percent of the total fish detected in that bin ($SLPE_V$), and 4) the number of fish passing through a specific volumetric bin and subsequently passing the spillway as a percent of the total fish detected in that bin (SPE_V). We calculated $SLPE_D$ by dividing the forebay into vertical planes 10 m apart and parallel to the dam. There were a total of 10 planes beginning 10 m upstream of the sluiceway entrances and extending out to 100 m from the sluiceway entrances. We calculated $SLPE_V$ and SPE_V to determine which species-specific travel routes resulted in the highest ice and trash sluiceway and spillway passage efficiencies. The forebay between the east end of the earthen dam array to the spillway was divided into volumes, hereafter referred to as bins. Each bin was 20 x 20 m and extended from the water surface to the bottom of the reservoir.

Table 1-1. Definitions of fish passage metrics used in the 3D acoustic telemetry behavior analysis for data collected at The Dalles Dam in 2004.

Parameter	Descriptor	Estimator
$SLPE_{MU1}$	Sluiceway passage efficiency at Main Unit 1 of the total number of fish detected in the forebay	$SLPE_{MU1}$ = SLP/(SLP+Non-SLP), where SLP = fish passing the sluiceway at Main Unit 1, Non-SLP = fish not passing the sluiceway
$SLPE_{MU18}$	Sluiceway passage efficiency at Main Unit 18 of the total number of fish detected in the forebay	$SLPE_{MU18}$ = SLP/(SLP+Non-SLP), where SLP = fish passing the sluiceway at main Unit 18, Non-SLP = fish not passing the sluiceway
$SLPE_D$	Sluiceway passage efficiency at Main Unit 1 of fish detected at 10 distances from 10-100 m from the sluiceway	$SLPE_D = SLP_D / (SLP_D + Non\text{-}SLP_D)$, where SLP_D = fish detected by distance that pass the sluiceway at Main Unit 1, $Non\text{-}SLP_D$= fish detected by distance that did not pass the sluiceway
$SLPE_V$	Sluiceway passage efficiency at Main Unit 1 of fish detected in 20 m x 20 m volumes in the forebay that extended from the water surface to the bottom	$SLPE_V = SLP_v / (SLP_v + Non\text{-}SLP_v)$, where SLP_v = fish detected in volumes in the forebay that pass the sluiceway at Main Unit 1, $Non\text{-}SLP_v$= fish detected in volumes in the forebay that did not pass the sluiceway
SPE_V	Spillway passage efficiency of fish detected in 20 m x 20 m volumes in the forebay that extended from the water surface to the bottom	$SPE_V = SP_v / (SP_v + Non\text{-}SP_v)$, where SP_v = fish detected in volumes in the forebay that pass the spillway, $Non\text{-}SP_v$= fish detected in volumes in the forebay that did not pass the spillway
SPE	Spillway passage efficiency of fish detected in the forebay	SPE = SP / (SP + Non-SP), where SP = fish detected in the forebay that pass the spillway, Non-SP= fish detected in the forebay that did not pass the spillway

Behavioral Guidance Structure Feasibility

We developed a simple model using the 3D data collected at The Dalles Dam in 2004 to examine the influence of different BGS configurations on spillway passage efficiency (SPE). This model has the capabilities of varying the length, depth, downstream angle from the powerhouse, and the location of the structure on or near the dam. This model recalculates SPE in the presence of a BGS by species. First, the number of fish intersecting a structure with a given length, depth, angle, and location in the forebay is estimated from our 2004 data set assuming any fish that would have made contact with the structure as diverted. Next, we calculated SPE for a volume that was 40 x 40 m and extended from the water surface to the bottom (Figure 1-5). The volumetric SPE was then multiplied by the total number of fish diverted, resulting in the number of fish passing the spillway of the total number diverted. The number of diverted and non-diverted fish that passed the spillway was summed. This collective number of fish that passed the spillway was then divided by the entire number of tagged fish present in the forebay giving the recalculated SPE.

Results

Dam Operations

Two sluiceway treatments were tested at The Dalles Dam during the salmonid passage evaluations conducted in 2004 (Tables 1-2, 1-3). These treatments included: 1) only the sluiceway entrance at main turbine unit 1 open with a flow of 3.3 thousand cubic feet per second (kcfs), and 2) both sluiceway entrances at main turbine unit 1 and main turbine unit 18 open with a flow of 2.8 kcfs and 1.1 kcfs respectively with a forebay elevation of 48.2 m. Total spill for The Dalles Dam was 40% of the total dam discharge throughout the study.

During the study from 29 April through 26 July, discharge at The Dalles Dam was relatively low compared to the ten year average. On 18 July 2004, the total discharge through The Dalles Dam averaged 91.7 kcfs, the lowest flow through the dam during the

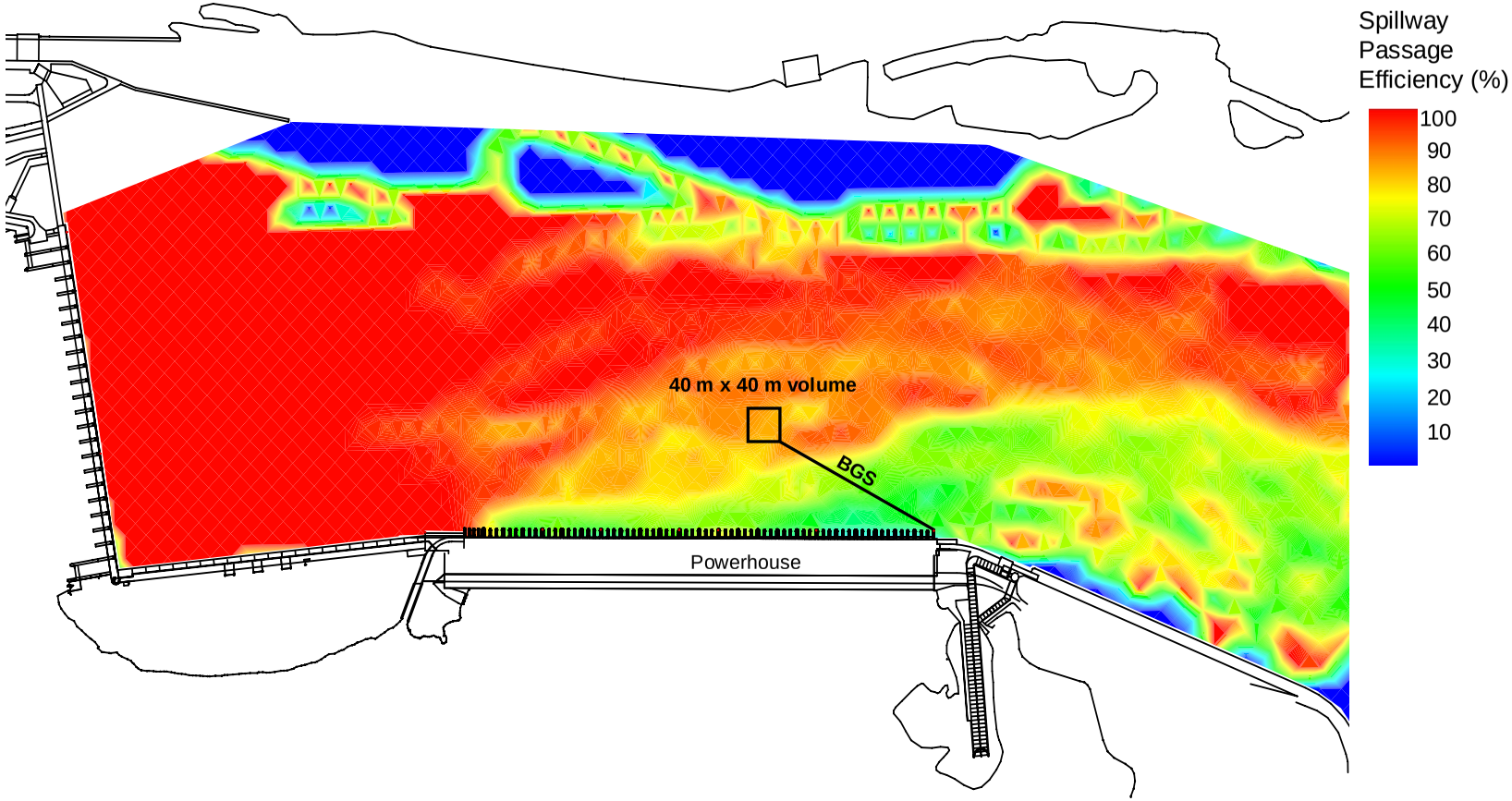

Figure 1-5. The 275 m line at the end of main turbine unit 22 represents the location of a BGS with a 30 degree angle from the face of the dam. The box on the end of the BGS is a 40 x 40 m volume that extends from the surface to the bottom of the river and is used in part to recalculate the modified spill passage efficiency of those fish that came in contact with the BGS and were deemed to be diverted into this volume.

Table 1-2. Spring 2004 treatment schedule for main turbine unit 1 and 18 sluiceway entrances at The Dalles Dam. Treatments were randomized within a two-day block. Open and closed events are for 24 h. Treatments begin and end at 0800 hours for each day. The sluiceway entrance at main turbine unit 1 is open unless otherwise noted.

18 **April**	19 Closed	20 Open (MU1 Closed 1000-1400)	21 Open	22 Closed (MU18 Open 0800-1000)	23 Open	24 Closed
25 Open	26 Closed	27 Closed	28 Open	29 Open	30 Closed	1 **May** Open
2 Open	3 Closed	4 Open	5 Closed	6 Open	7 Closed	8 Open
9 Open	10 Closed	11 Open	12 Closed	13 Open	14 Closed	15 Open
16 Closed	17 Closed	18 Open	19 Open	20 Closed	21 Closed (MU1 Closed) (MU18 Open 1230-1330)	22 Open
23 Open	24 Closed	25 Open	26 Closed	27 Open	28 Closed	29 Closed
30 Open	31 Closed	1 **June** Open	2 Open	3 Closed	4 Closed	5 Open

Table 1-3. Summer 2004 treatment schedule for main turbine unit 1 and 18 sluiceway entrances at The Dalles Dam. Treatments were randomized within a two-day block. Open and closed events are for 24 h. Treatments begin and end at 0800 hours for each day. The sluiceway entrance at main turbine unit 1 is open unless otherwise noted.

6 **June** Closed	7 Open	8 Open	9 Closed	10 Open	11 Closed	12 Open
13 Closed	14 Closed	15 Open	16 Open	17 Closed	18 Closed	19 Open
20 Closed	21 Open	22 Closed	23 Open	24 Closed	25 Open	26 Open
27 Closed	28 Open	29 Closed	30 Open	1 **July** Closed	2 Open	3 Closed
4 Closed	5 Open	6 Open	7 Closed	8 Closed	9 Open	10 Open
11 Closed	12 Open	13 Closed	14 Open	15 Closed	16 Closed	17 Open
18 Closed	19 Closed	20 Closed	21 Closed	22 Closed	23 Closed	24 Closed
25 Closed	26 Closed					

course of the study. On 31 May the total flow averaged 319.1 kcfs, the highest flow during the study (Figure 1-6). From 29 April through 26 July, flow through fish unit turbines 1 and 2 averaged 2 kcfs, flow through main unit turbines 1–22 averaged 106.3 kcfs with a range of 38.5-196.8 kcfs, and spill averaged 74.3 kcfs with a range of 29.5-145.3 kcfs. After the study started on 29 April, flow increased until 31 May, the final spring peak of river flow for 2004. During the summer study, flow through main unit turbines 1-22 averaged 60.7 kcfs with a range of 39.1-101.1 kcfs and spill averaged 47.0 kcfs with a range of 29.5-70.2 kcfs.

Three-dimensional System Accuracy

The accuracy of the 3D system was determined by repeated location of drogues. The range of median 3D system horizontal position accuracies was 1.3–4.0 m and the range of median vertical position accuracies was 1.0-7.2 m. These error estimates are conservative due to the tilt of the drogues in higher flows that resulted in a consistent 0.3-0.5 m downstream offset of 3D position estimates relative to the RTK GPS position estimates.

Fish Release, Travel Times, and Detection Rates

We tagged and released 366 juvenile hatchery steelhead, 357 yearling hatchery Chinook salmon, 364 subyearling hatchery and wild Chinook salmon, and 75 juvenile sockeye salmon during this study. We detected 93.7% (343 of 366) of released steelhead and obtained 3D position estimates for 97.7% (335 of 343) that were detected (Table 1-4). The first detections for 77.9% (261 of 335) of the steelhead occurred during the daytime and 22.1% (74 of 335) occurred during the nighttime (Table 1-5; Figure 1-7). The last detections (i.e., the last 3D position estimate obtained for a specific fish) for 75.2% (252 of 335) of the steelhead occurred during the daytime and 24.8% (83 of 335) occurred during the nighttime (Table 1-5 Figure 1-8). Steelhead travel times, from release to first detection, ranged from 7.3 to 110.8 h (Figure 1-9). The mean travel time

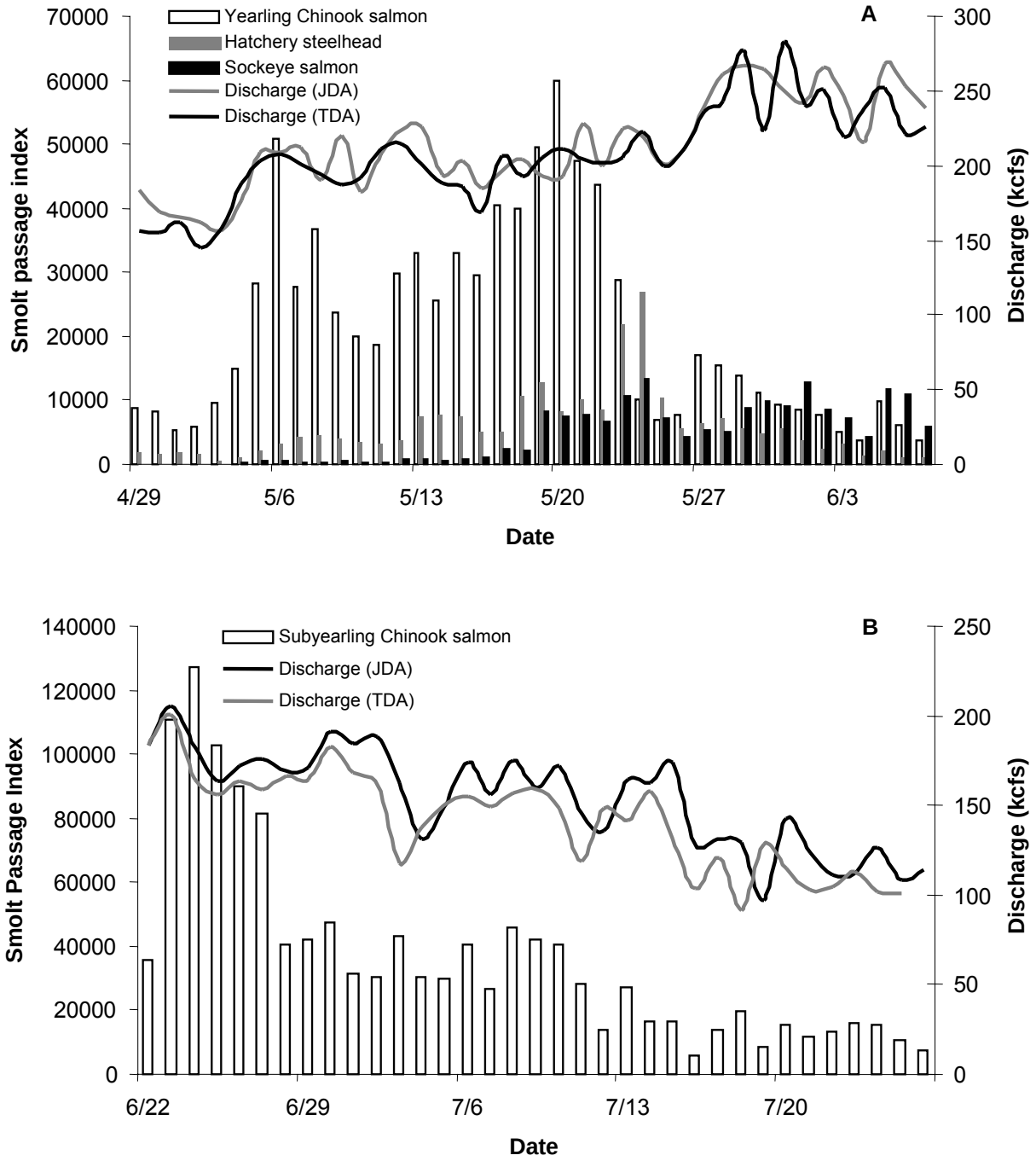

Figure 1-6. Mean daily discharge and passage indices. (A) Mean daily discharge at John Day Dam and The Dalles Dam and daily hatchery steelhead, yearling Chinook salmon, and sockeye salmon passage indices at John Day Dam during spring, 29 April to 7 June 2004. (B) Mean daily discharge at John Day Dam and The Dalles Dam and daily subyearling Chinook salmon passage index at John Day Dam during summer, 22 June to 26 July 2004. Passage indices were acquired from the Fish Passage Center (*www.fpc.org*) in October 2004.

Table 1-4. Number and percent of hatchery steelhead (HST), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOC) that were released, detected, and 3D tracked during spring and summer 2004 at The Dalles Dam.

Species	Number of fish released	Number of fish detected	Percent of fish detected	Number of 3D fish tracks	Percent of 3D fish tracks
HST	366	343	93.7	335	97.7
CH1	357	344	96.4	339	98.5
CH0	364	304	83.5	303	99.7
SOC	75	68	90.7	64	94.1
Total	1162	1059	91.1	1041	98.3

Table 1-5. Number and percent of hatchery steelhead (HST), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOC) first and last detected during daytime, 0530 to 2059 hours, and nighttime, 2100 to 0529 hours, during spring and summer 2004 at The Dalles Dam.

Species	Number of 3D fish tracks	Time of first detection		Time of last detection	
		Day Number of fish (%)	Night Number of fish (%)	Day Number of fish (%)	Night Number of fish (%)
HST	335	261 (77.9)	74 (22.1)	252 (75.2)	83 (24.8)
CH1	339	256 (75.5)	83 (24.5)	242 (71.4)	97 (28.6)
CH0	303	268 (88.4)	35 (11.6)	256 (84.5)	47 (15.5)
SOC	64	57 (89.1)	7 (10.9)	56 (87.5)	8 (12.5)
Total	1041	842 (80.9)	199 (19.1)	806 (77.4)	235 (22.6)

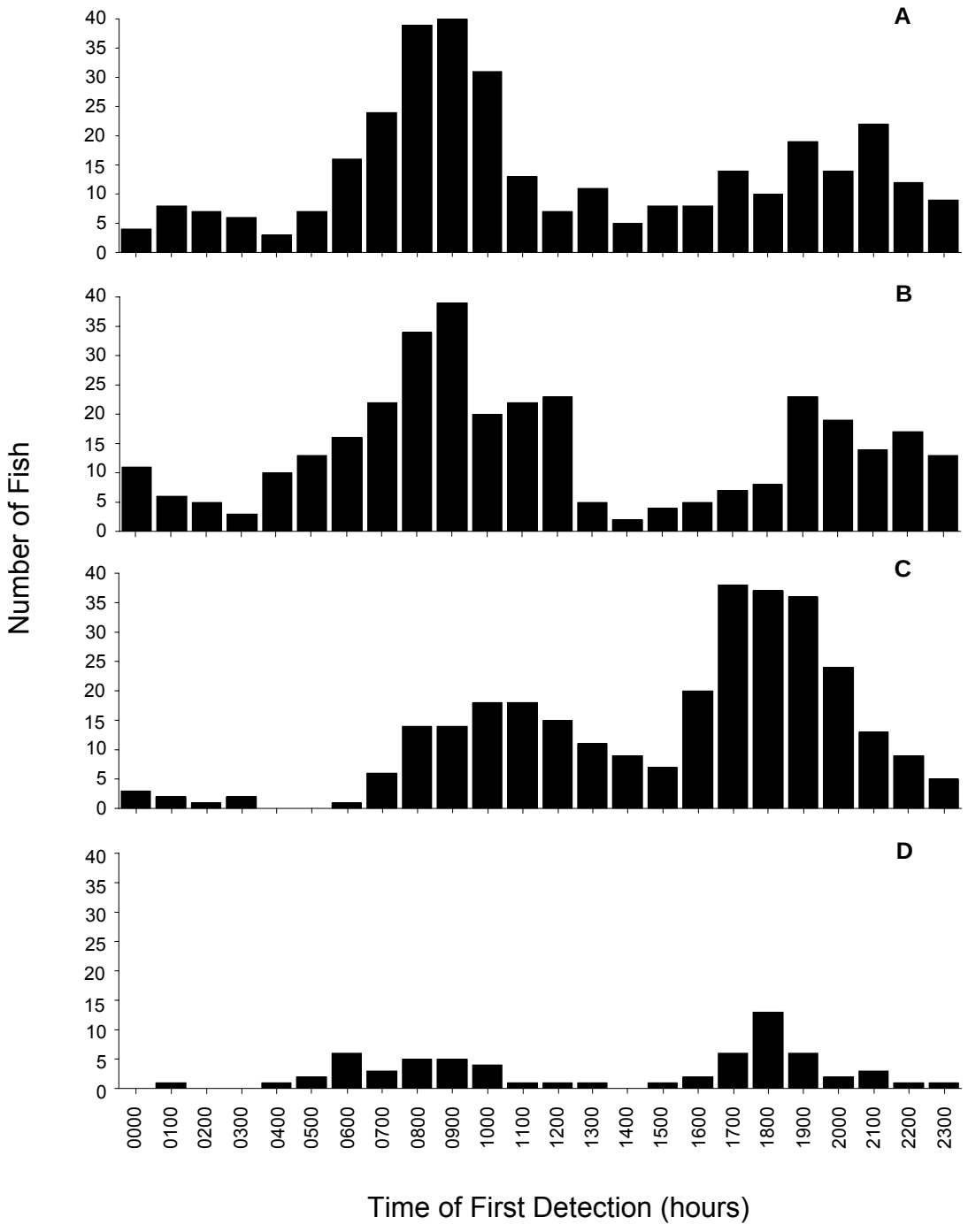

Figure 1-7. Time of first detection for (A) hatchery steelhead, (B) yearling Chinook salmon, (C) subyearling Chinook salmon, and (D) sockeye salmon during spring and summer 2004 at The Dalles Dam.

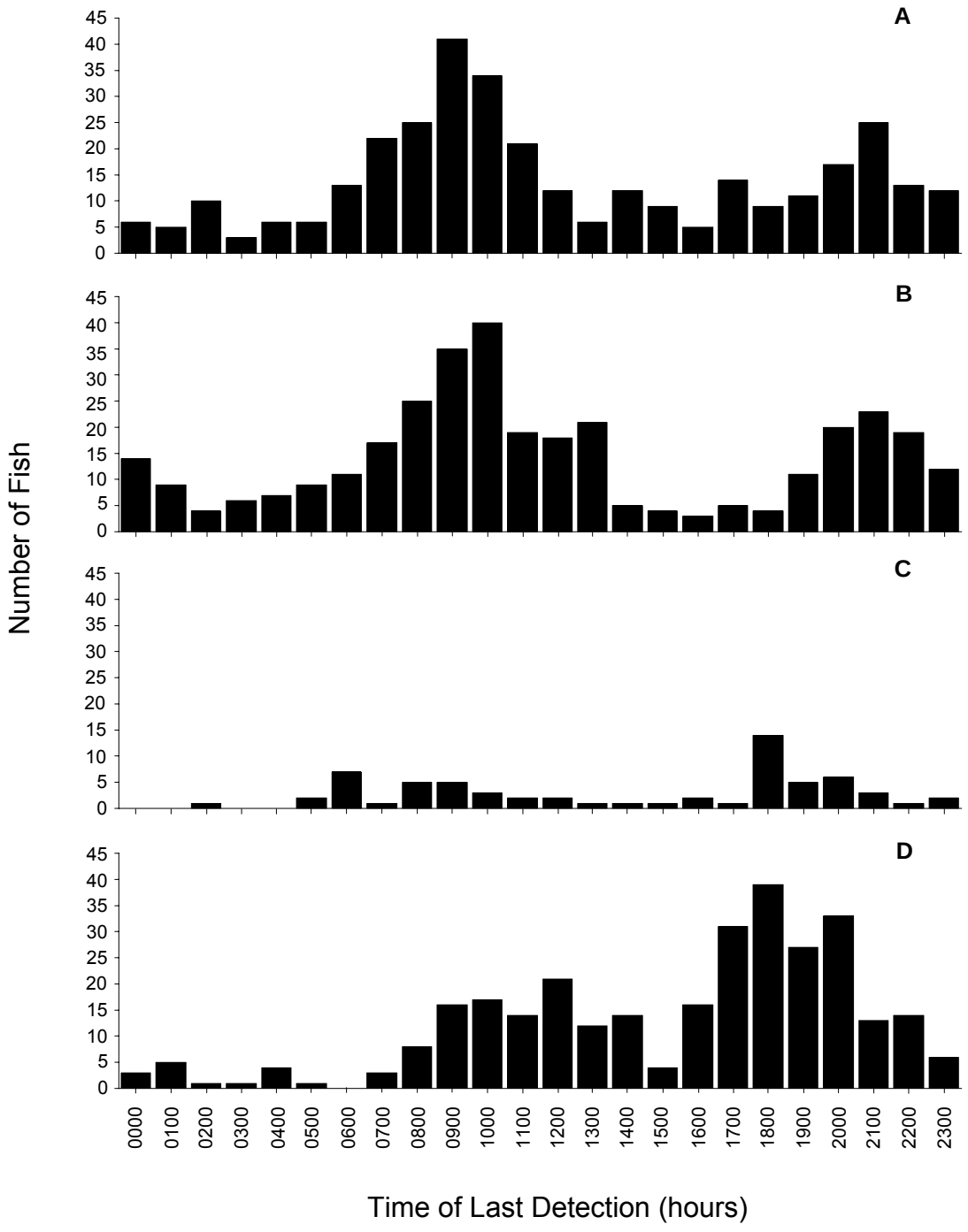

Figure 1-8. Time of last detection for (A) hatchery steelhead, (B) yearling Chinook salmon, (C) subyearling Chinook salmon, and (D) sockeye salmon during spring and summer 2004 at The Dalles Dam.

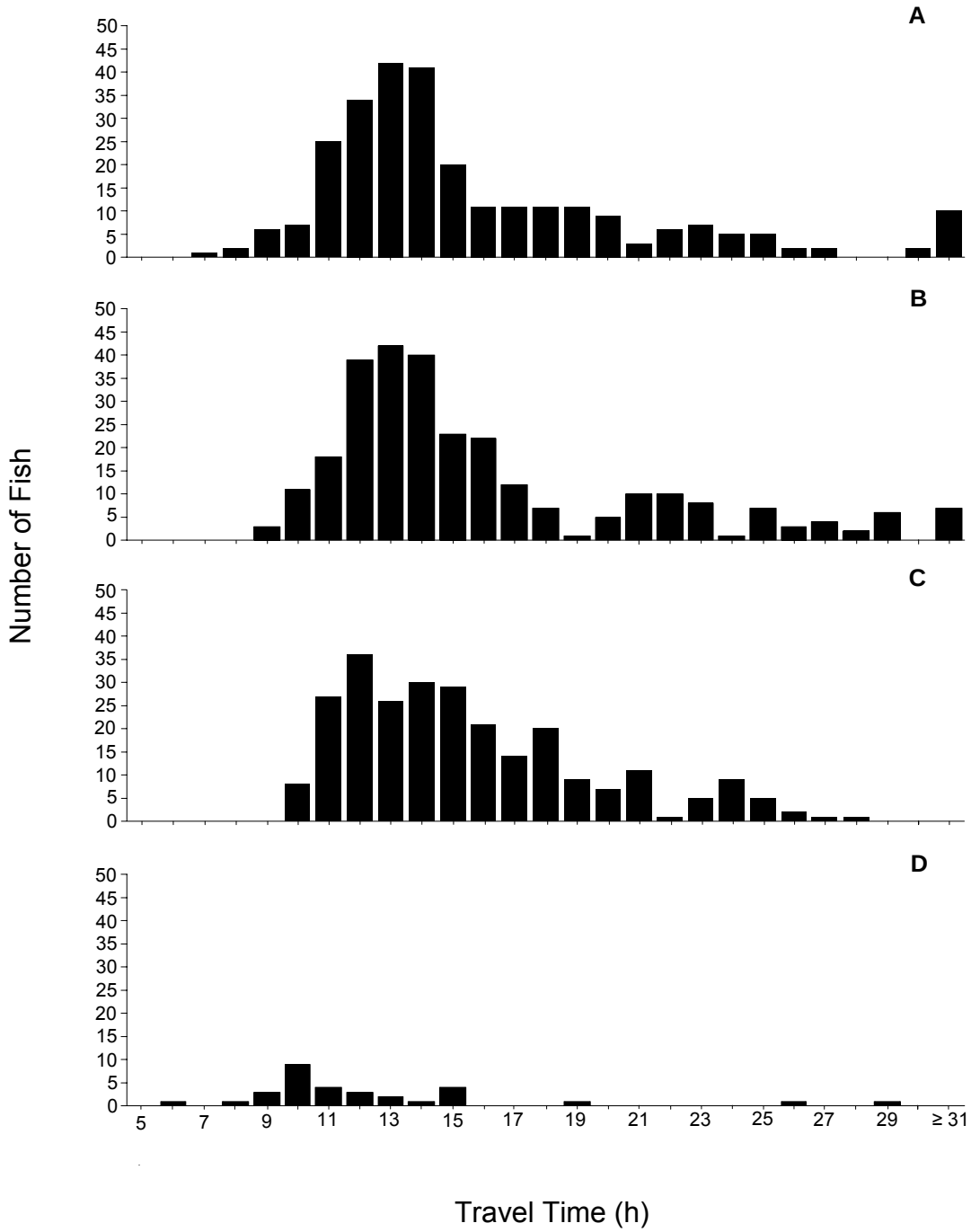

Figure 1-9. Travel times of (A) hatchery steelhead, (B) yearling Chinook salmon, (C) subyearling Chinook salmon, and (D) sockeye salmon from release to first 3D detection during spring and summer 2004 at The Dalles Dam .

of steelhead was 16.4 h. (SE = 0.6, median = 13.9 h; Table 1-6). Residence times of steelhead first detected in the most upstream hydrophone array ranged from 0.2 h to 93.0 h with a median of 0.8 h (Table 1-7; Figure 1-10).

We detected 96.4% (344 of 357) of tagged yearling Chinook salmon and obtained 3D position estimates for 98.5% (339 of 344) that were detected (Table 1-4). The first detections for 75.5% (256 of 339) of the yearling Chinook salmon occurred during the daytime and 24.5% (83 of 339) occurred during the nighttime (Table 1-5; Figure 1-7). The last detections for 71.4% (242 of 339) of the yearling Chinook salmon occurred during the daytime and 28.6% (97 of 339) occurred during the nighttime (Table 1-5; Figure 1-8). Yearling Chinook salmon travel times, from release to first detection, ranged from 8.7 to 49.9 h (Figure 1-9). The mean travel time of yearling Chinook salmon was 16.2 h (SE = 0.4, median = 14.1 h; Table 1-6). Residence times of yearling Chinook salmon first detected in the upstream hydrophone array ranged from 0.14 h to 13.4 h with a median of 0.9 h (Table 1-7 Figure 1-10).

We detected 83.5% (304 of 364) of released subyearling Chinook salmon and obtained 3D position estimates for 99.7% (303 of 304) that were detected (Table 1-4). The first detections for 88.4% (268 of 303) of the subyearling Chinook salmon occurred during the daytime and 11.6% (35 of 303) occurred during the nighttime (Table 1-5; Figure 1-7). The last detections for 84.5% (256 of 303) of the subyearling Chinook salmon occurred during the daytime and 15.5% (47 of 303) occurred during the nighttime (Table 1-5; Figure 1-8). Subyearling Chinook salmon travel times, from release to first detection, ranged from 10.1 to 28.1 h (Figure 1-9). The mean travel time of subyearling Chinook salmon was 15.5 h (SE = 0.2, median = 14.6 h) (Table 1-6). Residence times of subyearling Chinook salmon first detected in the upstream hydrophone array ranged from 0.25 h to 14.7 h with a median of 0.7 h (Table 1-7; Figure 1-10).

We detected 90.7% (68 of 75) of released sockeye salmon and obtained 3D position estimates for 94.1% (64 of 68) that were detected (Table 1-4). The first detections for 89.1% (57 of 64) of the sockeye salmon occurred during the daytime and 10.9% (7 of 64) occurred during the nighttime (Table 1-5; Figure 1-7). The last detections for 87.5% (56 of 64) of the sockeye salmon occurred during the daytime and 12.5% (8 of 64) occurred during the nighttime (Table 1-5; Figure 1-8). Sockeye salmon

Table 1-6. Travel times in hours from time of release to time of the first 3D detection of hatchery steelhead (HST), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOC) during spring and summer 2004 at The Dalles Dam.

Species	*n*	Minimum	Maximum	Mean	Median	S.D.	S.E.
HST	272	7.3	110.8	16.4	13.9	9.3	0.6
CH1	279	8.7	49.9	16.2	14.1	5.9	0.4
CH0	262	10.1	28.1	15.5	14.6	4.0	0.2
SOC	30	5.7	25.8	11.8	10.8	3.7	0.7
Total	843	5.7	110.8	15.9	14.1	6.7	0.2

Table 1-7. Residence times in hours from time of the first 3D detection to time of the last 3D detection of hatchery steelhead (HST), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOC) during spring and summer 2004 at The Dalles Dam.

Species	*n*	Minimum	Maximum	Mean	Median	S.D.	S.E.
HST	258	0.20	93.0	2.3	0.8	7.2	0.4
CH1	267	0.14	13.4	1.5	0.9	2.5	0.2
CH0	257	0.25	14.7	2.0	0.7	3.5	0.2
SOC	29	0.39	12.6	1.2	0.6	2.2	0.4
Total	811	0.14	93.0	1.9	0.8	4.8	0.2

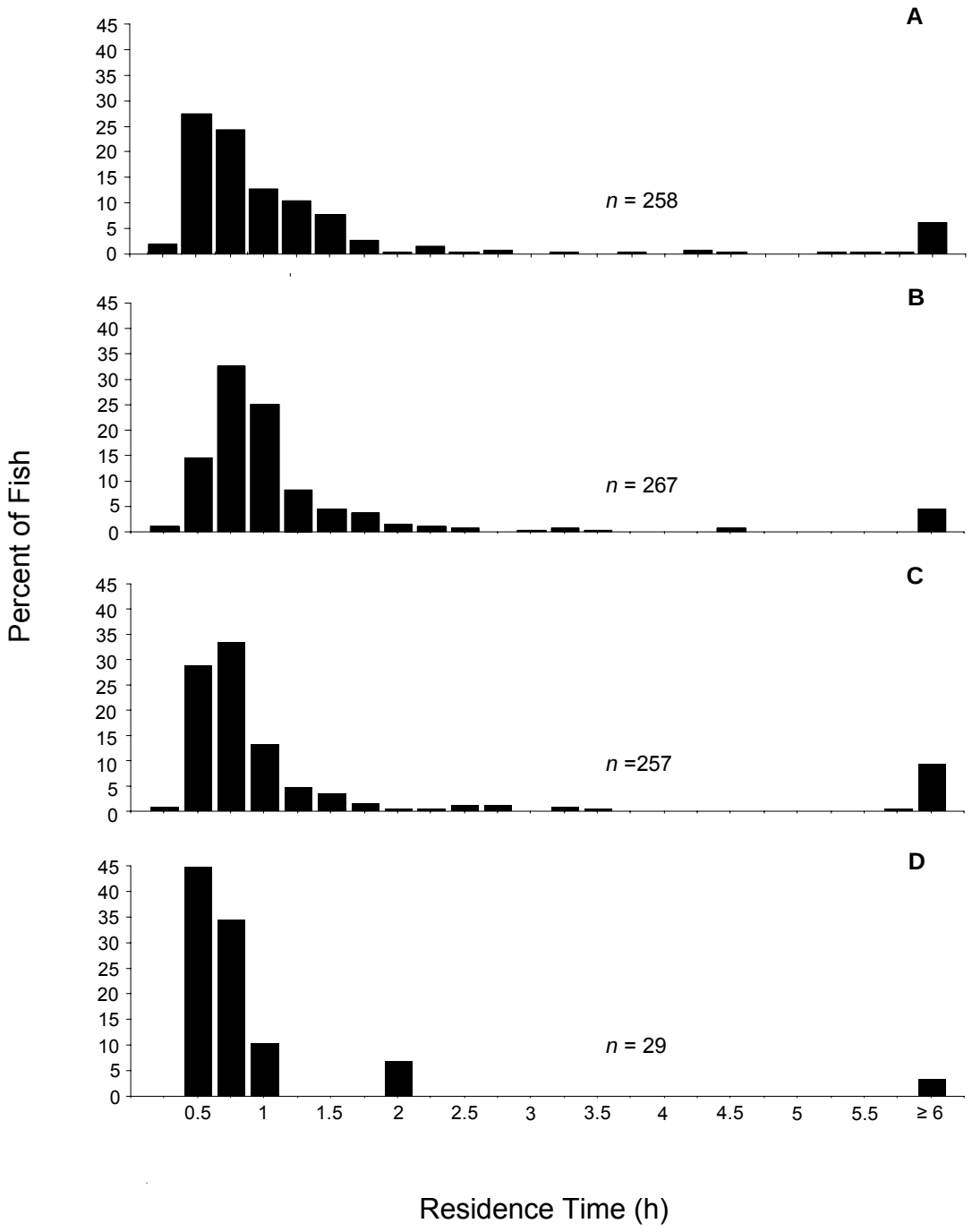

Figure 1-10. Forebay residence times of (A) hatchery steelhead, (B) yearling Chinook salmon, (C) subyearling Chinook salmon, and (D) sockeye salmon during spring and summer 2004 at The Dalles Dam.

travel times, from release to first detection, ranged from 5.7 to 25.8 h (Figure 1-9). The mean travel time of sockeye salmon was 11.8 h (SE = 0.7, median = 10.8 h) (Table 1-6). Residence times of sockeye salmon first detected in the upstream hydrophone array ranged from 0.39 h to 12.6 h with a median of 0.6 h (Table 1-7; Figure 1-10).

Approach Path

During the spring, hatchery steelhead, and yearling Chinook salmon had some common behavioral traits as they approached The Dalles Dam. There are two submerged islands located at the upstream boundary of 3D detection that influenced fish approach to the forebay. Louise Island is located along the earthen dam at the upstream end of Big Eddy and Grave Island is located slightly upstream and toward mid-river from Louise Island. As fish entered the upstream end of the study area, fish generally followed the deeper channel on the north side of Grave Island and to the south along the channel between Grave Island and Louise Island. As fish approach the downstream edge of Big Eddy their paths tended to converge in a relatively deep area at the upstream end of the powerhouse. As fish continued to move downstream, their paths diverged into two general areas. Some fish turned toward the powerhouse and moved downstream along the powerhouse. Other fish took a more direct path toward the spillway. Downstream of the powerhouse, the paths of fish traveling along the powerhouse and the fish traveling in mid-river converged as they neared open spillbays 1-6.

The diel patterns of approach were less distinct for hatchery steelhead than for yearling and subyearling Chinook salmon. In general, fish were more likely to travel in the mid-river area during the nighttime. Steelhead approached the spillway more directly during the nighttime compared to daytime when their paths often shifted toward the powerhouse (Figures 1-11, 1-12). During the daytime, the mode of the steelhead distribution, including about 40-60% of the fish, approached the powerhouse at an angle and continued along the powerhouse past main turbine unit 16 until they were some distance along the non-overflow wall. Once the steelhead reached the non-overflow wall

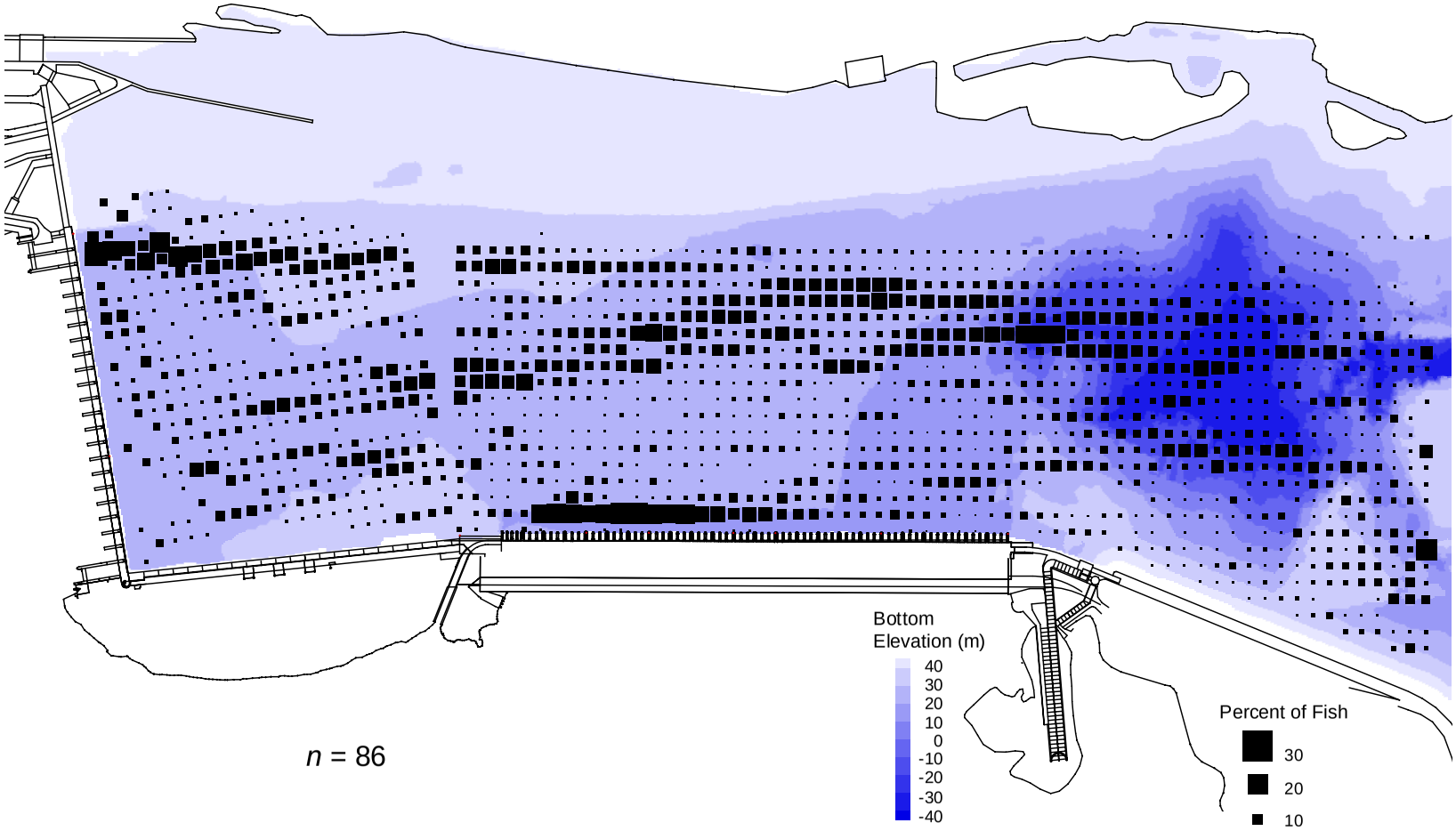

Figure 1-11. Horizontal distributions of acoustically-tagged hatchery steelhead entering the forebay of The Dalles Dam during nighttime, 2100 to 0529 hours, from 29 April to 7 June 2004. Fish approach paths were constructed by dividing the forebay into 19 vertical planes parallel to the spillway and 60 vertical planes perpendicular to the powerhouse that were spaced 20 m apart. Each plane was divided into 20 m wide bins represented by the black squares. The size of the squares represents the number of fish swimming through a specific bin as a percent of the total number of fish crossing the specific plane. The deepest regions of the forebay are represented in dark blue by the bathymetry map in the background.

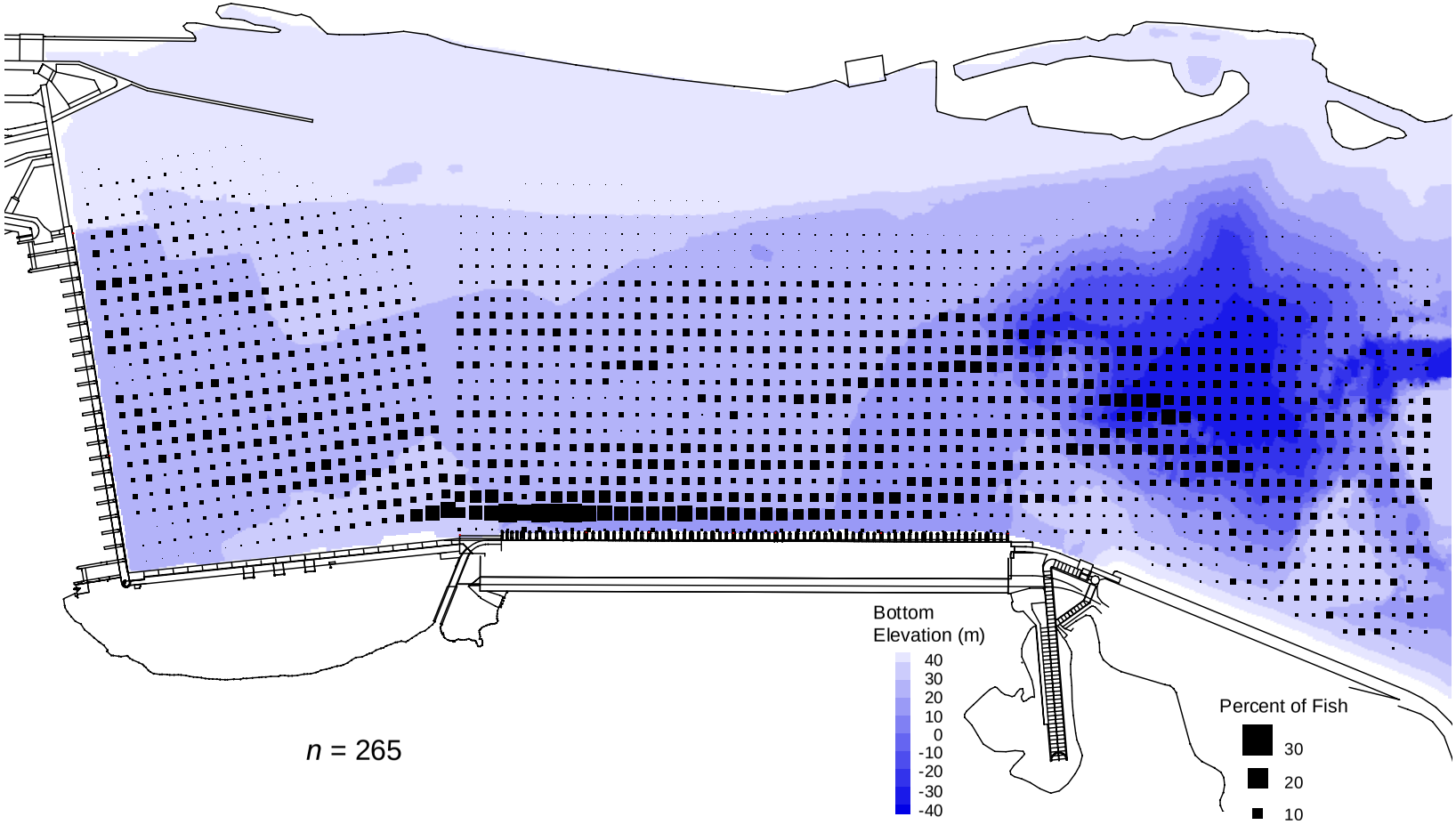

Figure 1-12. Horizontal distributions of acoustically-tagged hatchery steelhead entering the forebay of The Dalles Dam during daytime, 0530 to 2059 hours, from 29 April to 7 June 2004. Fish approach paths were constructed by dividing the forebay into 19 vertical planes parallel to the spillway and 60 vertical planes perpendicular to the powerhouse that were spaced 20 m apart. Each plane was divided into 20 m wide bins represented by the black squares. The size of the squares represents the number of fish swimming through a specific bin as a percent of the total number of fish crossing the specific plane. The deepest regions of the forebay are represented in dark blue by the bathymetry map in the background.

area, they traveled along a relatively straight line towards the open spillbays 1-6. During the nighttime, about 20-40% of the steelhead approach paths were directed towards the powerhouse. Daytime and nighttime steelhead approach paths to the powerhouse were similar.

A higher percentage of yearling Chinook salmon approached the spillway along a direct path during the nighttime than during the daytime (Figures 1-13, 1-14). During the daytime, about 75-85% of yearling Chinook salmon approached the powerhouse. During the nighttime, 25-45% approached the powerhouse prior to approaching the spillway. Yearling Chinook salmon generally approached the powerhouse in the area of main turbine unit 16. Once at the powerhouse, these fish swam along the dam face until near the non-overflow wall area and then angled towards the open spillbays. The pattern of powerhouse approach paths of yearling Chinook salmon at nighttime was similar to the pattern observed for steelhead. Although the percent of fish approaching the powerhouse differed between daytime and nighttime, the paths along which yearling Chinook salmon approached the powerhouse were similar during daytime and nighttime.

As they traveled through the forebay, paths for subyearling and yearling Chinook salmon were similar. A higher percentage of subyearling Chinook salmon directly approached the spillway during the nighttime than during the daytime (Figures 1-15, 1-16). During the daytime, 70-80% of the subyearling Chinook salmon approached the powerhouse after entering the east end of the study area. These fish were first detected near main turbine units 1-9. Once at the powerhouse, subyearling Chinook salmon swam along the powerhouse until they passed the fish turbine units and then angled toward the open spillbays. During the nighttime, 10-35% of the fish paths approached the powerhouse rather than directly approaching the spillway. These fish were first detected near main turbine units 16-22.

During the daytime, hatchery steelhead, yearling Chinook salmon, and subyearling Chinook salmon were widely distributed in the water column as they approached the earthen dam. In the area of the earthen dam, the forebay depth varies from 12-92 m with the deeper portion being in the thalweg. Shifts in fish approach depths were associated with a decrease in forebay depth. Downstream of the earthen dam the bathymetry rises and becomes more uniform at 24 m in depth. The vertical

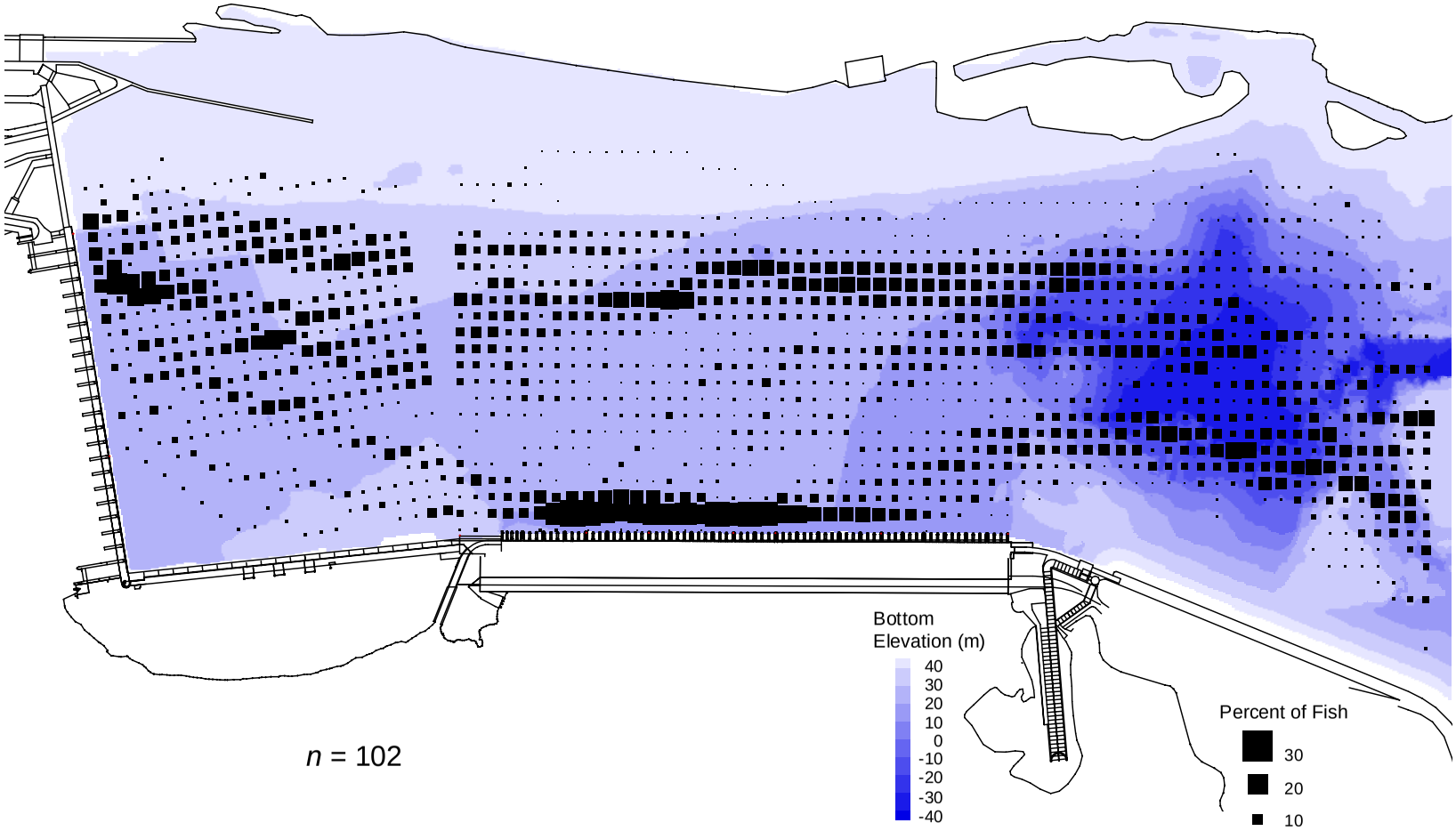

Figure 1-13. Horizontal distributions of acoustically-tagged yearling Chinook salmon entering the forebay of The Dalles Dam during nighttime, 2100 to 0529 hours, from 29 April to 7 June 2004. Fish approach paths were constructed by dividing the forebay into 19 vertical planes parallel to the spillway and 60 vertical planes perpendicular to the powerhouse that were spaced 20 m apart. Each plane was divided into 20 m wide bins represented by the black squares. The size of the squares represents the number of fish swimming through a specific bin as a percent of the total number of fish crossing the specific plane. The deepest regions of the forebay are represented in dark blue by the bathymetry map in the background.

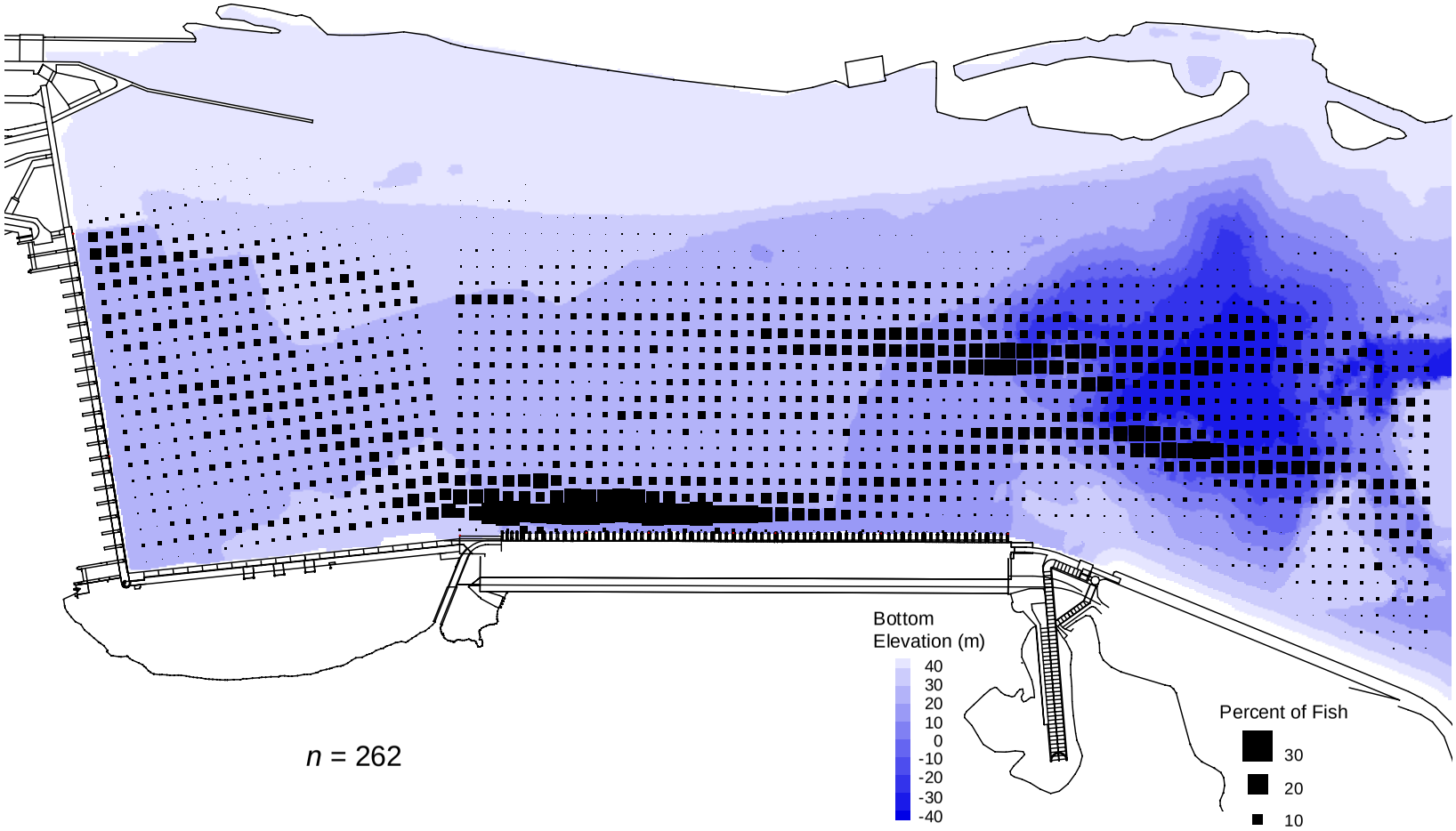

Figure 1-14. Horizontal distributions of acoustically-tagged yearling Chinook salmon entering the forebay of The Dalles Dam during daytime, 0530 to 2059 hours, from 29 April to 7 June 2004. Fish approach paths were constructed by dividing the forebay into 19 vertical planes parallel to the spillway and 60 vertical planes perpendicular to the powerhouse that were spaced 20 m apart. Each plane was divided into 20 m wide bins represented by the black squares. The size of the squares represents the number of fish swimming through a specific bin as a percent of the total number of fish crossing the specific plane. The deepest regions of the forebay are represented in dark blue by the bathymetry map in the background.

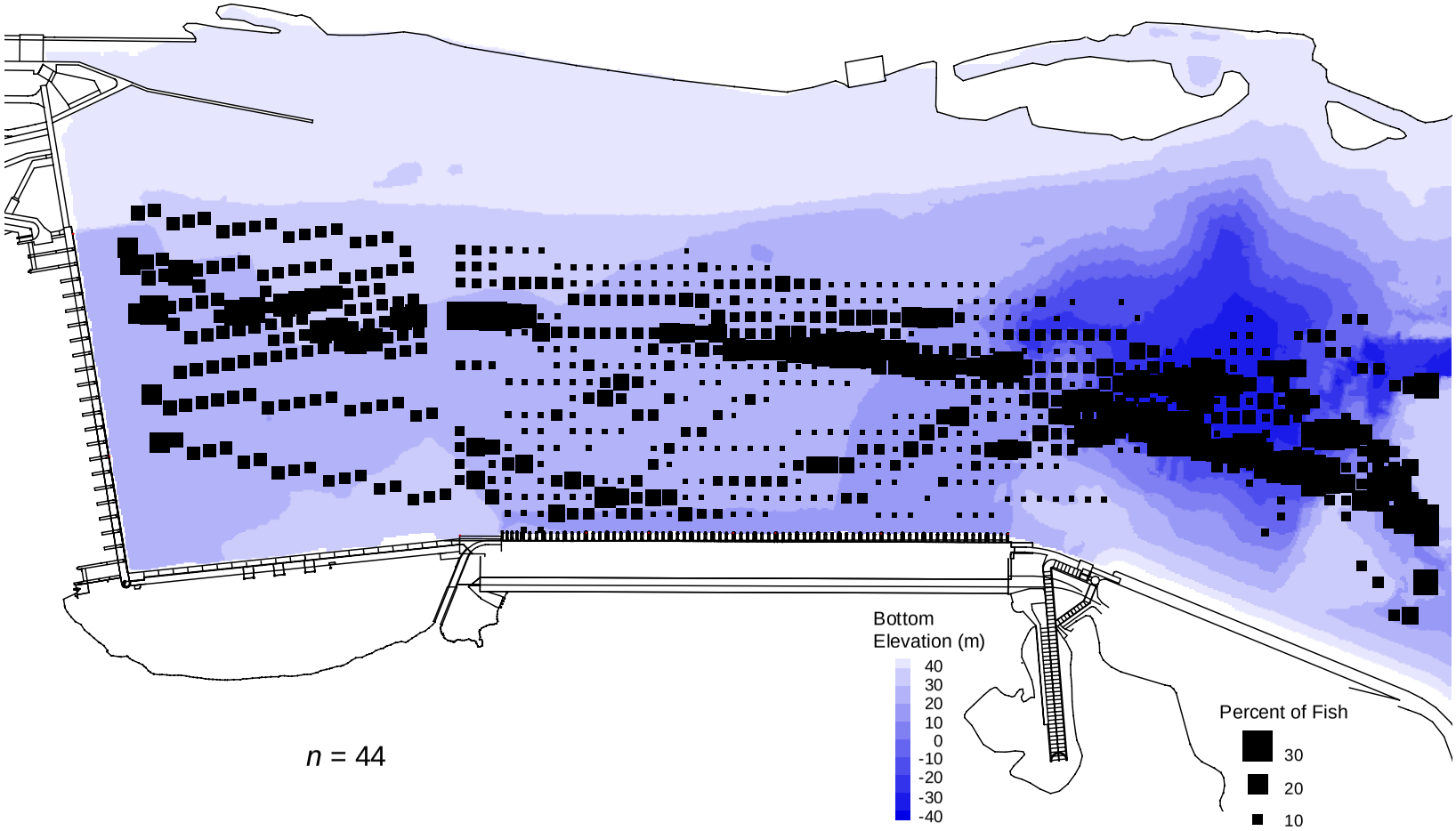

Figure 1-15. Horizontal distributions of acoustically-tagged subyearling Chinook salmon entering the forebay of The Dalles Dam during nighttime, 2100 to 0529 hours, from 22 June to 26 July 2004. Fish approach paths were constructed by dividing the forebay into 19 vertical planes parallel to the spillway and 60 vertical planes perpendicular to the powerhouse that were spaced 20 m apart. Each plane was divided into 20 m wide bins represented by the black squares. The size of the squares represents the number of fish swimming through a specific bin as a percent of the total number of fish crossing the specific plane. The deepest regions of the forebay are represented in dark blue by the bathymetry map in the background.

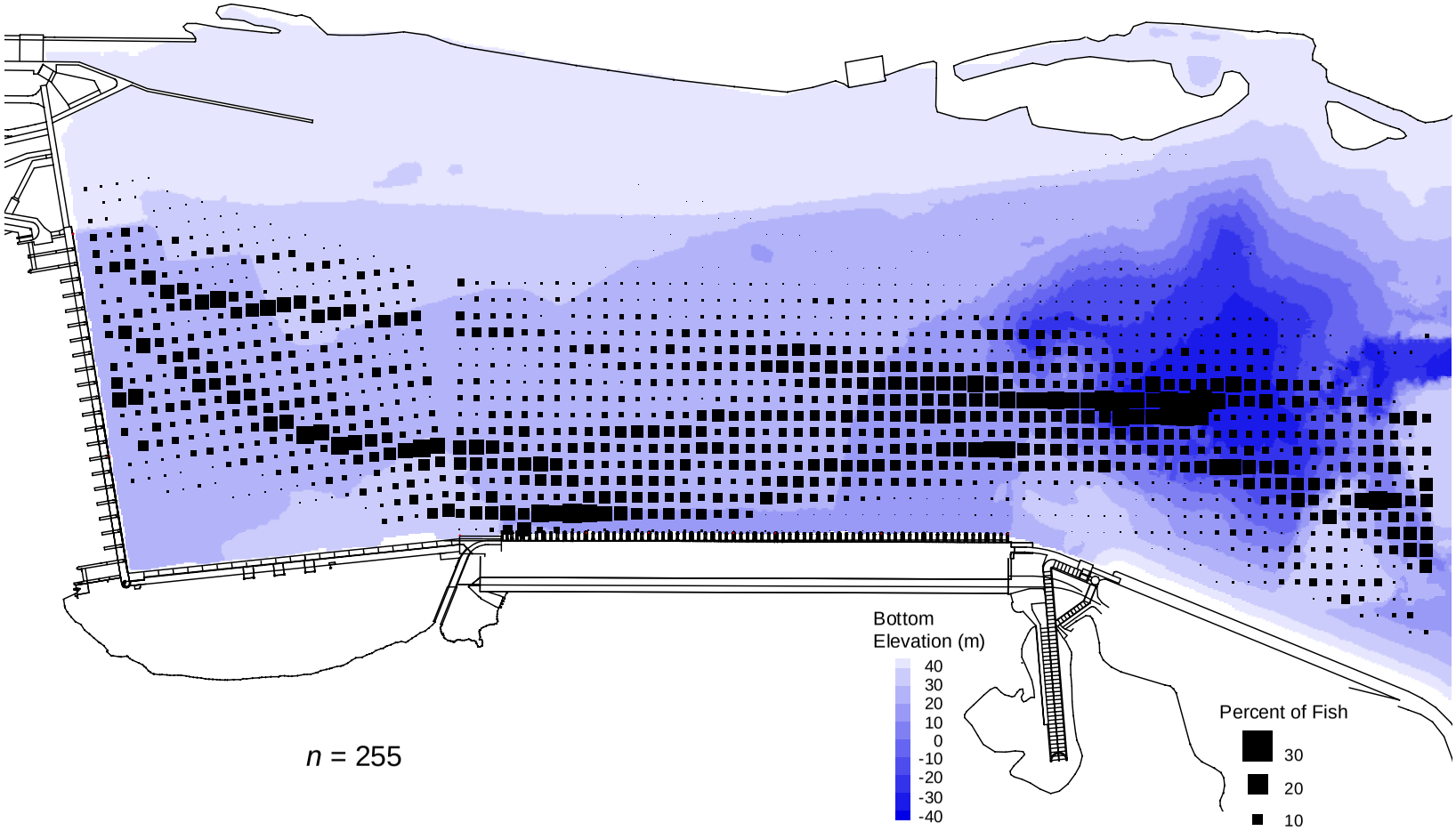

Figure 1-16. Horizontal distributions of acoustically-tagged subyearling Chinook salmon entering the forebay of The Dalles Dam during daytime, 0530 to 2059 hours, from 22 June to 26 July 2004. Fish approach paths were constructed by dividing the forebay into 19 vertical planes parallel to the spillway and 60 vertical planes perpendicular to the powerhouse that were spaced 20 m apart. Each plane was divided into 20 m wide bins represented by the black squares. The size of the squares represents the number of fish swimming through a specific bin as a percent of the total number of fish crossing the specific plane. The deepest regions of the forebay are represented in dark blue by the bathymetry map in the background.

distribution of all species shifted toward the surface of the water as forebay depth became shallower (Figure 1-17). Additionally, all species of fish at greater distance from the powerhouse were generally deeper and moved toward the surface as they approached the powerhouse.

Depth of approach differed by diel period between steelhead and Chinook salmon. Yearling and subyearling Chinook salmon approached deeper during the daytime than at nighttime. During the daytime 60-90% of the yearling and subyearling Chinook salmon approached the dam at a depth greater than 6 m (Figures 1-18, 1-19). During the nighttime 60-90% of the yearling and subyearling Chinook salmon approached the dam at a depth less than 6 m (Figures 1-20, 1-21). Conversely, hatchery steelhead approached deeper during the nighttime than during the daytime. For example, most of the steelhead approach depths were distributed between 0 and 7 m during the daytime whereas during the nighttime approach depths were more evenly distributed between 0 and 20 m (Figures 1-22, 1-23).

Approach Velocity and Residence

Regardless of species, tagged fish had the highest approach velocities in locations with the highest water velocities. Maximum fish approach velocities were concentrated near open spillbays and the sluiceway entrances. In general, average approach velocities of fish did not change from the time they approached the earthen dam until passage at the spillway. Hatchery steelhead had the highest average approach velocity at 2.1 m/s for all species during the daytime (Figure 1-24). During the nighttime, yearling Chinook salmon had the highest average approach velocity at 1.7 m/s of all species (Figure 1-25). Higher approach velocities were generally related to lower residence times of fish in the individual bins. All species had shorter residence times during the daytime than during the nighttime (Figures 1-26, 1-27). Furthermore, the shortest residence times were associated with areas of high water velocities, such as upstream of the spillway. Longer residence times were observed for all species around the west end of the powerhouse in the area of the main turbine unit 1 sluiceway entrance.

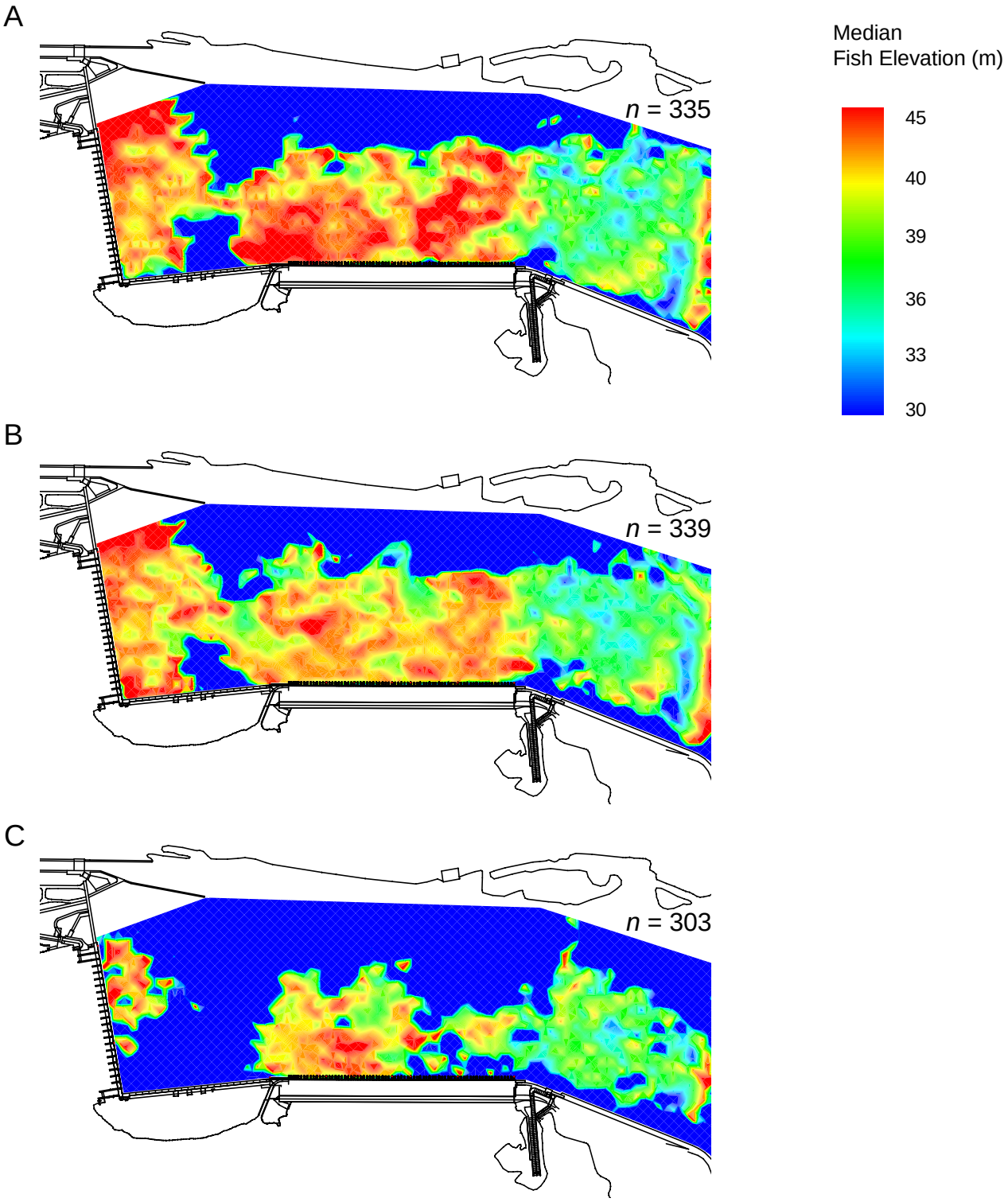

Figure 1-17. Plan views of median fish elevation for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during 2004 at The Dalles Dam.

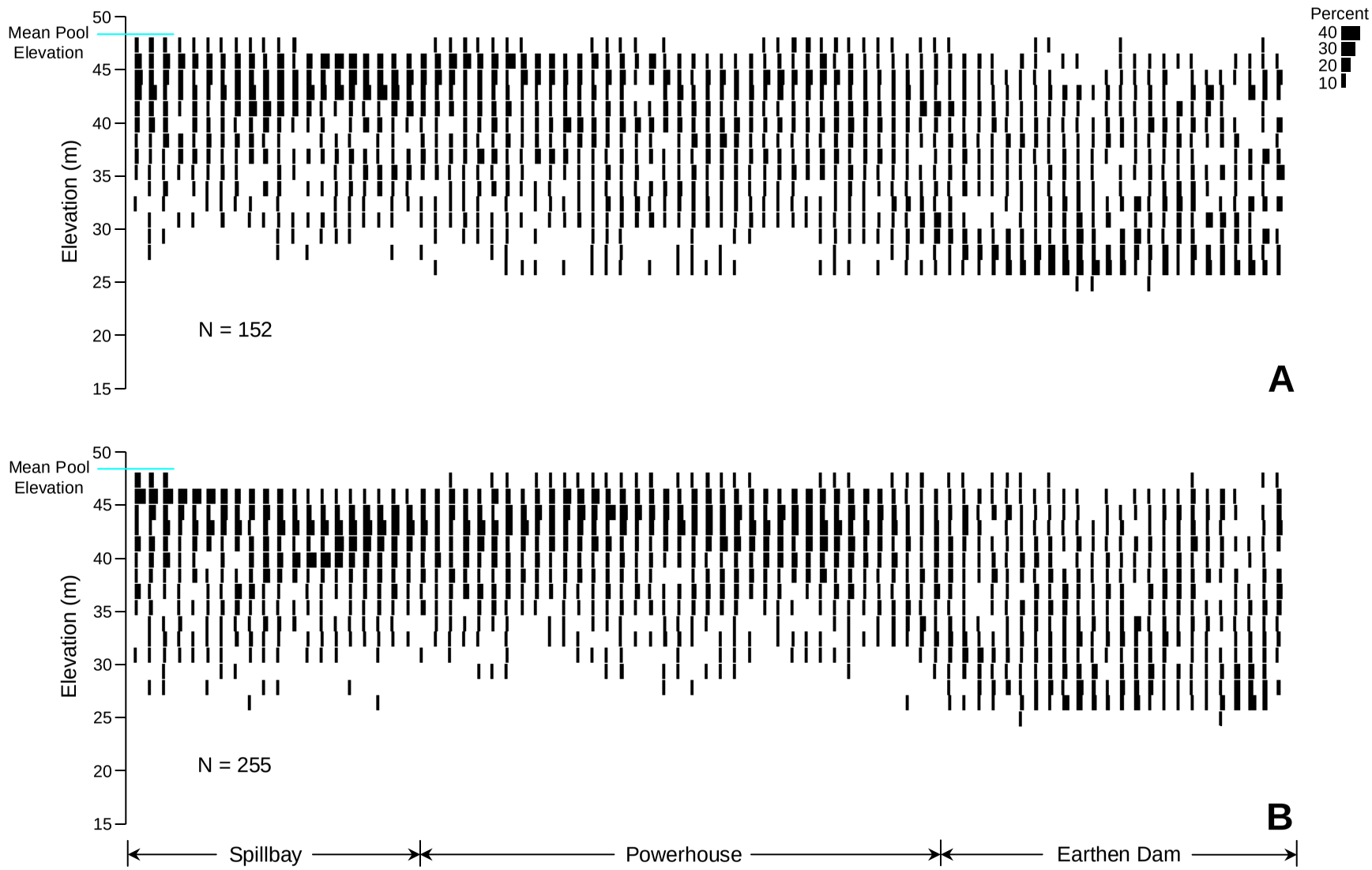

Figure 1-18. Vertical distributions of yearling Chinook salmon entering the forebay of The Dalles Dam in 2004 during daytime, 0530 to 2059 hours, for (A) fish more than 180 m from the non-overflow wall or powerhouse, and (B) fish within 180 m of the non-overflow wall or powerhouse.

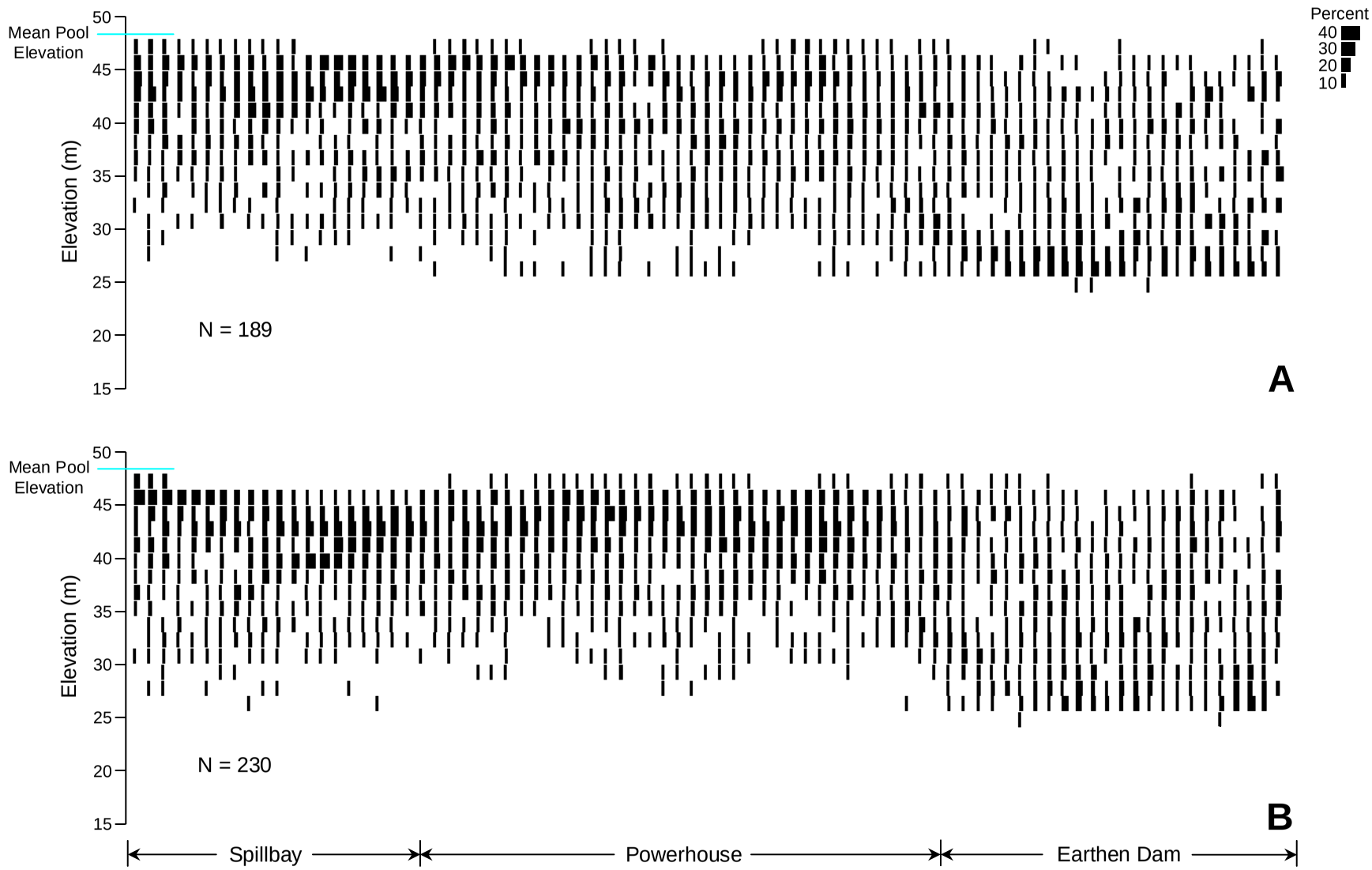

Figure 1-19. Vertical distributions of subyearling Chinook salmon entering the forebay of The Dalles Dam in 2004 during daytime, 0530 to 2059 hours, for (A) fish more than 180 m from the non-overflow wall or powerhouse, and (B) fish within 180 m of the non-overflow wall or powerhouse.

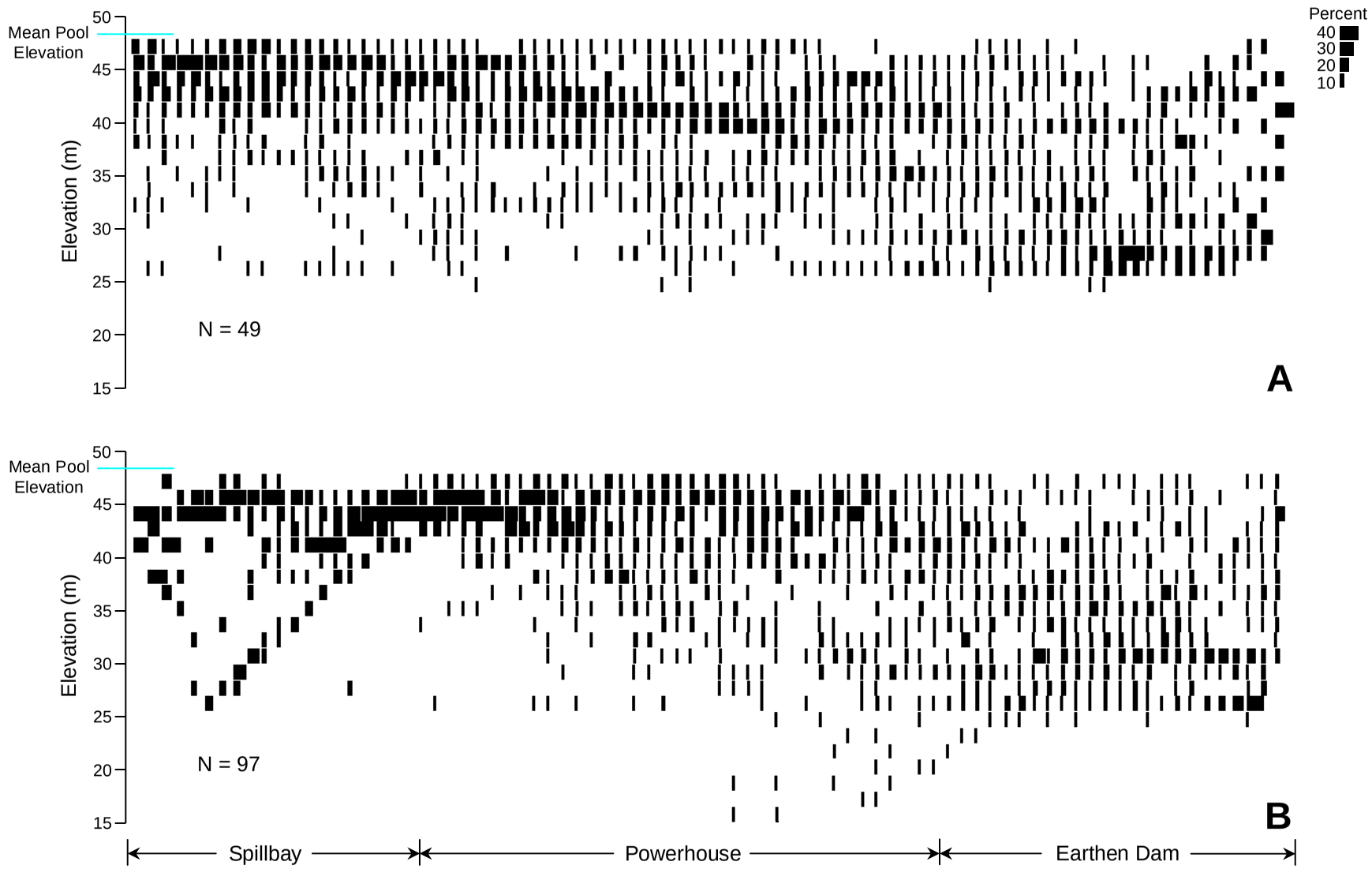

Figure 1-20. Vertical distributions of yearling Chinook salmon entering the forebay of The Dalles Dam in 2004 during nighttime, 2100 to 0529 hours, for (A) fish more than 180 m from the non-overflow wall or powerhouse, and (B) fish within 180 m of the non-overflow wall or powerhouse.

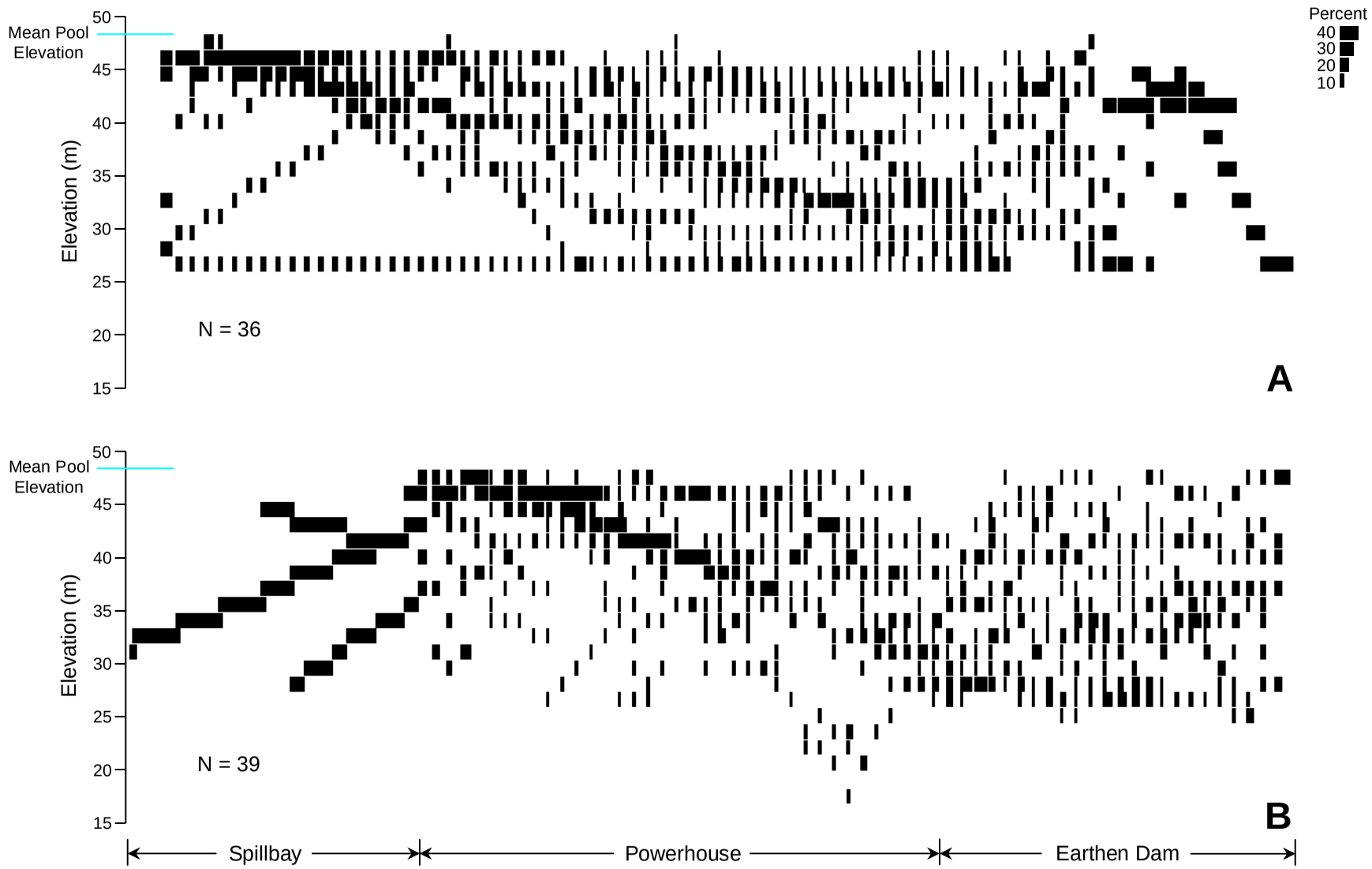

Figure 1-21. Vertical distributions of subyearling Chinook salmon entering the forebay of The Dalles Dam in 2004 during nighttime, 2100 to 0529 hours, for (A) fish more than 180 m from the non-overflow wall or powerhouse, and (B) fish within 180 m of the non-overflow wall or powerhouse.

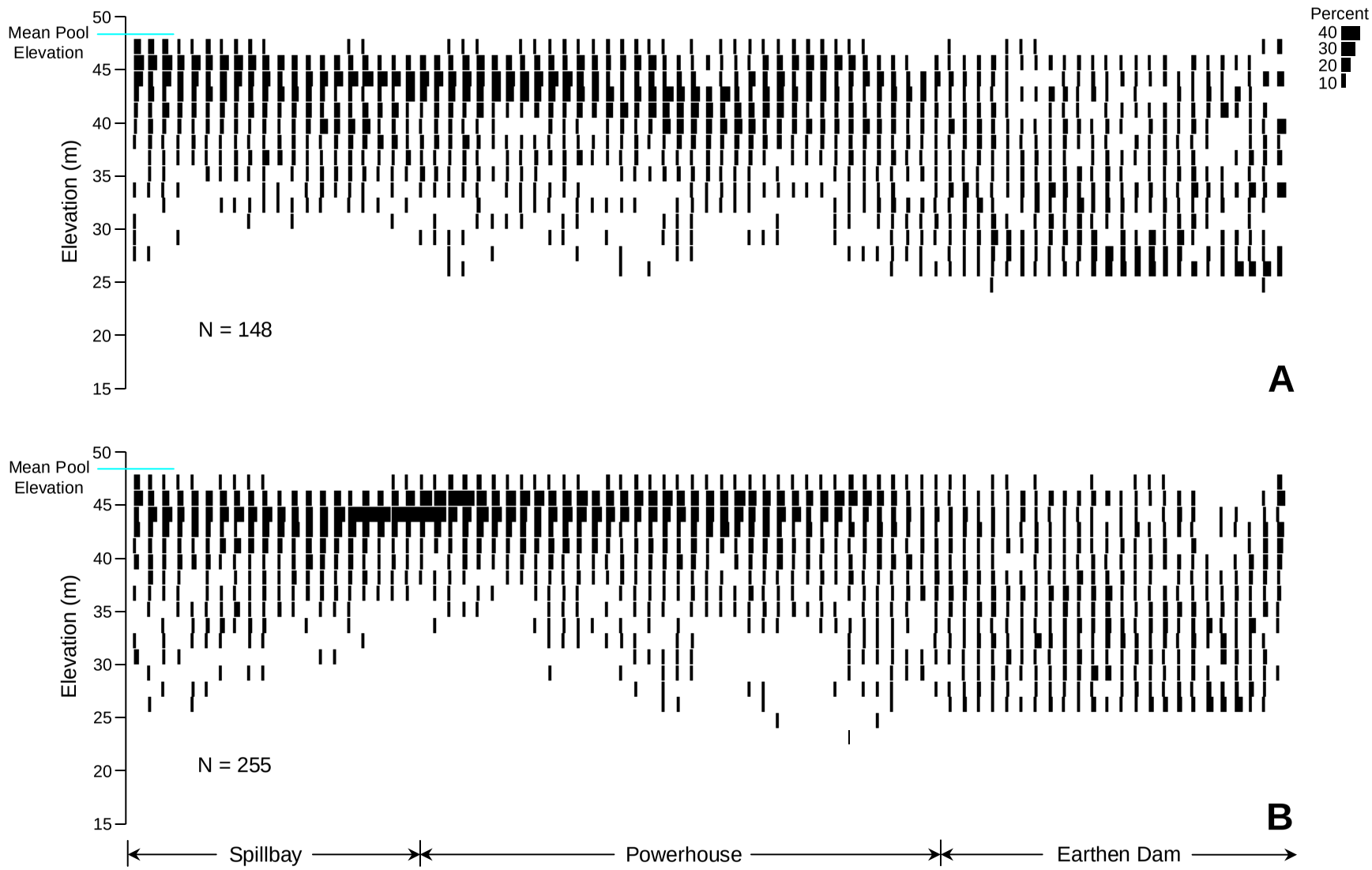

Figure 1-22. Vertical distributions of hatchery steelhead entering the forebay of The Dalles Dam in 2004 during daytime, 0530 to 2059 hours, for (A) fish more than 180 m from the non-overflow wall or powerhouse, and (B) fish within 180 m of the non-overflow wall or powerhouse.

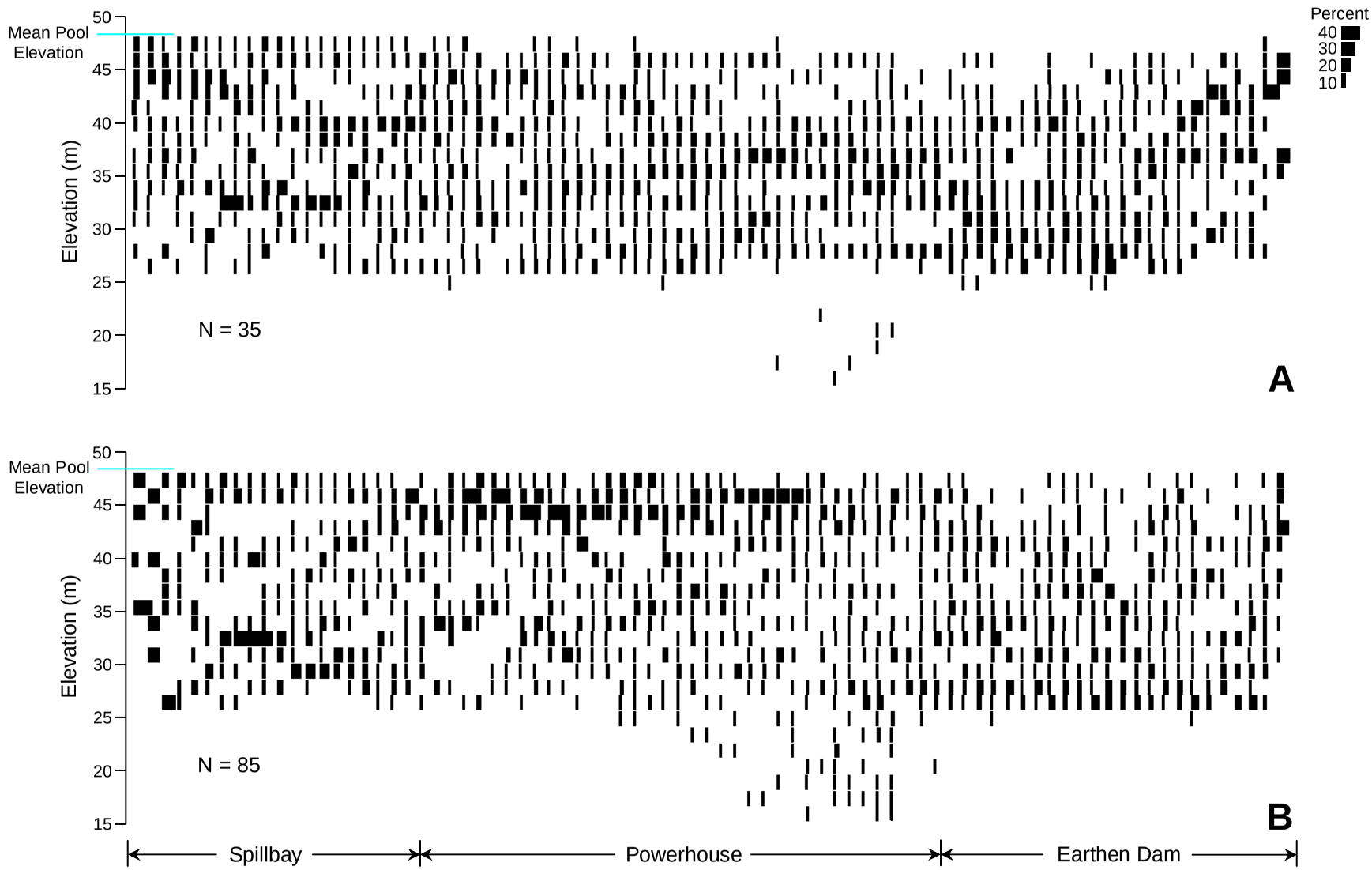

Figure 1-23. Vertical distributions of hatchery steelhead entering the forebay of The Dalles Dam in 2004 during nighttime, 2100 to 0529 hours, for (A) fish more than 180 m from the non-overflow wall or powerhouse, and (B) fish within 180 m of the non-overflow wall or powerhouse.

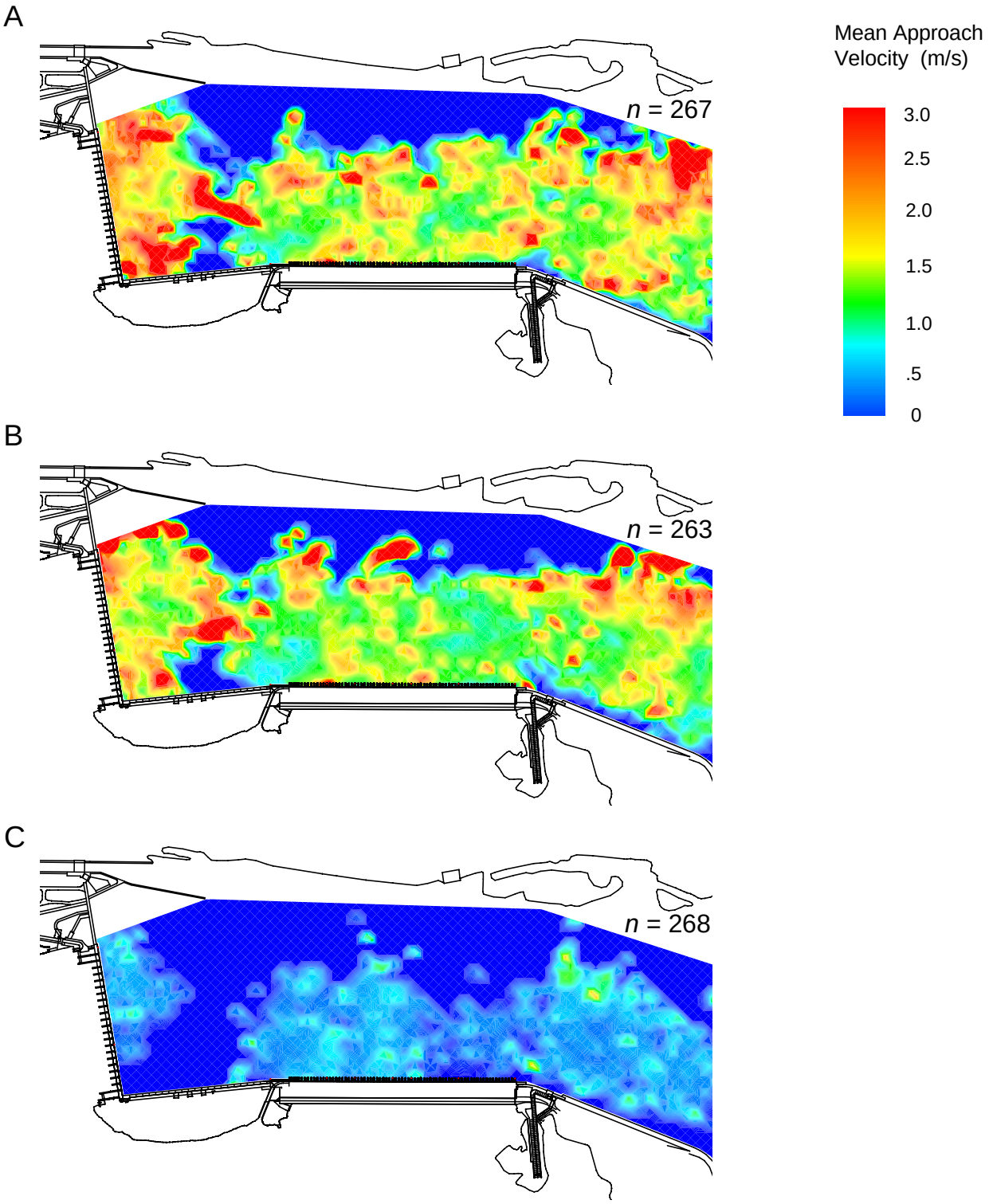

Figure 1-24. Plan views of mean approach velocity for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during daytime, 0530 to 2059 hours, during 2004 at The Dalles Dam.

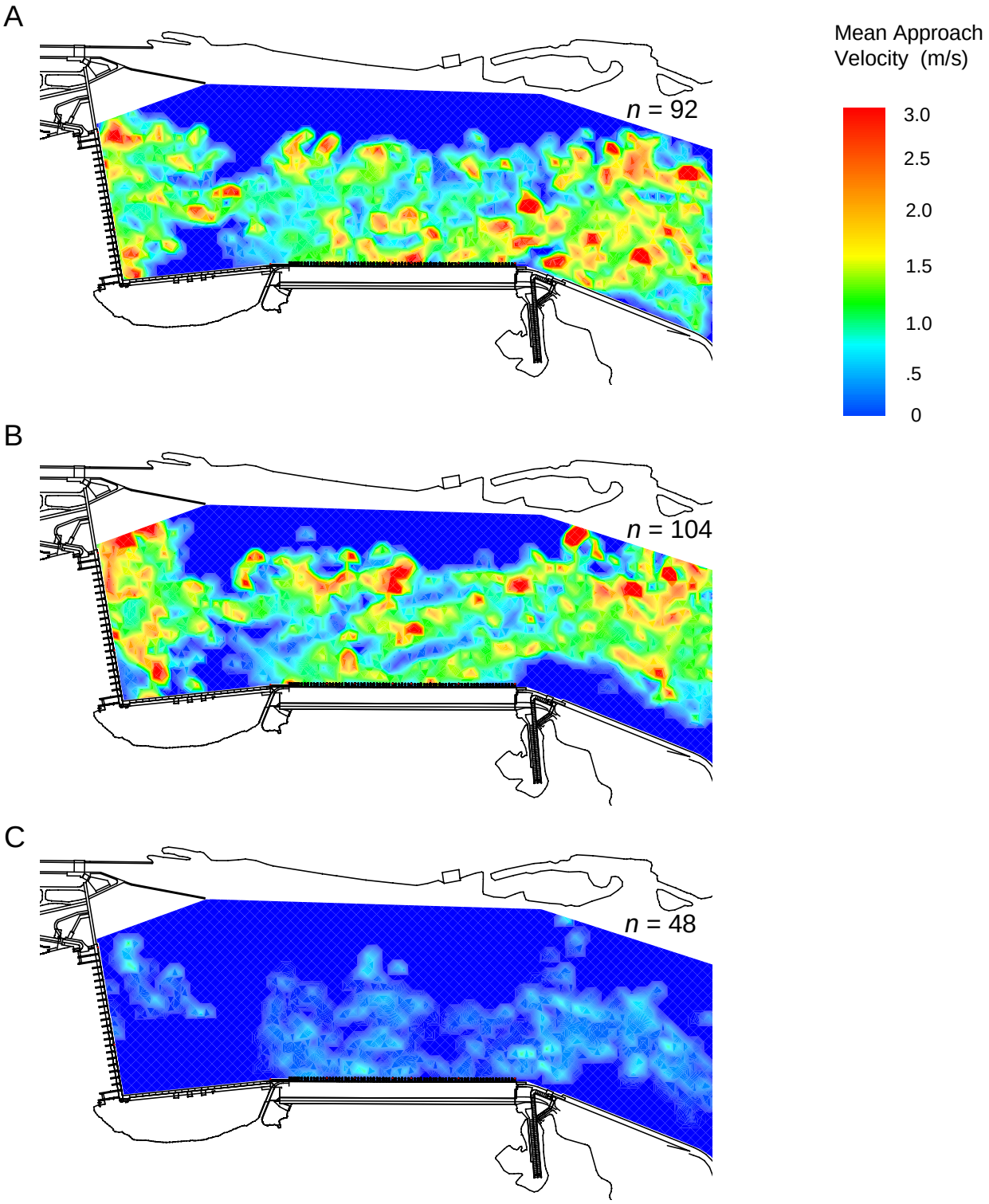

Figure 1-25. Plan views of mean approach velocity for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during nighttime, 2100 to 0529 hours, during 2004 at The Dalles Dam.

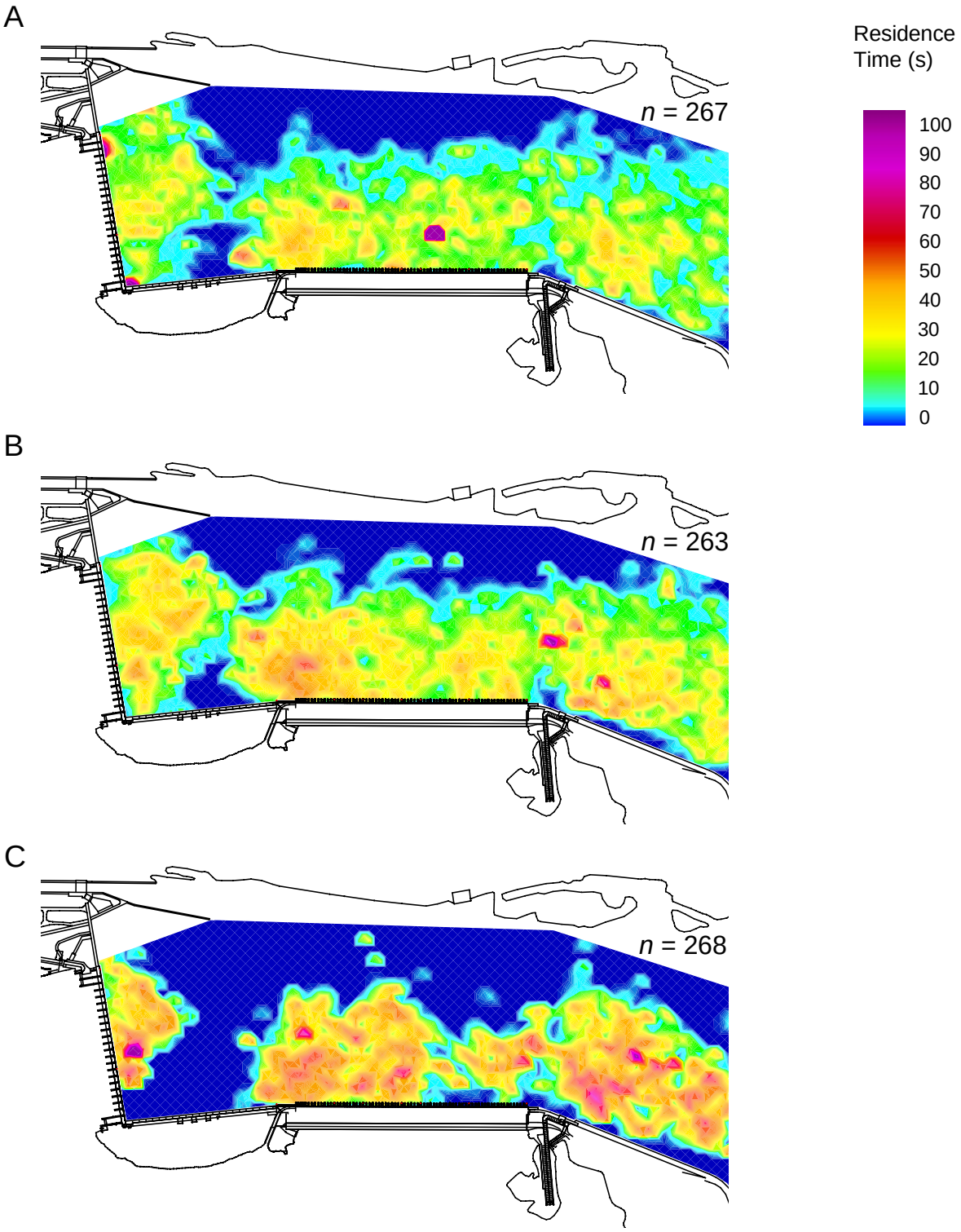

Figure 1-26. Plan views of median residence time for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during daytime, 0530 to 2059 hours, during 2004 at The Dalles Dam.

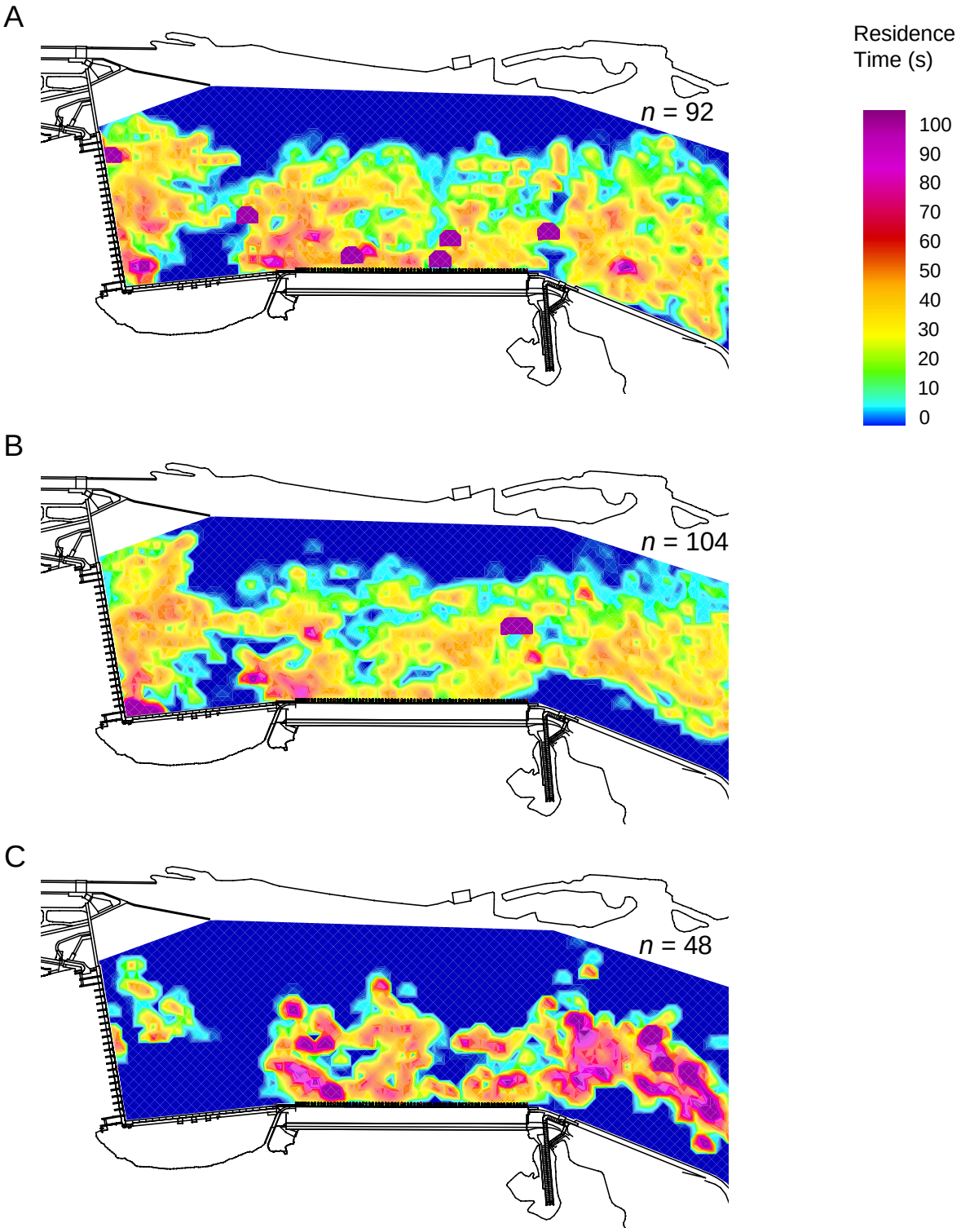

Figure 1-27. Plan views of median residence time for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during nighttime, 2100 to 0529 hours, during 2004 at The Dalles Dam.

Ice and Trash Sluiceway and Spillway Passage Efficiency

We calculated overall passage efficiency of fish passing through the sluiceway as a percent of the total number of fish detected in the forebay during two test configurations. During the study when the sluiceway entrance at main turbine unit 1 was open and 18 was closed, $SLPE_{MU1}$ was slightly higher for yearling Chinook salmon than for hatchery steelhead. When the sluiceway entrance at main turbine unit 1 was open and 18 was closed, $SLPE_{MU1}$ was 6.2% (11 of 178) for steelhead, 7.7% (13 of 168) for yearling Chinook salmon, and 1.9% (4 of 206) for subyearling Chinook salmon. When the sluiceway entrances at main turbine unit 1 and 18 were open, $SLPE_{MU1}$ was 3.1% (5 of 159) for steelhead, 7.5% (13 of 173) for yearling Chinook salmon, and 0% (0 of 97) for subyearling Chinook salmon. When the sluiceway entrances at main turbine unit 1 and 18 were open, $SLPE_{MU18}$ for steelhead, yearling Chinook salmon, and subyearling Chinook salmon were 1.2% (2 of 159), 0.6% (1 of 173), and 0.1% (1 of 97), respectively.

We calculated sluiceway passage efficiency ($SLPE_D$) for fish swimming within a specific distance of the sluiceway entrances and subsequently passing through the sluiceway as a percent of the total number of fish detected within that distance. Passage efficiencies were calculated for ten distances from the sluiceway entrance spaced 10 m apart from 10 m upstream of the sluiceway entrances to 100 m upstream of the sluiceway entrances. $SLPE_D$ was at least 7% for all fish that swam within 10 m of the main turbine unit 1 sluiceway entrance. At 50 m from the main turbine unit 1 sluiceway entrance, hatchery steelhead and yearling Chinook salmon $SLPE_D$ was greater than 17%, whereas subyearling Chinook salmon $SLPE_D$ was less than 7%. $SLPE_D$ declined as distance increased from the sluiceway entrances, but the rate of decline was relatively small for distances between 50 and 100 m (Figure 1-28).

We calculated the volumetric sluiceway passage efficiency ($SLPE_V$) of fish detected within a specific bin and subsequently passing through the ice and trash sluiceway entrances as a percent of the total number of fish detected within the bin. We observed $SLPE_V$ between 5-30% for the sluiceway entrances at main turbine unit 1 for

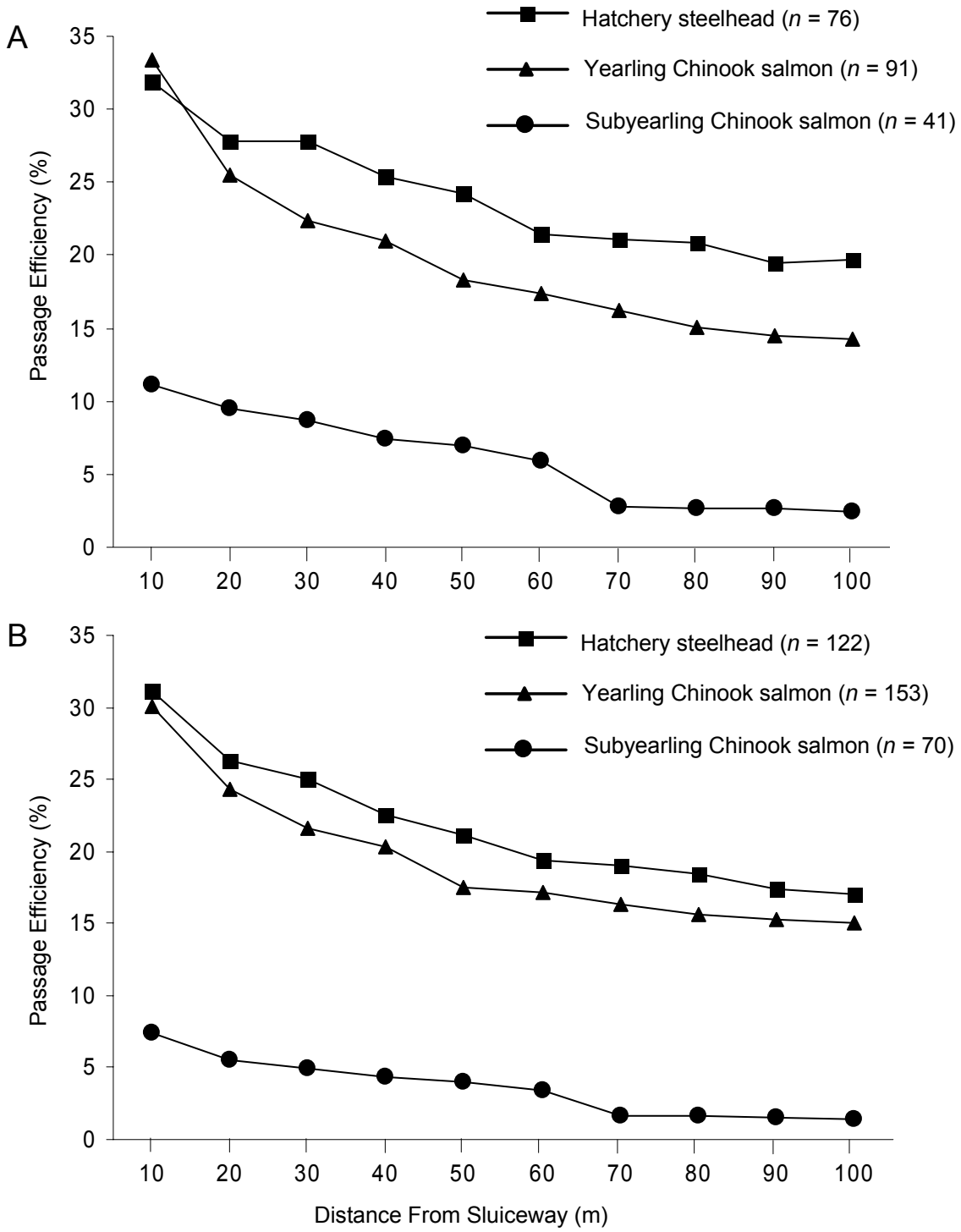

Figure 1-28. The sluiceway passage efficiencies of hatchery steelhead, yearling Chinook salmon, and subyearling Chinook salmon swimming within a specific distance of the sluiceway entrance at main turbine unit 1 while (A) the sluiceway entrance at main turbine unit 18 was closed and while (B) the sluiceway entrance at main turbine unit 18 was open. Passage efficiencies are the number of fish passing through the sluiceway entrance at main turbine unit 1 as a percent of the total fish detected within that distance of the sluiceway entrance.

fish passing through bins upstream and near the powerhouse (Figure 1-29). $SLPE_V$ for subyearling Chinook salmon at the sluiceway entrance at main turbine unit 1 were lower (6-19%) than for hatchery steelhead and yearling Chinook salmon (15-30%).

We calculated the volumetric spillway passage efficiency (SPE_V) of fish detected within a specific bin and subsequently passing through the spillway as a percent of the total number of fish detected within the bin. SPE_V was 100% for steelhead, yearling Chinook salmon, and subyearling Chinook salmon passing through bins directly upstream of the spillway for both daytime and nighttime (Figures 1-30, 1-31). All species had SPE_V greater than 80% further away from the powerhouse near mid-channel during the nighttime. During the daytime hatchery steelhead and yearling Chinook salmon had SPE_V greater than 80% for most bins in the forebay except within 30 m of the powerhouse. However, subyearling Chinook salmon had daytime SPE_V greater than 80% for most bins in the forebay including those within 30 m of the powerhouse.

Behavioral Guidance Structure Feasibility

We developed a simple model to estimate changes in SPE at the spillway if a BGS is installed. We assumed that fish approaching the BGS would be guided along the BGS to the downstream end. We also assumed that fish guided to the volume of water at the end of the BGS would then experience a SPE similar to that estimated for tagged fish in our 2004 field studies. Fish tracks that approached the BGS at elevations below the bottom of the BGS were assumed to continue their trajectories unchanged.

Flexibility in the model allowed us to look at many variations in length, depth, and angle of the potential guidance structure. We examined the number of hatchery steelhead and yearling Chinook salmon contacts if the BGS was attached to the upstream end of main turbine unit 22. The angle of the BGS relative to the face of the powerhouse began at 15 degrees and the length of the BGS ranged from 0 to 275 m with 25 m intervals. At each length the SPE was calculated for fish approaching the BGS less than 5 m, 10 m, and 15 m deep (Tables 1-8, 1-9). As the angle was increased in 5-degree increments from 15 to 45 degrees, SPE generally increased. Increasing structure length could result in either an increase or decrease in SPE. For example, with the BGS at an

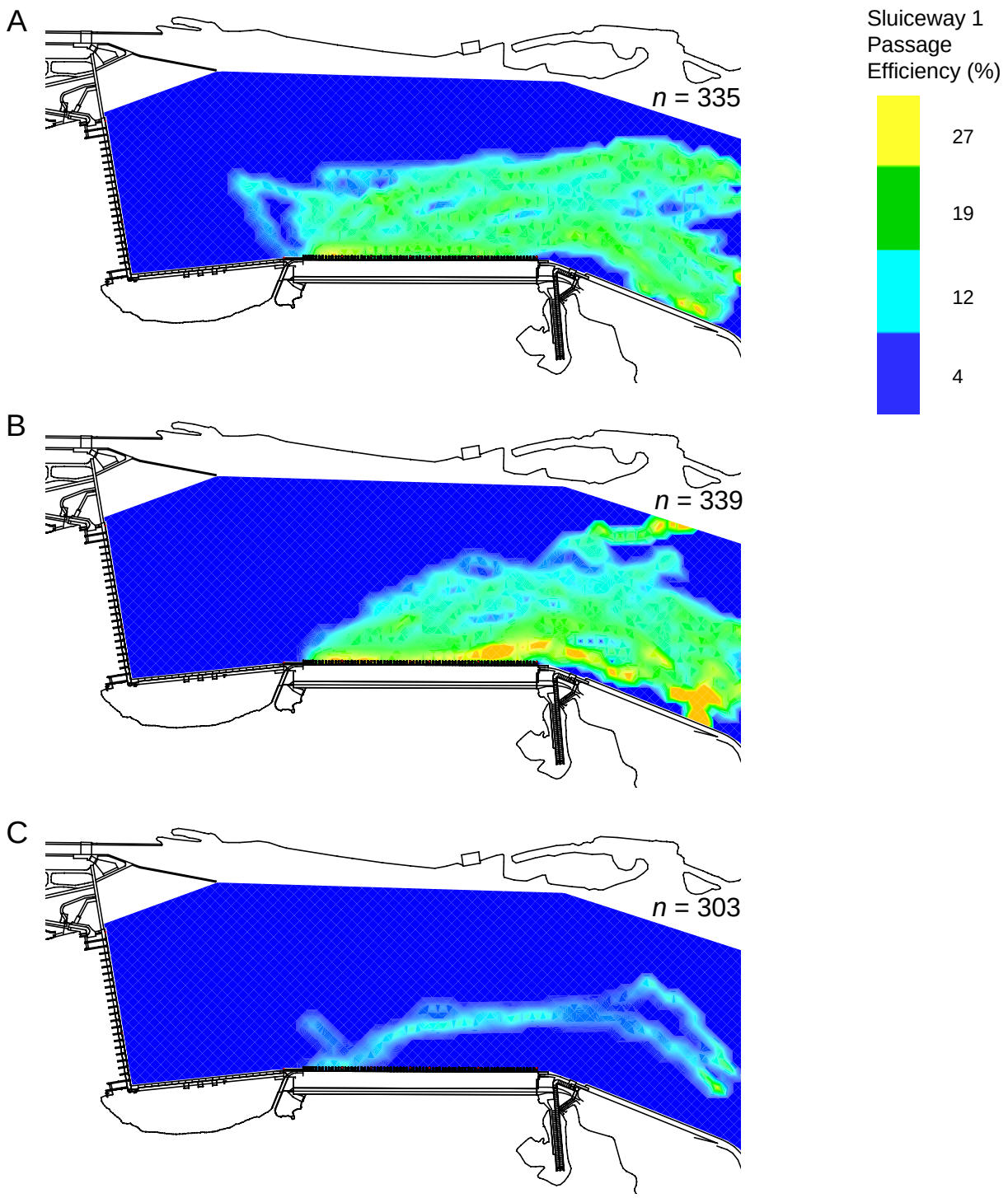

Figure 1-29. Plan views of volumetric sluiceway passage efficiency for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during 2004 at The Dalles Dam. Volumetric passage efficiency was calculated by the number of fish passing through a specific bin and subsequently passing through the sluiceway entrance at main turbine unit 1 as a percentage of the total fish detected in that bin.

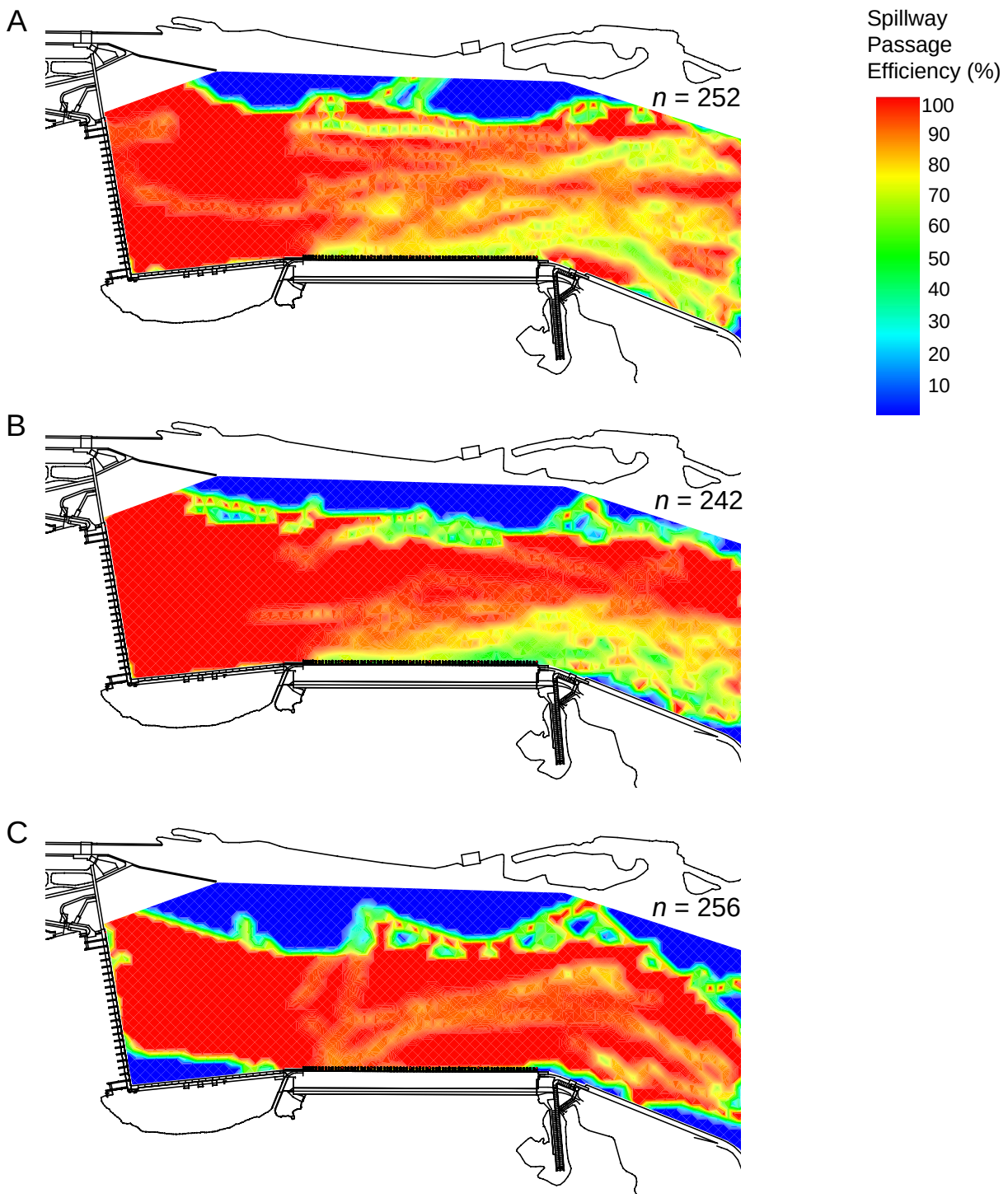

Figure 1-30. Plan views of volumetric spillway passage efficiency for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during 2004 at The Dalles Dam during daytime, 0530 to 2059 hours. Volumetric passage efficiency was calculated by the number of fish passing through a specific bin and subsequently passing through the spillway as a percentage of the total fish detected in that bin.

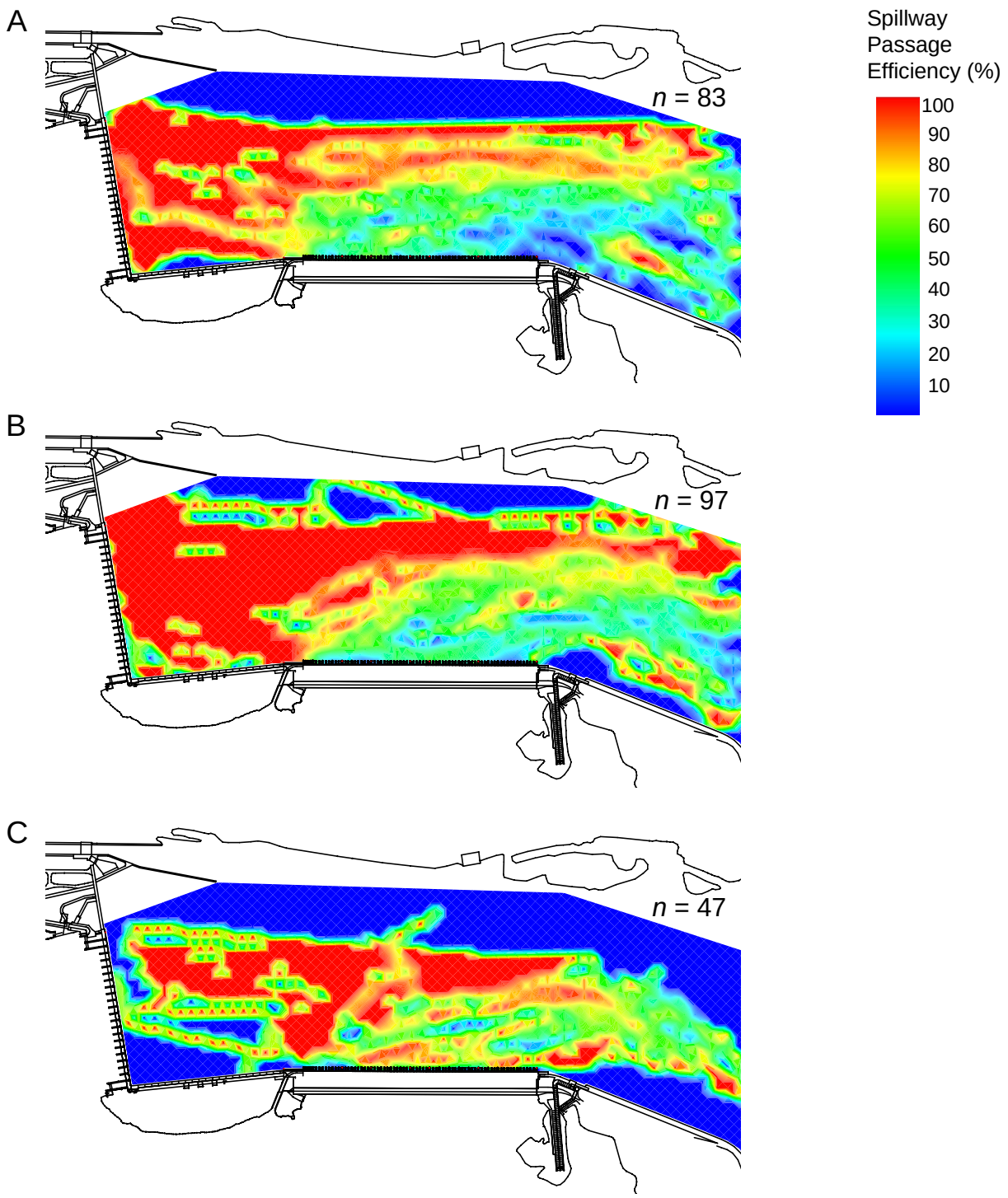

Figure 1-31. Plan views of volumetric spillway passage efficiency for (A) hatchery steelhead, (B) yearling Chinook salmon, and (C) subyearling Chinook salmon during 2004 at The Dalles Dam during nighttime, 2100 to 0529 hours. Volumetric passage efficiency was calculated by the number of fish passing through a specific bin and subsequently passing through the spillway as a percentage of the total fish detected in that bin.

Table 1-8. Change in spillway passage efficiency (SPE) for hatchery steelhead (HST) with differences in the length, angle, and depth of a proposed behavioral guidance structure (BGS) that begins at the upstream corner of main turbine unit 22 and is anchored downstream at an angle relative to the plane of the powerhouse.

Species	Angle of BGS (degrees)	Length of BGS (meters)	SPE 5 m Depth (percent)	SPE 10 m Depth (percent)	SPE 15 m Depth (percent)
HST	15	0	81.8	81.8	81.8
HST	15	25	81.8	82.1	82.1
HST	15	50	82.1	81.5	81.5
HST	15	75	81.8	81.5	81.8
HST	15	100	82.1	82.4	82.4
HST	15	125	81.8	82.1	82.4
HST	15	150	81.5	82.4	83.0
HST	15	175	82.4	83.6	84.6
HST	15	200	82.4	83.6	84.6
HST	15	225	82.1	83.0	84.0
HST	15	250	82.4	83.6	84.6
HST	15	275	82.4	84.0	84.9
HST	20	0	81.8	81.8	81.8
HST	20	25	81.8	81.8	81.8
HST	20	50	81.8	81.5	81.5
HST	20	75	81.8	81.8	81.8
HST	20	100	81.8	82.1	82.4
HST	20	125	81.2	81.8	82.4
HST	20	150	82.1	83.0	84.6
HST	20	175	82.1	82.7	84.3
HST	20	200	81.8	82.7	84.0
HST	20	225	82.4	83.3	84.6
HST	20	250	82.1	83.3	84.9
HST	20	275	81.5	82.4	84.0
HST	25	0	81.8	81.8	81.8
HST	25	25	81.8	81.8	81.8
HST	25	50	81.8	81.8	81.8
HST	25	75	82.1	81.8	82.1
HST	25	100	81.5	81.5	82.1
HST	25	125	82.1	82.4	84.3
HST	25	150	82.1	82.4	84.3
HST	25	175	82.4	82.7	84.6
HST	25	200	82.1	82.4	84.0
HST	25	225	82.1	82.4	84.0
HST	25	250	83.0	84.0	86.4
HST	25	275	83.0	84.3	86.4

Table 1-8. Continued.

Species	Angle of BGS (degrees)	Length of BGS (meters)	SPE 5 m Depth (percent)	SPE 10 m Depth (percent)	SPE 15 m Depth (percent)
HST	30	0	81.8	81.8	81.8
HST	30	25	81.8	81.8	81.8
HST	30	50	81.8	81.5	81.5
HST	30	75	82.1	81.8	81.8
HST	30	100	81.8	81.8	82.4
HST	30	125	82.7	82.7	84.3
HST	30	150	82.7	83.0	84.3
HST	30	175	81.8	81.5	82.7
HST	30	200	82.7	82.7	84.0
HST	30	225	83.3	83.3	85.2
HST	30	250	84.0	84.3	86.1
HST	30	275	83.3	83.6	85.5
HST	35	0	81.8	81.8	81.8
HST	35	25	81.8	81.8	82.1
HST	35	50	81.8	81.5	81.8
HST	35	75	81.8	81.5	81.8
HST	35	100	81.8	82.1	83.0
HST	35	125	82.7	83.0	84.6
HST	35	150	82.7	83.0	84.6
HST	35	175	81.8	81.5	83.0
HST	35	200	81.8	81.5	83.0
HST	35	225	83.6	84.3	86.4
HST	35	250	83.0	83.0	84.9
HST	35	275	82.1	82.1	84.0
HST	40	0	81.8	81.8	81.8
HST	40	25	81.8	81.8	81.8
HST	40	50	81.5	81.5	81.8
HST	40	75	81.5	81.8	81.8
HST	40	100	82.4	83.0	84.0
HST	40	125	83.0	83.6	84.9
HST	40	150	82.4	83.3	84.3
HST	40	175	81.2	81.2	82.1
HST	40	200	82.4	83.0	84.0
HST	40	225	84.0	84.9	86.1
HST	40	250	84.0	84.9	86.1
HST	40	275	83.3	84.0	85.2
HST	45	0	81.8	81.8	81.8
HST	45	25	81.8	81.8	81.8
HST	45	50	81.5	81.2	81.8
HST	45	75	82.1	81.5	82.1
HST	45	100	82.7	83.3	84.6
HST	45	125	83.0	83.6	84.9
HST	45	150	81.5	81.8	82.4
HST	45	175	82.4	82.7	83.6
HST	45	200	83.3	84.0	85.2
HST	45	225	84.6	85.5	87.0
HST	45	250	83.6	84.3	85.2
HST	45	275	83.3	84.0	84.9

Table 1-9. Change in spillway passage efficiency (SPE) for yearling Chinook salmon (CH1) with differences in the length, angle, and depth of a proposed behavioral guidance structure (BGS) that begins at the upstream corner of main turbine unit 22 and is anchored downstream at an angle relative to the plane of the powerhouse.

Species	Angle of BGS (degrees)	Length of BGS (meters)	SPE 5 m Depth (percent)	SPE 10 m Depth (percent)	SPE 15 m Depth (percent)
CH1	15	0	83.5	83.5	83.5
CH1	15	25	83.8	83.8	83.8
CH1	15	50	83.5	83.8	83.5
CH1	15	75	84.1	84.4	84.1
CH1	15	100	84.7	84.7	84.7
CH1	15	125	85.0	85.9	85.9
CH1	15	150	85.3	86.5	86.5
CH1	15	175	85.9	86.8	86.8
CH1	15	200	85.6	86.5	86.5
CH1	15	225	86.2	87.7	87.7
CH1	15	250	86.2	87.4	87.4
CH1	15	275	86.5	88.3	88.3
CH1	20	0	83.5	83.5	83.5
CH1	20	25	83.5	83.8	83.5
CH1	20	50	83.8	83.8	83.5
CH1	20	75	84.1	84.1	83.8
CH1	20	100	85.0	84.7	84.7
CH1	20	125	85.9	85.9	85.9
CH1	20	150	86.2	86.5	86.5
CH1	20	175	86.8	87.1	87.1
CH1	20	200	87.4	88.0	88.0
CH1	20	225	87.1	87.7	87.7
CH1	20	250	87.4	88.0	88.0
CH1	20	275	87.7	88.9	88.6
CH1	25	0	83.5	83.5	83.5
CH1	25	25	83.5	83.8	83.5
CH1	25	50	83.8	83.8	83.5
CH1	25	75	84.4	84.7	84.7
CH1	25	100	85.0	85.0	84.7
CH1	25	125	85.9	86.2	85.9
CH1	25	150	86.2	86.8	86.5
CH1	25	175	87.1	88.3	88.3
CH1	25	200	87.4	88.3	88.3
CH1	25	225	86.8	87.7	87.7
CH1	25	250	87.7	89.2	89.2
CH1	25	275	88.3	89.8	89.8

Table 1-9. Continued.

Species	Angle of BGS (degrees)	Length of BGS (meters)	SPE 5 m Depth (percent)	SPE 10 m Depth (percent)	SPE 15 m Depth (percent)
CH1	30	0	83.5	83.5	83.5
CH1	30	25	83.5	83.8	83.5
CH1	30	50	83.8	83.8	83.5
CH1	30	75	85.0	85.0	84.7
CH1	30	100	85.0	85.0	85.0
CH1	30	125	86.5	87.1	86.8
CH1	30	150	87.7	89.2	89.5
CH1	30	175	87.4	89.2	89.2
CH1	30	200	86.5	88.0	87.7
CH1	30	225	87.4	89.2	89.2
CH1	30	250	87.4	89.5	89.2
CH1	30	275	88.3	91.3	91.0
CH1	35	0	83.5	83.5	83.5
CH1	35	25	83.5	83.8	83.5
CH1	35	50	83.5	83.8	83.5
CH1	35	75	85.0	85.0	84.7
CH1	35	100	85.6	85.3	85.3
CH1	35	125	87.1	87.4	87.7
CH1	35	150	88.6	90.4	91.0
CH1	35	175	88.0	89.5	89.8
CH1	35	200	87.4	88.3	88.3
CH1	35	225	87.7	89.2	89.2
CH1	35	250	88.9	91.3	91.6
CH1	35	275	88.3	90.4	90.4
CH1	40	0	83.5	83.5	83.5
CH1	40	25	83.5	83.8	83.5
CH1	40	50	83.5	83.8	83.2
CH1	40	75	85.0	84.7	84.4
CH1	40	100	85.6	85.6	85.3
CH1	40	125	86.8	88.3	88.9
CH1	40	150	88.3	90.4	91.0
CH1	40	175	87.4	88.6	89.2
CH1	40	200	87.1	88.0	88.6
CH1	40	225	88.0	89.5	90.1
CH1	40	250	88.6	90.4	91.3
CH1	40	275	87.4	88.6	89.2
CH1	45	0	83.5	83.5	83.5
CH1	45	25	83.5	83.8	83.5
CH1	45	50	83.5	83.8	83.2
CH1	45	75	84.7	84.4	84.1
CH1	45	100	85.9	85.6	85.6
CH1	45	125	86.2	88.6	88.9
CH1	45	150	86.8	88.9	89.5
CH1	45	175	86.2	87.4	88.0
CH1	45	200	85.9	86.8	87.1
CH1	45	225	87.1	89.2	90.1
CH1	45	250	86.8	88.3	88.9
CH1	45	275	86.8	88.3	89.2

angle of 40 degrees and 15 m deep, the SPE at 150 m is 84.3% for hatchery steelhead. At the next length of 175 m the SPE drops to 82.1% and then increases to 84% at 200 m. Variation in the estimated SPE can occur because each length of the BGS guides fish into a unique volume in the forebay (Figure 1-32). A similar effect can also be observed by varying the angle of the BGS (Figure 1-33). The observed SPE for each unique volume at the end of the BGS was then used to recalculate SPE. Inasmuch as the observed SPE varied across the forebay due to the behavior of tagged fish, the results of the modeling effort varied because we used observed data as part of the estimate of SPE with a BGS.

Spillway passage efficiency generally increased as the length of the structure was increased. At each angle and depth, SPE was plotted against increasing BGS length in Figures 1-34 through 1-41 for both species of fish. Steelhead SPE generally increased as BGS length increased for all angles and depths. For example, with a 75 to 275 m length increase, SPE increased more than 2% for the 8 m depth at a 25 degree angle. We observed similar changes in SPE for yearling Chinook as BGS length increased for all angles and depths. For example, a BGS angle of 35 degrees, depth of 8 m, and length increase from 75 to 275 m, increases the SPE by 4%.

The U.S. Army Corps of Engineers has considered a structure with a downstream angle of 30 degrees relative to the powerhouse. We calculated the change in SPE for structures at varying angles to the powerhouse. For example, we looked at the effect of a structure anchored at main turbine unit 22 with a length of 275 m, depth of 5 m, and an angle of 25, 30, and 35 degrees on hatchery steelhead and yearling Chinook salmon SPE. SPE increased for hatchery steelhead from 83% with a 25^0 BGS angle to 83.3% with a 30^0 BGS angle. Hatchery steelhead SPE decreased to 82.1% as BGS angle increased to 35^0. No change in yearling Chinook salmon SPE (88.3%) was observed as BGS angle changed.

Estimating the SPE resulting from a structure with an angle varying between 25 and 40 degrees and a depth of 4 to 8 m at main turbine unit 22, we tested a fixed angle and depth at several locations. We found that varying the depth of the BGS between 5 m and 8 m resulted in a less than or equal to 1% change in SPE regardless of the length. We looked at an angle of 30 degrees with a depth of 6 m at each upstream piernose from main turbine units 11 through 22 at The Dalles Dam with the BGS length varying from

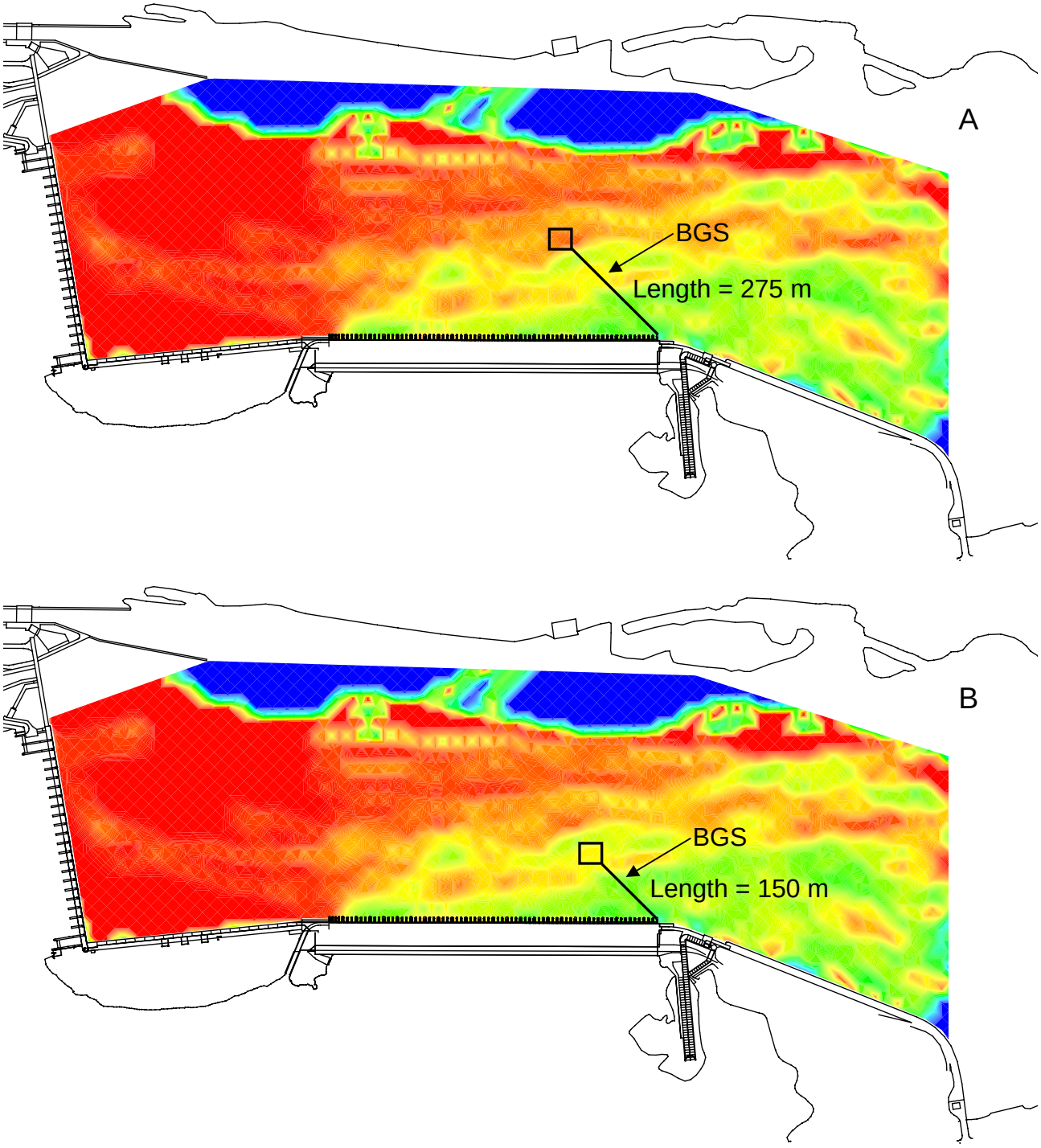

Figure 1-32. Length of BGS of (A) 275 m and (B) 150 m at main turbine unit 22. The box on the end of the BGS represents a 40 m x 40 m volume from the surface to the bottom for use in calculations of the BGS modified spill passage efficiency.

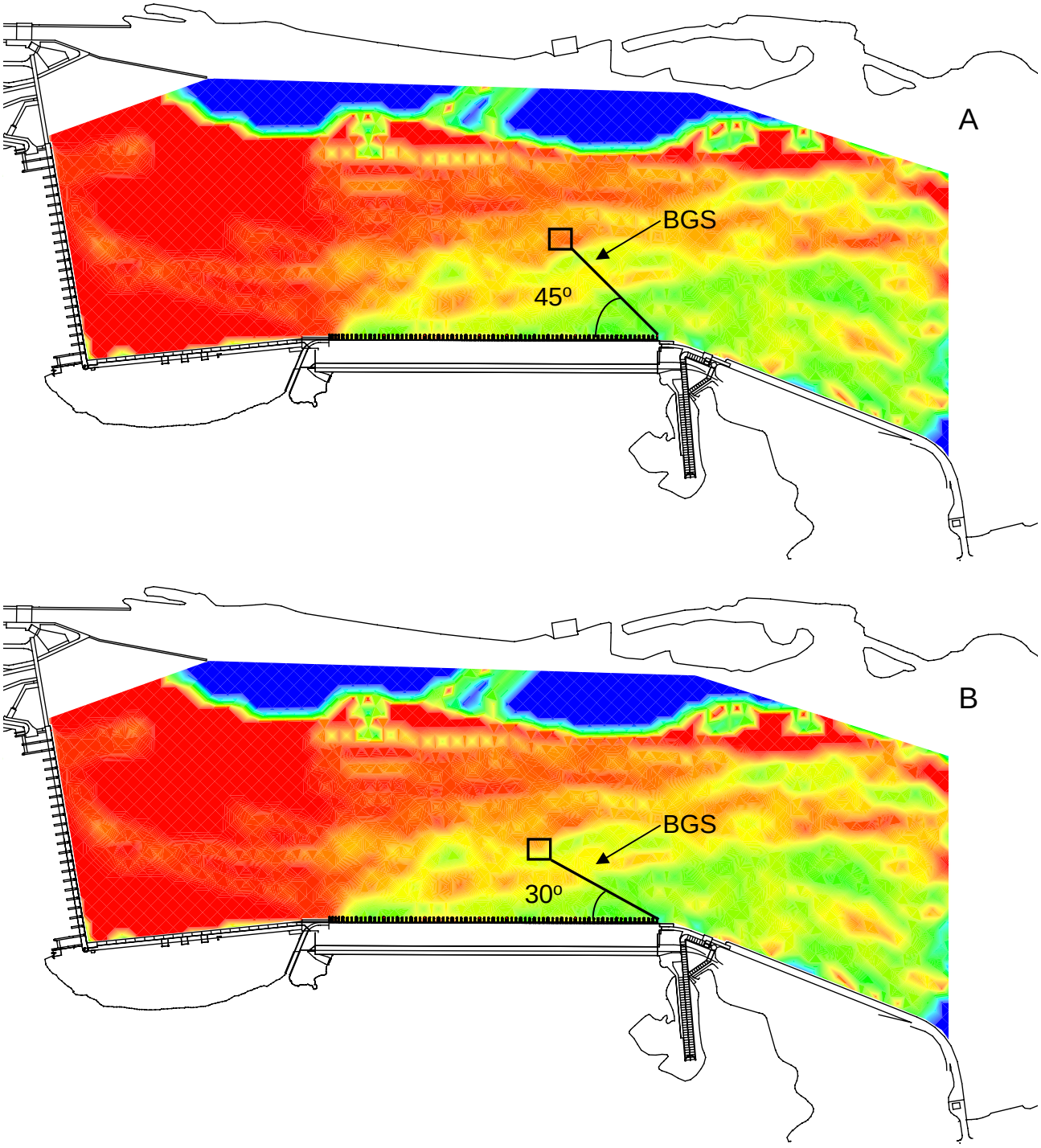

Figure 1-33. Angle of BGS at (A) 45 degrees and (B) 30 degrees at main turbine unit 22. The box on the end of the BGS represents a 40 m x 40 m volume from the surface to the bottom for use in calculations of the BGS modified spill passage efficiency.

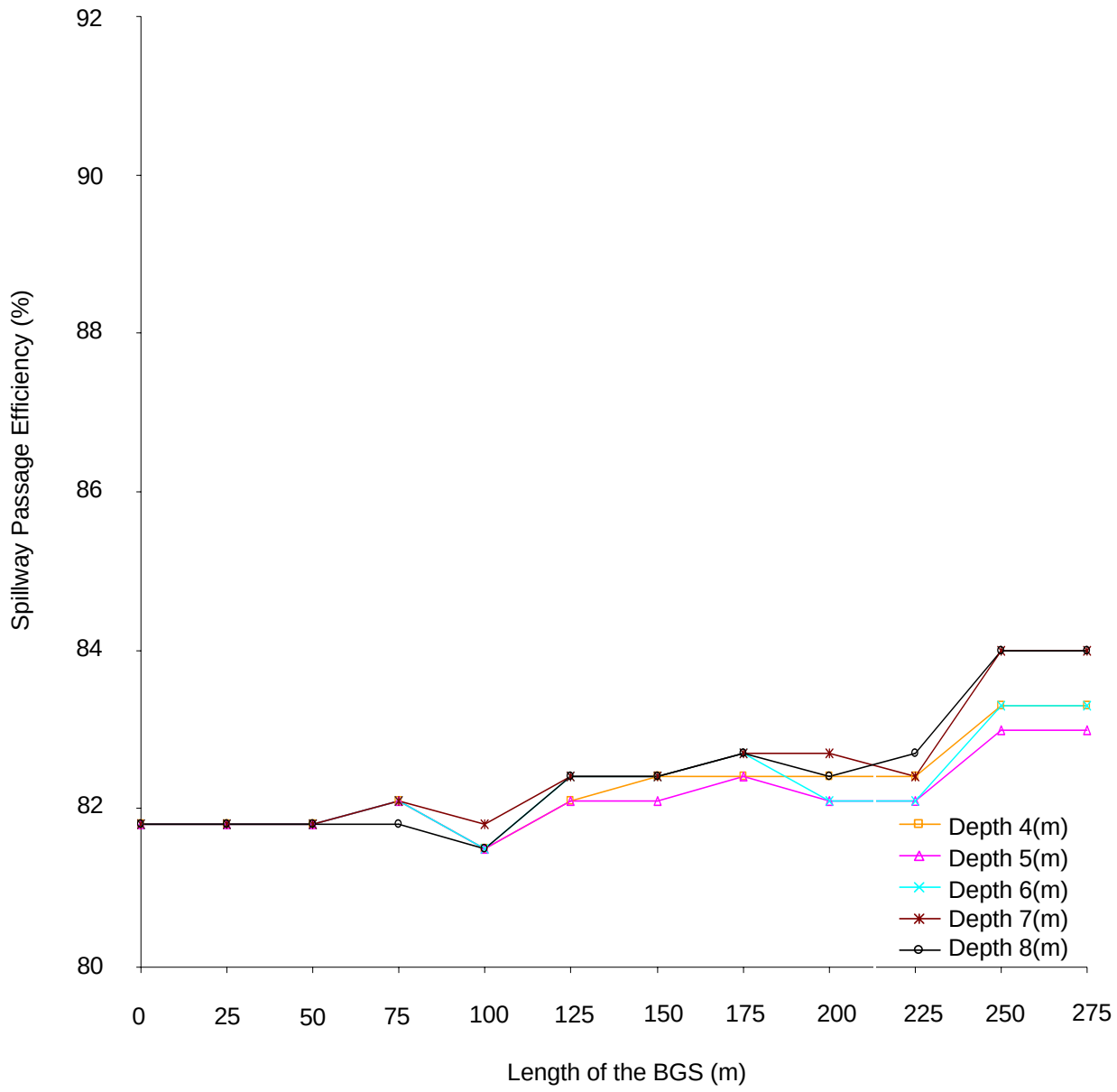

Figure 1-34. Change in spillway passage efficiency for hatchery steelhead with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 25 degree angle relative to the plane of the powerhouse.

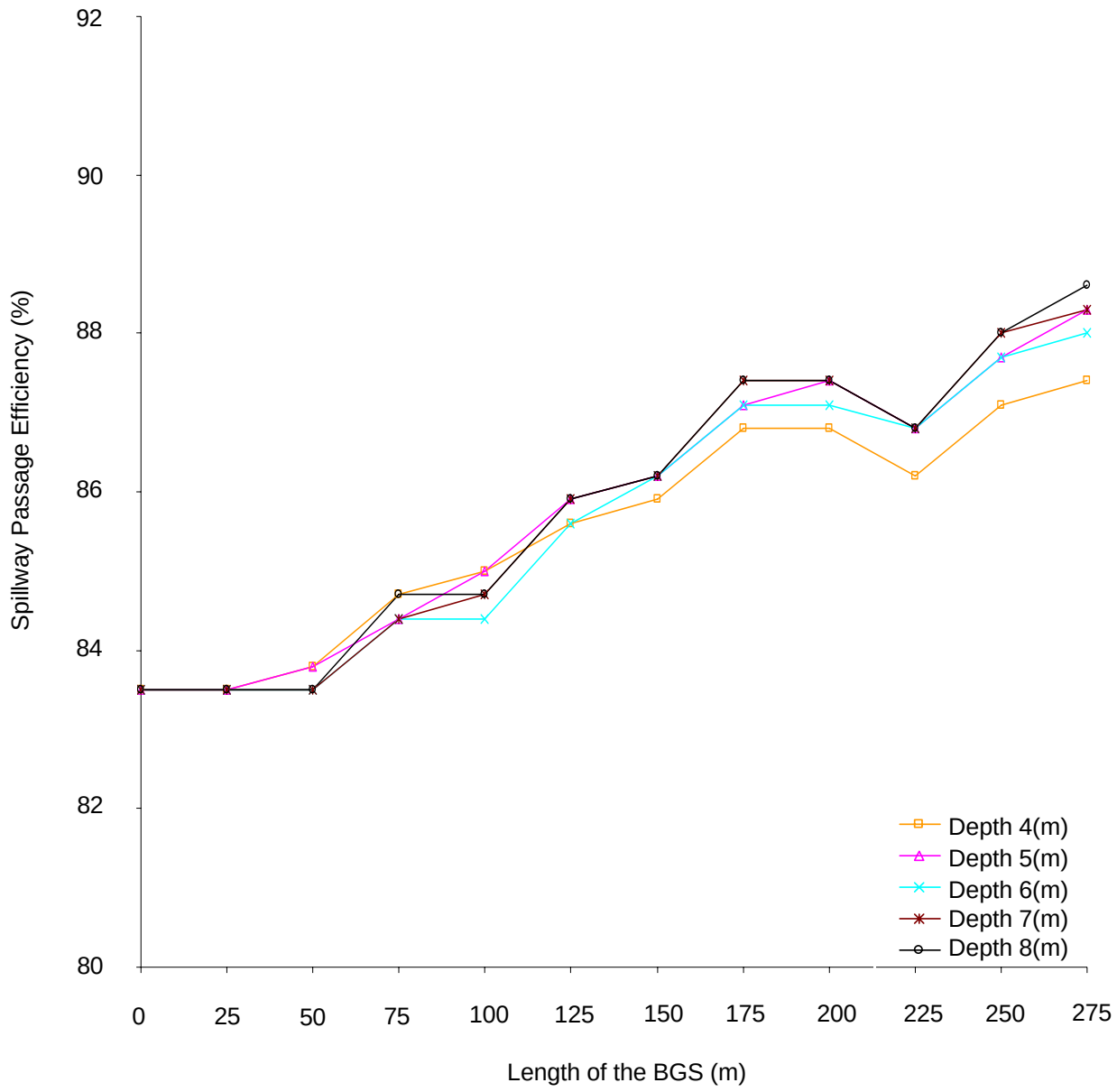

Figure 1-35. Change in spillway passage efficiency for yearling Chinook salmon with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 25 degree angle relative to the plane of the powerhouse.

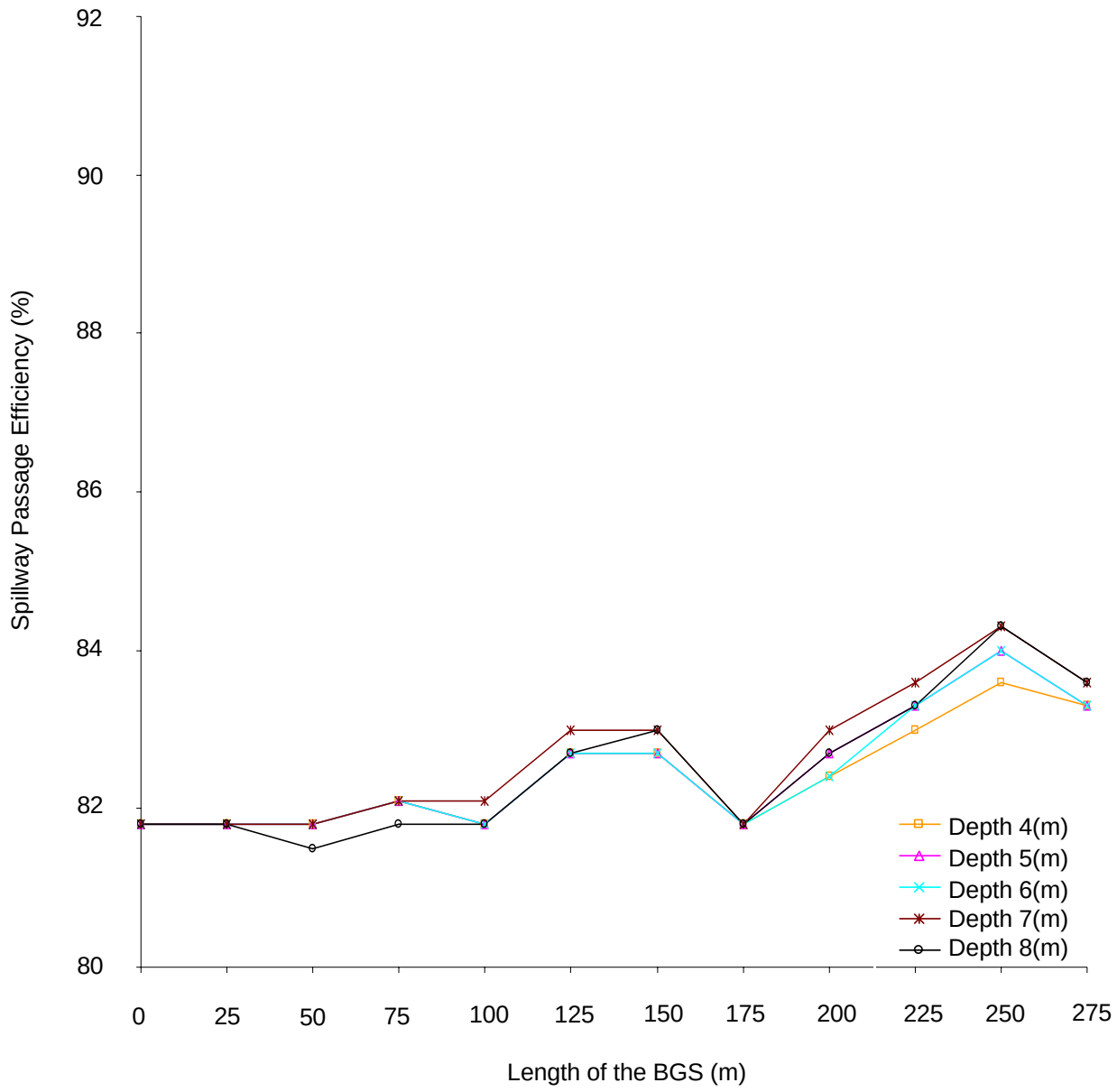

Figure 1-36. Change in spillway passage efficiency for hatchery steelhead with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 30 degree angle relative to the plane of the powerhouse.

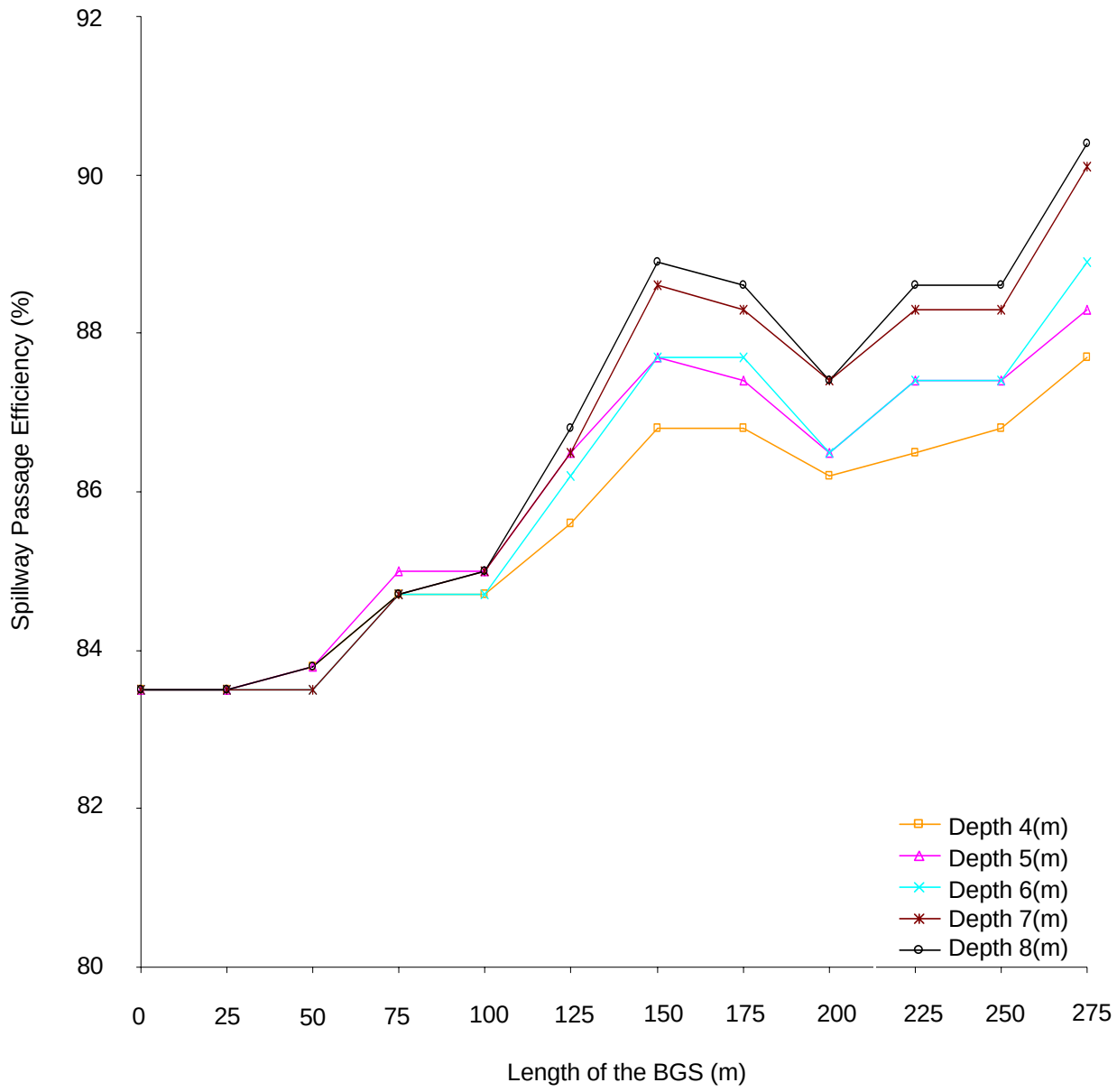

Figure 1-37. Change in spillway passage efficiency for yearling Chinook salmon with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 30 degree angle relative to the plane of the powerhouse.

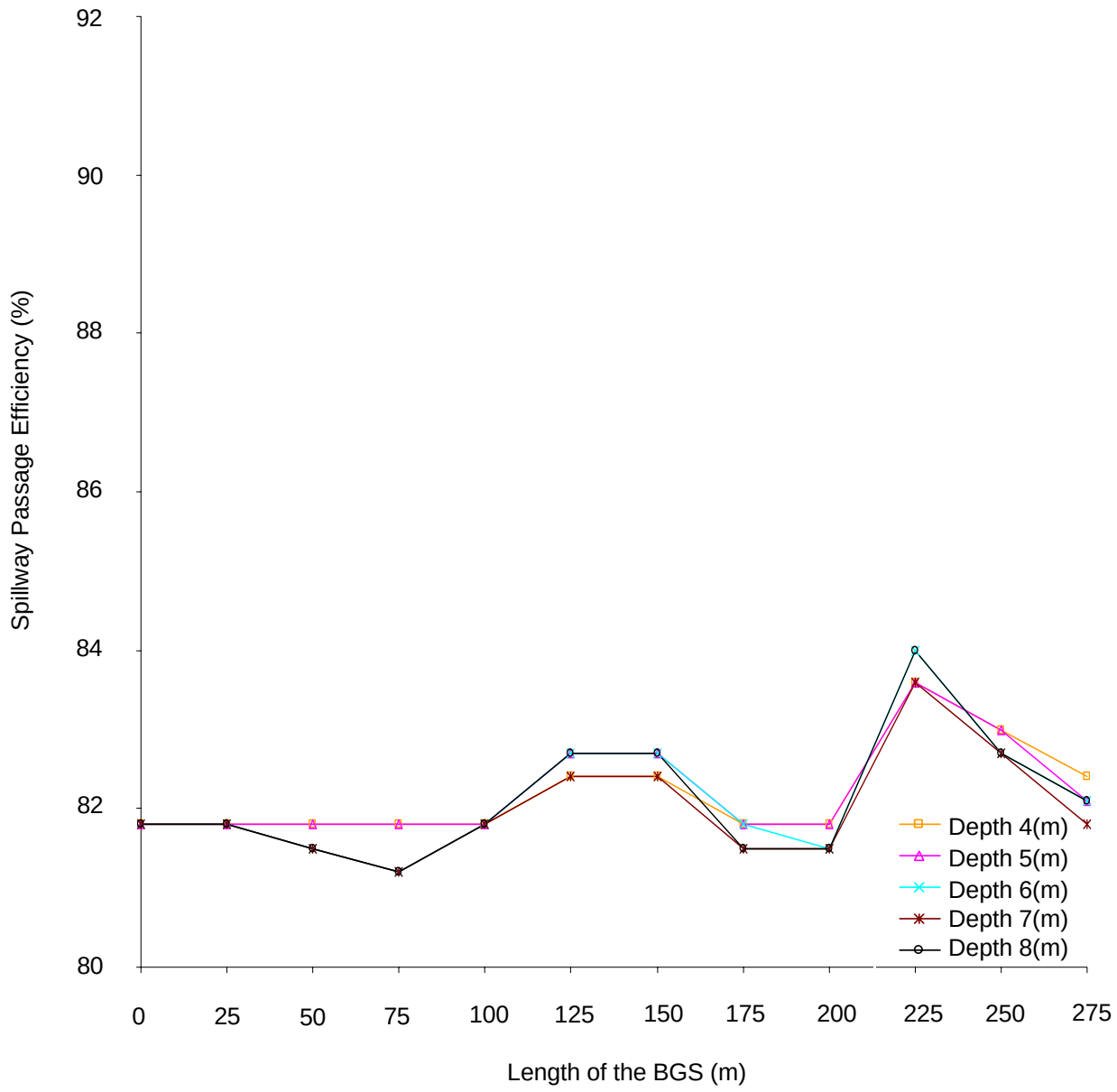

Figure 1-38. Change in spillway passage efficiency for hatchery steelhead with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 35 degree angle relative to the plane of the powerhouse.

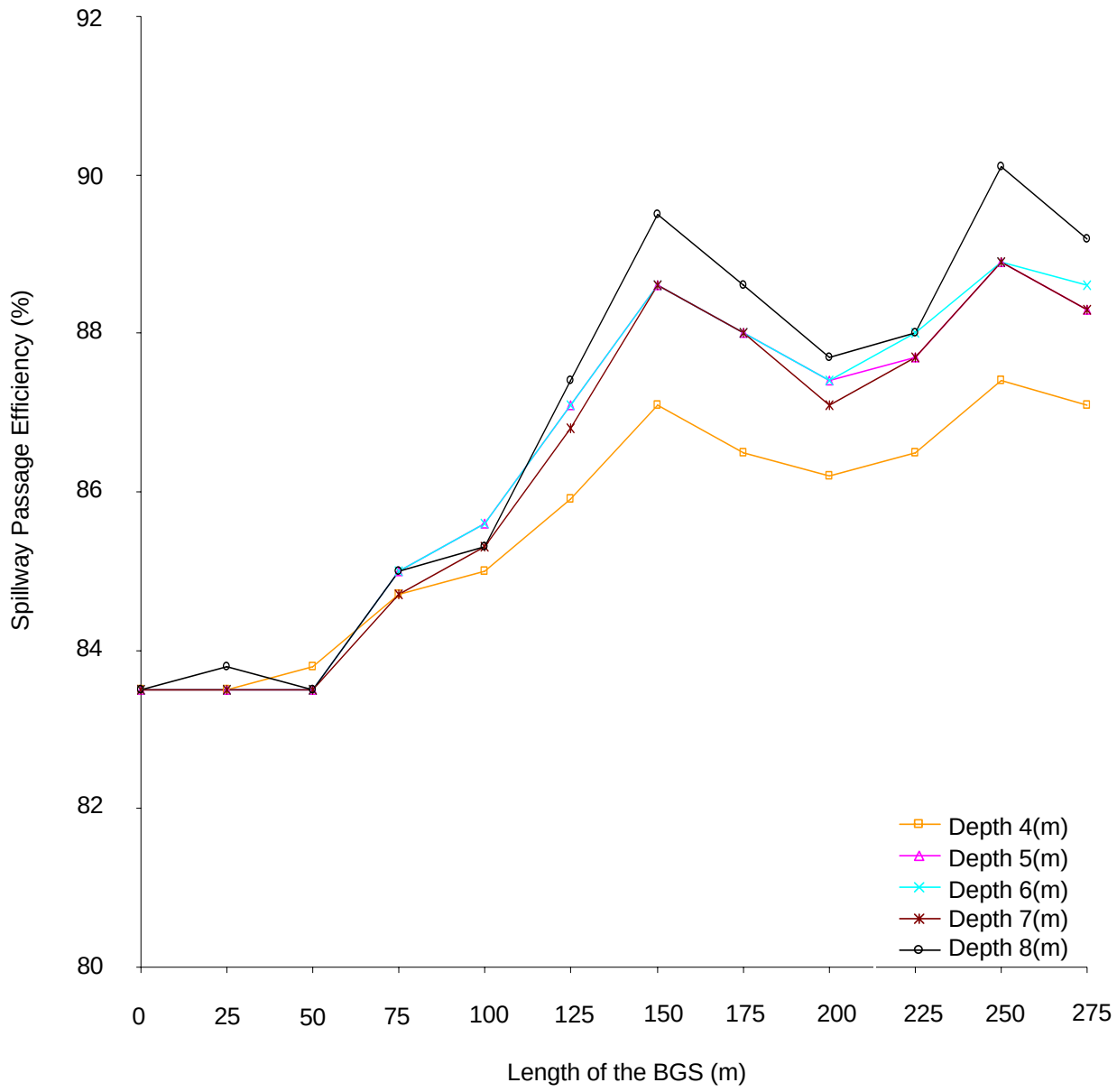

Figure 1-39. Change in spillway passage efficiency for yearling Chinook salmon with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 35 degree angle relative to the plane of the powerhouse.

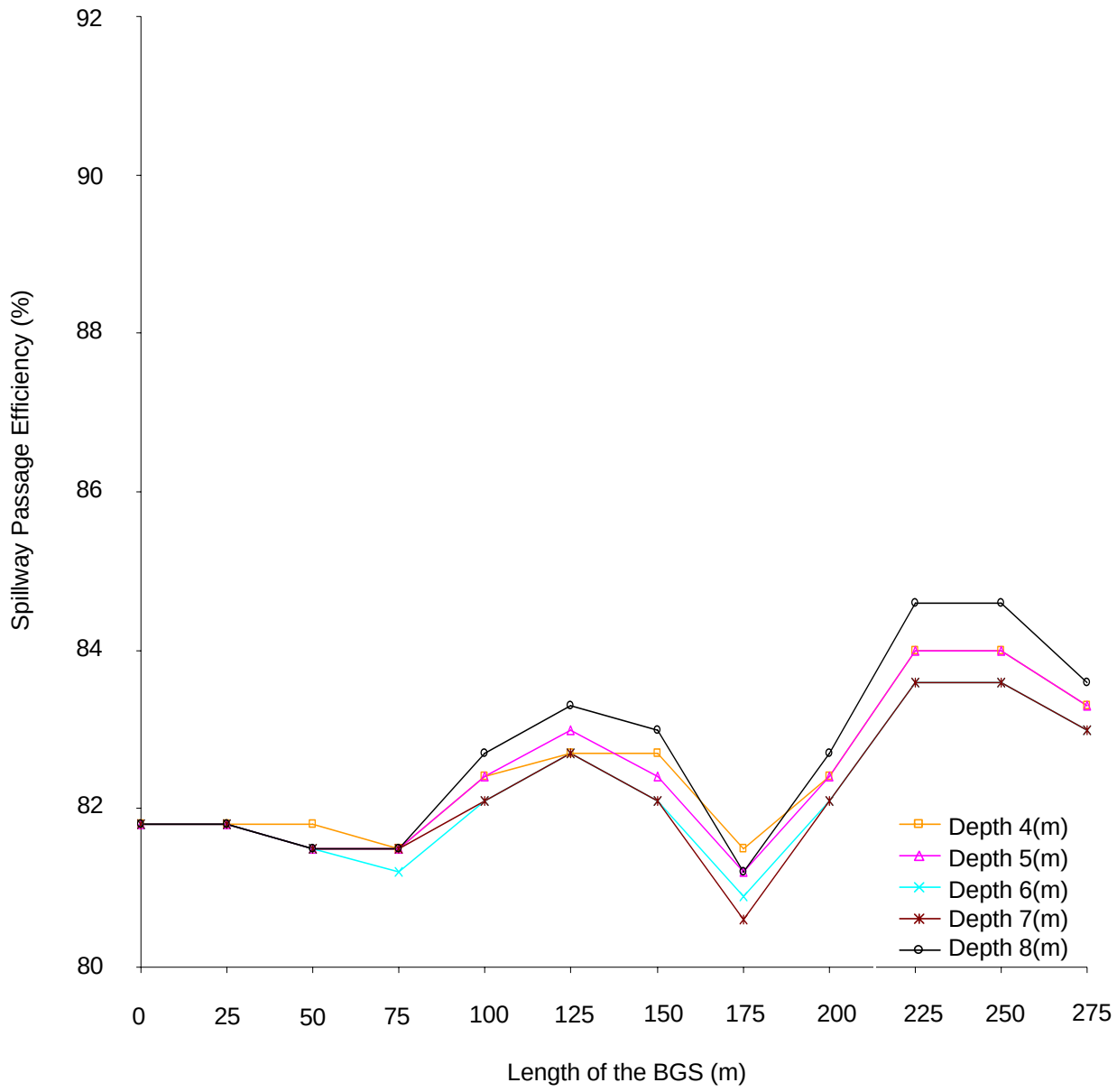

Figure 1-40. Change in spillway passage efficiency for hatchery steelhead with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 40 degree angle relative to the plane of the powerhouse.

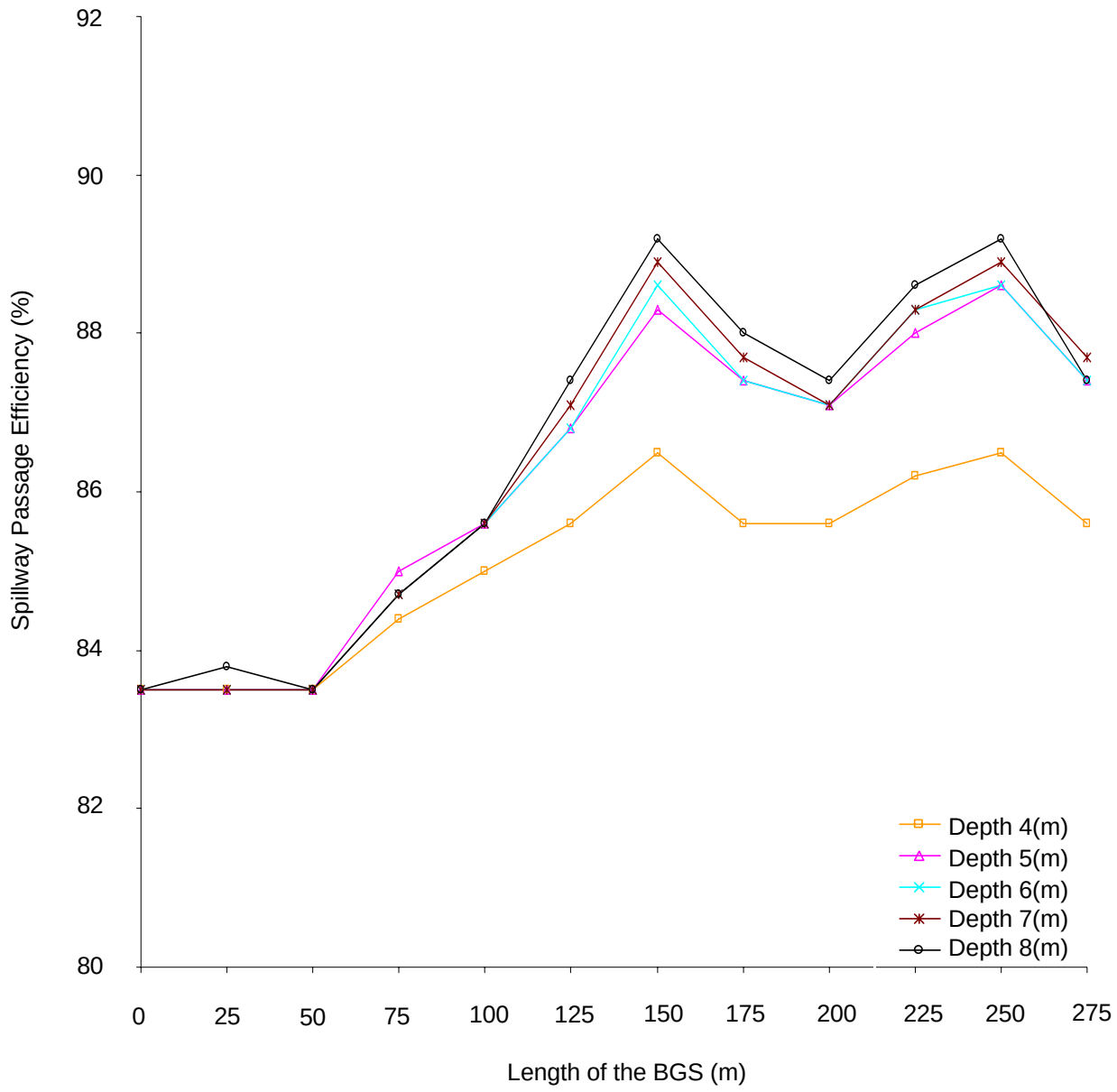

Figure 1-41. Change in spillway passage efficiency for yearling Chinook salmon with change in length and depth of a proposed behavioral guidance structure that is anchored at the upstream corner of main turbine unit 22 and extends downstream at a 40 degree angle relative to the plane of the powerhouse.

0 to 275 m. BGS location and length both contributed most to the variation in SPE for BGS depths from 4 to 8 m. For hatchery steelhead, the highest potential SPE for this configuration was at main turbine unit 13 with a structure length of 275 m. Yearling Chinook salmon had the highest SPE at main turbine unit 22 with a BGS length of 275 (Figure 1-42).

Computational Fluid Dynamics Model Data

Computational fluid dynamics (CFD) models will be developed for the 2004 study season to describe hydraulic conditions associated with the sluiceway entrances, powerhouse turbine operation, and spill. We have cooperated with U.S. Army Corps of Engineers staff to select a small number of flows and dam operating configurations for subsequent CFD modeling. Integration of CFD results with our results will be presented in a separate discussion.

Discussion

The array of hydrophones we installed in the forebay of The Dalles Dam enabled us to obtain 3D fish tracks describing the behavior of juvenile salmonids as they approached and passed the dam. The array of 76 hydrophones was maintained throughout the study period and the array had a high degree of reliability. We released 1,162 juvenile salmonids during 2004 and detected 85-95% of those fish. We have substantially reduced the data processing time and costs compared to recent years by automating certain steps in the tracking process. The reduction in time to mark and track acoustic signals has enabled experienced staff to spend more time on data analysis. As a result of the improved data processing, this report can be released in a timely manner for consideration by the decision makers.

The horizontal and vertical distribution of approach paths of fish in the forebay should provide valuable insight for locating fish guidance structures in the forebay. We collected 3D data at Lower Granite Dam prior to The Dalles Dam 2004 study for several years beginning in 1999. We observed many trends in overall fish behavior at The Dalles

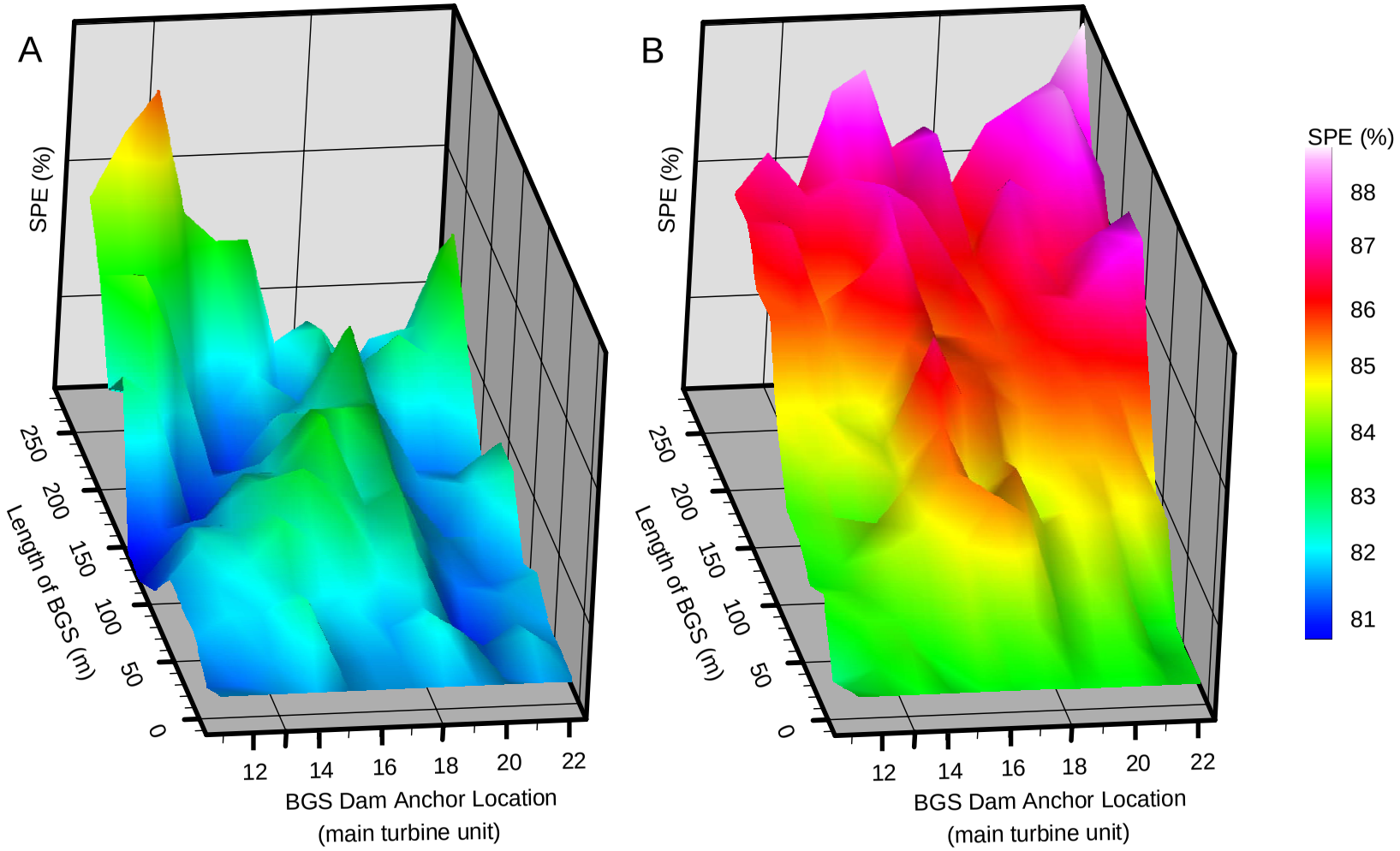

Figure 1-42. Change in spillway passage efficiency (SPE) for (A) hatchery steelhead and (B) yearling Chinook salmon with the behavioral guidance structure (BGS) at a constant 30 degree downstream angle from the plane of the powerhouse and 6 m depth. Color scale and elevation changes represent differences in SPE as a result of variations in BGS anchor location on the dam, the upstream end of main turbine unit 22 to the upstream end of main turbine unit 11, and length of the BGS, 0 m to 275 m in 25 m increments.

Dam which were similar to fish behavior at Lower Granite Dam. At Lower Granite Dam, as fish approach the spillway, their depth tends to decrease. We found depth of fish decreased as fish approached the spillway at The Dalles Dam. We also found diel patterns in depth distribution were similar at Lower Granite and The Dalles dams.

We believe the two approach paths on the north and south side of Grave Island and subsequent convergence of fish approach paths at a mid-river location upstream of the east end of the powerhouse are significant findings. The subsequent divergent paths where fish appear to segregate and either move toward the powerhouse or continue more directly toward the spillway is also important. If the paths of fish moving toward the powerhouse could be altered to increase the proportion traveling more directly to the spillway, then survival may be increased. We believe that this might be achieved through early intervention using a guidance structure near the east end of the powerhouse.

Although we have much greater insight into fish behavior at The Dalles Dam, we have also identified additional information gaps. The data reported here was collected during one year and includes little prior knowledge of approach paths through the forebay. Furthermore, flows and dam operations in 2004 appeared to be unique compared to recent years. The mean discharge was low relative to the ten-year average and daily project operations were more variable than in previous years. Although that may reflect a trend in management of the operations at The Dalles Dam, it also makes it more difficult to attribute a specific fish behavior pattern to a specific dam operation. About 25% of the fish paths were collected at night, thus limiting the strength of the conclusions we have drawn about fish behavior at night. This is important because we have observed significantly different behavior patterns between fish approaching the dam during the day and night. These differences can be partially attributed to differences between steelhead and Chinook salmon. Inasmuch as a forebay guidance structure would be expected to have a high level of efficacy for all species, these observed differences should be considered. We were successful in our tests to tag juvenile sockeye salmon, however in the future the need for behavioral data on juvenile sockeye salmon should be considered carefully to ensure that fish guidance structures will also benefit sockeye.

The hydraulic environment around Grave Island and in the region of the deep hole at the upper end of the forebay, known as Big Eddy, likely influenced the patterns of fish

approach distributions. The nearly vertical walls of the underwater canyon undoubtedly create a hydraulic environment that is unique from the rest of the forebay. Previous research at Lower Granite Dam showed fish concentrated in regions with high values of strain, along two steel structures anchored in the forebay (Cash et al. 2005a, Cash et al. 2005b). Lateral approach paths of fish at The Dalles Dam notably converged at the downstream edge of Big Eddy. While the cause of this convergence may be related to the hydraulic environment, CFD data is currently unavailable for comparison.

Forebay depth influenced the vertical and lateral distributions of fish. Upstream of the powerhouse, the depth of the forebay varied greatly. A shallow shelf that is only about 10 m deep exists adjacent to the earthen dam. Further out, the forebay depth increases to more than 90 m. Horizontal distributions of approach patterns showed that fish tended to avoid the shallow area and travel along the edge of the shelf in deeper water. Vertical distributions showed more fish traveling deeper in the area off-shore of the earthen dam, and an upward shift in distributions as fish approached the powerhouse. Though the approach distributions indicated a preference for the deeper water, the affect may have had more to do with hydraulic conditions than topography. The thalweg arcs from the underwater canyon to meet the upstream end of the powerhouse, and a deep trench continues down the length of the powerhouse about 40 m out. Horizontal distributions showed a high proportion of fish traveling along the edge of the trench that follows the powerhouse.

The volume of flow through turbines also had a significant influence on the lateral approach distributions of fish in the forebay at The Dalles Dam. From the downstream edge of Big Eddy where fish paths converged, approach distributions generally split into two distinct modes. Except for hatchery steelhead during daytime, fish tended to either approach at an angle toward the powerhouse or maintain the mid-river course directly toward the open spillbays. A distinct mode in distribution directed toward the open spillbays was not exhibited for hatchery steelhead during daytime. Although spill discharge was maintained at 40% of total discharge through the dam, more fish approached the powerhouse during daytime when peak turbine loading occurred. The volumetric flood plots of median depth did not indicate a substantial difference in depth for fish that swam along the powerhouse compared to mid-river fish.

Horizontal approach path distributions showed that many steelhead and Chinook salmon traveled along the powerhouse and passed in front of the main turbine unit 1 sluiceway entrance without entering. Hence, sluiceway passage efficiency was low by all measures. Overall, sluiceway passage efficiencies only ranged between 1.9-7.7%. Where the thalweg meets the upstream end of the powerhouse a trench begins that runs the length of the powerhouse. A large proportion of approach paths followed along the inside edge of this trench, with about 20-25% of all fish approaching within 40 m of the sluiceway entrance at main turbine unit 1. Distributions showed that few fish approached within 20 m of the sluiceway. The volume of flow into the sluiceway may not have been significant enough to attract fish. Flow through the sluiceway at main turbine unit 1 ranged between 2.8-3.3 kcfs, while spill discharge averaged 74.3 kcfs throughout the study. The trench terminates near main turbine unit 1, and approach distributions showed that many fish continued downstream. Fish either turned at an angle toward the open spillbays or continued along the face of the non-overflow wall toward the spillway.

The hydraulic conditions at the entrance to the sluiceway may have resulted in the low sluiceway passage efficiencies observed. Surface oriented fish passage structures can be an efficient means to facilitate the downstream migration of juvenile salmonids. Ransom and Steig (1995) found the passage efficiency of sluiceways to be a 13:1 ratio of percent total fish to percent total river flow passed, compared to about a 1:1 ratio of fish to flow through conventional spillways. However, the performance of surface-oriented passage structures depends upon the hydraulic environment at entrances to the structures. Evaluations of the Surface Bypass Collector at Lower Granite Dam, a surface-oriented fish passage structure, found lower passage efficiencies in comparison to surface collection systems at other dams (Adams et al. 2001; Plumb et al. 2002). Results of radio telemetry research indicated that the lower passage efficiencies observed for the Surface Bypass Collector were the product of insufficient or inadequate flows to attract fish at the Surface Bypass Collector entrances (Adams et al. 2001; Plumb et al. 2002). With less than 2% of total discharge passing through the sluiceway entrance at main turbine unit 1, the hydraulic conditions at the entrance were insufficient to attract fish. Rather than entering the sluiceway, fish within 40 m of the sluiceway tended to continue downstream following flow through the open spillbays.

While relatively more fish swam toward the powerhouse during daytime when discharge through turbines was higher, flood plots of SPE_V showed lower spillway passage efficiency for fish approaching the powerhouse at nighttime. A reduction in SPE_V for steelhead and yearling Chinook salmon within about 40-100 m of the powerhouse was observed during daytime, however, reduced SPE_V was more extensive at nighttime inasmuch as steelhead and yearling Chinook salmon within about 300 m of the powerhouse exhibited even lower passage efficiencies than observed during daytime. The volumetric spillway passage efficiency for subyearling Chinook salmon that approached within 40-100 m of the powerhouse was similar during daytime and nighttime.

Diel and species-specific differences in depth distributions were similar to those observed at other large-scale hydroelectric dams. Fish distributions at The Dalles Dam were concentrated toward the surface during daytime for steelhead and during nighttime for both yearling and subyearling Chinook salmon. The observed diel differences between steelhead and yearling Chinook salmon depth distributions were similar to acoustic-telemetry findings in the forebay at Lower Granite Dam during multiple years of research (Cash et al. 2002, Cash et al. 2005a). The highest average approach velocities were observed for fish with shallow depth distributions; hence, steelhead had the highest average approach velocity during daytime and yearling Chinook salmon had the highest average approach velocity during nighttime.

The simple BGS/SPE model demonstrated flexibility to estimate the effect on SPE for any proposed structure at various locations on the dam. We have also studied the behavior of hatchery steelhead and yearling Chinook salmon at Lower Granite Dam as they approach the BGS. This knowledge will allow us to improve relative predictions of fish response to a guidance structure at The Dalles Dam. This tool could be used in conjunction with the fish surrogate model being developed by the U.S. Army Corps of Engineers staff to determine feasibility and design of a behavioral guidance structure.

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Chapter Two

Juvenile Salmonid Passage at The Dalles Dam

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Introduction

This chapter describes a three-dimensional (3D) acoustic telemetry study of yearling and subyearling Chinook salmon (*Oncorhynchus tshawytscha*), juvenile sockeye salmon (*O. nerka*) and juvenile hatchery steelhead (*O. mykiss*) passage at The Dalles Dam. The study was conducted jointly by Pacific Northwest National Laboratory and the U.S. Geological Survey for the U.S. Army Corps of Engineers, Portland District in 2004. The purpose of this portion of the study was to determine fish passage efficiency, spill passage efficiency, and sluiceway passage efficiency and the distribution of fish passage at The Dalles Dam in the spring and summer of 2004. The study was funded under the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program.

Background

Extensive efforts have been made by the fishery and hydropower managers of the Columbia River to increase the survival of juvenile salmonids passing Columbia River hydroelectric dams during their downstream migration. Such efforts have been directed at The Dalles Dam where project operations have been managed to maximize the survival of juvenile salmonids past that hydroelectric facility. The strategy to reduce the mortality of juvenile salmonids past The Dalles Dam has been to divert them away from routes at the dam that have lower relative survival compared to other routes, and to direct flow and juvenile salmonids toward routes where the survival of juvenile salmonids is highest (Johnson et al. 1992; Giorgi and Stevenson 1995). Possible routes for passage at The Dalles Dam include the turbines, spillways, and the ice trash sluiceway whereby fish navigate from upstream to downstream by passing through one of these routes. Turbine routes have generally caused higher mortality than spillway routes at The Dalles Dam (81-86% turbine survival versus 92-96% spillway survival), and the survival through the ice and trash sluiceway has been relatively high (92-93%) (Ploskey et al. 2001a).

Acting to satisfy requirements of the National Oceanic and Atmospheric Administration's Biological Opinion (NOAA – BiOP), the U.S. Army Corps of Engineers and regional fishery managers chose to operate the dam in 2004 at 40% spill

throughout the spring and summer outmigration of juvenile salmonids. The purpose of these operations was to pass fish through non turbine routes, until a permanent juvenile bypass structure can be constructed. The sluiceway has also been operated as a route of fish passage for the past 20 years, primarily with gates open above turbine unit 1 on the downstream portion of the powerhouse (Nichols 1979; Nichols and Ransom 1982). In 2004, the sluiceway was tested to determine if opening gates above unit 18 would increase fish passage on the eastern (and upstream) portion of the powerhouse, however emphasis has been placed on passing fish over the spillway due to flow limitations at the sluiceway. Prior studies that have investigated juvenile salmonid behavior in the forebay have shown a propensity for a majority of juvenile salmonids to follow the historic river channel in their outmigration, and in doing so they are typically following the bulk flow (Cash et al. 2000; Faber et al. 2001). This is the premise for operating the spillway at the high level of 40% spill with the intent to pass a substantial proportion of the juvenile salmonids.

Several metrics have been formulated to measure the success of these efforts, including Fish Passage Efficiency (FPE), Spill Passage Efficiency (SPE) and Sluiceway Passage Efficiency (SLPE). Since 1997, these metrics have been used for studies at The Dalles Dam to describe the effectiveness of passing juvenile salmon around non turbine routes (Moursund et al. 2001; Ploskey et al. 2001a; Ploskey et al. 2001b; Johnson et al. 2002; Moursund et al. 2002). FPE is the percentage of fish for both the sluiceway and spillway that do not pass the turbines, similarly SPE is the percentage of fish that pass the spill compared to all other routes, and SLPE is the percentage of fish that pass the sluiceway compared to all other routes. The FPE at The Dalles Dam has ranged from a low of 73% to a high of 97% since 1997 for the spring outmigration, under various spillway discharges when studied with radio telemetry (Ploskey et al. 2001a). Hatchery steelhead generally had higher FPE than did yearling Chinook salmon. In 2000, FPE was 91% and 85% for steelhead and yearling Chinook salmon, respectively, when discharge at the spillway was at a relatively high 39% continuous spill, similar to the 40% spill in 2004. However, the pattern of spill was very different from 2004 due to the use of most

of the southern spillbays rather than the northern bays during that study. The resultant change in FPE from switching the spill pattern to the north was one focus of our investigation.

Objectives

The objective of this portion of the 3D evaluation of juvenile salmonids was to determine the passage metrics such as FPE, SPE, and SLPE by day/night, spring/summer and by individual stock of juvenile salmonids. The stocks of salmonids we studied were yearling Chinook salmon, juvenile hatchery steelhead, juvenile sockeye salmon, and subyearling Chinook salmon. We also determined the fish passage distribution at the powerhouse and spillway in order to determine what routes were predominant among various stocks of fish. We investigated the passage timing of our 3D tagged fish, and finally determined the relationship between our mobile hydroacoustic survey from the spring and summer of 2003 and related the forebay distribution of fish to our 3D tracked fish.

Methods

Study Area

The study was conducted at The Dalles Dam from 29 April to 7 June for the spring and from 23 June to 26 July 2004 for the summer. The Dalles Dam is located 309 river kilometers (RKM) upstream of the mouth of the Columbia River and is composed of 22 turbine bays and 23 spillbays. The Dalles Dam is unique in its layout and design, in that its powerhouse is oriented parallel to the historic river channel (thalweg) and the spillway is perpendicular to the flow (Figure 2-1).

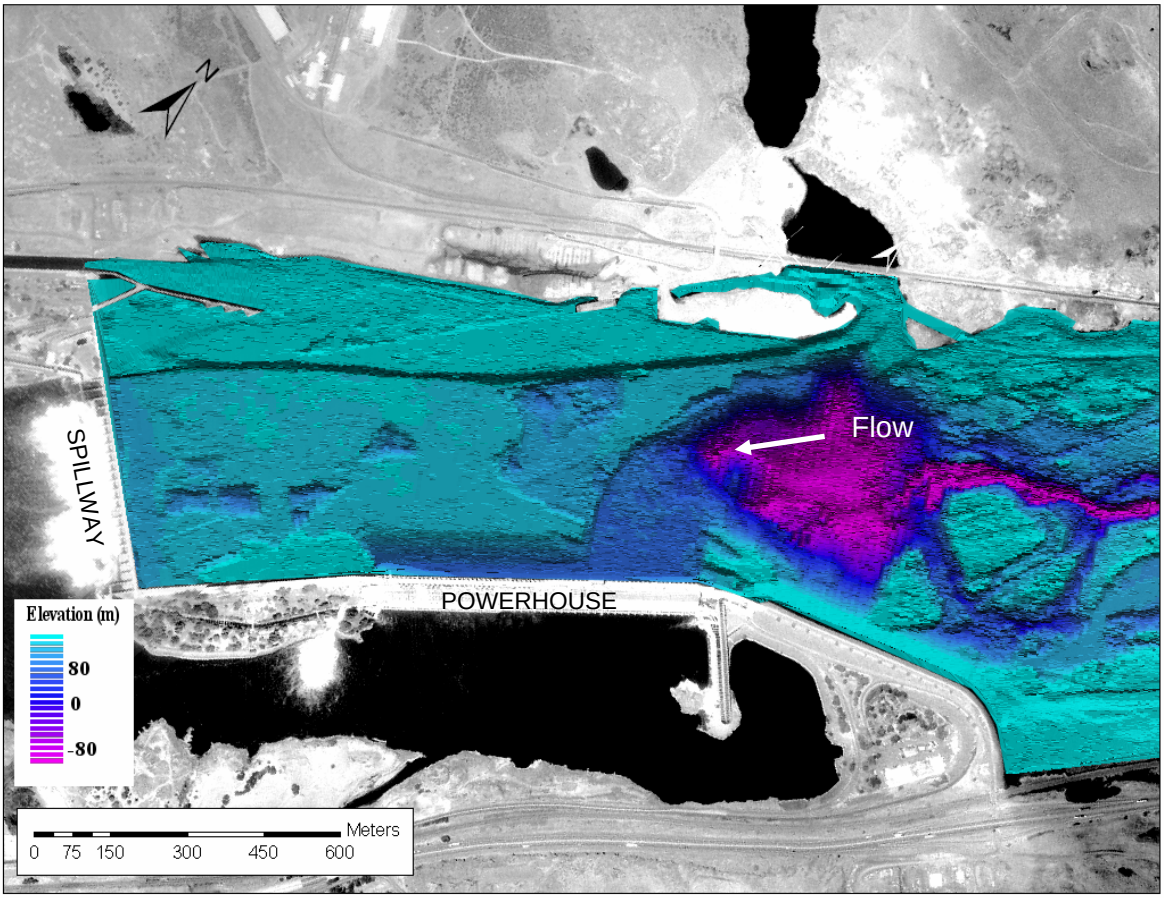

Figure 2-1. Bathymetric map of The Dalles Dam forebay. Elevation is shown in meters from deep (purple) to shallow (light blue).

Fish Tagging and Releases

We used the same fish to calculate passage results as those used for the behavioral investigation outlined in Chapter 1 of this report. The following is a review of those methods. A total of 357 juvenile hatchery yearling Chinook salmon, 366 juvenile hatchery steelhead, 75 juvenile sockeye salmon, and 364 wild and hatchery subyearling Chinook salmon were acquired from the smolt monitoring facility at John Day Dam, tagged, and released below John Day Dam. Yearling Chinook salmon, hatchery steelhead, and sockeye salmon were released from 29 April to 7 June 2004, and subyearling Chinook salmon were released from 23 June to 26 July 2004, which corresponded to their in-river migration timing. All fish were released in the mid-channel of the Columbia River immediately downstream of the tailrace boat restricted zone (BRZ) in the tailrace of the John Day Dam.

Each fish was anaesthetized with tricaine methanesulfonate (MS-222, 70 mg L^{-1}) prior to and during surgery and implanted with a transmitter. Model 795-E acoustic transmitters were used with yearling Chinook salmon and hatchery steelhead, and model 795-M acoustic transmitters were used with sockeye salmon and subyearling Chinook salmon. The transmitters were manufactured by Hydroacoustic Technology Inc. (HTI) of Seattle, Washington. The surgical methods used to implant the acoustic transmitters are the same as those detailed in Adams et al. (1998) for implantation of small radio transmitters. The procedure was identical except that we did not have to accommodate a radio telemetry antenna, a step that was described in the Adams et al. (1998) paper. The transmitters had a minimum weight of 0.75 g in air and were a minimum of 6.0 mm in diameter and 15.0 mm in length. Acoustic transmitters emitted a pulse every 0.7 to 1.5 seconds with a frequency-modulated pulse width of 3 ms. With these parameters, it was expected that a transmitter's battery life would be 10 to 12 days, which was adequate to gain behavioral and passage information from our release site below the John Day Dam tailrace through to The Dalles Dam, an expected travel time of 18-22 hours (Beeman et al. 2003).

Acoustic Telemetry Systems

We used the same acoustic telemetry array as that outlined in Chapter 1 of this report. The array consisted of 76 hydrophones and five separate HTI model 290 systems, and was sufficient to track individual fish into all openings at the spillway, turbines, and sluiceway (Figure 2-2).

The hydrophone array provided 3D coverage upstream of spillbays 1-10 to approximately 180 m and north of the powerhouse out to 280 m including all main turbine units 1-22. The coverage also included the sluiceway units 1 and 18 and the two fish turbine units on the west end of the powerhouse. There were no plans to open the remaining spillbays (11-23) for spring or summer 2004, except in the case of a flood event, which did not occur. The only downstream opening that was not covered by the array was the navigation lock adjacent to the Washington State shoreline. The lock was not considered to be a significant passage point for juvenile salmonids due to the sporadic scheduling of locking events and indications from prior research studies using radio telemetry that juvenile salmonids do not often use this route (Hensleigh et al. 1999).

Operations

The Dalles Dam spring and summer operations were set to 40% spill of the total river discharge and 60% was allocated for powerhouse operations. Priority for spill was directed toward the north shore of the Columbia River at spillbays 1-6. This operation directed flow north of a newly constructed flow guide wall that was designed to improve tailrace conditions for egress of juvenile salmonids. The openings for water at bays 1-6 were operated identically, with the occasional opening of bays 7-10 to compensate for tail-water elevation constraints (Laurie Ebner; personal communication, U.S. Army Corps of Engineers).

The ice-trash sluiceway at The Dalles Dam was operated with two distinct treatments. The first treatment was with the sluiceway gate above turbine unit 1 operating and the second was the sluiceway gates at both turbine unit 1 and turbine unit 18 open. The treatments were randomized in two day blocks in the spring and summer

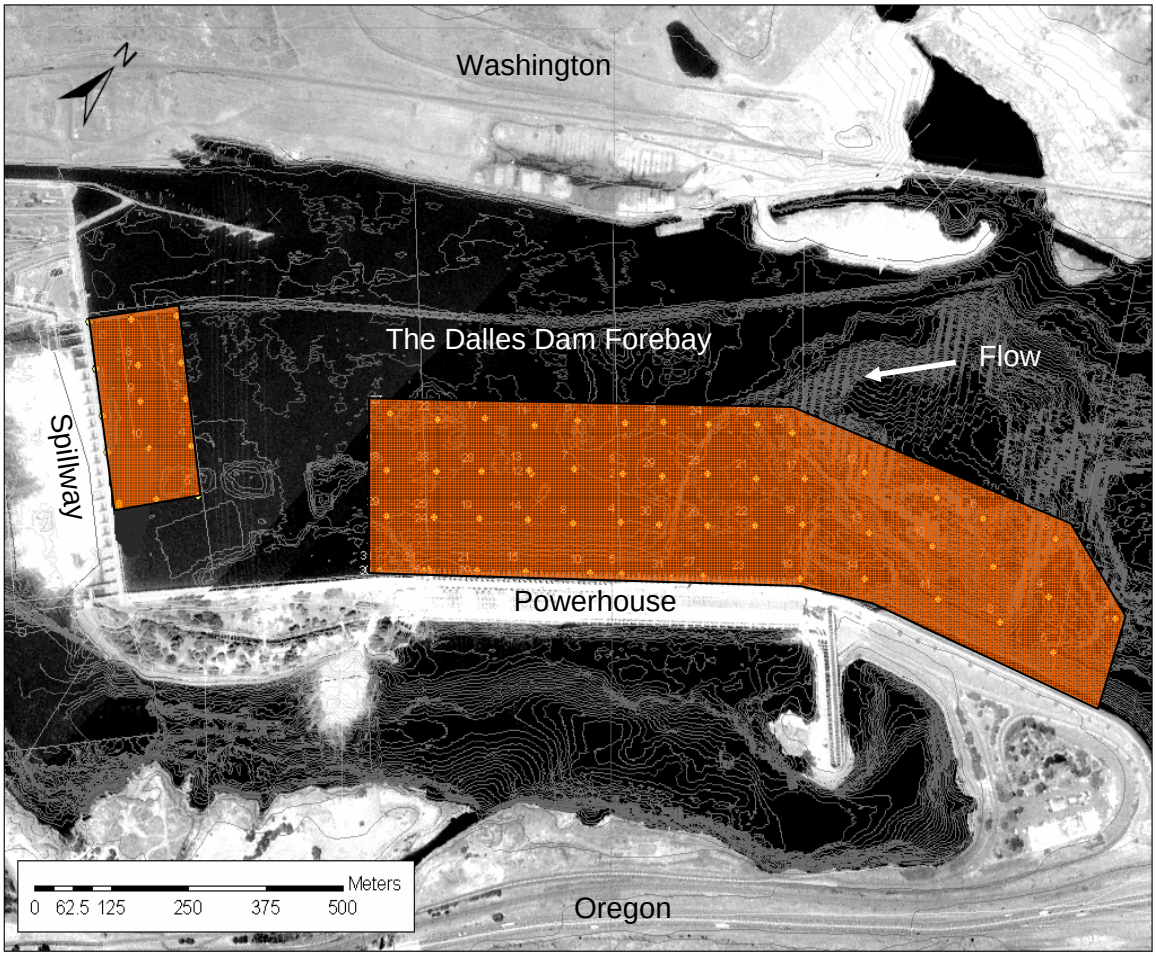

Figure 2-2. Shaded areas are showing the minimum extent of 3D coverage area for the acoustic telemetry systems that were deployed at The Dalles Dam 2004. All exit points at the powerhouse and spillway were monitored in order to determine fish passage.

sampling seasons. As mentioned in Chapter 1, powerhouse operations were the main source of discharge fluctuations due to the increased generation during periods of peak power demand.

Data Processing

The acoustic receivers collected the incoming signals from the hydrophones and stored the data in hourly files. The acoustic telemetry system accuracy was sufficient to track individuals into specific routes of passage. The files that contained fish detections for those released at John Day Dam were then identified and tracked using a two-stage effort. The first tracking effort was conducted using a newly developed autotracker, created specifically to handle the massive dataset from this study. The accuracy of the 3D system as determined from drogue releases was 4 to 7 m in the horizontal and vertical plane for 3D positions using the GPS positions of floating hydrophones and the MarkTags™ Autotracker (Chapter 1). The Autotracker performed well for the intended resolution of the 3D tracks (4-7 m). However, the Autotracker 3D tracks of a fish often ended before a definite exit location could be determined; we therefore had to manually track the final hour of every fish to resolve a passage point for each fish.

The two most common issues related to autotracking the transmitter echoes were the misidentification of multipath as a true-path signal and the lack of Autotracker results for the last portion of a transmitter's track for each hydrophone. Determination of the tagged fish's exit point was done manually as described below using the last 3D tracked fish position and the final fish heading to categorize the exit route of a tagged fish. We used drogue releases to verify Autotracker accuracy in the forebay but not at the spillways or at the entrances to the turbine units; therefore, the exact resolution of 3D positions used for passage results is not known. However it is likely that any error was less than the 4 to 7 m observed in the drogue tracks that were used for the behavioral portion of the study due to the use of manual echo tracking for the final hour of each fish.

To determine the exit location of tagged juvenile salmonids, we used four separate tracking parameter settings in the AcousticTag™ software to determine the last portion of a fish's 3D track. The settings included both the "normal" and "advanced" tracking ability of the positioning algorithm within the AcousticTag™ software (Model 290 Acoustic Tag System Manual 2004). The four tracks were then combined to determine the final location of a fish in The Dalles Dam forebay.

The relative location of the final points and the final heading of the fish were used to determine the exit location independently by two tracking technicians. The two technicians compared exit points to fish tracks and identified any inconsistencies. If an exit point at a spillbay, turbine unit, or sluiceway could not be determined, we used the final transmitter receptions of individual hydrophones to determine exit location. The reception of a transmitter signal at the final hydrophone can be very telling as to where a fish exited. Factors such as the proximity to the exit, line of sight from the hydrophone to the exit, and hydrophone directionality were all used to determine the exit location from the raw echo file. If these methods were not sufficient to determine the exit location of a fish, then we assigned a general exit such as the spillway or powerhouse. If we could not determine a general exit point, the fish was assigned an "unknown" exit value. Only fish with known exits were used to determine passage distribution across the powerhouse and spillway.

Data Analysis

Passage exit data were derived from the final location of a tagged fish and were summarized into metrics used to describe the passage of juvenile salmonids. Passage information was compared in relation to seasonal and diel patterns. This study did not use large-scale treatments that manipulated a substantial proportion of the river flow through the spillway or turbines as had been done for previous studies at The Dalles Dam. An example of a treatment of this type was a study conducted in 1999, where spill was manipulated by diverting up to 60% of the total river discharge through the spillways (Ploskey et al. 2001b).

The only treatments conducted during our study tested the influence of the sluiceway above unit 18 (<3% of total river flow), where the sluiceway was opened and closed at set intervals (Table 2-1). During the sluiceway entrance 18 opening, we only had 3 of 1,020 fish enter the sluiceway above turbine unit 18, and therefore we could not separate FPE results by sluiceway gate at unit 18 open or closed. Therefore, we chose to include all sluiceway-passed fish in the FPE results. However, we did investigate the localized influence of the sluiceway operations on fish passage at the sluiceway, and investigated possible changes in sluiceway passage based on operations at unit 18.

Estimates of FPE were calculated for the total number of juvenile salmonids by season and diel pattern (spring and summer; day and night) and by species. The FPE was then calculated by time of day (i.e., spring-nighttime) by calculating the number passing the spillway and sluiceway, divided by the total passing the project and multiplying the total by 100. Similarly, SPE was the total number of fish by time period or species that passed the spillway compared to all other routes multiplied by 100; and SLPE was the total number of fish passing the sluiceway compared to the total number passing the project. The daytime hours for the diel periods were defined as those after 0530 hours and before 2100 hours whereas nighttime hours were the remaining hours in a 24-h day. Spring fish were defined as those that were released between April 29 and June 7, and summer fish were those released between June 23 and July 26, 2004.

Distribution across the powerhouse and spillway was calculated as a percentage of the total number of fish known to pass a certain exit (e.g., turbine or spillbay) compared to all fish known to pass that region of the dam. Therefore, the percentage of fish passing that route was calculated from the total passing either the spillway or powerhouse.

We also studied the distribution of fish across individual spillbays. At each bay we determined the horizontal distribution across the bay in six 3-m increments. The last 3D position of a fish was used to determine the exit point in that 3-m increment spanning a total distance of 18-m from piernose to piernose (Figure 2-3). The last position had to be less than or equal to 15 m upstream of the tainter gate to be included in the distribution. This data is useful in determining the influence that spillbay structures may have on the population of fish passing individual spillbays.

Table 2-1. Number of 24-h blocks during which the sluiceway entrances were opened. The sluiceway entrance at main turbine unit 1 was open for the duration of the study period. The sluiceway entrance at main turbine unit 18 was open and closed for 24-h periods.

	24-Hour Blocks		
	Total	Spring	Summer
Sluiceway 1 only	41	20	21
Sluiceway 1 + 18	33	20	13

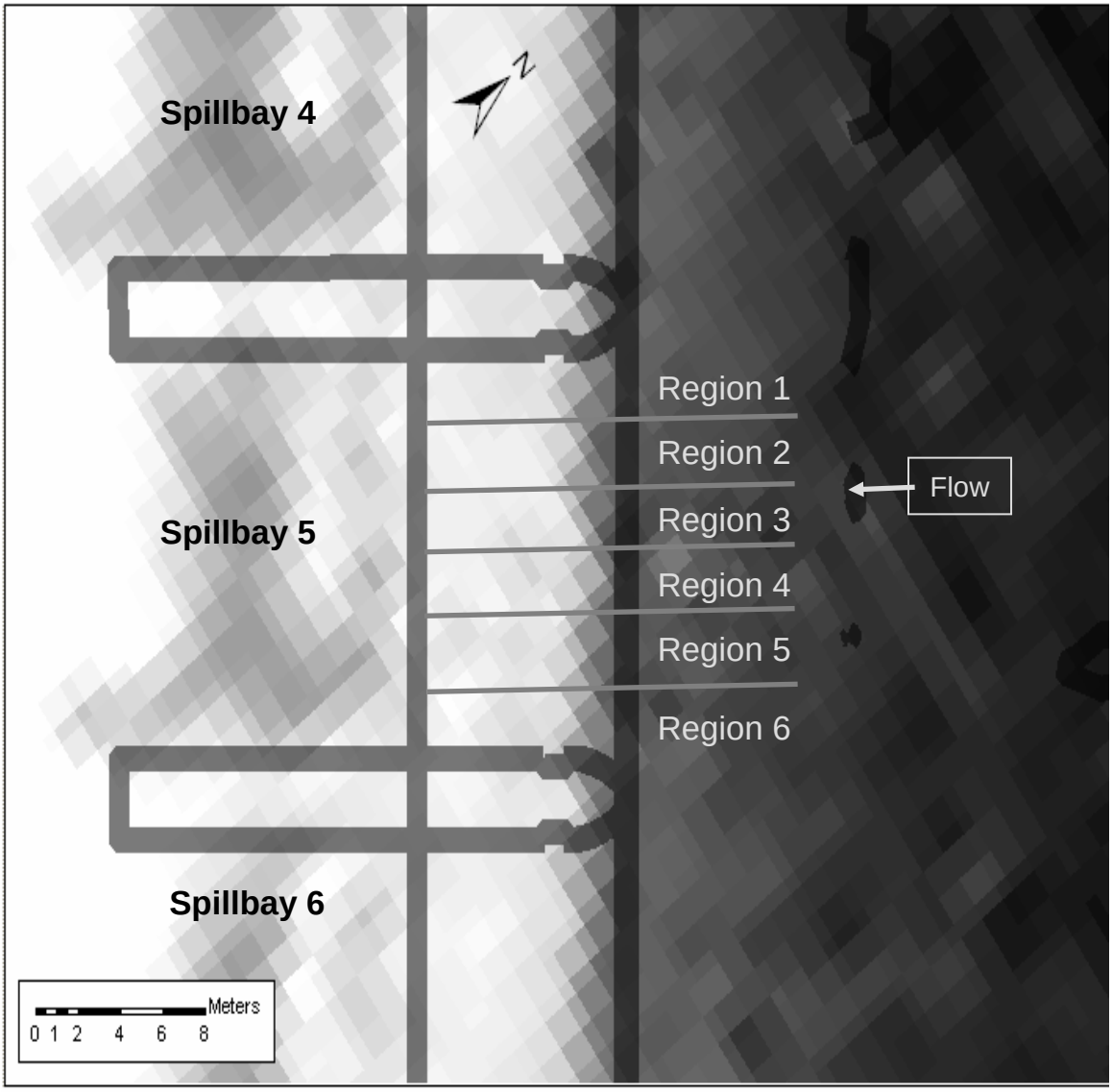

Figure 2-3. Each spillbay was divided into six regions in order to determine the distribution of fish as they passed individual bays. Region 1 was closest to the Washington or north shore, and region 6 was closest to the Oregon or south shore. Fish were counted as passing each region if their last 3D tracked location was within 15 m of the tainter gate.

Results

Fish Passage Efficiency

We calculated passage metrics for The Dalles Dam including fish passage efficiency, spill passage efficiency, and sluiceway passage efficiency. Sluiceway passage efficiency was calculated using overall project passage and with powerhouse passage only. Metrics for total passage and species passage are included in Table 2-2. These metrics were summarized further into diel passage in Table 2-3. Overall FPE for all species was high, with a strong diel component. Daytime FPE for all species was very high (>90%), primarily due to a large number of fish exiting through the spillway. Nighttime FPE results (67-87%) were much lower than the daytime FPE results for all species, due to higher turbine passage at night and a lower proportion of fish using the spillway and sluiceway at night. The sluiceway was the primary route of passage at the powerhouse compared to turbine units, yielding passage efficiencies for the sluiceway between 44 and 66% during spring (referenced to powerhouse passage), and 20% for the summer. All species had higher sluiceway passage during the daytime than during the nighttime.

Powerhouse Distribution

The distribution of juvenile salmonid passage across the powerhouse was relatively even for operating turbine units 3 to 22 (Figure 2-4). Turbine units 1 and 2 had greater passage than all other units. The sluiceway at main turbine unit 1 collected the majority of the fish passing at the powerhouse. The sluiceway entrance at main turbine unit 18 showed comparatively little passage for all juvenile salmonids compared to the sluiceway entrance at main turbine unit 1, and turbine unit 18 also passed relatively few fish (Table 2-4). The powerhouse distributions were marked by a shift in fish passage between daytime and nighttime. Most of the fish passage through turbines occurred at nighttime; and most of the passage through the sluiceway passage occurred during the

Table 2-2. The fish passage efficiency (FPE), spillway passage efficiency (SPE), and the sluiceway passage efficiency (SLPE) with reference to overall project passage (SLPE Project), and powerhouse passage (SLPE Powerhouse) for all four species.

	Combined Species *n* = 1020	**Yearling Chinook Salmon** *n* = 333	**Hatchery Steelhead** *n* = 324	**Sockeye Salmon** *n* = 62	**Subyearling Chinook Salmon** *n* = 301
FPE	92.3	92.2	90.1	98.4	93.4
SPE	86.1	83.5	81.8	95.2	91.7
SLPE Project	6.2	8.7	8.3	3.2	1.7
SLPE Powerhouse	44.4	52.7	45.7	66.7	20.0

Table 2-3. The fish passage efficiency (FPE), spillway passage efficiency (SPE), and the sluiceway passage efficiency (SLPE) with reference to overall project passage (SLPE Project), and powerhouse passage (SLPE Powerhouse) for all four species combined along with values for individual species efficiencies for both daytime and nighttime.

	Combined Species		**Yearling Chinook Salmon**		**Hatchery Steelhead**		**Sockeye Salmon**		**Subyearling Chinook Salmon**	
	Day *n* = 784	Night *n* = 236	Day *n* = 239	Night *n* = 97	Day *n* = 244	Night *n* = 80	Day *n* = 54	Night *n* = 8	Day *n* = 250	Night *n* = 51
FPE	97.5	75.0	97.9	78.3	96.7	70.0	100.0	87.5	97.2	74.5
SPE	92.2	65.7	90.3	67.0	88.9	60.0	98.2	75.0	96.0	70.6
SLPE Project	5.2	9.3	7.6	11.3	7.8	10.0	1.8	12.5	1.2	3.9
SLPE Powerhouse	67.2	27.2	78.3	34.4	70.4	25.0	100.0	50.0	30.0	13.3

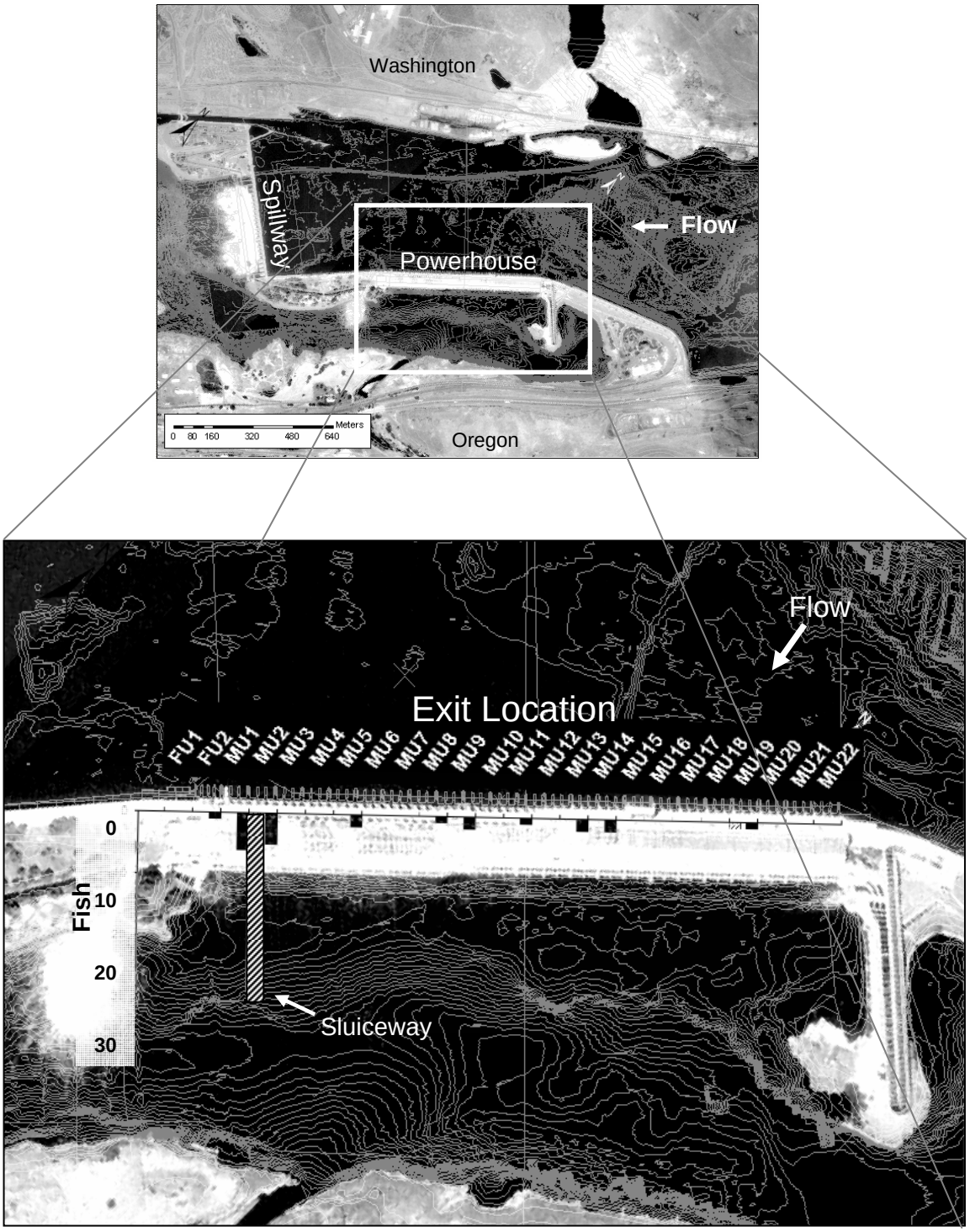

Figure 2-4. Powerhouse at The Dalles Dam showing location and a representative passage graph at numbered fish turbine units (FU), main turbine units (MU) and sluiceway (striped).

Table 2-4. Ratios of fish passing through the sluiceway calculated as the number of fish passing with the sluiceway entrance at main turbine unit 1 open only, or both sluiceway 1 and sluiceway 18 entrances open and divided by the number of 24-h blocks available for each treatment. The values in parentheses are the N values for each group.

	All Fish			**Spring Fish**		
	Total	Day	Night	Total	Day	Night
Sluiceway 1 only	0.88 (36)	0.61 (25)	0.27 (11)	1.60 (32)	1.10 (22)	0.50 (10)
Sluiceway 1 + 18	0.82 (27)	0.48 (16)	0.33 (11)	1.30 (26)	0.80 (16)	0.50 (10)

	Yearling Chinook Salmon	**Hatchery Steelhead**	**Subyearling Chinook Salmon**
Sluiceway 1 only	0.65 (13)	0.85 (17)	0.19 (4)
Sluiceway 1 + 18	0.80 (16)	0.50 (10)	0.08 (1)

daytime. Those trends appeared in the subsets of the data by season and species, although fewer subyearling Chinook salmon and sockeye salmon passed the sluiceway than did yearling Chinook salmon and hatchery steelhead overall (Figures 2-5 to 2-10).

Spillway Distribution

The distribution of juvenile salmonids in the spring and summer indicated a preference for spillbay 6, which passed 23.4% of the tagged fish. Spillbays 1 and 4 passed the fewest fish of spillbays 1 to 6, which were operated identically throughout the season (Figure 2-11). Spillbays 7-10 were the most effective at passing fish based on the amount of water spilled through those bays (Figures 2-12, 2-13), although spillbays 7-10 were opened only intermittently to allow the tailwater to adjust to changing operations at The Dalles Dam. We observed more fish passing the spillway during daytime than nighttime (721 and 155 fish, respectively) (Figure 2-14). The daytime distribution of juvenile salmonids was similar to the total distribution in the spring and summer; however, at nighttime the distribution was greater at spillbays 2 and 3 (Figures 2-15, 2-16).

Species differences in passage distributions were evident at the spillway (Figure 2-17). Yearling Chinook salmon and hatchery steelhead appeared to follow the same pattern, showing a preference for passage at spillbay 6. The only difference we could identify between the two species was that more yearling Chinook salmon passed spillbay 2. Sockeye salmon passed in equal percentages at spillbays 1 and 6. Subyearling Chinook salmon passed more often at spillbay 5 than spillbay 6, but most of these fish were still distributed toward the southern spillbays. Daytime distributions of salmonids were similar to their overall distributions. Spillbays 3 and 6 were similarly attractive to hatchery steelhead at night and subyearling Chinook salmon preferred spillbay 5 during nighttime hours (Figures 2-16, 2-18).

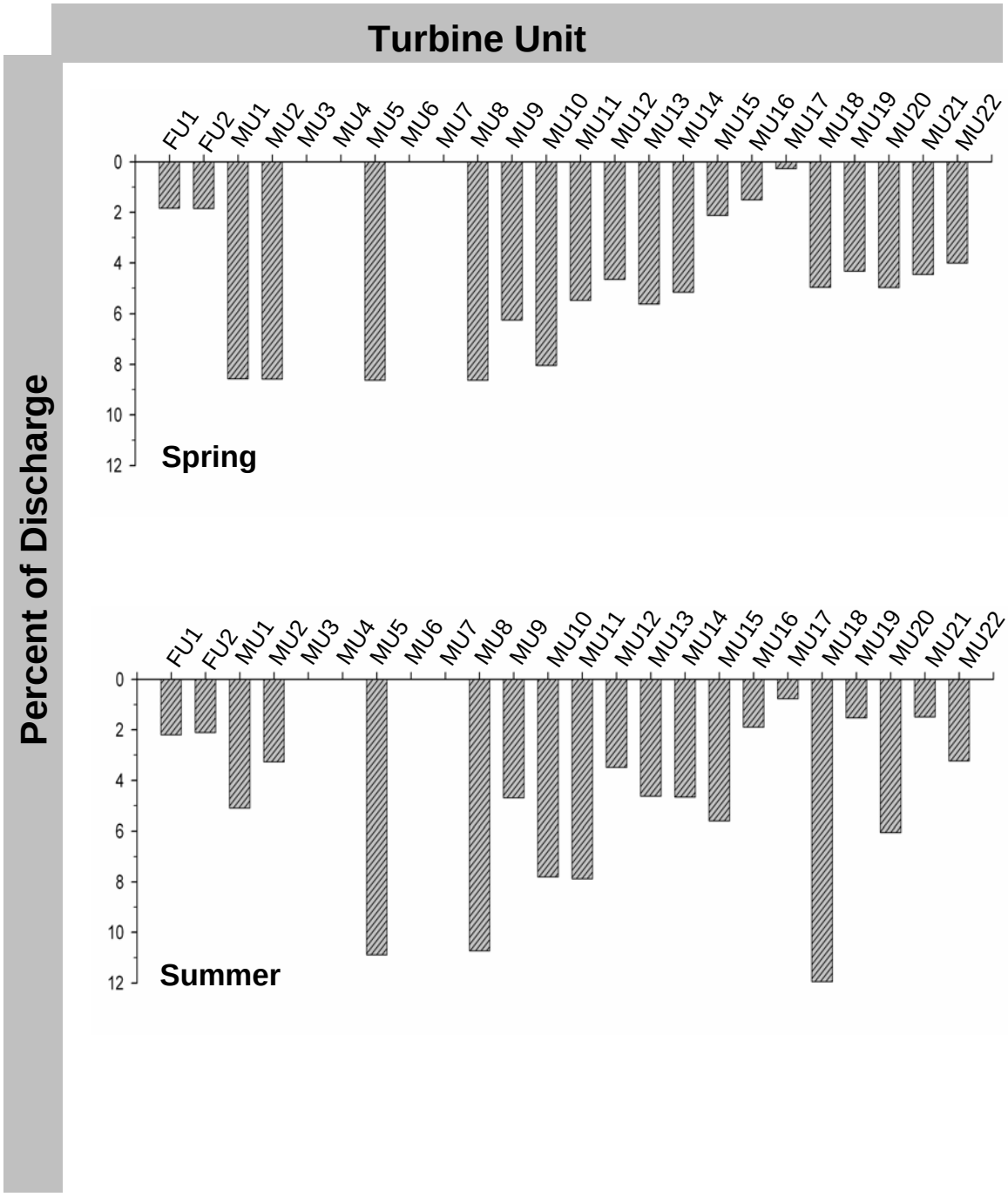

Figure 2-5. Percent of total discharge for the powerhouse by turbine unit for the spring and summer sampling seasons. Spring data was summarized from April 29 to June 7, and summer data was summarized from June 23 through July 18, 2004

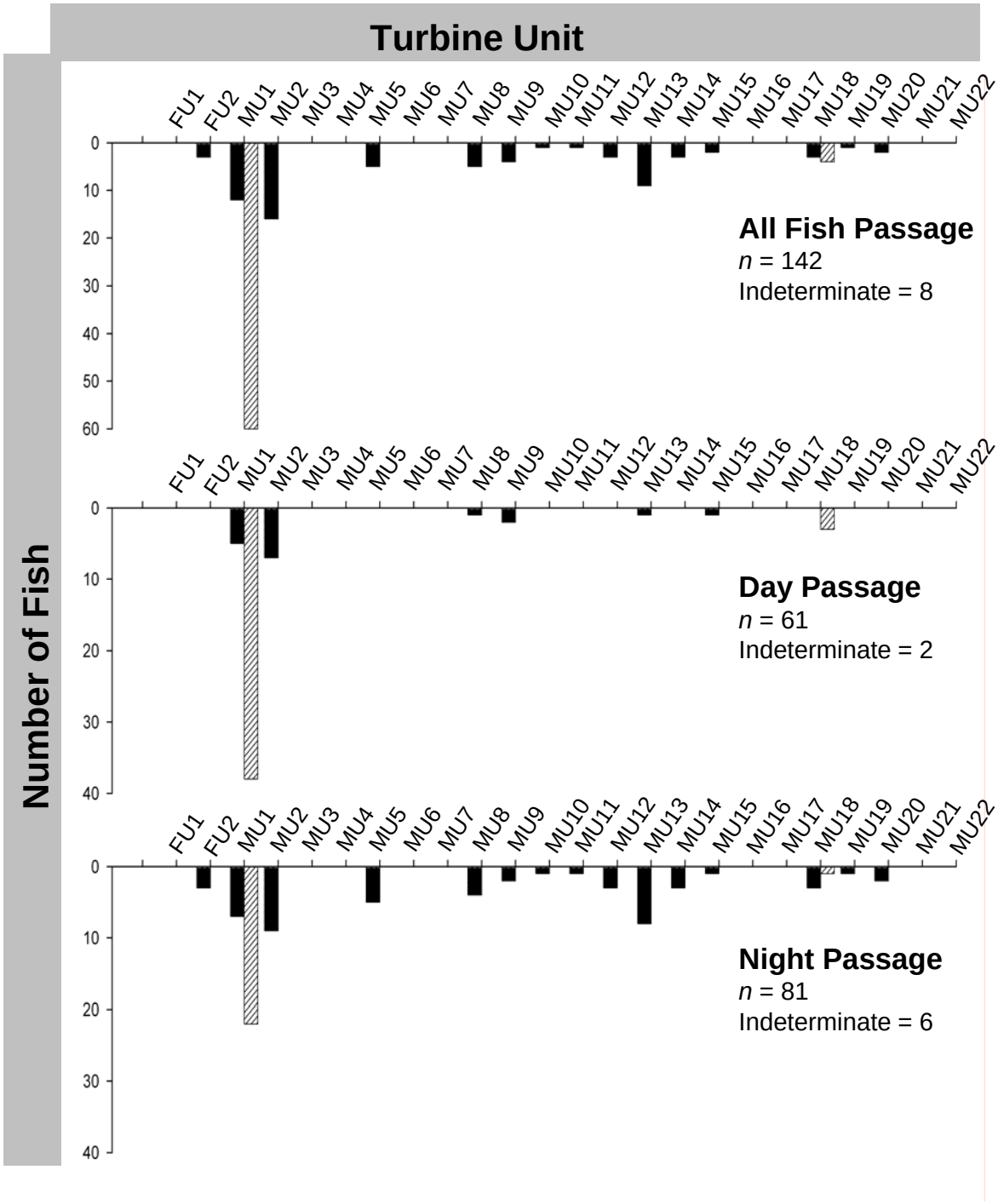

Figure 2-6. Number of fish passing the powerhouse by exit for both spring and summer. Indeterminate numbers are those fish that were detected in the powerhouse array, but were not close enough to a specific turbine unit so that we could differentiate a specific exit. The lighter bars at main turbine units 1 and 18 represent the fish passing into the sluiceway entrance above those units.

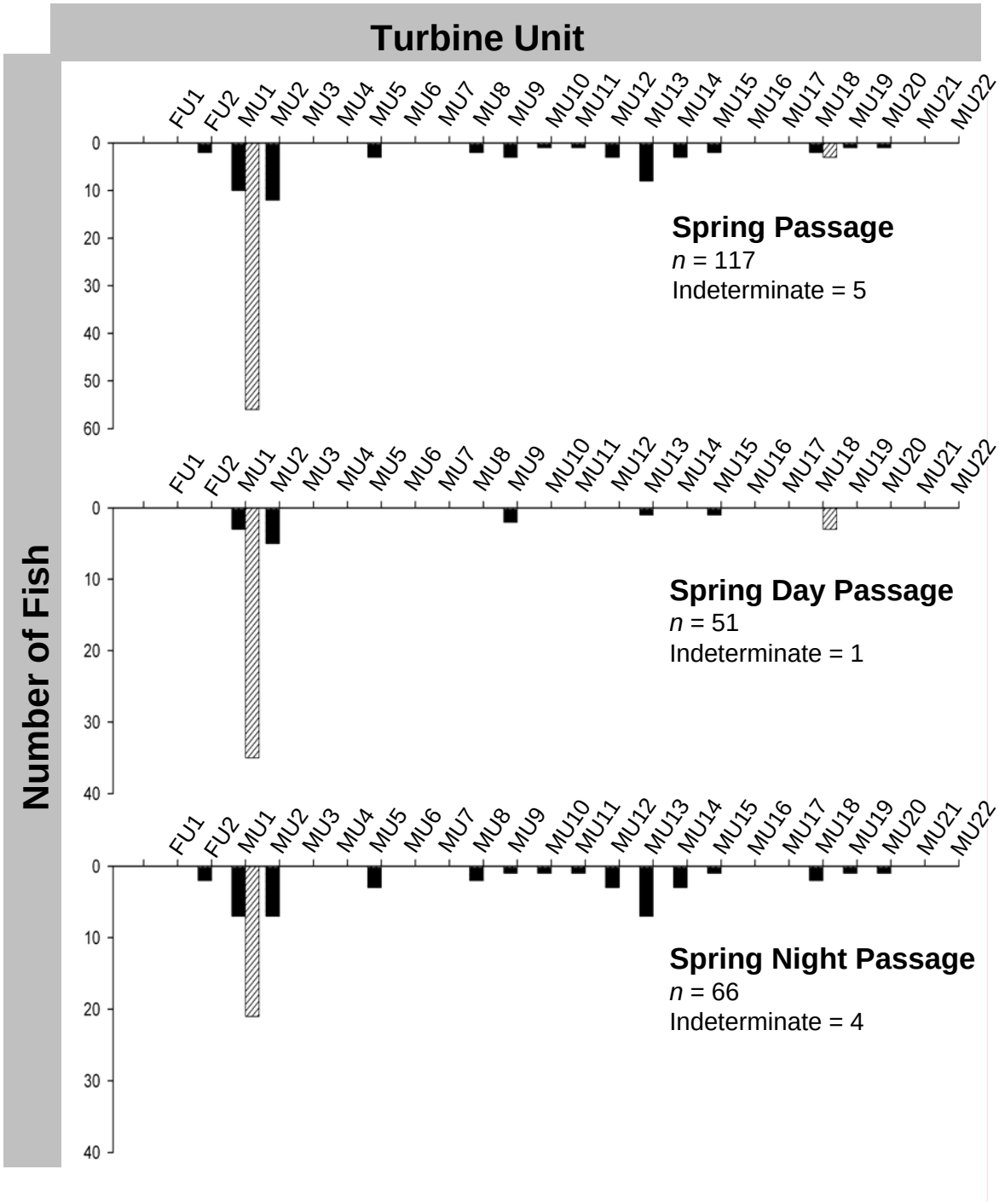

Figure 2-7. Number of fish passing the powerhouse by exit for spring samples. Indeterminate numbers are those fish that were detected in the powerhouse array, but were not close enough to a specific turbine unit so that we could differentiate a specific exit. The lighter bars at main turbine units 1 and 18 represent the fish passing into the sluiceway entrance above those units.

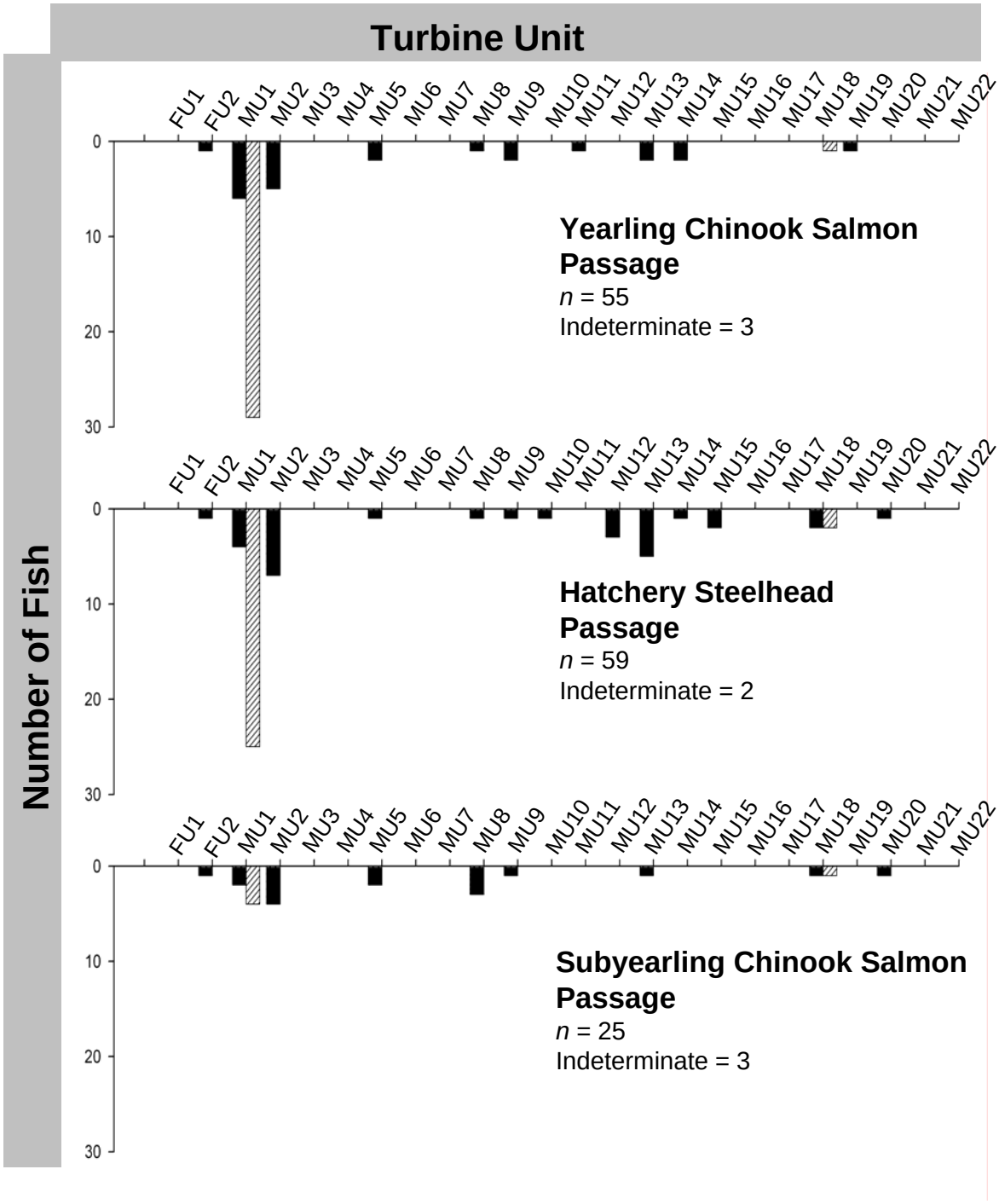

Figure 2-8. Number of fish passing the powerhouse by exit for each species. Indeterminate numbers are those fish that were detected in the powerhouse array, but were not close enough to a specific turbine unit so that we could differentiate a specific exit. The lighter bars at main turbine units 1 and 18 represent the fish passing into the sluiceway entrance above those units.

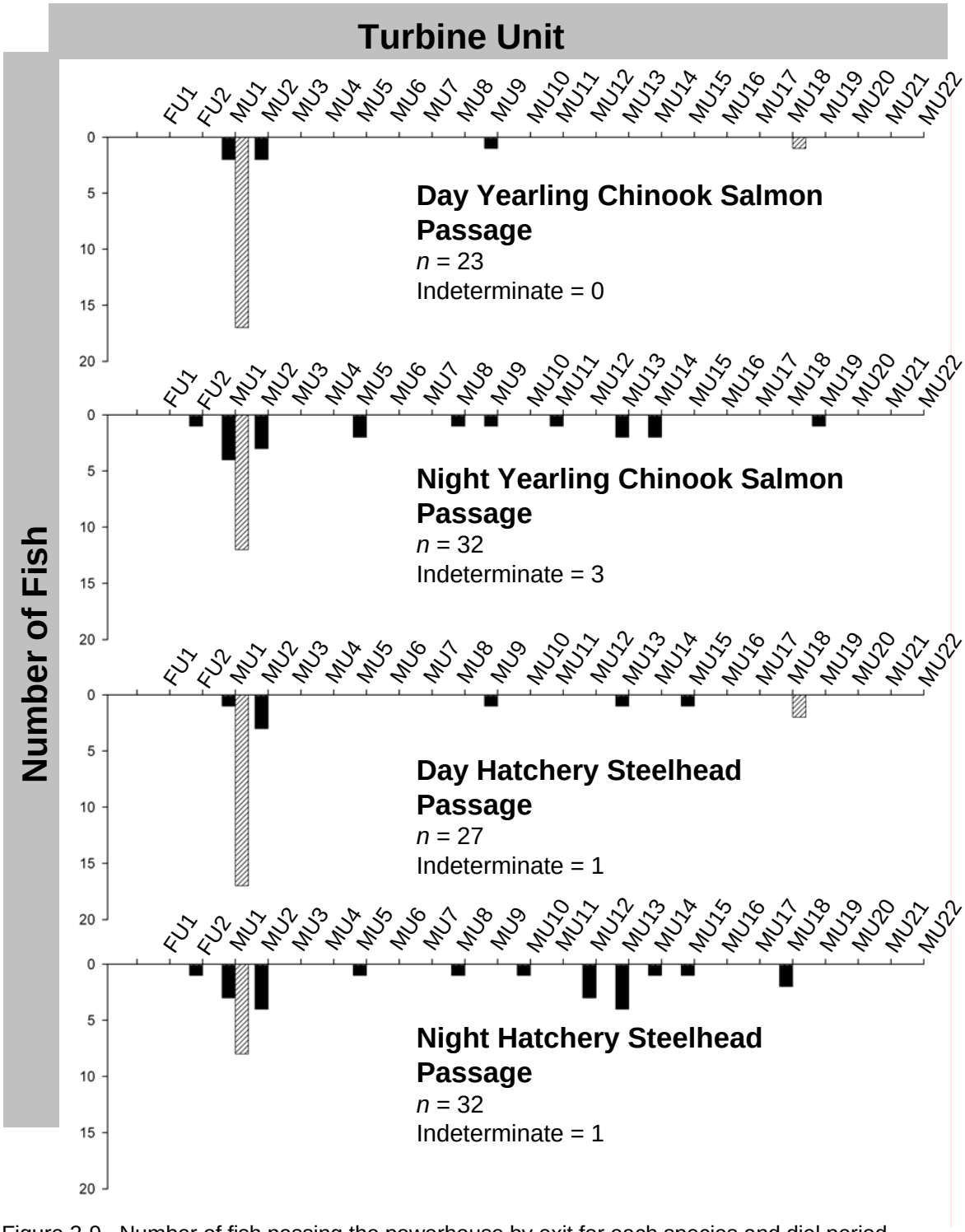

Figure 2-9. Number of fish passing the powerhouse by exit for each species and diel period. Indeterminate numbers are those fish that were detected in the powerhouse array, but were not close enough to a specific turbine unit so that we could differentiate a specific exit. The lighter bars at main turbine units 1 and 18 represent the fish passing into the sluiceway entrance above those units.

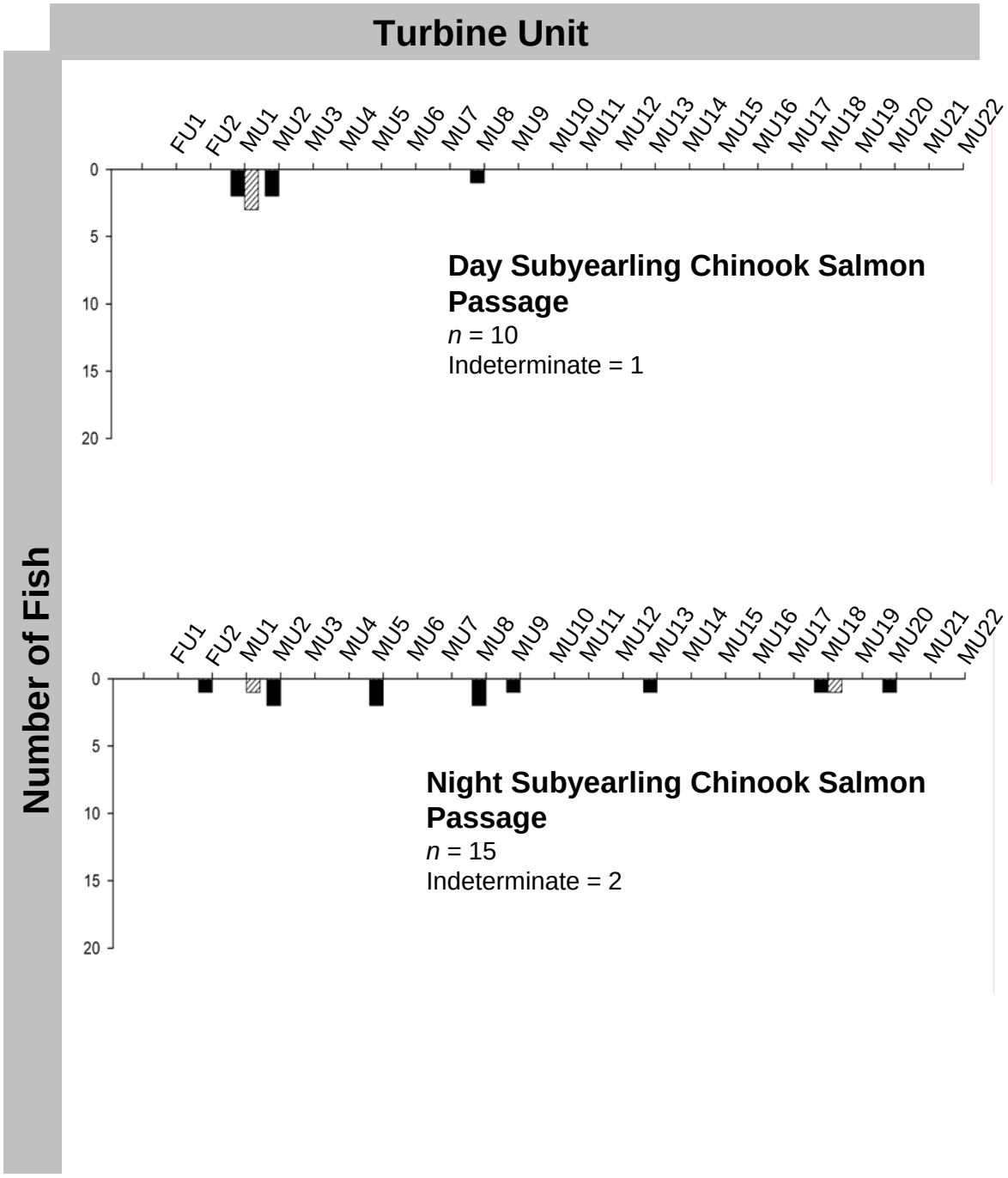

Figure 2-10. Number of fish passing the powerhouse by exit for each species and diel period. Indeterminate numbers are those fish that were detected in the powerhouse array, but were not close enough to a specific turbine unit so that we could differentiate a specific exit. The lighter bars at main turbine units 1 and 18 represent the fish passing into the sluiceway entrance above those units.

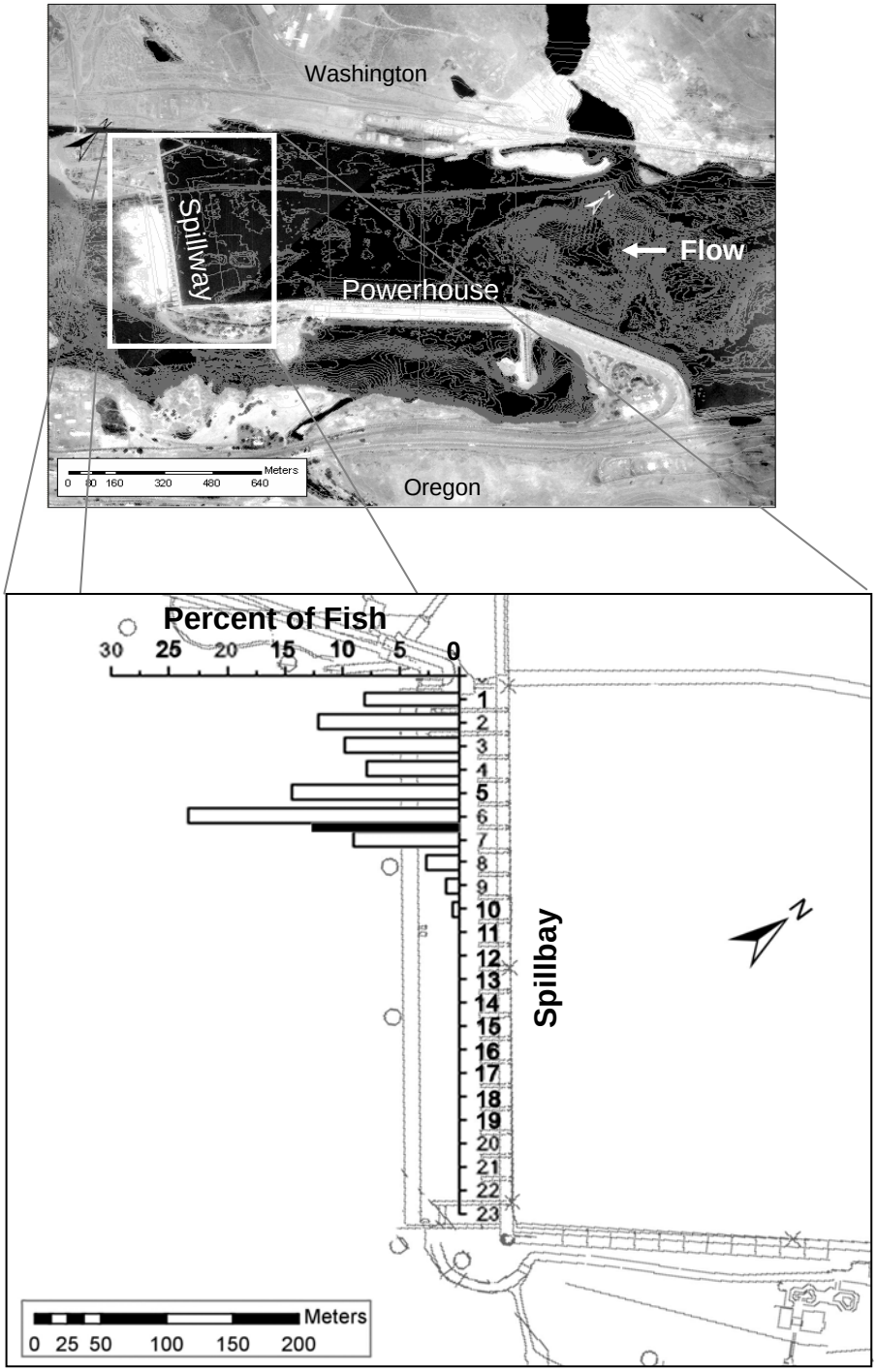

Figure 2-11. Spillway at The Dalles Dam showing location and representative passage at numbered spillbays (1-23). Only spillbays 1-10 were operated for our spring and summer seasons, with priority for 40% flow through spillbays 1-6. Y-axis displays the spillbay, X-axis is the percentage of fish passing an individual spillbay for Figures 11 to 19. The dark line downstream of bays 6 and 7 represents a guide-wall installed in spring 2004.

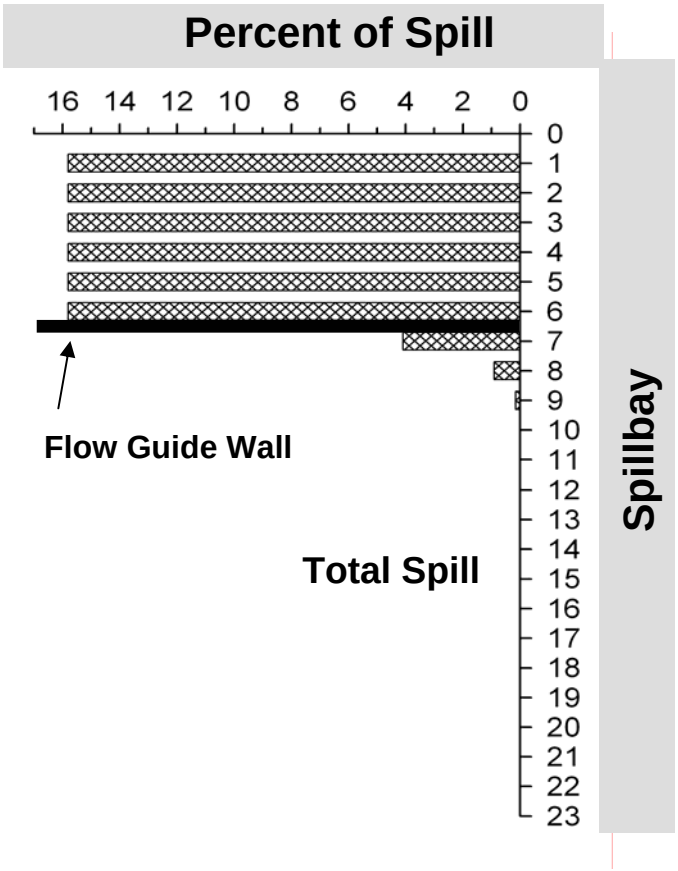

Figure 2-12. Spillway at The Dalles Dam showing location and representative spill percentage for the spring and summer seasons at numbered spillbays (1-23). Only spillbays 1-10 were operated for our spring and summer seasons, with priority on spillbays 1-6. Y-axis displays the spillbay, X-axis is the percentage of water passing individual spillbays.

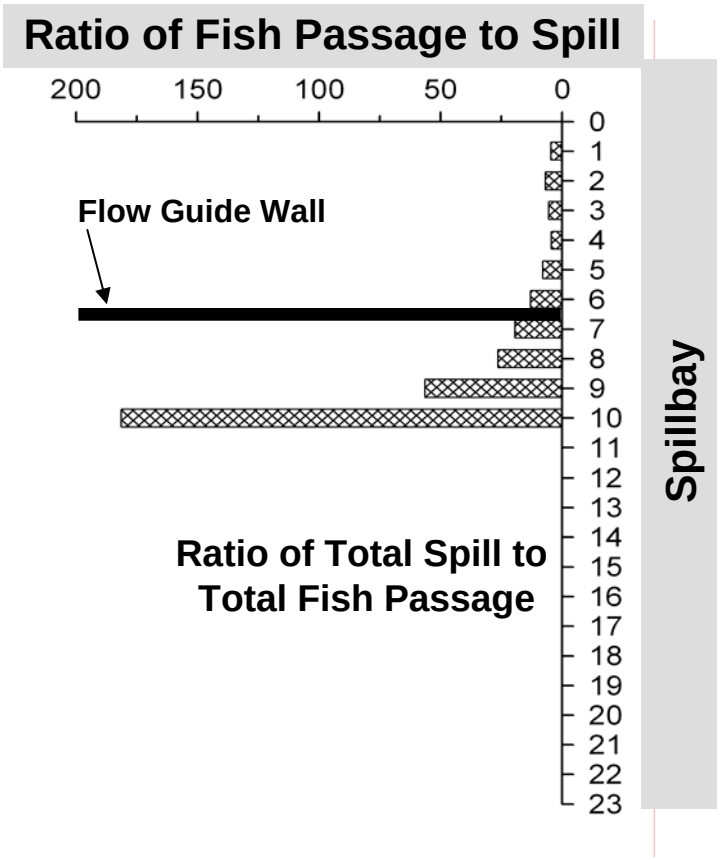

Figure 2-13. Ratio of fish passage to percent spill (e.g., effectiveness) calculated using the total spill of each spillbay for the season divided into the number of fish passing that exit. Spillbay 10 was opened briefly during the summer season. Spill at spillbay 10 was only 0.02% of total spill for the period of the study.

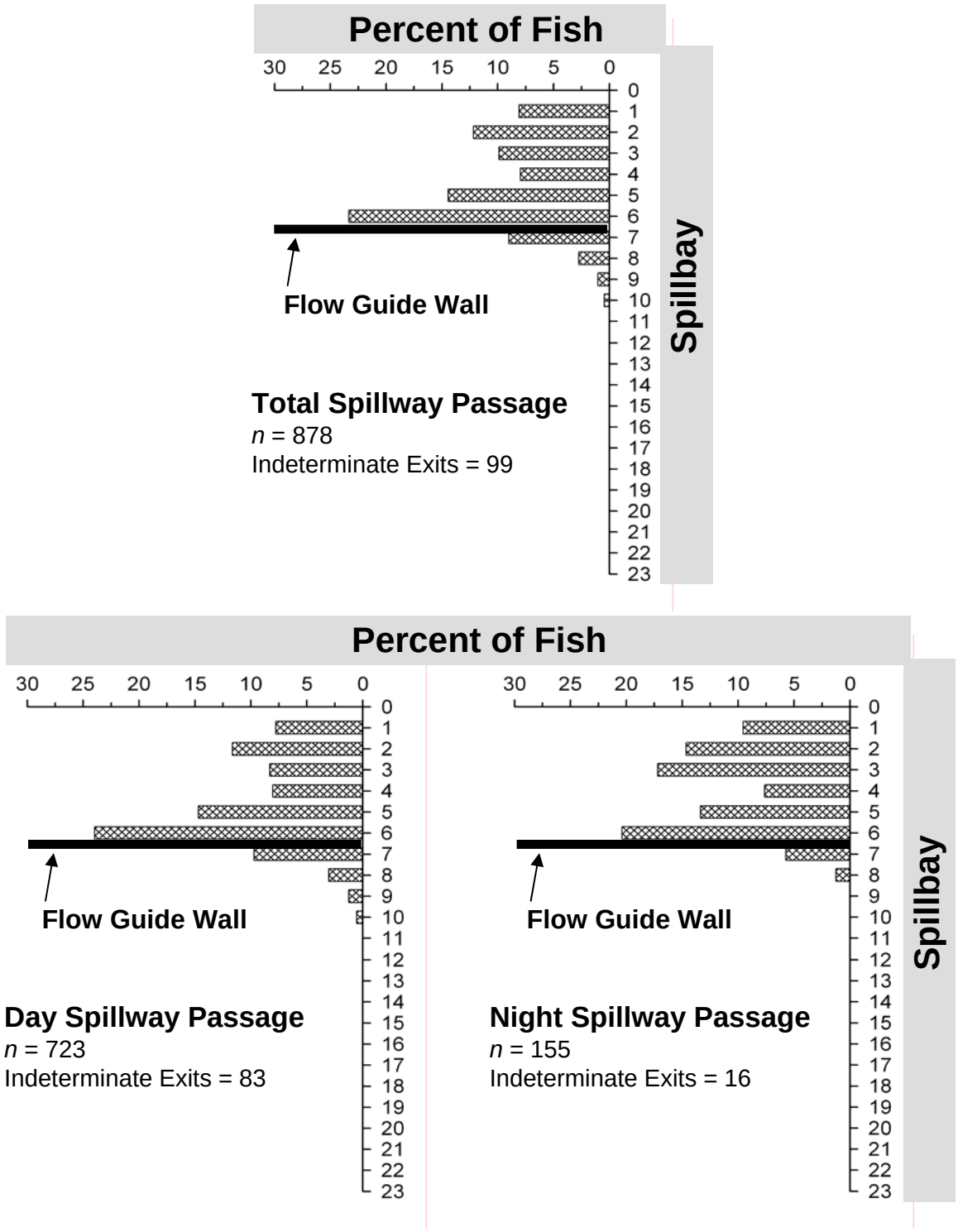

Figure 2-14. Percent of fish exiting through the spillway by individual spillbay for both spring and summer samples. Indeterminate numbers included those fish detected in the spillway array but not close enough to a specific exit point to identify an exit location.

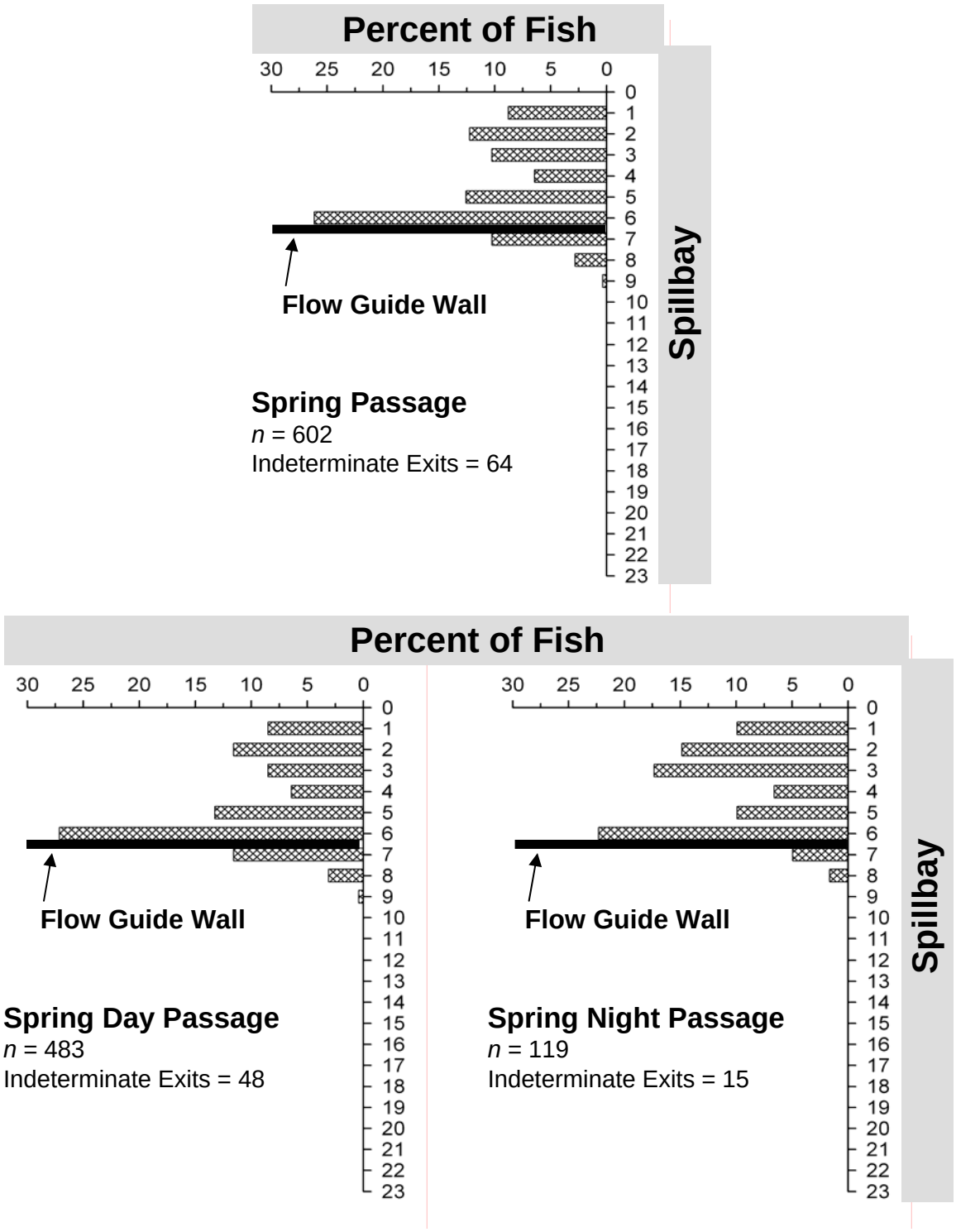

Figure 2-15. Percent of fish exiting through the spillway by individual spillbay for springtime samples. Indeterminate numbers included those fish detected in the spillway array but not close enough to a specific exit point to identify an exit location.

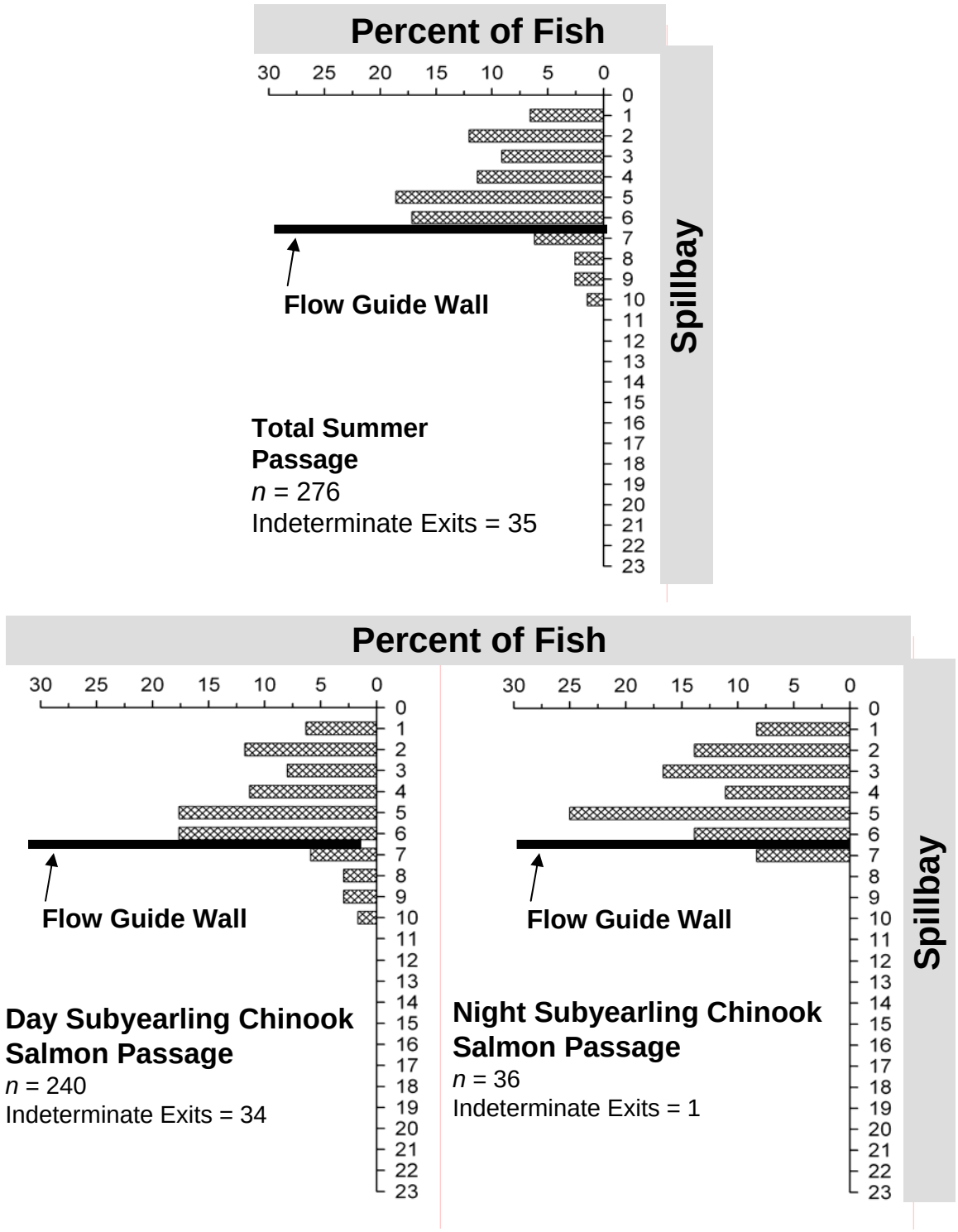

Figure 2-16. Percent of fish exiting through the spillway by individual spillbay for summer and diel period of subyearling Chinook salmon. Indeterminate numbers included those fish detected in the spillway array but not close enough to a specific exit point to identify an exit location.

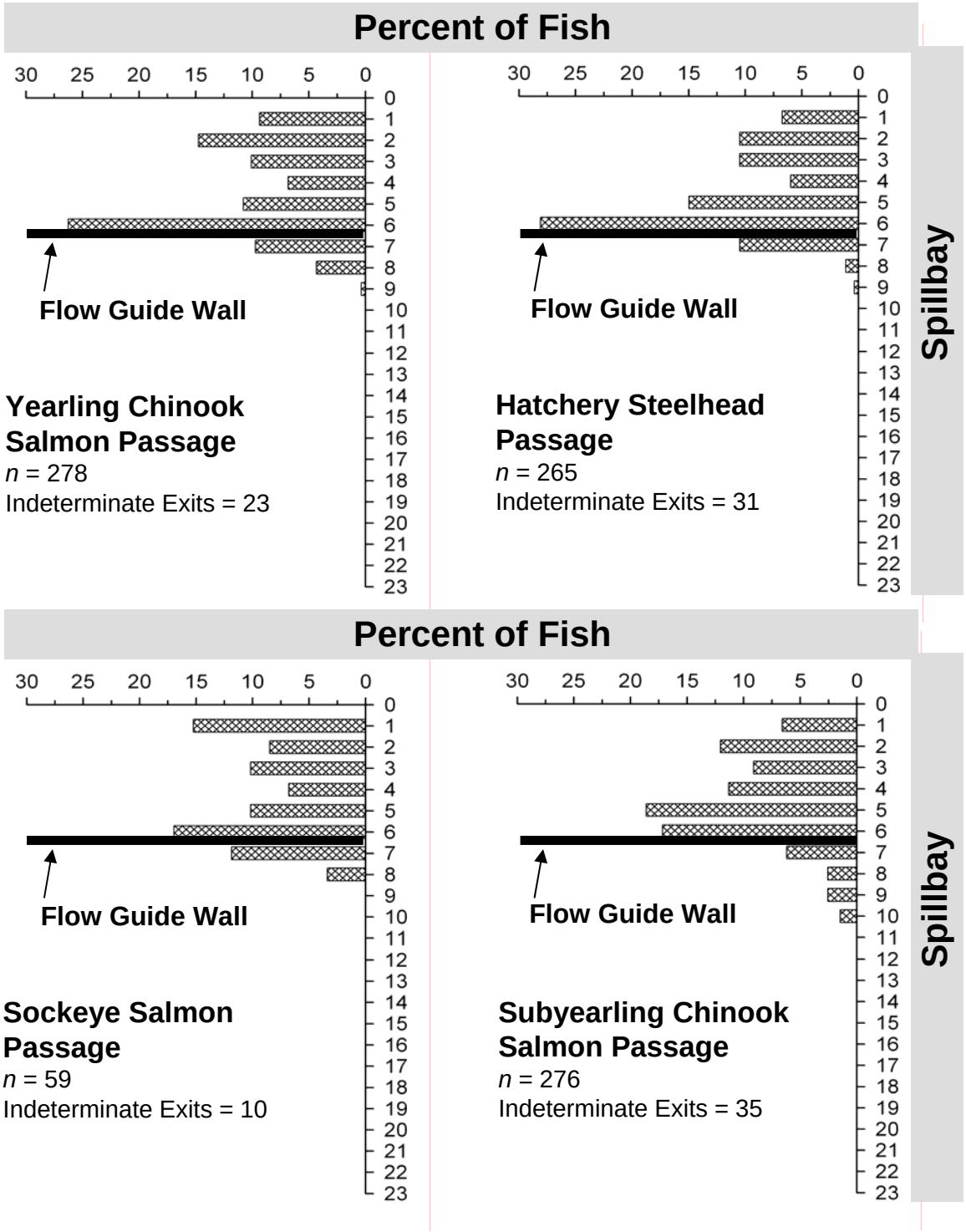

Figure 2-17. Percent of fish exiting through the spillway by individual spillbay for all species. Indeterminate numbers included those fish detected in the spillway array but not close enough to a specific exit point to identify an exit location.

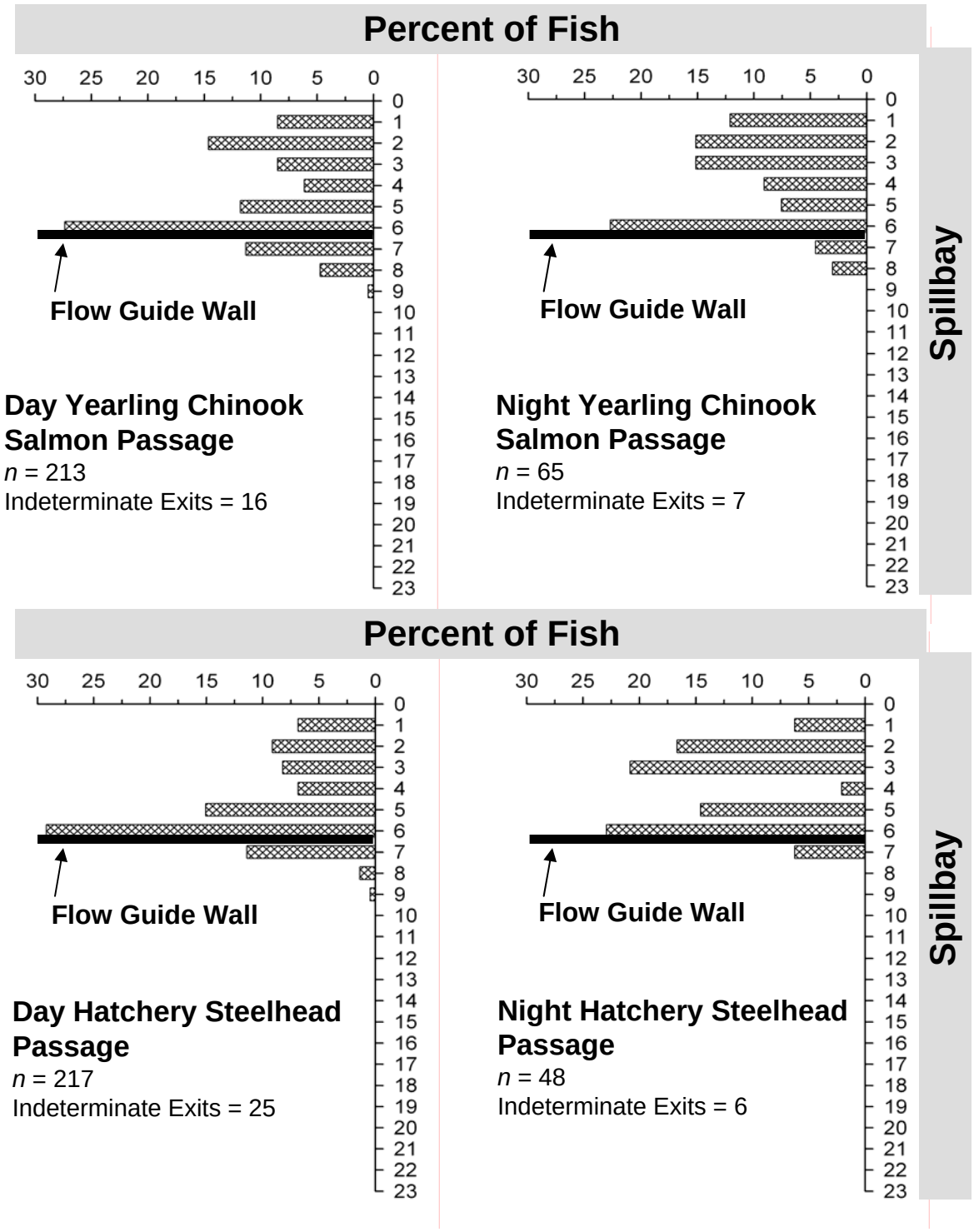

Figure 2-18. Percent of fish exiting through the spillway by individual spillbay for species and diel period. Indeterminate numbers included those fish detected in the spillway array but not close enough to a specific exit point to identify an exit location.

Spillbay Passage Effectiveness

To determine spill passage effectiveness, we divided the number of fish passing each spillbay by the percent of spill passing that spillbay to create a ratio of fish passage to the amount of water passed throughout the spring and summer outmigration period. Using this method, spillbays 7 through 10 were the most effective passage points. During the spring season, spillbays 7 and 9 were most effective at passing all species, but yearling Chinook salmon passed most effectively at spillbay 8 (Figure 2-19). During the summer, spillbays 9 and 10 were the most effective. Spillbay 10, which had the most effective spillbay passage, was only open in the summer season for short durations but passed four subyearling Chinook salmon using the relatively small amount of water it passed (Figure 2-20).

Individual Spillbay Distribution

We calculated passage distributions for each spillbay by dividing each spillbay into six equal regions that extended 15 m upstream from the spillbay. Distributions were calculated for total passage, diel passage, and species passage. Passage at spillbays 1, 4, and 6 was distributed around the southern half (regions 4 through 6) of those spillbays. Passage was evenly distributed across spillbays 2 and 5. Spillbay 3 distributions were slightly higher at the northern end (regions 1, 2, and 3) but daytime distributions for spillbay 3 were evenly distributed around the center of the spillbay (Figures 2-21 to 2-26). When distributions at the spillbays were separated by species, distributions showed more variation but the low fish count made it difficult to determine any real patterns. Passages for spillbays 1 and 6 were distributed at the southern end of the spillbay for each species. Passage at spillbays 2, 3, 4, and 5 was variable across the spillbays and between species (Figure 2-27 to 2-32).

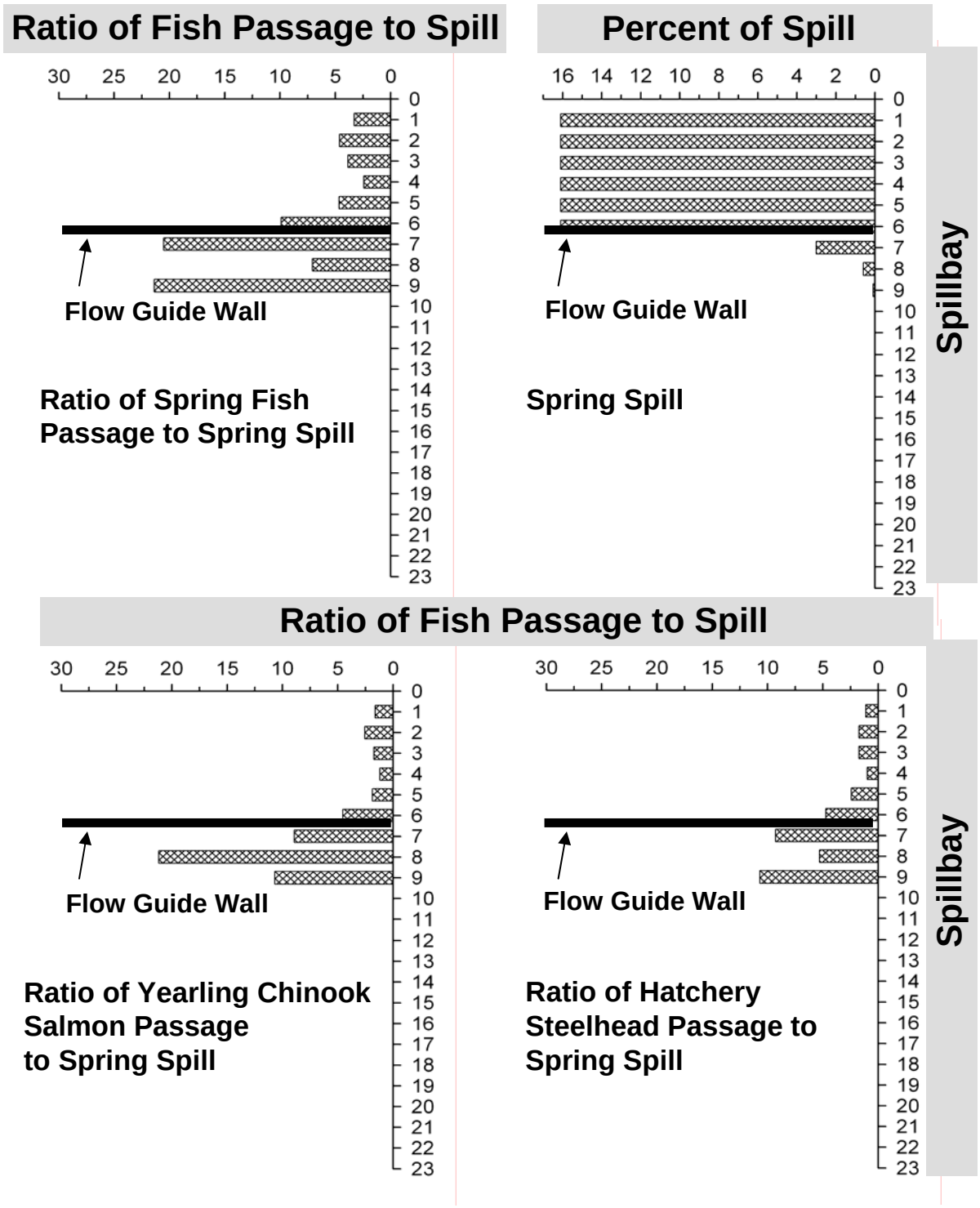

Figure 2-19. Effectiveness of fish passage calculated using the total spill of each spillbay and dividing into the number of fish passing that exit. Graphs are organized by species. The spring spill graph is showing the percentage of spill through individual spillbays throughout the season.

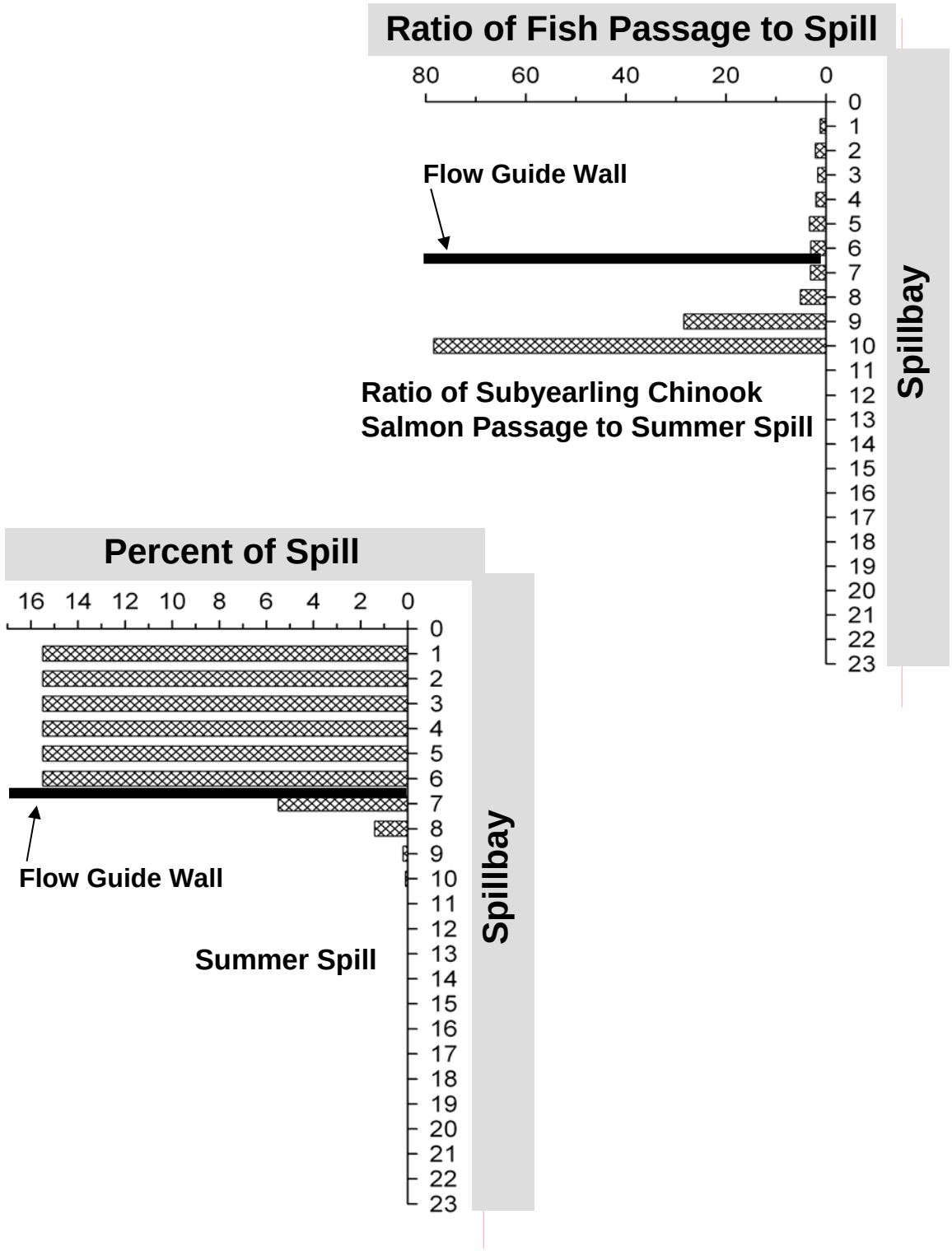

Figure 2-20. Effectiveness of fish passage calculated using the total spill of each spillbay and dividing into the number of fish passing that exit. The summer spill graph is showing the percentage of spill through individual spillbays throughout the season.

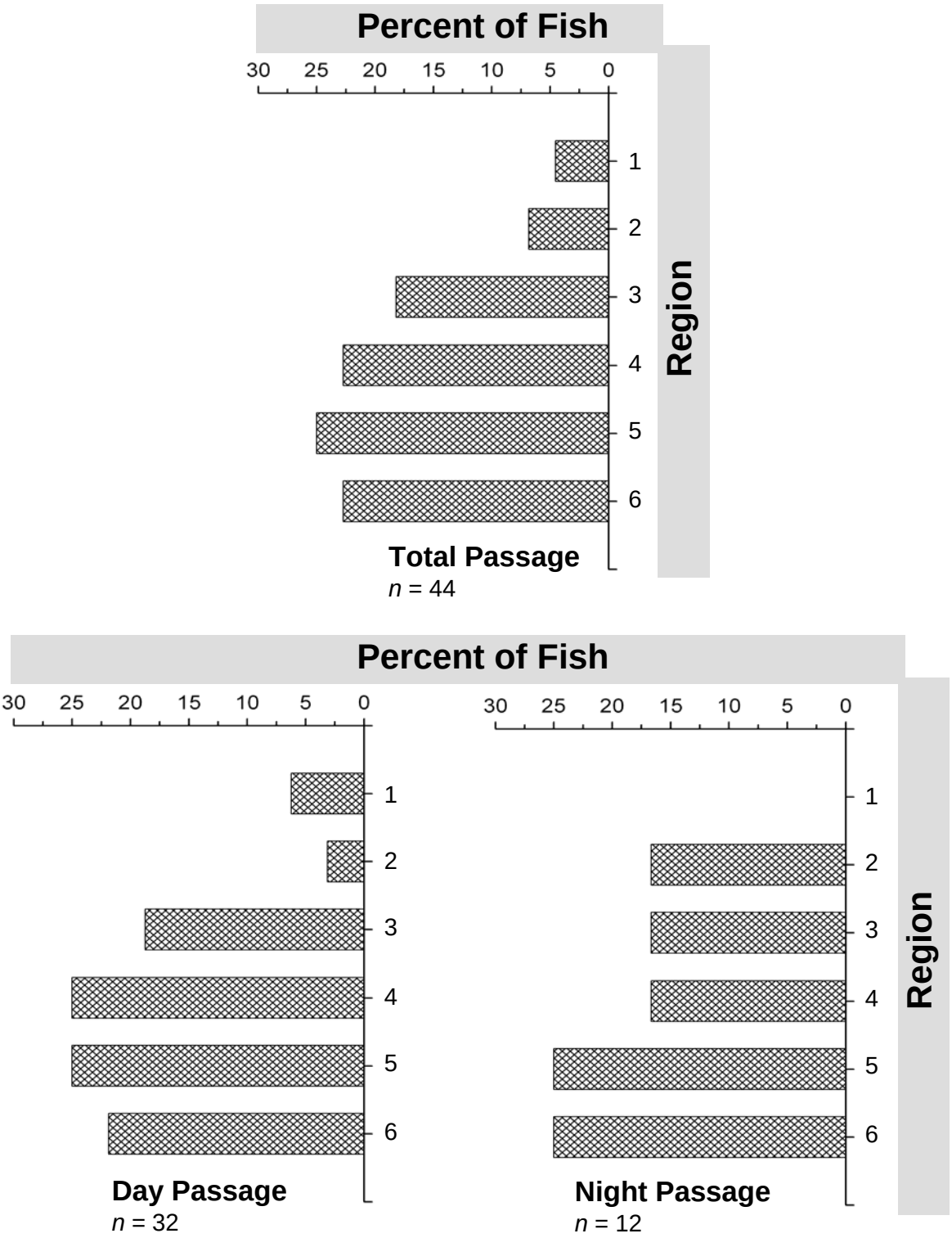

Figure 2-21. Percent distribution of fish passing at spillbay 1. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore.

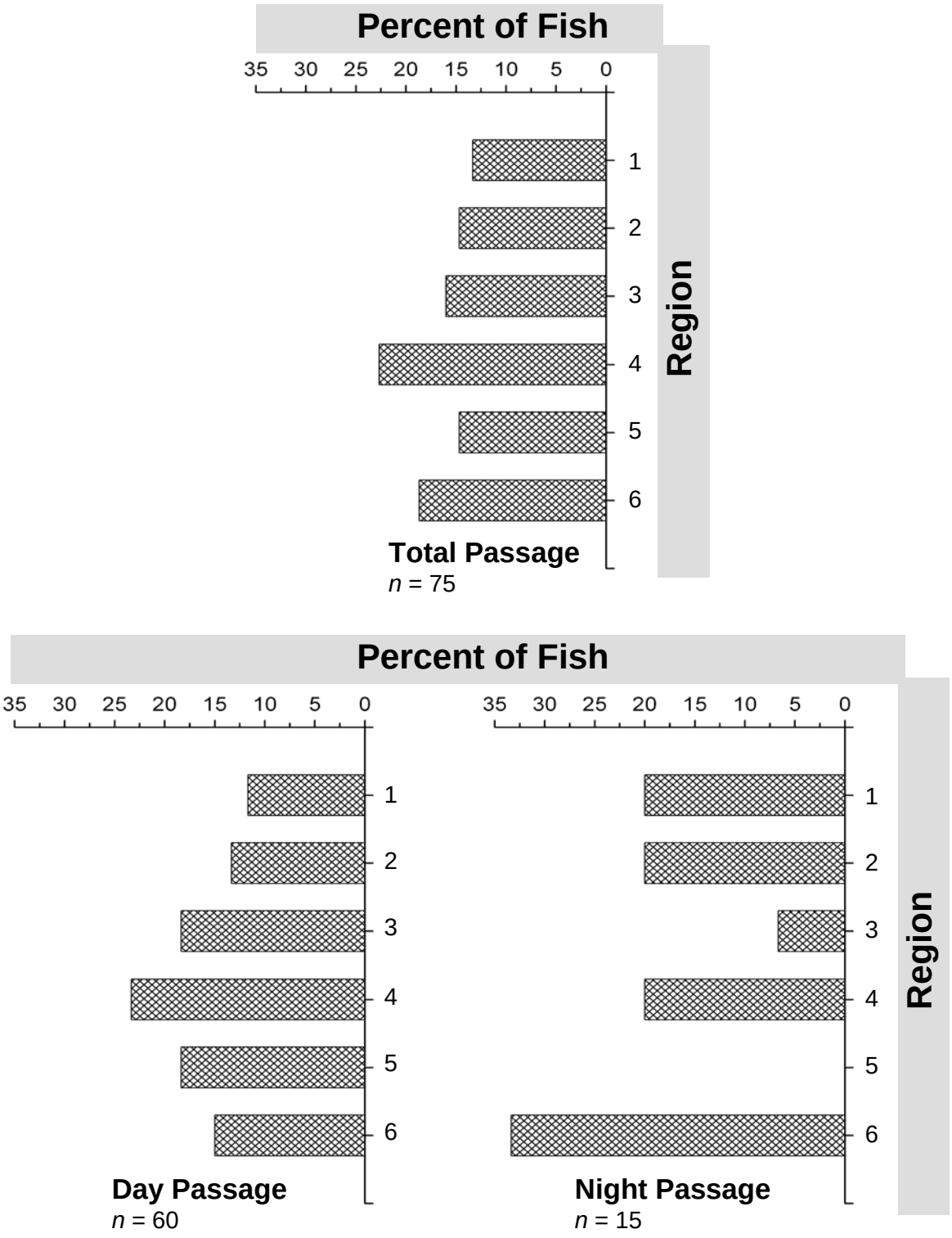

Figure 2-22. Percent distribution of fish passing at spillbay 2. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore.

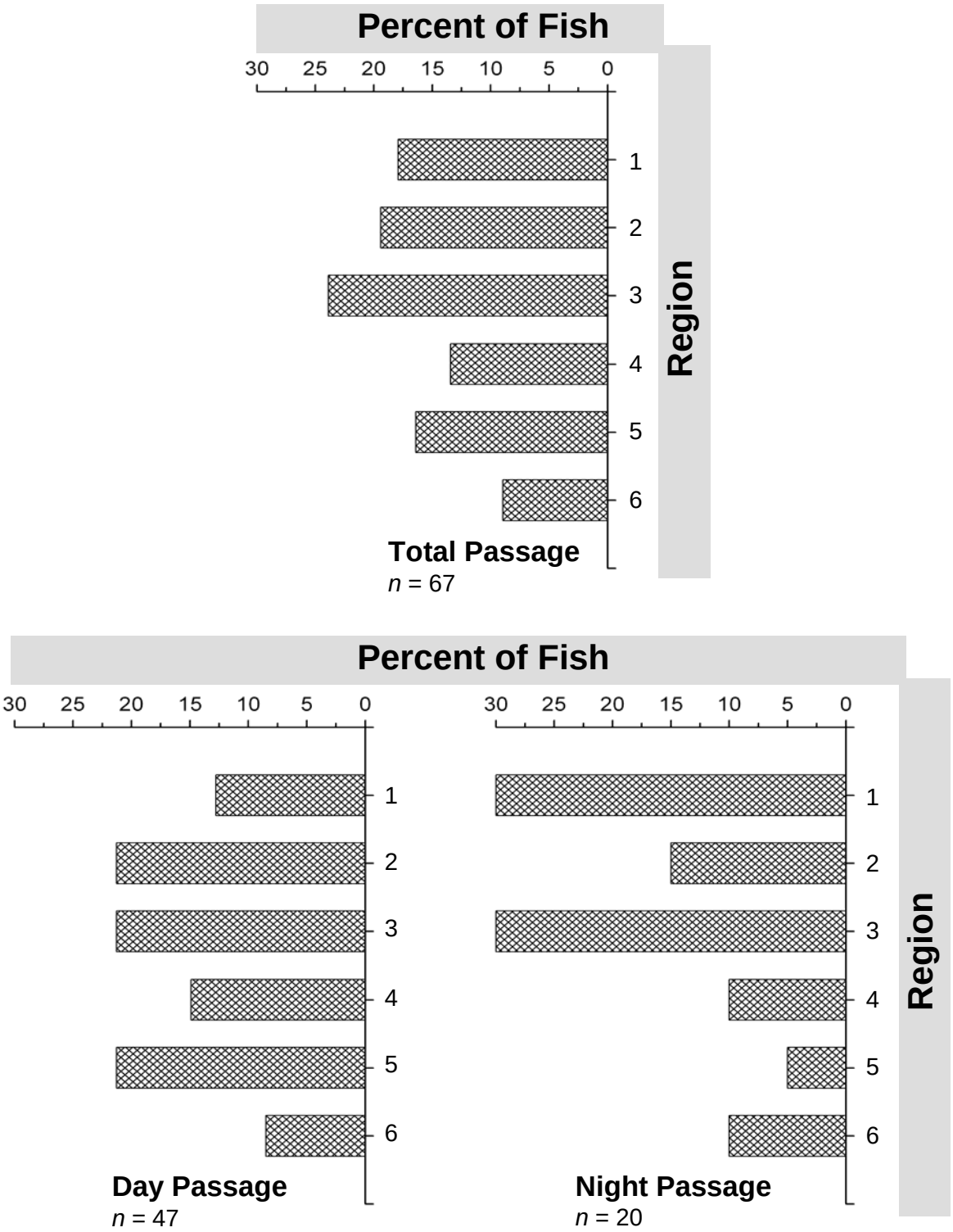

Figure 2-23. Percent distribution of fish passing at spillbay 3. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore.

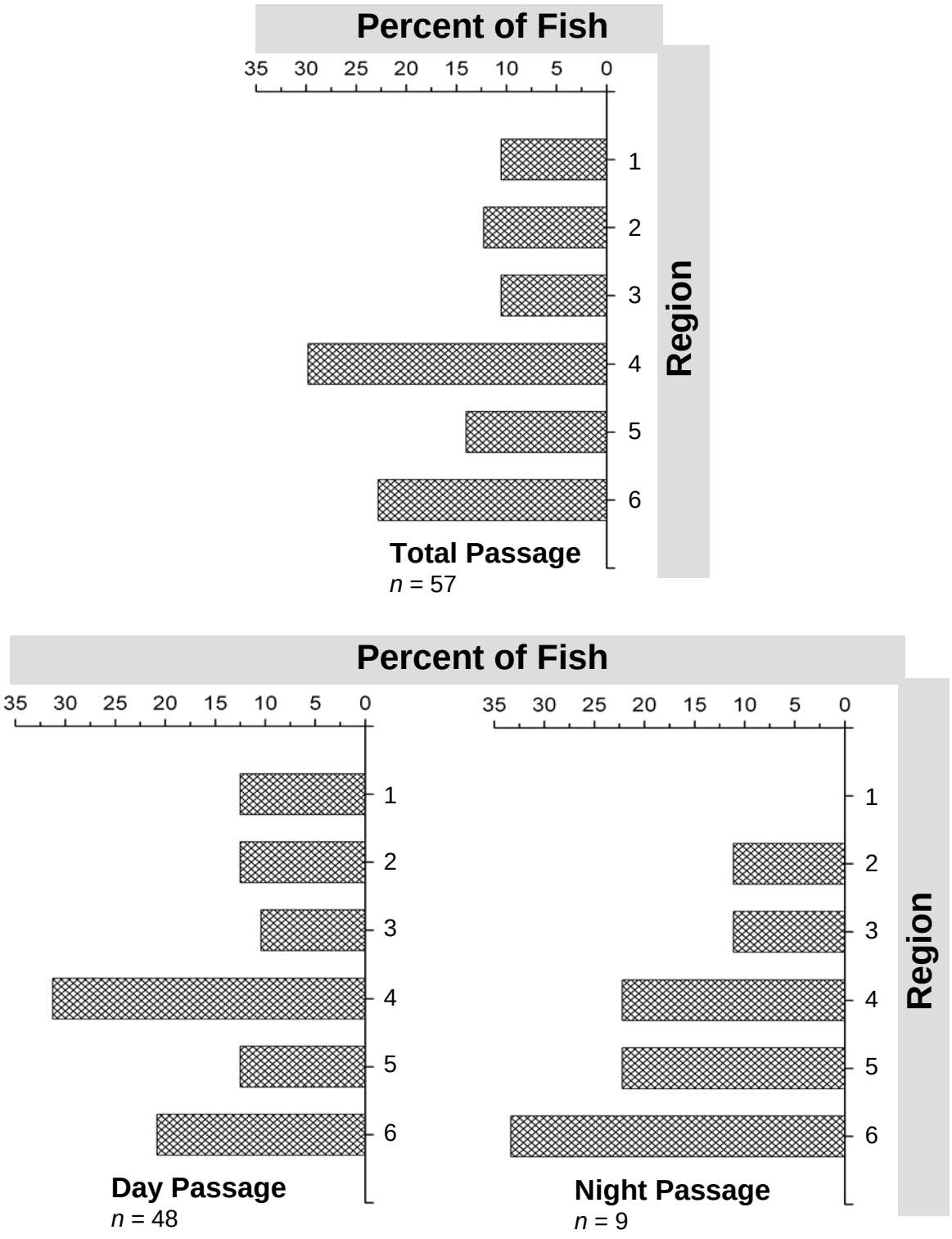

Figure 2-24. Percent distribution of all fish passing at spillbay 4. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore.

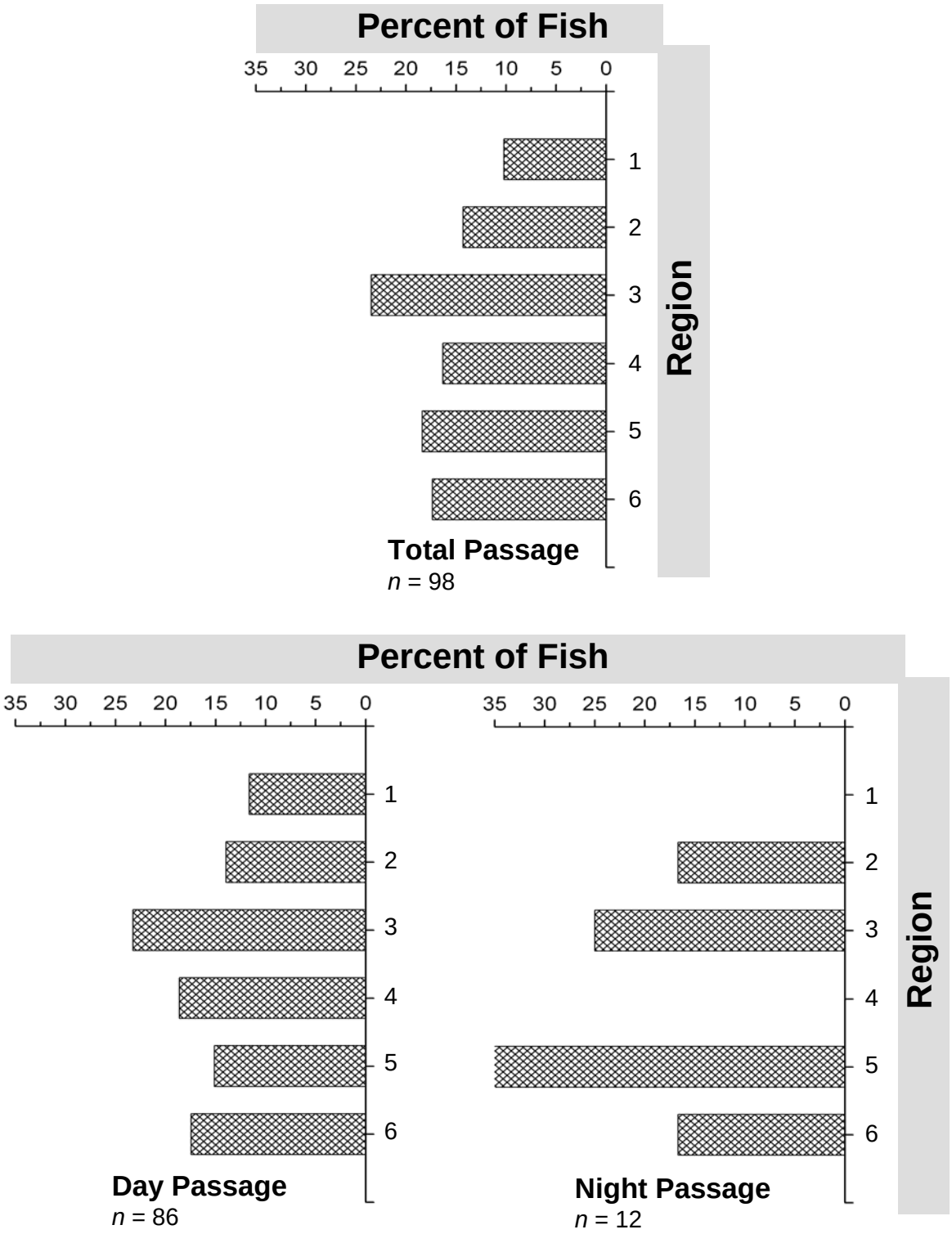

Figure 2-25. Percent distribution of all fish passing at spillbay 5. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore.

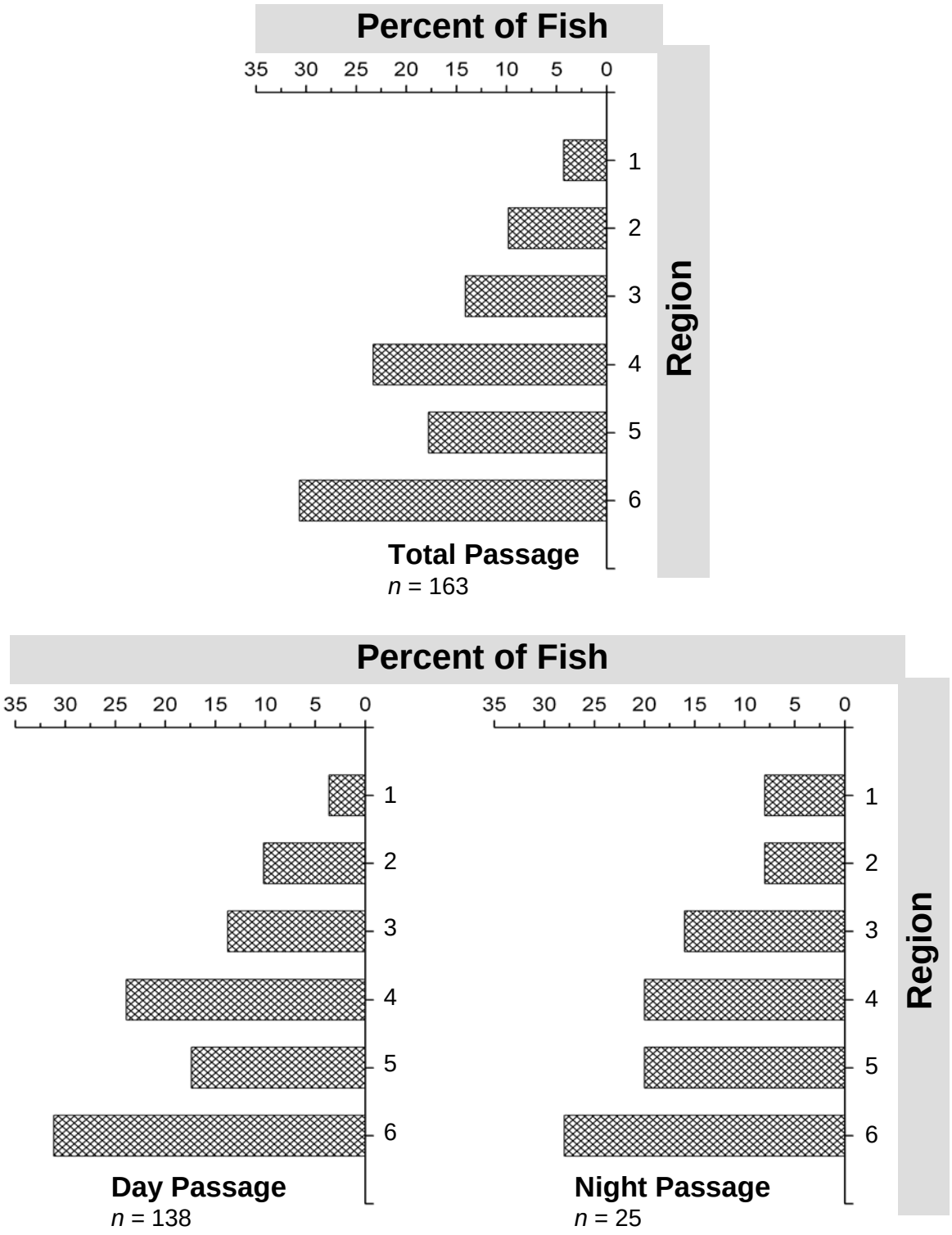

Figure 2-26. Percent distribution of all fish passing at spillbay 6. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore.

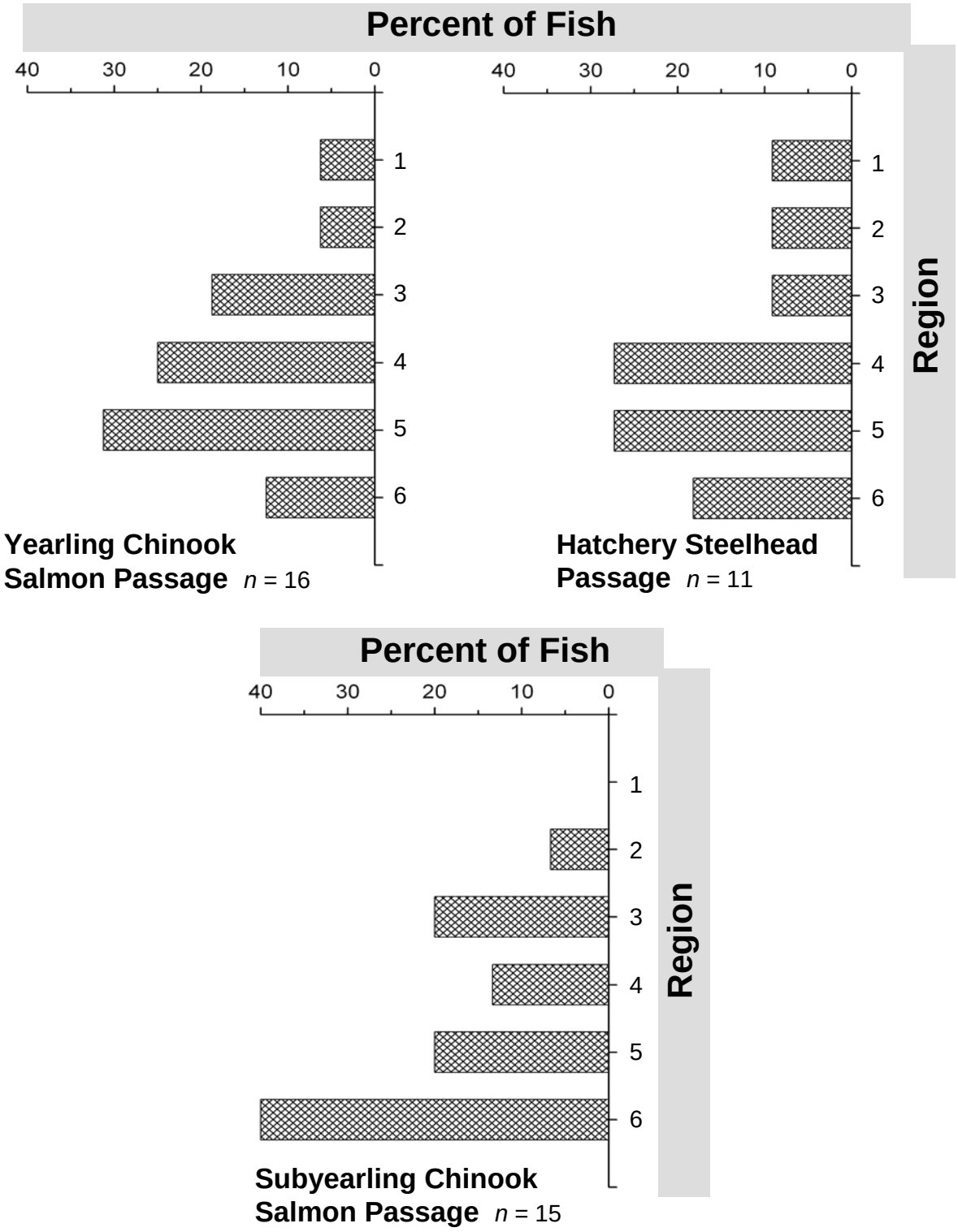

Figure 2-27. Percent distribution of fish species passing at spillbay 1. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore. Spillbay 1 included two sockeye salmon passing through regions 3 and 4.

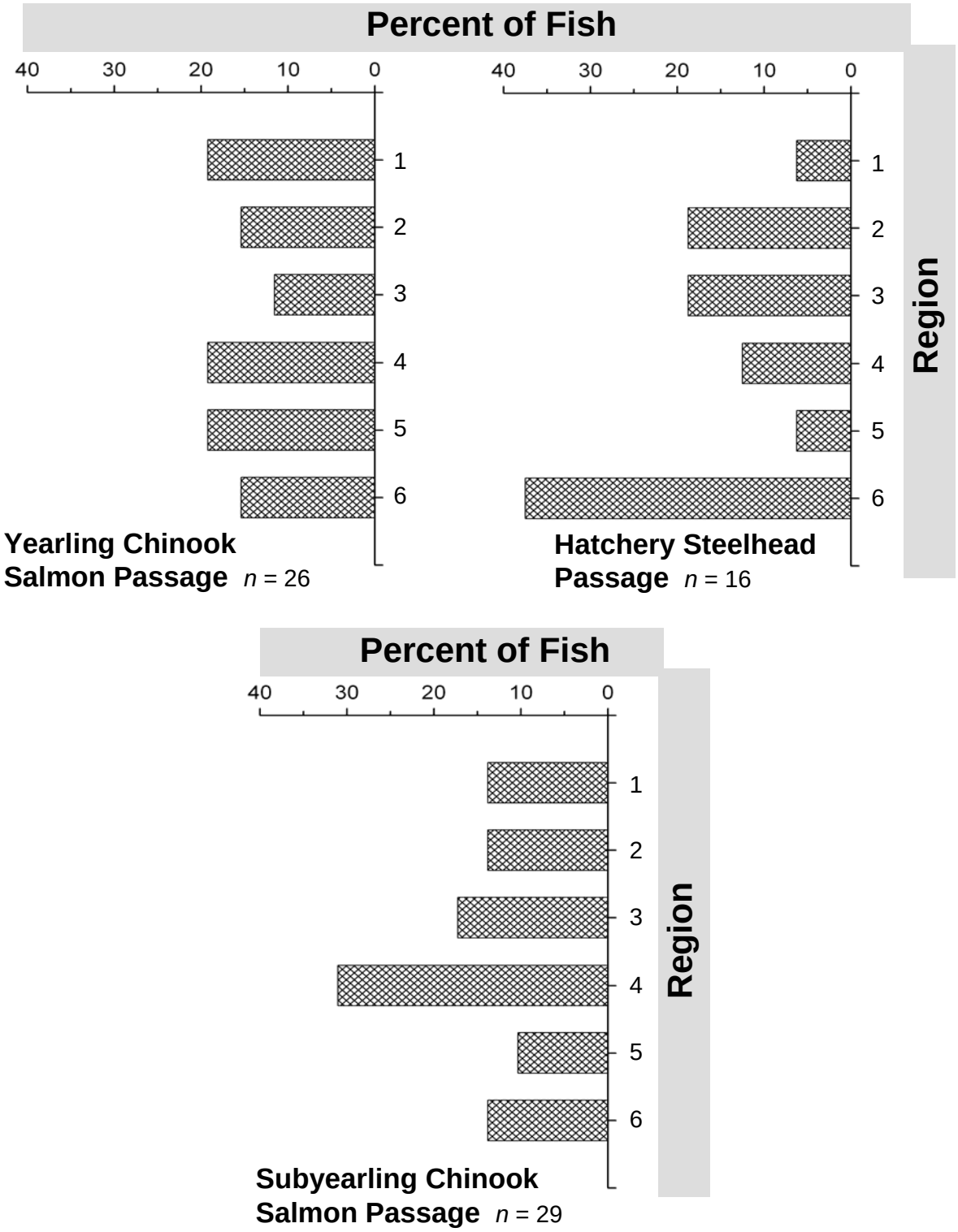

Figure 2-28. Percent distribution of fish species passing at spillbay 2. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore. Spillbay 2 included four sockeye salmon passing through regions 3, 4 and 5.

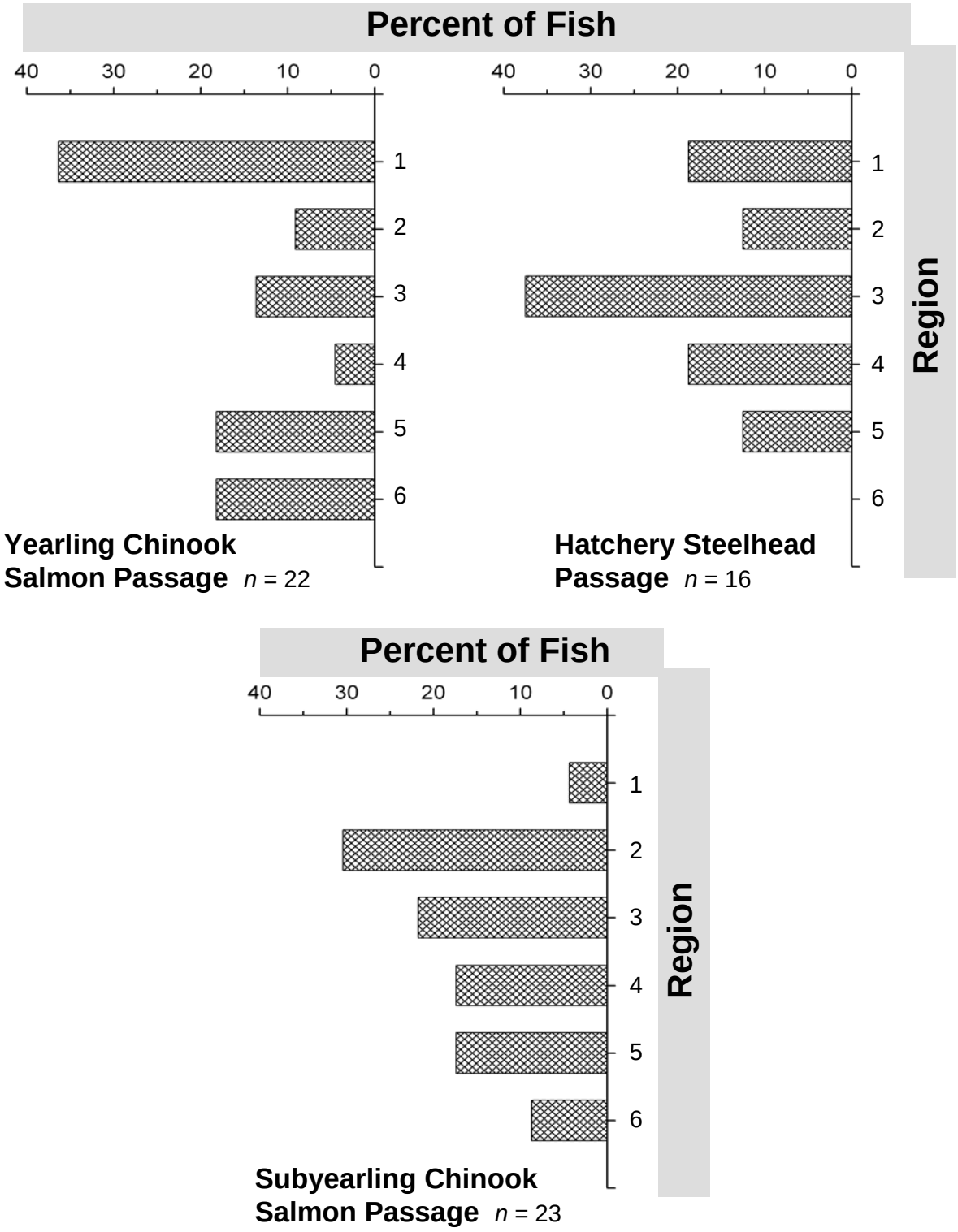

Figure 2-29. Percent distribution of individual fish species passing at spillbay 3. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore. Spillbay 3 included six sockeye salmon passing through regions 2, 3, 4, and 5.

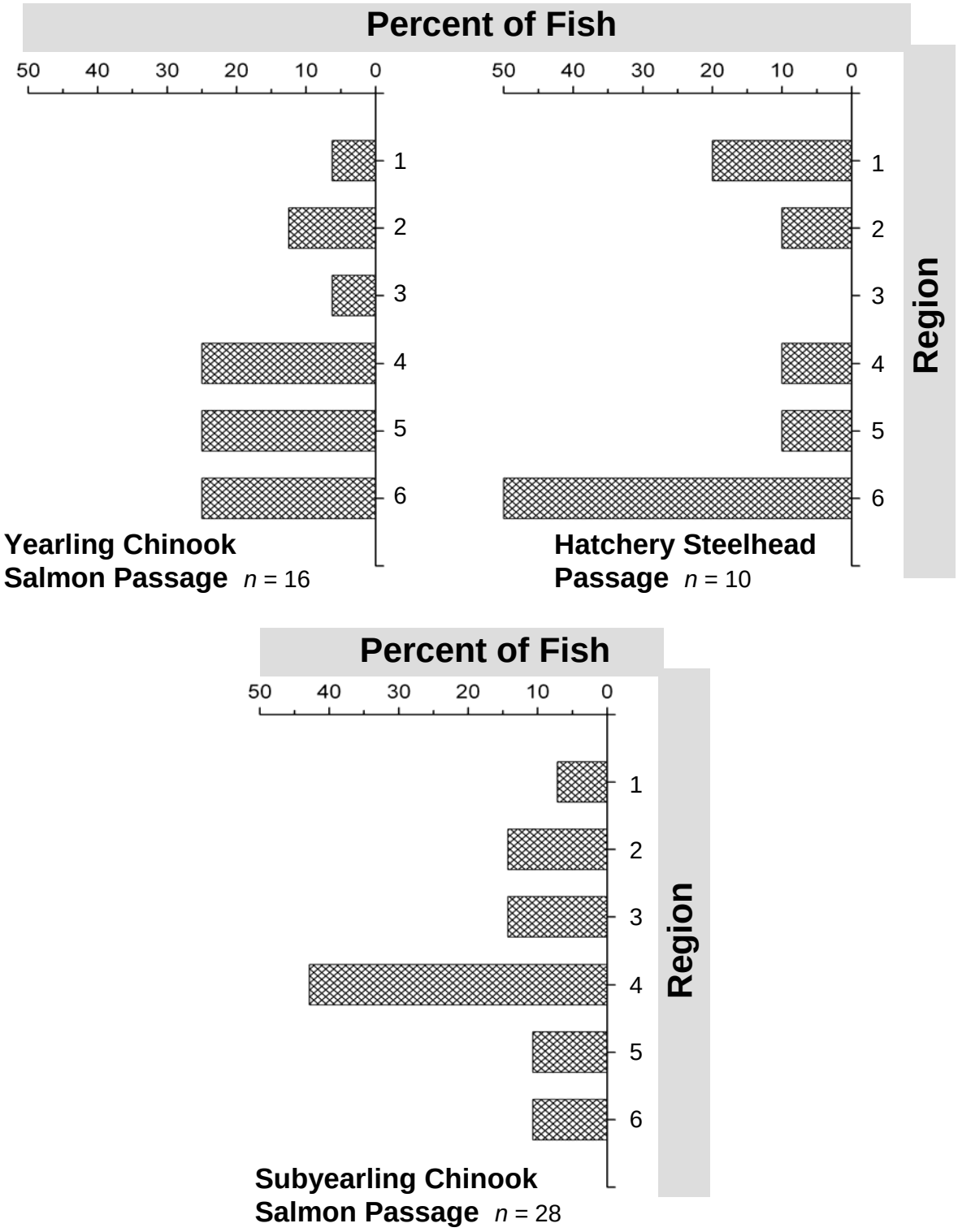

Figure 2-30. Percent distribution of individual fish species passing at spillbay 4. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore. Spillbay 4 included three sockeye salmon passing through regions 1, 3, and 6.

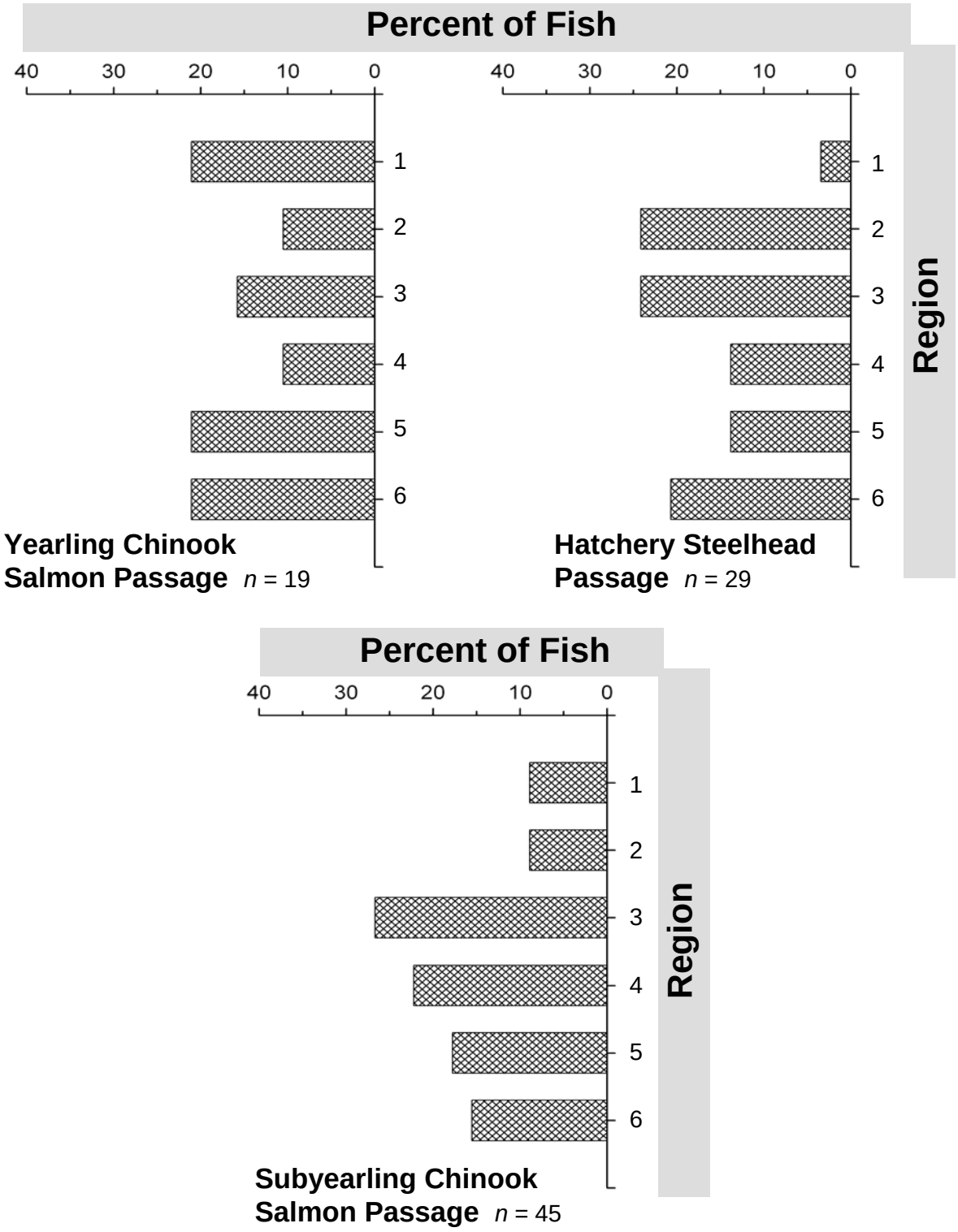

Figure 2-31. Percent distribution of individual fish species passing at spillbay 5. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore. Spillbay 5 included five sockeye salmon passing through regions 1, 2, 3, and 5.

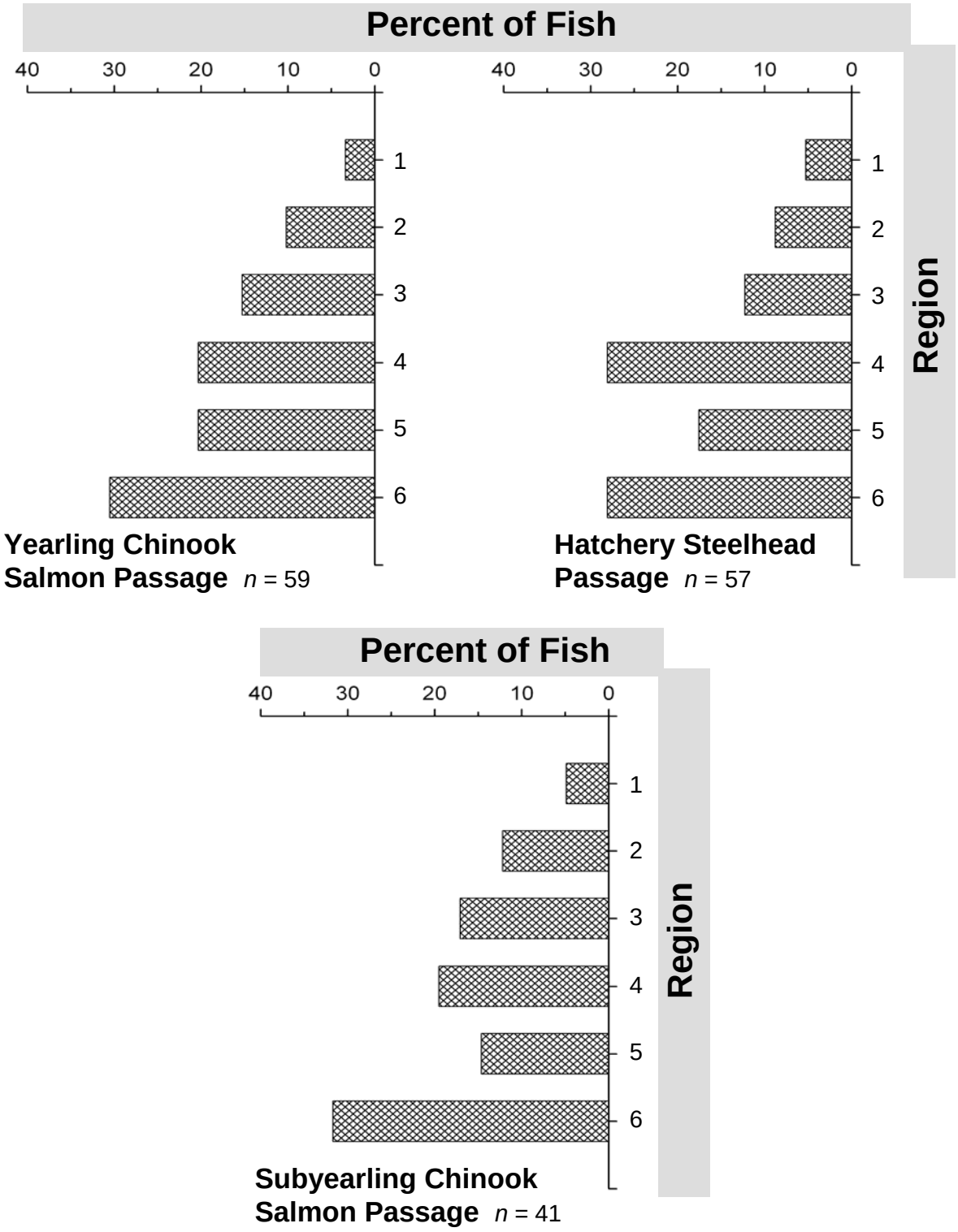

Figure 2-32. Percent distribution of fish by individual species passing at spillbay 6. The spillbay was divided into six equal regions with region 1 closest to the Washington or north shore. Spillbay 6 included six sockeye salmon passing through regions 4, 5, and 6.

Hourly Distributions

We calculated hourly passage distributions by area of passage (turbine units, sluiceway, and spillway) and species (Figures 2-33 to 2-38). The distributions were bimodal across all categories. We observed two separate peaks in passage timing, with the majority of fish passing during the daytime (797 daytime, 244 nighttime). Peak total passage occurred at 1000 and 2100 hours (mid-morning and just before dark, respectively). Passage through the turbines was concentrated at dusk (2100 – 2200 hours). The sluiceway passage was spread across the morning (0600 – 1000 hours), but also showed a peak at dusk (2000 hours). Fish passage at the spillway occurred primarily during the daylight hours with a peak at 0900 – 1000 hours. Hourly distributions for yearling Chinook salmon, hatchery steelhead, and sockeye salmon were similar to those of the total passage distributions. Subyearling Chinook salmon passage occurred primarily in the hours just before dark (1800 – 2000 hours).

Acoustic Telemetry Compared to 2003 Mobile Hydroacoustics

In 2003, Pacific Northwest National Laboratory conducted a mobile hydroacoustic survey, and summarized the transect data by dividing the forebay into 61 x 61 m grids (Faber et al. 2004). We used the same grid and summary techniques to compare that data to the 3D data collected in the spring of 2004. We plotted the results for yearling Chinook salmon only for spring daytime and nighttime samples, because the majority of juvenile salmon in the forebay during spring 2003 were likely yearling Chinook salmon. Hydroacoustics cannot differentiate species, but it can determine the size of targets. Therefore, every target less than 300 mm was included in the fish distribution map for the spring 2003 samples. The species composition statistics were derived from the Fish Passage Center at John Day Dam (FPC 2003) and were adjusted for a 16-h travel time to The Dalles Dam, to determine likely species composition in the forebay at The Dalles Dam during our hydroacoustic sampling. Yearling Chinook

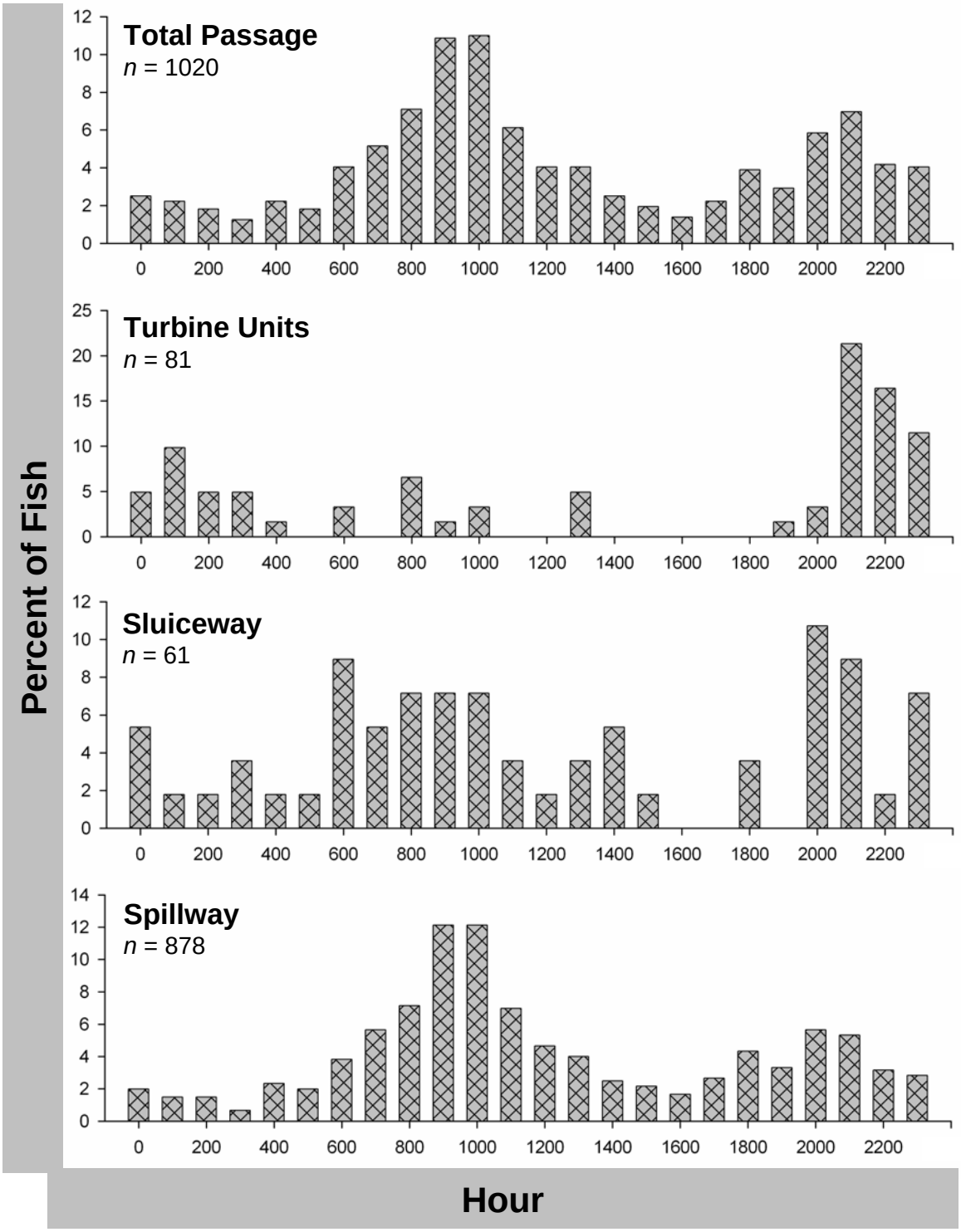

Figure 2-33. Hourly distributions of fish passage. All species are represented in these graphs. Total passage was the sum of all fish that passed through any exit at each of the passage regions.

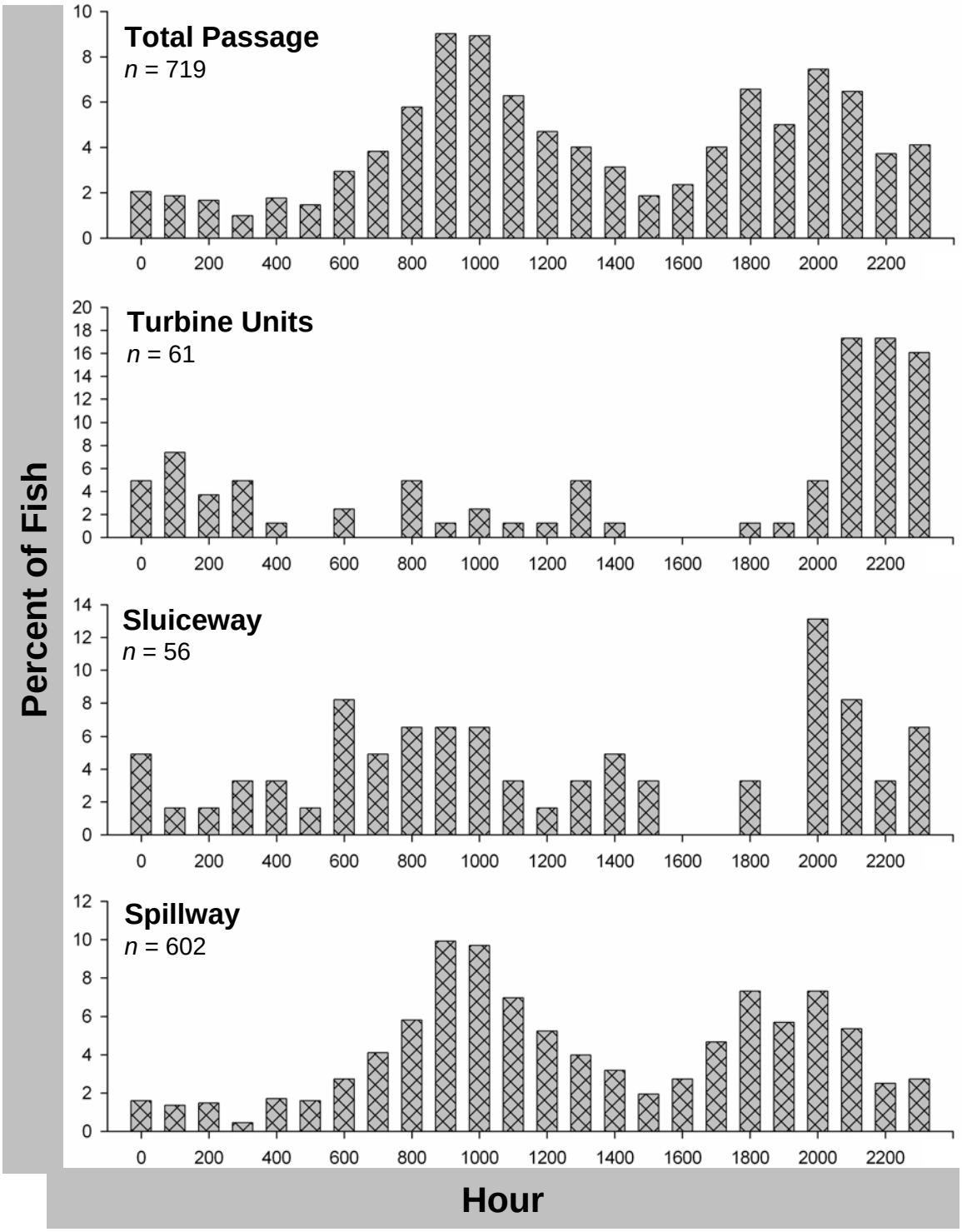

Figure 2-34. Hourly distributions of spring fish passage. Yearling Chinook salmon, hatchery steelhead, and sockeye salmon are represented in these graphs (spring samples). Total passage is the sum of all fish that passed through any of the passage regions (turbines, sluiceway, or spillway).

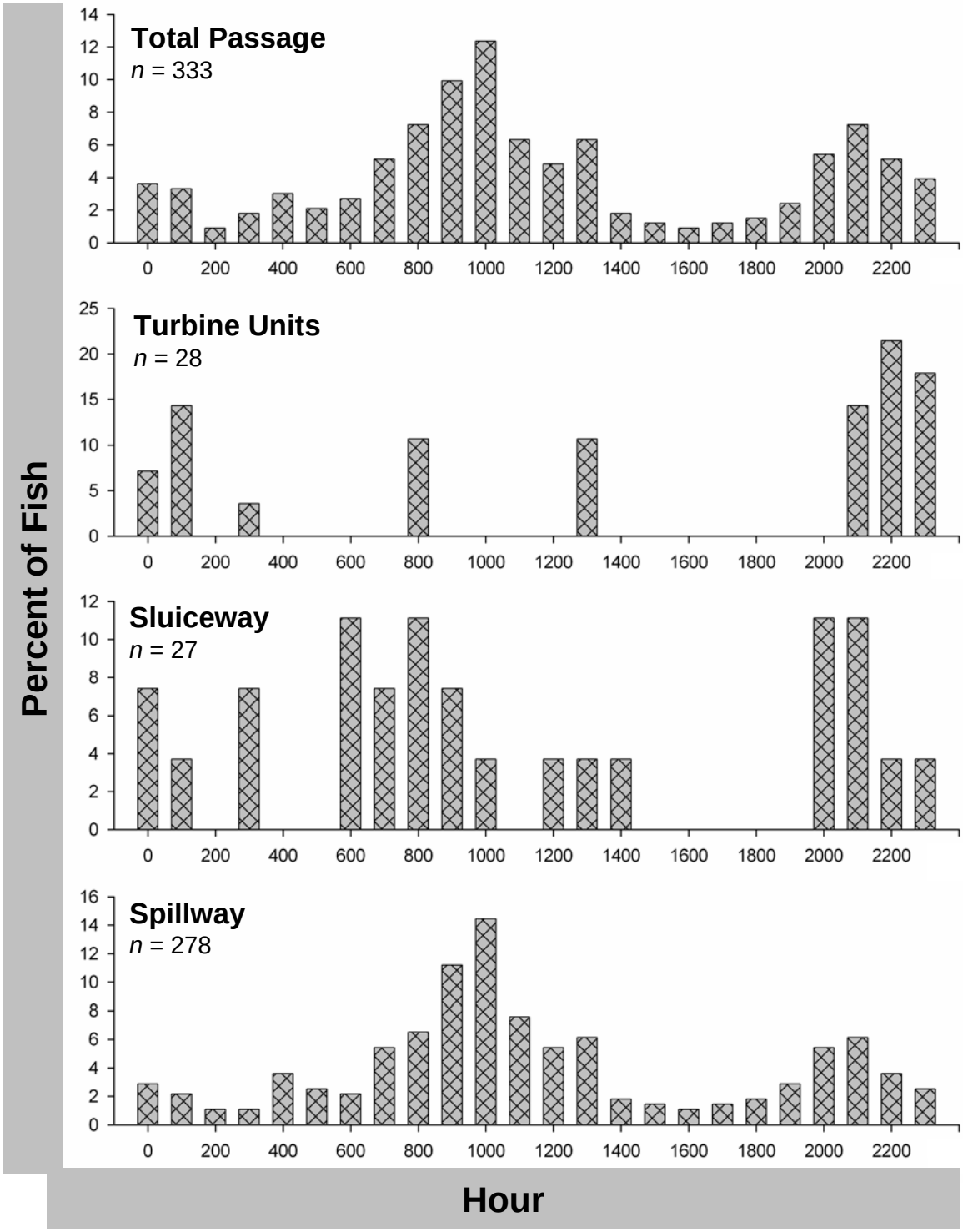

Figure 2-35. Hourly distributions of subyearling Chinook salmon passage. Total passage is the sum of all fish that passed through any of the passage regions (turbines, sluiceway, or spillway).

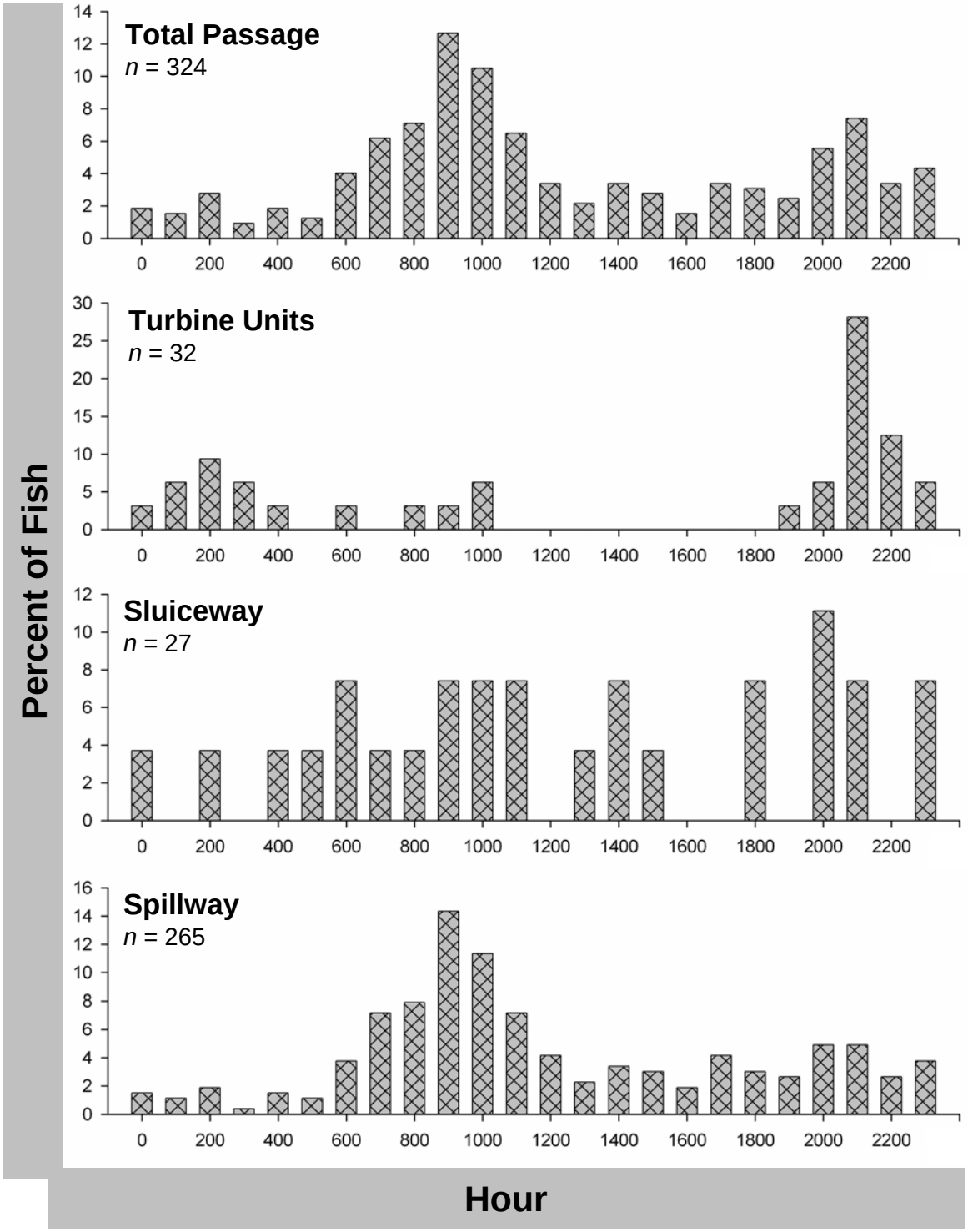

Figure 2-36. Hourly distributions of hatchery steelhead passage. Total passage is the sum of all fish that passed through any of the passage regions (turbines, sluiceway, or spillway).

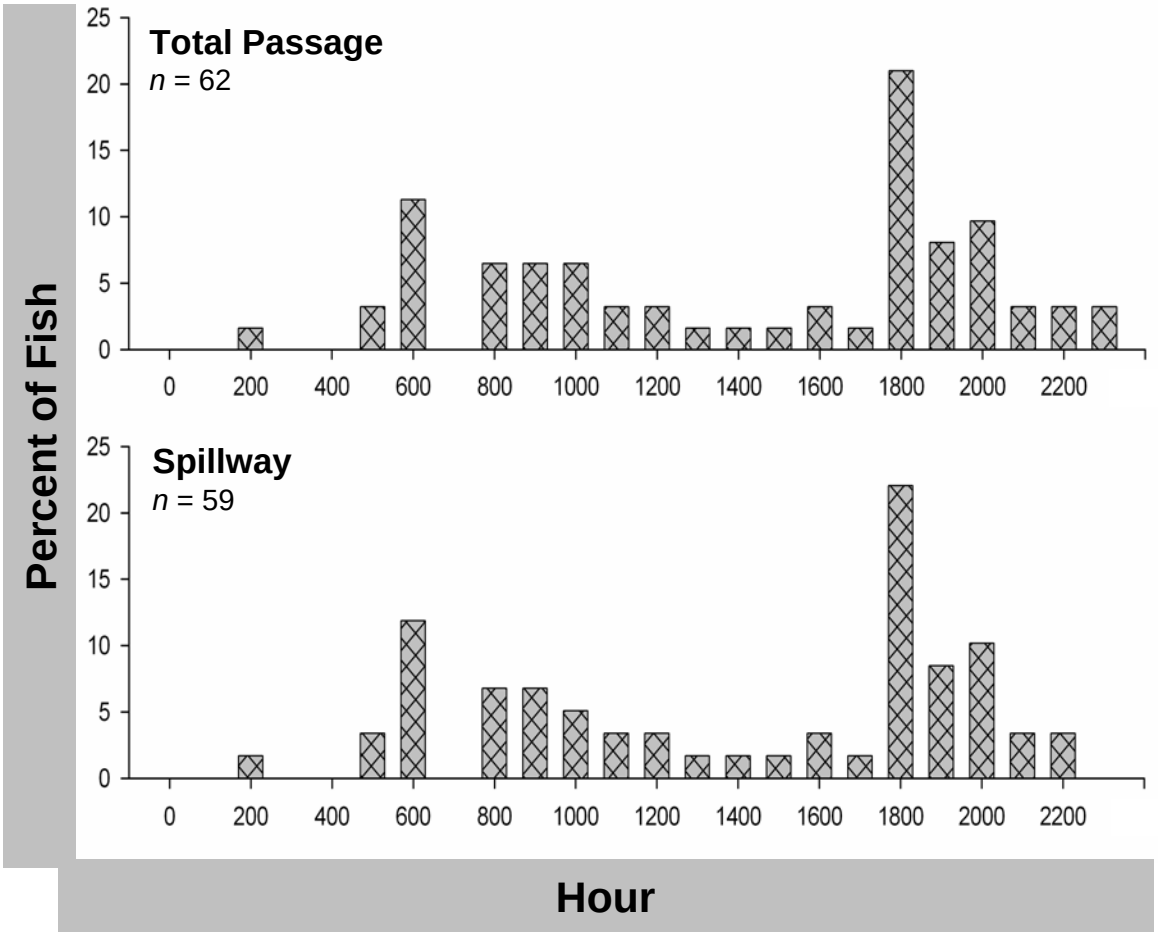

Figure 2-37. Hourly distributions of sockeye salmon passage. Total passage is the sum of all fish that passed through any of the passage regions (turbines, sluiceway, or spillway).

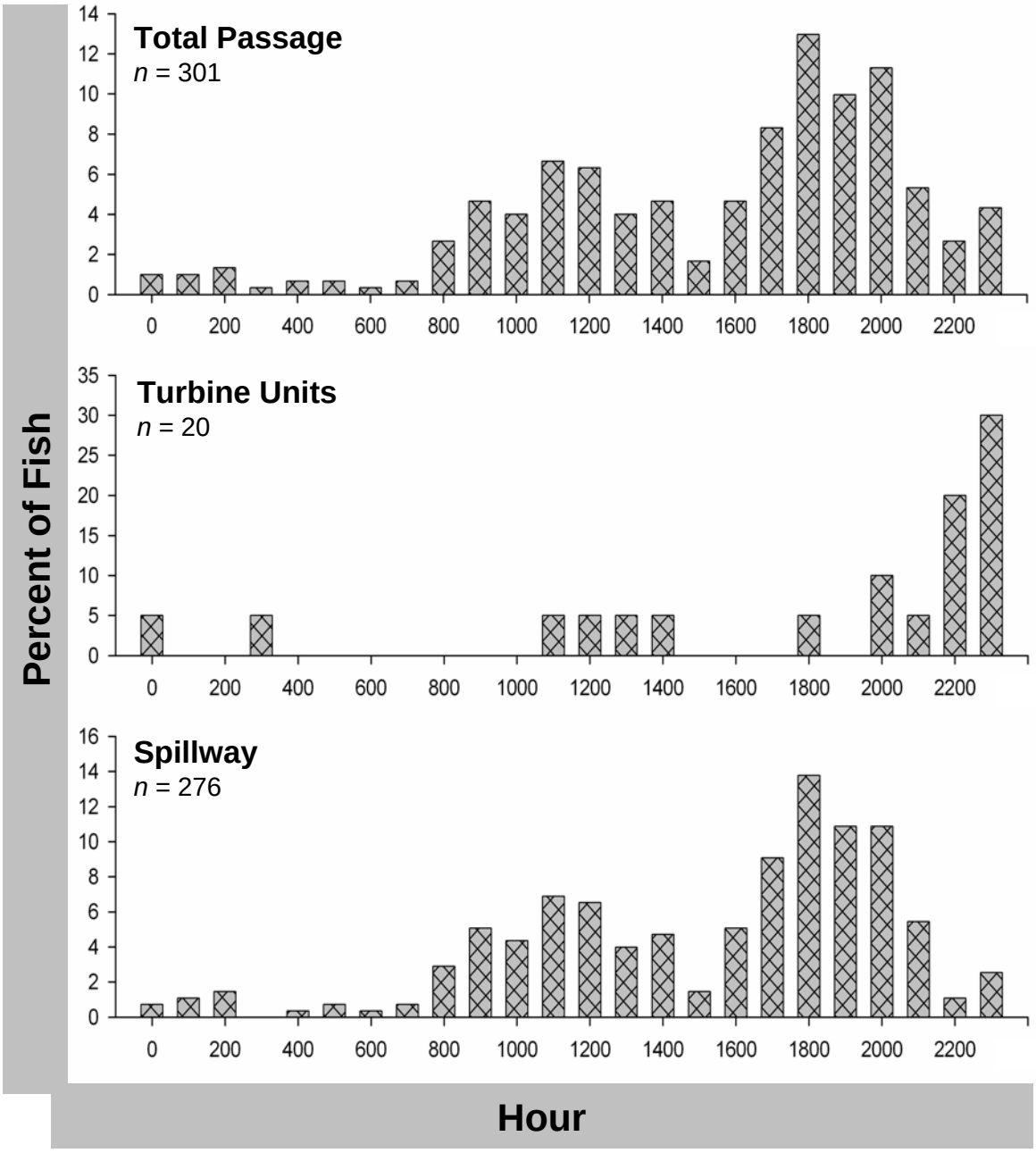

Figure 2-38. Hourly passage distributions for subyearling Chinook salmon. Sluiceway passage included five subyearling Chinook salmon. Total passage is the sum of all fish that passed through any of the passage regions (turbines, sluiceway, or spillway).

salmon were overwhelmingly the most common out migrating salmon less than 300 mm during the spring out-migration of 2003 (71%, for six springtime samples), and therefore were the likely source of the majority of our hydroacoustic targets that were used to calculate density.

The summer 2003 mobile hydroacoustic data were not compared to the 2004 3D results because of a likely bias in density estimates due to the summer migration of adult American shad (*Alosa sapsidissima*). The density of shad when compared to our measured fish density from mobile hydroacoustics had a better correlation value than did our intended targets of subyearling Chinook salmon. Therefore, we did not compare these hydroacoustic results to the distribution of subyearling Chinook salmon from the 3D fish tracks.

We compared the results of spring 2003 daytime and nighttime mobile hydroacoustics to the distributions of yearling Chinook salmon derived from the 3D fish tracks collected in 2004. Overall, the distribution maps showed daytime distributions of fish were similar (Figures 2-39, 2-40). There were high concentrations of fish targets (2003 mobile hydroacoustic data) and yearling Chinook salmon (3D data) near the sluiceway entrance at main turbine unit 1. We observed similar high concentrations, upstream and north of the powerhouse that is above the large depression in the forebay. The comparison of nighttime results also showed high concentrations of acoustic targets and yearling Chinook salmon adjacent to the sluiceway entrance at main turbine unit 1. However, nighttime 3D data showed high concentrations of yearling Chinook salmon in the northwestern part of the powerhouse array, whereas the mobile hydroacoustics did not indicate many fish in this area (Figures 2-41, 2-42). Mobile hydroacoustics indicated high concentrations of fish near the Washington shoreline where 3D acoustic telemetry coverage was lacking.

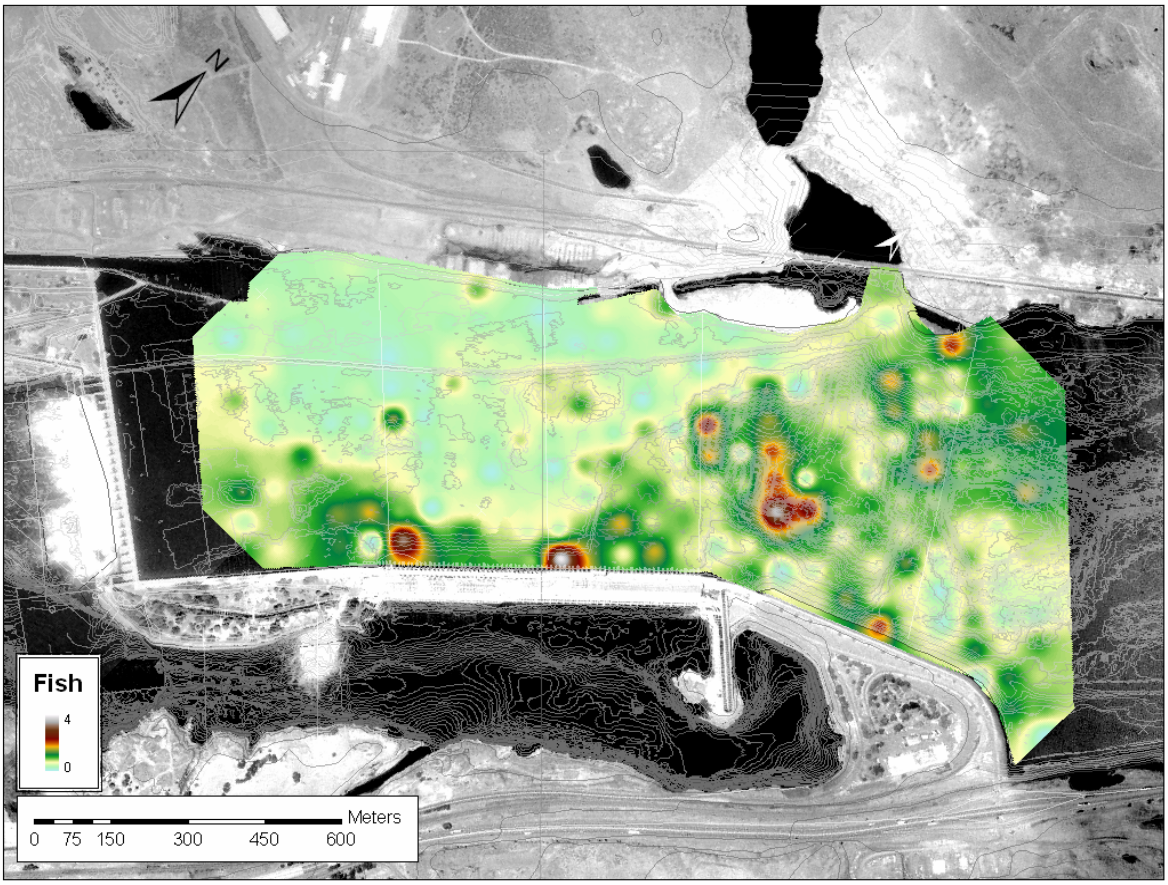

Figure 2-39. The density of fish distribution for spring daytime mobile hydroacoustic samples in 2003. The area shown was the extent of mobile transects. The distribution of fish density was interpolated between grids of 61 x 61 m.

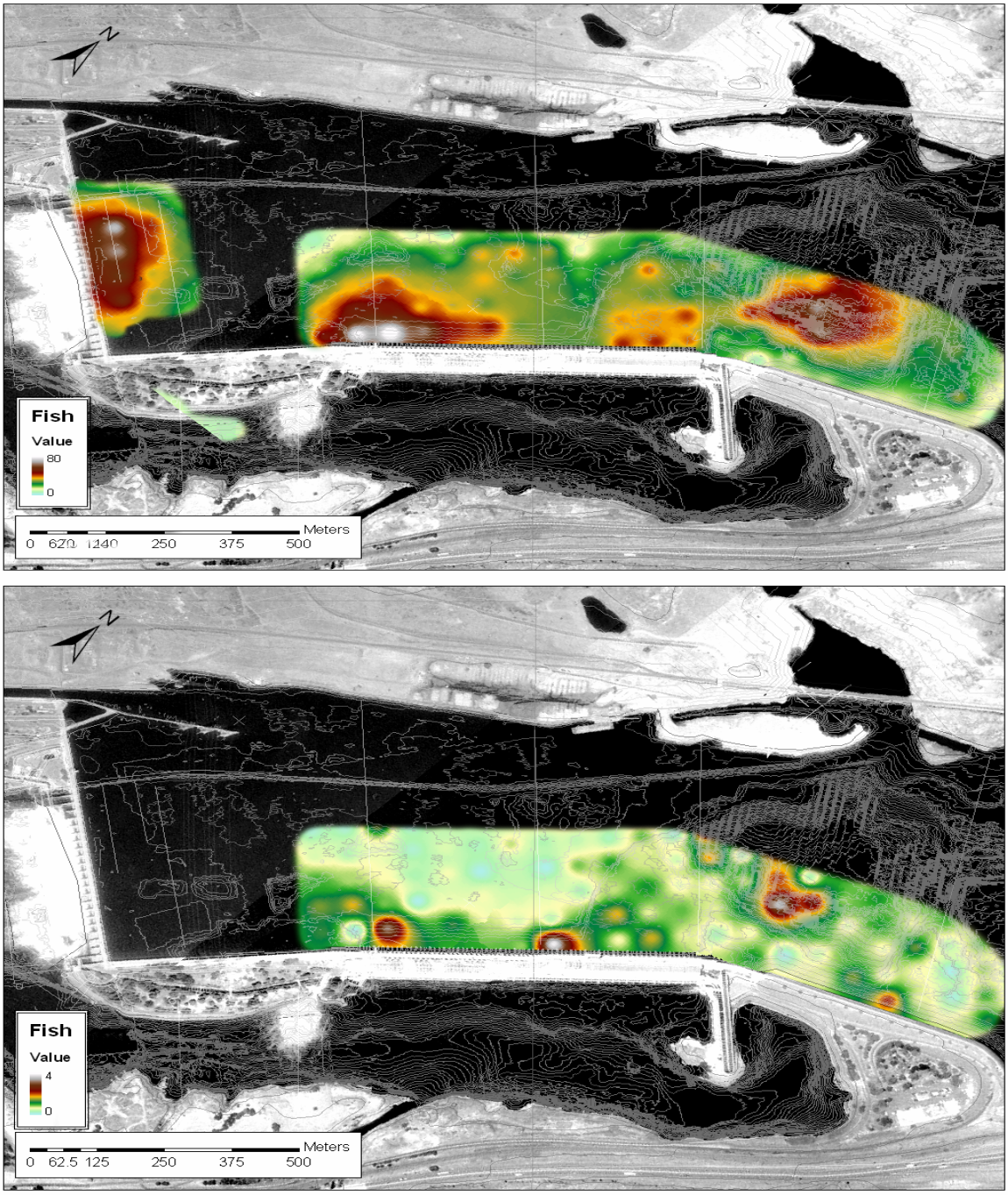

Figure 2-40. The relative distribution of yearling Chinook salmon during spring daytime for 3D acoustic telemetry data in 2004 (upper map) and the density of fish distribution for spring daytime mobile hydroacoustic samples in 2003 (lower map). The displayed distribution was within the minimum area that was covered by the 3D hydrophone array. Distributions were interpolated between grids of 61 x 61 m.

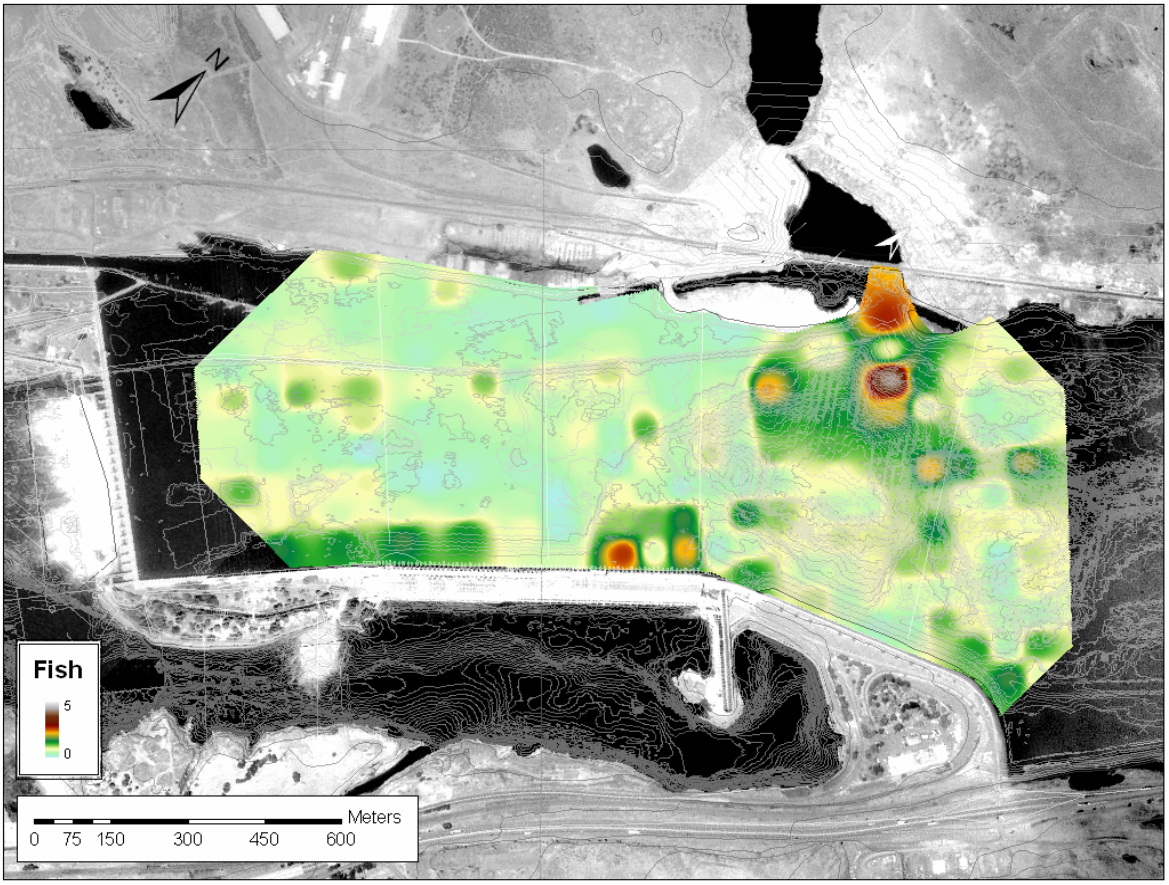

Figure 2-41. The density of fish distribution for spring nighttime mobile hydroacoustic samples in 2003. The area shown was the extent of mobile transects. The distribution of fish density was interpolated between grids of 61 x 61 m.

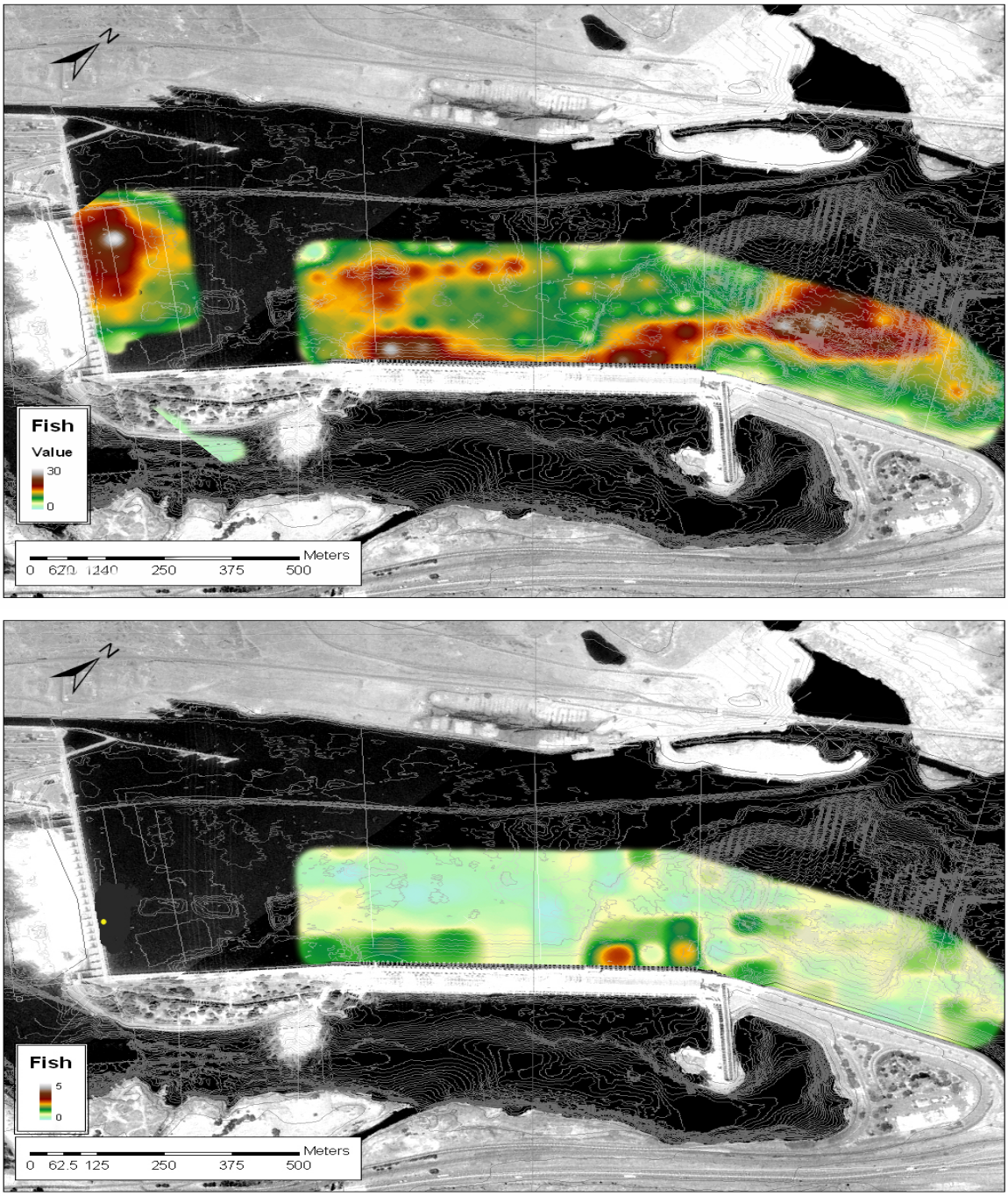

Figure 2-42. The relative distribution of yearling Chinook salmon during spring nighttime for 3D acoustic telemetry data in 2004 (upper map), and the density of fish distribution for spring nighttime mobile hydroacoustic samples in 2003 (lower map). The displayed distribution was within the minimum area that was covered by the 3D hydrophone array. Distributions were interpolated between grids of 61 x 61 m.

Discussion

Project operations at The Dalles Dam probably contributed to the high FPE observed in 2004. Spill was 40% of the total river discharge and was directed toward the northern spillbays. This spill configuration directed much of the bulk flow to the northern portion of the river and created a hydrodynamic environment that was favorable for high FPE results (Allen et al. 2000; Allen et al. 2001).

As described in Chapter 1 of this report, the concentration of 3D tagged fish of all species was more skewed toward the powerhouse in the daytime. However, the number of fish passing at the powerhouse during the daytime did not increase in proportion to the number that came in close proximity to the powerhouse. The majority of these fish "swooped" in the northerly direction from near the west end of the powerhouse and eventually passed at the spillway.

During the nighttime fish approached the forebay in two clear paths: one group approached the spillway directly and the other approached the powerhouse (Chapter 1). These approach paths originated from a position upstream of the powerhouse and over the large depression in the historic river channel. The passage of juvenile salmonids at the powerhouse was greater during the nighttime than during the daytime. However, the "swoop" path from the west end of the powerhouse to the southern part of the spillway was still present during the daytime. This behavior and subsequent passage influenced the distribution of passage that we observed at the powerhouse and at the spillway.

Powerhouse Passage Distribution

Fish passage at the powerhouse was evenly distributed across all operating units except for units 1 and 2, with more juvenile salmonids passing those units. A possible explanation for the higher passage at turbine units 1 and 2 was the existence of more attractive hydraulic conditions near the sluiceway entrance above turbine unit 1. Passage for hatchery steelhead and yearling Chinook salmon was substantially greater at turbine unit 1 than at the other turbine units. Sockeye salmon and subyearling Chinook salmon did not show significant passage at the turbine units below sluiceway entrances. Forebay

distribution showed concentrations of 3D tracked fish were higher near the sluiceway entrance than at the rest of the powerhouse. This distribution in the area adjacent to the sluiceway was proportional to passage, especially for yearling Chinook salmon and hatchery steelhead.

The path that juvenile salmonids followed from the west portion of the powerhouse and toward the south of the operating spillbays had the effect of concentrating fish upstream of spillbay 6. Their passage reflected this approach path in that the majority of fish that passed the spillway passed at spillbay 6. This relation was most evident for yearling Chinook salmon and hatchery steelhead during the daytime. Subyearling Chinook salmon also showed this pattern, although passage at spillbays 5 and 6 was greater than at spillbays 1-3. Sockeye salmon had relatively high levels of passage at the north and south ends of the spillway. Because the sample size of sockeye salmon was low, the paths of sockeye salmon in the forebay did not provide an adequate sample to identify pathways that could be related to passage.

Spillway Passage Distribution

Spillbays 1-6 were operated consistently throughout the season while spillbays 7-10 were not. However, bays 7-10 showed greater effectiveness at passing fish relative to passing water. A much greater proportion of fish passed through bays 7-10 than bays 1-6 when compared to the amounts of water spilled. This suggests a strong preference for fish passage at the southern spillbays.

One implication for fish passing bays 7-10 maybe that they were passed into an unfavorable environment for egress. A wing-wall was constructed downstream of spillbays 6 and 7 in 2004 to reduce the recirculation (eddy) in the tailrace. The wing-wall was designed to expedite the egress of juvenile salmonids in the tailrace and reduce exposure to salmonid predators, such as northern pikeminnow (*Ptychocheilus oregonensis*). However, spilling through spillbays 7-10 created a large eddy in the tailrace on the south side of the wing wall and possibly delayed egress. As a result,

juvenile salmonids may have spent more time in areas with large numbers of predators, likely causing increased mortality. Hence, the operation of spillbays 7-10 in concert with spillbays 1-6 will likely reduce the overall survival of juvenile salmonids passing the spillway.

Distribution at Spillbays

We also examined the distribution of fish passage by spillbay. The distributions may provide insight into the effect of certain passage conditions. For instance, at spillbay 6, the survival of juvenile salmonids through a vortex near the south pier was lower than the two other release locations (Heisey et al. 2004). We found the distribution at bay 6 was skewed toward this vortex, which suggested a large proportion of fish passed near the south pier and possibly thru the vortex. The remaining bays had distributions that were more evenly distributed across each bay, except for spillbay 1, which also showed a southerly trend in passage. The distribution at bay 6 is consistent with the path of fish approaching from the powerhouse to the spillway. Numerous fish exited in spillway 6, the first spillway they encountered. The direct path of fish traveling along the north part of the forebay (Chapter 1) is consistent with fish passing in a more normal distribution at the central bays.

Passage Timing

The passage timing throughout the day was attributable to our release strategy. Our fish were released at approximately 0800 and 2000 hours each release day, at the tailrace of John Day Dam. Fish had mean travel times to the forebay of 16 h for hatchery steelhead, 16 h for yearling Chinook salmon, 15 h for subyearling Chinook salmon, and 12 h for sockeye salmon (Chapter 1). Peaks in passage timing were bimodal and occurred for spillway-passed fish at around 1000 and 2100 hours for hatchery steelhead and yearling Chinook salmon and 0900 and 1900 hours for sockeye salmon and subyearling Chinook salmon.

The distribution of passage for juvenile salmonids at the powerhouse turbine units was neither normally distributed nor bimodal. There was a distinct peak in passage that coincided with dusk. A peak in passage was observed at The Dalles Dam in the 2002 hydroacoustic studies (Moursund et al. 2001), when a surge in hydroacoustic targets was observed after sunset. This nighttime passage was reflected in lower FPE estimates for nighttime samples (72.5% overall, Table 2-2) than daytime samples (95.9% overall, Table 2-2). This behavior may result in a greater number of juvenile salmonids passing under a behavioral guidance structure during the nighttime than during the daytime. We have observed juvenile salmonids sounding and staying deep during studies at Lower Granite and Bonneville dams (Cash et al. 2001; Faber et al 2001; Cash et al. 2003).

Movements of juvenile salmonids were more direct and followed the surrounding flow conditions at night. Nighttime residence times in the forebay were shorter than daytime residences. Nighttime juvenile salmonids were less likely to display milling behavior and were more likely to sound for an exit when compared to daytime juvenile salmonids (Steig et al. 1998; Steig and Timko 2000; Faber et al. 2001). This data suggests that juvenile salmonids more actively search for an exit during the daytime, presumably responding to visual cues. Conversely their approach path during nighttime is more direct, and with the absence of visual cues, they could be responding to the physical cues from the surrounding hydraulics to navigate, and then pass at hydroelectric projects. However, due to our release strategy, the number of fish observed passing at night was not sufficient to thoroughly address this question. Our release strategy was sufficient to gain a basic understanding of behavior and passage at The Dalles Dam in relation to seasonal and diel effects. However, a release strategy that involves releases of fish randomly or systematically throughout the day may better capture diel differences in movement and would be more representative of the population as a whole.

Acoustic Telemetry Compared to 2003 Mobile Hydroacoustics

The distribution of juvenile salmon in the forebay of The Dalles Dam in 2003 and 2004 revealed similar patterns when two different sampling techniques were used. Our 2004 yearling Chinook salmon 3D fish tracks had distributions similar to those from mobile hydroacoustic surveys conducted in 2003. High fish densities were found adjacent to the sluiceway at turbine unit 1, adjacent to turbine units 16-22, and near an area east of the powerhouse and in the vicinity of the 100-m-deep depression. We found higher fish densities in these areas during daytime and nighttime using the two techniques (Figures 2-39 to 2-42). One exception to this is that high concentrations of fish upstream of the powerhouse were absent from the hydroacoustic surveys but present in the 3D fish tracks. High concentrations of fish were observed adjacent to turbine units 1-4 and near turbine units 16-20 for both 3D and hydroacoustic data. The 3D tracks revealed a concentration of yearling Chinook salmon located mid-channel and north of the powerhouse, presumably in a position to pass at the spillway. This was not evident from hydroacoustics results. The hydroacoustic data for spring nighttime samples also indicate a concentration of juvenile salmon-sized fish near the Washington shoreline, but this was outside of the 3D study area.

Tagged yearling Chinook salmon and mobile hydroacoustic data showed similarities in forebay distribution for both 2003 and 2004, in daytime and nighttime samples. However, the three other species tagged in 2004 were too underrepresented in the hydroacoustic sample to make inferences between years. Changing flow conditions, temperature, or other environmental factors may have greater impacts on these fish species from year to year than they did for yearling Chinook salmon. In particular, a broader understanding of subyearling Chinook salmon behavior is needed in the forebays of hydroelectric projects. They have been underrepresented in prior investigations due to transmitter size limitations. If subyearling Chinook salmon are to be represented in a behavioral model, such as the Numerical Fish Surrogate Model (Goodwin 2004), a more substantial set of information is necessary to determine how they respond to hydraulic cues and environmental changes that are integral to the model. Substantial 3D data has

been obtained on yearling Chinook salmon and hatchery steelhead; however, relatively little information has been obtained for subyearling Chinook salmon that could support these efforts.

Guidance Structure

The U.S. Army Corps of Engineers is currently planning to use the behavioral and fish passage information from hydroacoustic, radio-telemetry, and acoustic telemetry studies that were conducted in the spring and summers of 2003 and 2004 to construct a behavioral guidance structure. The structure will guide fish away from turbines and direct them toward spillways. The information that we have collected on passage of acoustically tagged juvenile salmonids suggests that this will be successful if fish are diverted to the northern portion of the forebay. If the spill volume and powerhouse operations are similar for a given a water year; FPE will increase with such a device. However, the nighttime effectiveness of the guidance device is not as certain given the passage information using 3D acoustic telemetry. FPE results were considerably lower for the nighttime, and this would likely translate to a greater number of fish sounding under any behavioral guidance structure during nighttime hours. The diel effect of fish behavior on passage and distribution must be considered when operating and constructing any fish guidance device at The Dalles Dam.

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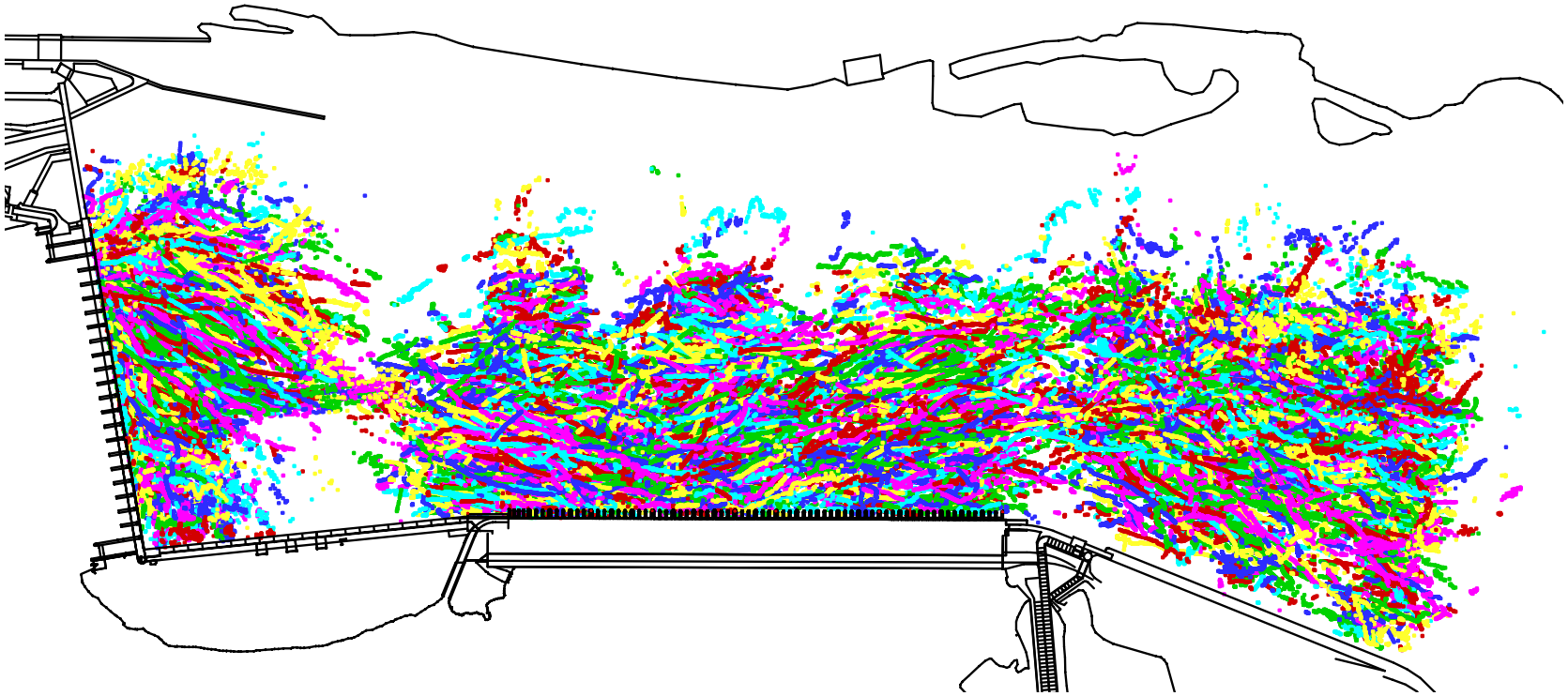
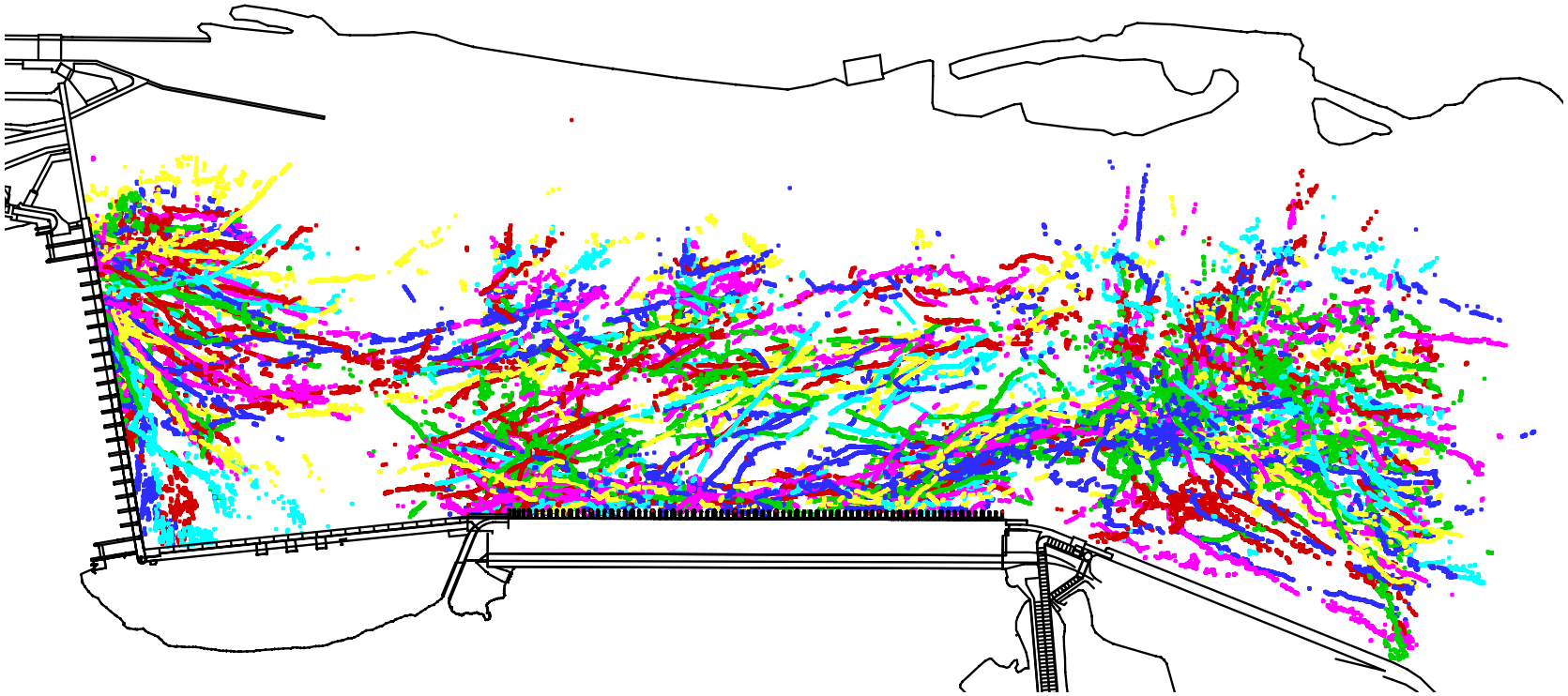
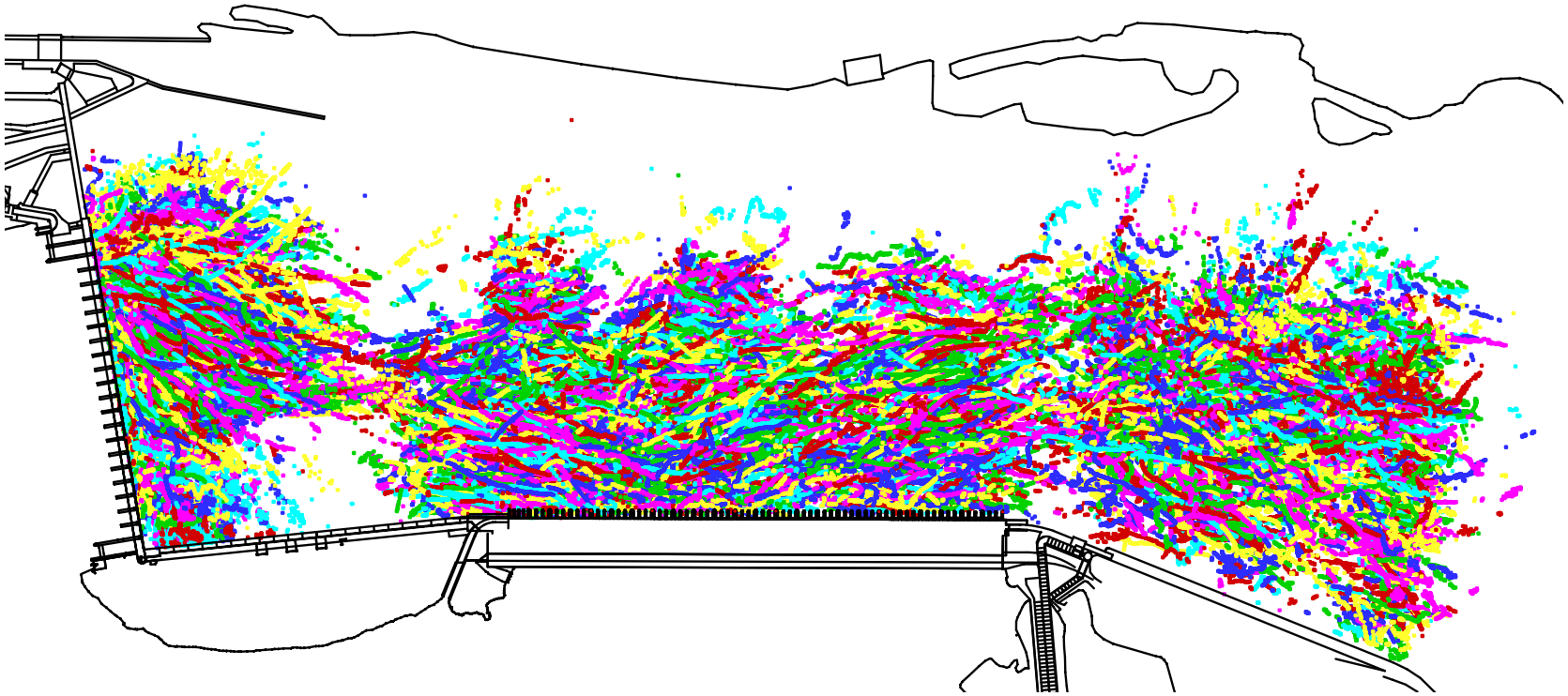
Appendix Figures



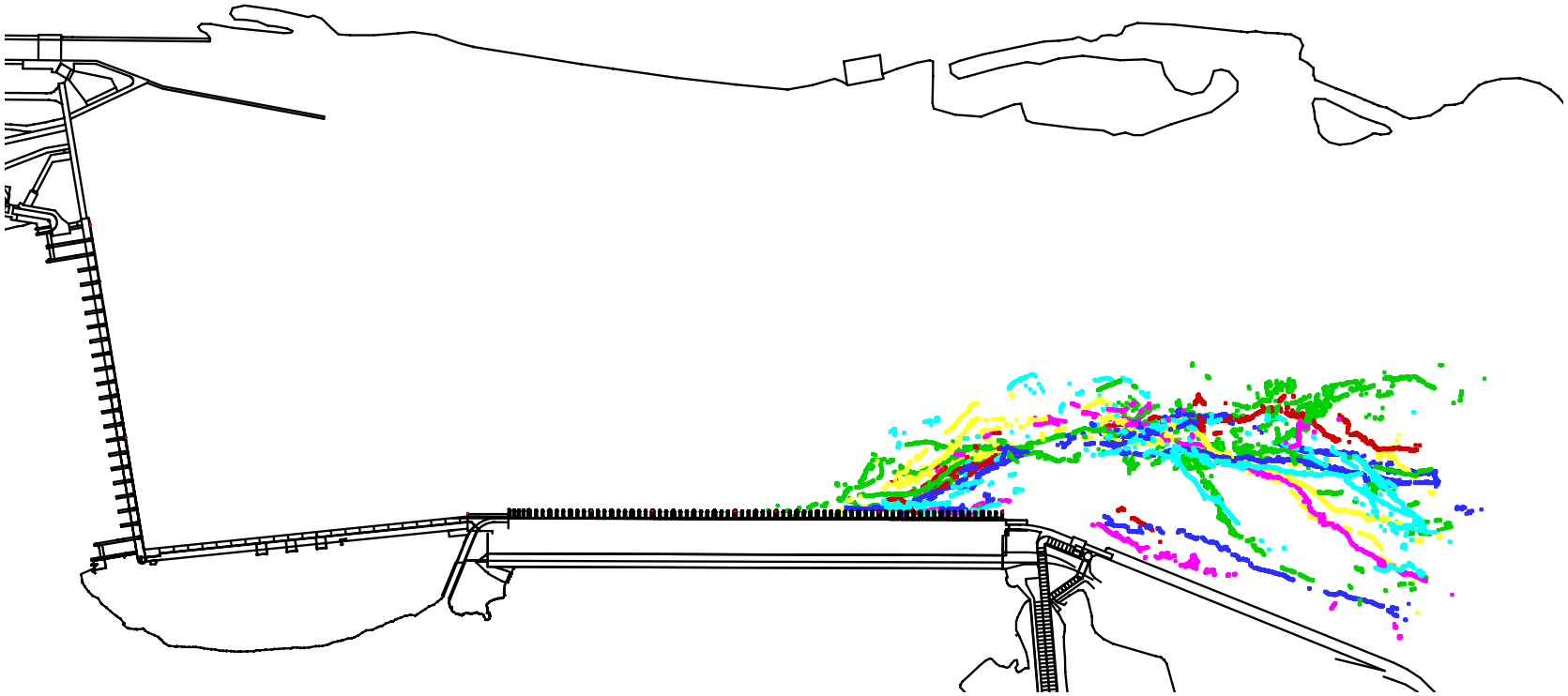
Appendix Figure 1-A.1. Plan view of fish tracks of hatchery steelhead, yearling Chinook salmon, subyearling Chinook salmon, and sockeye salmon approaching The Dalles Dam during daytime, 0530 to 2059 hours, during 2004 at The Dalles Dam. Individual fish have a unique color.



Appendix Figure 1-A.2. Plan view of fish tracks of hatchery steelhead, yearling Chinook salmon, subyearling Chinook salmon, and sockeye salmon approaching The Dalles Dam during nighttime, 2100 to 0529 hours, during 2004 at the Dalles Dam. Individual fish have a unique color.

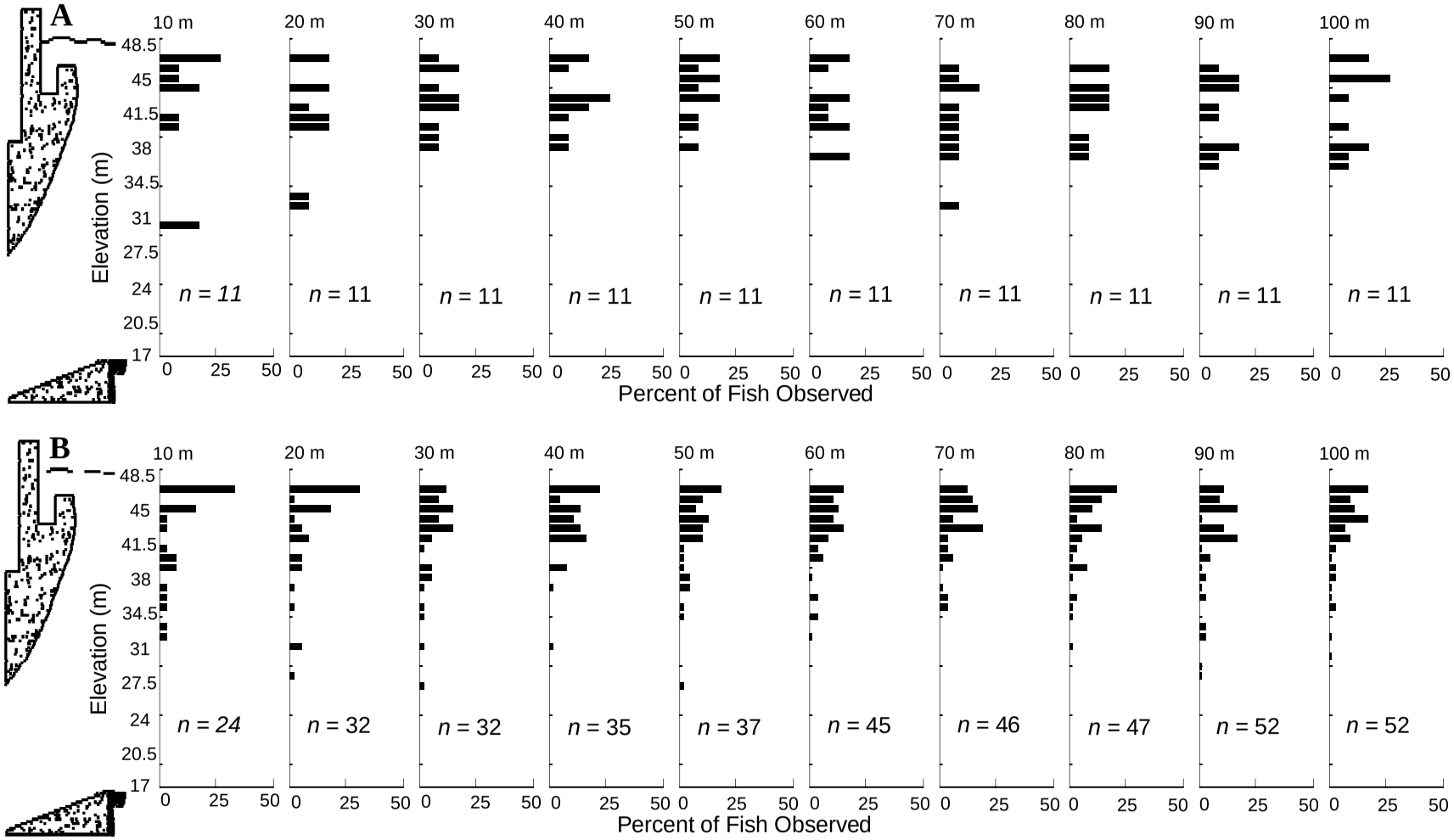


Appendix Figure 1-A.3. Plan view of fish tracks of hatchery steelhead, yearling Chinook salmon, subyearling Chinook salmon, and sockeye salmon passing through the spillway during 2004 at The Dalles Dam. Individual fish have a unique color.

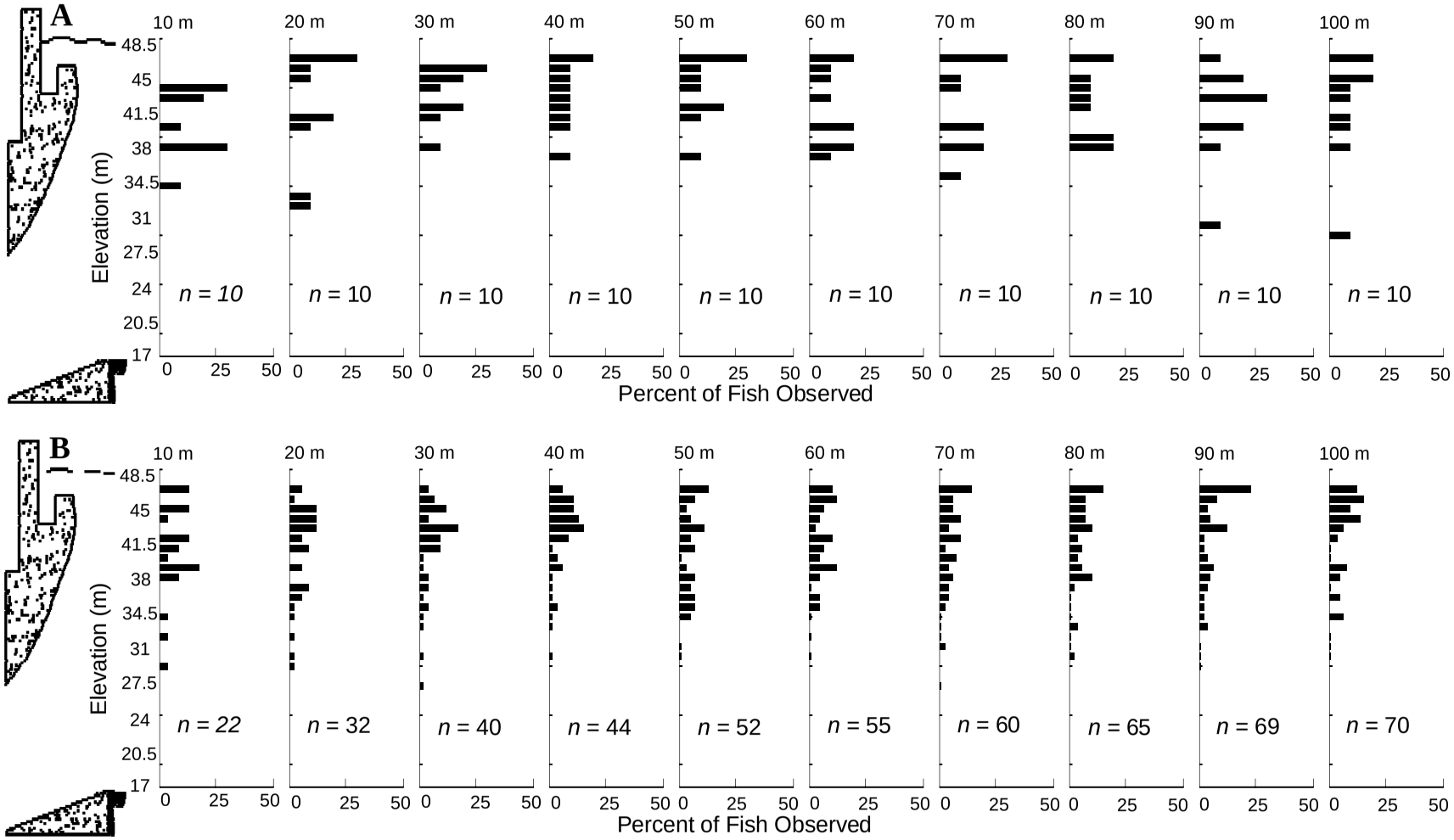


Appendix Figure 1-A.4. Plan view of fish tracks of hatchery steelhead, yearling Chinook salmon, subyearling Chinook salmon, and sockeye salmon passing through main turbine units 11-22 and the sluiceway entrance at main turbine unit 18 in the powerhouse during 2004 at The Dalles Dam. Individual fish have a unique color.

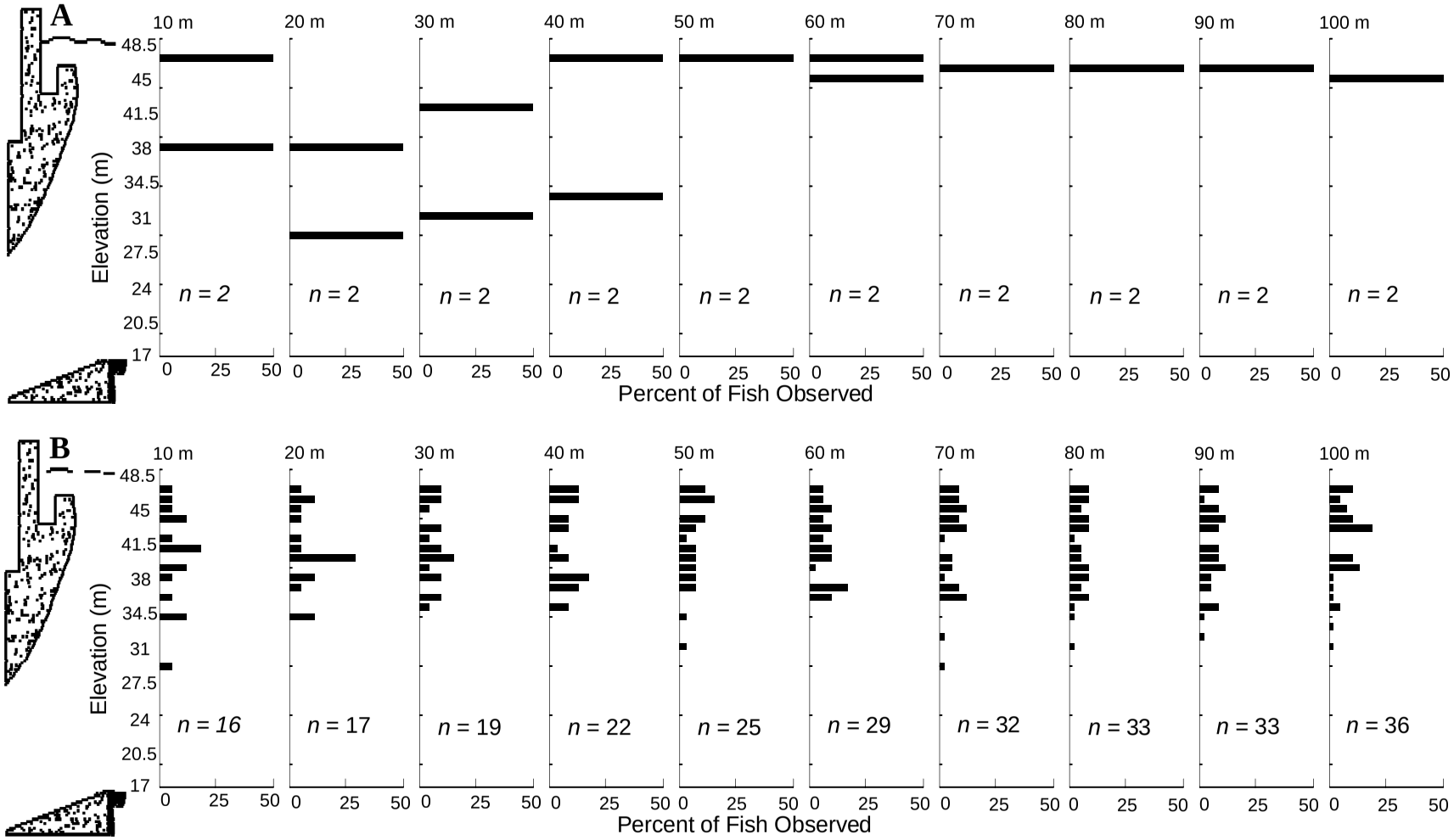
Appendix Figure 1-A.5. Plan view of fish tracks of hatchery steelhead, yearling Chinook salmon, subyearling Chinook salmon, and sockeye salmon passing through main turbine units 1-10, fish turbine units 1-2, and the sluiceway entrance at main turbine unit 1 in the powerhouse at The Dalles Dam during 2004 field studies. Individual fish have a unique color.



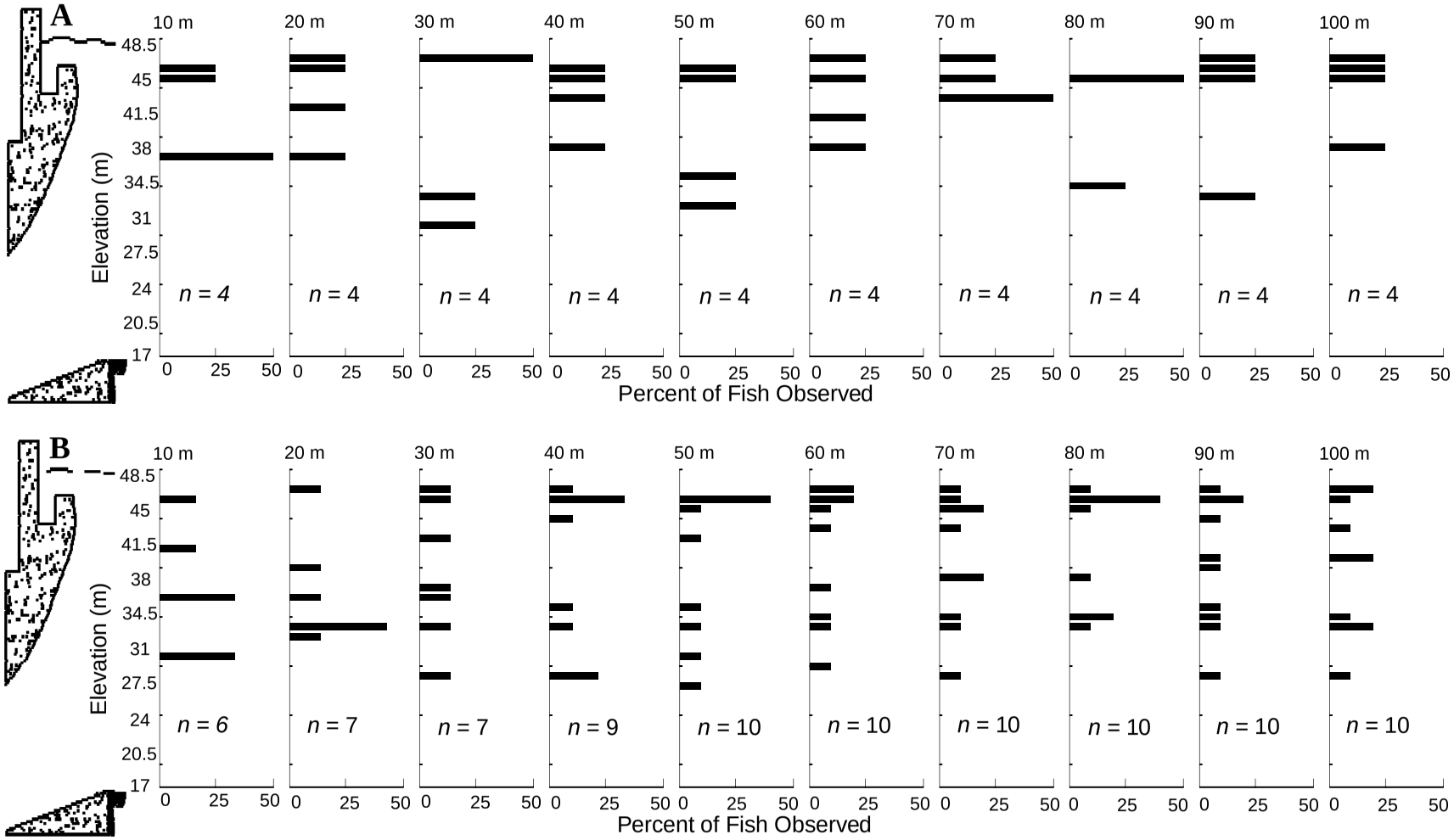
Appendix Figure 1-B.1. Vertical distributions of hatchery steelhead crossing vertical planes located at 10-m intervals in front of the sluiceway entrance at main turbine unit 1 during daytime, 0530 to 2059 hours. (A) Vertical distributions of hatchery steelhead crossing vertical planes and passing through the sluiceway entrance at main turbine unit 1 during daytime. (B) Vertical distributions of hatchery steelhead crossing vertical planes and not passing through the sluiceway entrance at main turbine unit 1 during daytime.



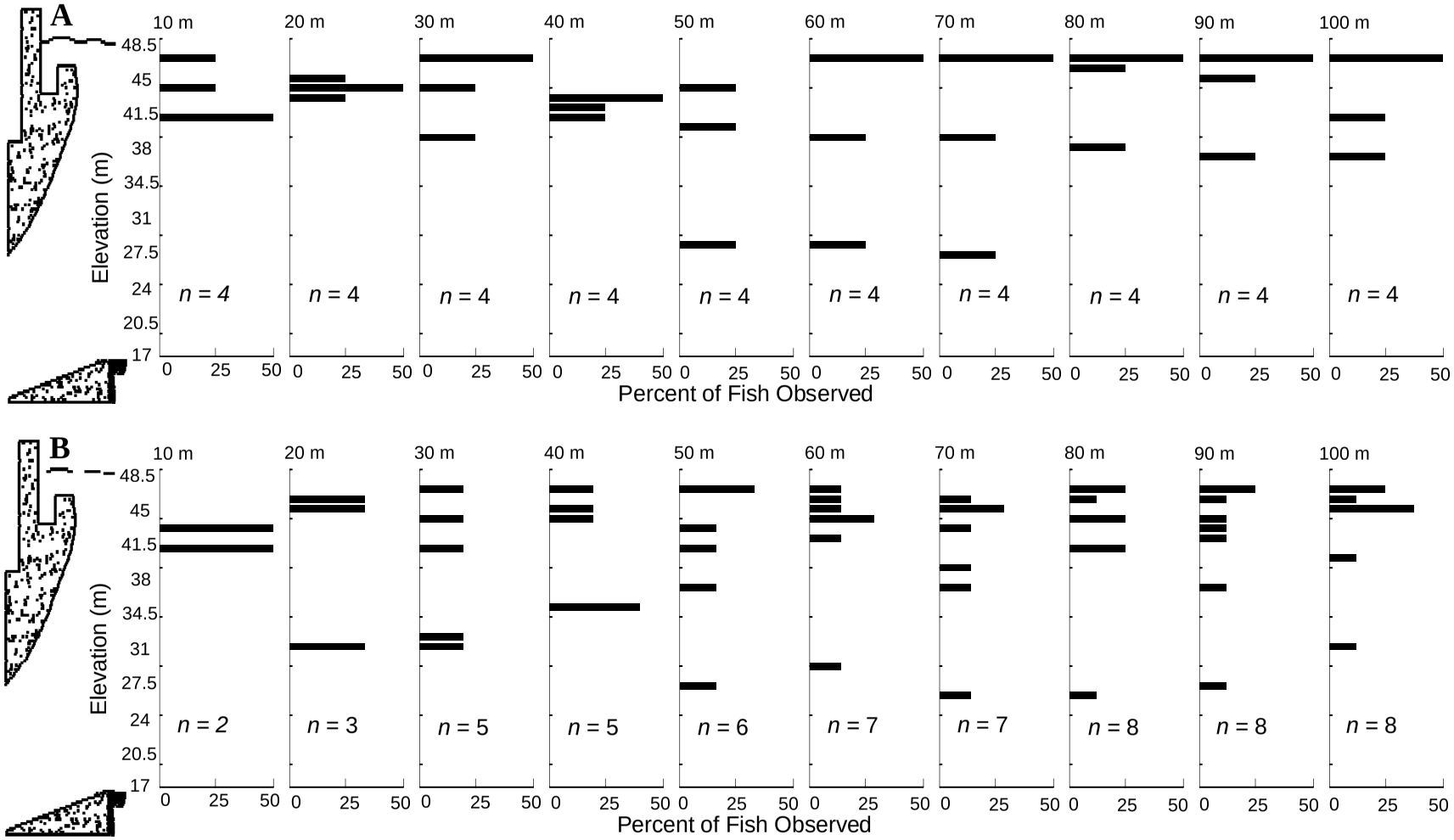
Appendix Figure 1-B.2. Vertical distributions of yearling Chinook salmon crossing vertical planes located at 10-m intervals in front of the sluiceway entrance at main turbine unit 1 during daytime, 0530 to 2059 hours. (A) Vertical distributions of yearling Chinook salmon crossing vertical planes and passing through the sluiceway entrance at main turbine unit 1 during daytime. (B) Vertical distributions of yearling Chinook salmon crossing vertical planes and not passing through the sluiceway entrance at main turbine unit 1 during daytime.



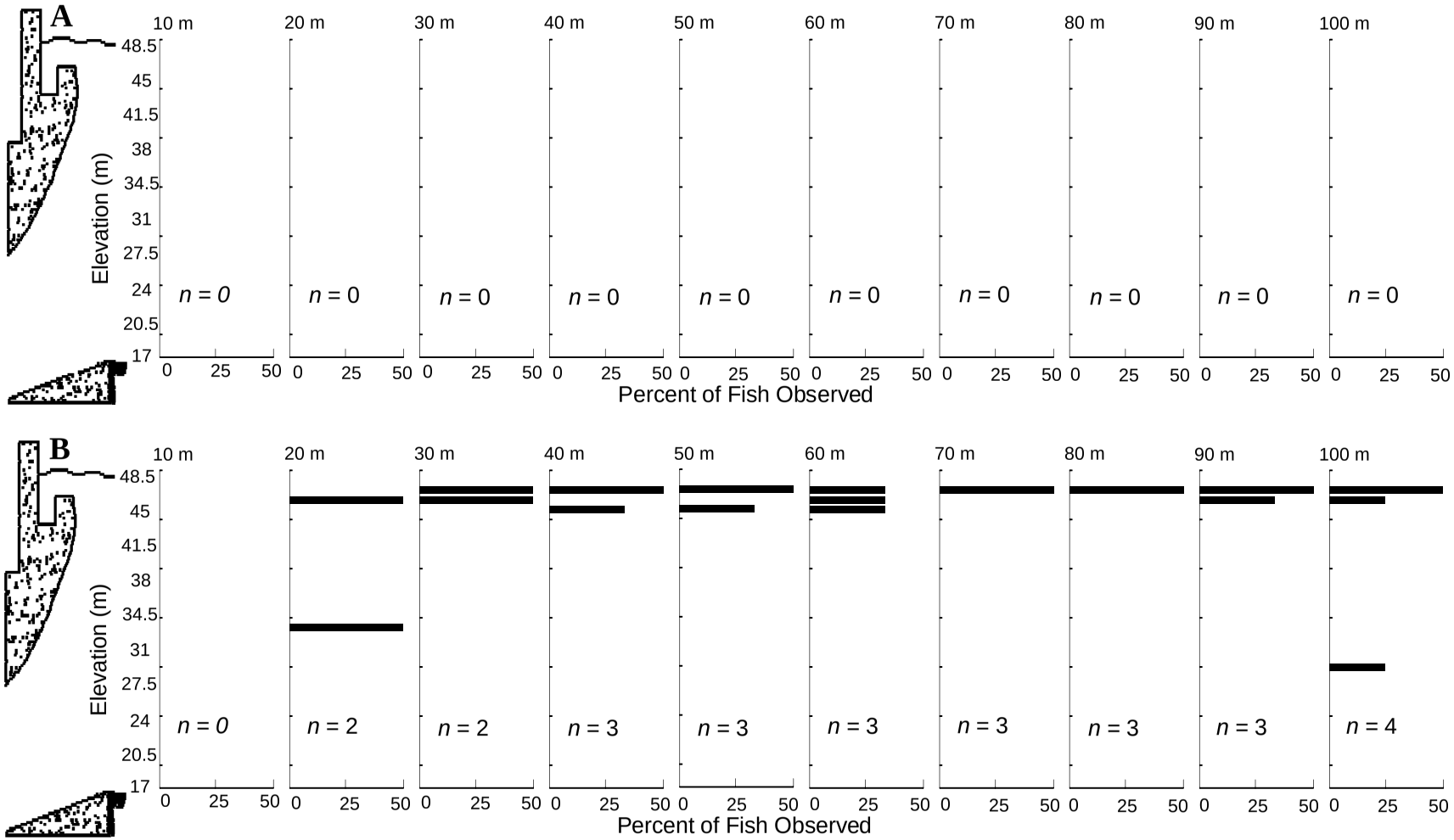
Appendix Figure 1-B.3. Vertical distributions of subyearling Chinook salmon crossing vertical planes located at 10-m intervals in front of the sluiceway entrance at main turbine unit 1 during daytime, 0530 to 2059 hours. (A) Vertical distributions of subyearling Chinook salmon crossing vertical planes and passing through the sluiceway entrance at main turbine unit 1 during daytime. (B) Vertical distributions of subyearling Chinook salmon crossing vertical planes and not passing through the sluiceway entrance at main turbine unit 1 during daytime.



Appendix Figure 1-B.4. Vertical distributions of hatchery steelhead crossing vertical planes located at 10-m intervals in front of the sluiceway entrance at main turbine unit 1 during nighttime, 2100 to 0529 hours. (A) Vertical distributions of hatchery steelhead crossing vertical planes and passing through the sluiceway entrance at main turbine unit 1 during nighttime. (B) Vertical distributions of hatchery steelhead crossing vertical planes and not passing through the sluiceway entrance at main turbine unit 1 during nighttime.



Appendix Figure 1-B.5. Vertical distributions of yearling Chinook salmon crossing vertical planes located at 10-m intervals in front of the sluiceway entrance at main turbine unit 1 during nighttime, 2100 to 0529 hours. (A) Vertical distributions of yearling Chinook salmon crossing vertical planes and passing through the sluiceway entrance at main turbine unit 1 during nighttime. (B) Vertical distributions of yearling Chinook crossing vertical planes and not passing through the sluiceway entrance at main turbine unit 1 during nighttime.



Appendix Figure 1-B.6. Vertical distributions of subyearling Chinook salmon crossing vertical planes located at 10-m intervals in front of the sluiceway entrance at main turbine unit 1 during nighttime, 2100 to 0529 hours. (A) Vertical distributions of subyearling Chinook salmon crossing vertical planes and passing through the sluiceway entrance at main turbine unit 1 during nighttime. (B) Vertical distributions of subyearling Chinook salmon crossing vertical planes and not passing through the sluiceway entrance at main turbine unit 1 during nighttime.