



Status and Habitat Use of Snake River White Sturgeon Associated with the Hells Canyon Complex

Ken Lepla
Project Biologist

**Technical Report
Appendix E.3.1-6**

Hells Canyon Complex
FERC No. 1971

Revised July 2003

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Physical Habitat Use and Water Quality Criteria for Snake River White Sturgeon

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Chapter 2

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ABSTRACT

This chapter describes the physical Snake River habitats used by various life stages of white sturgeon (*Acipenser transmontanus*) based on an evaluation of the literature and observations made during 10 years of study between Bliss Dam and the confluence with the Salmon River. Reproductive white sturgeon were located at spawning sites from March through early June while temperatures were between 7.0 and 18.8 °C. We often located spawning sturgeon in pools and runs with nearby high, turbulent water velocities such as those associated with high-gradient runs, tailouts from rapids, or dam tailraces. Mean column velocities and depths measured over telemetered sturgeon at the spawning sites ranged from 0.0 to 2.72 m/s and from 2 to 21 m. Embryonic development of white sturgeon eggs indicated that most spawning activity occurred within a temperature range of 12 to 16 °C (mean = 14 °C), which is considered to be optimal for egg development. Incubating eggs were commonly associated with turbulent pools and runs with mean column velocities ranging from 0.1 to 2.0 m/s and depths of 4 to 19 m. Based on temperature regimes in the Snake River and the timing of most egg collections (12–16 °C), peak spawning activity occurs from mid-March to the end of May upstream of the Hells Canyon Complex (HCC) and from late April to mid-June downstream of the HCC. Egg incubation primarily occurs from mid-March through early June upstream of the HCC and from late April to the end of June downstream of the complex. Larval collections occurred at depths of 4 to 14 m, mean column velocities of 0.0 to 0.90 m/s, and temperatures of 17.0 to 18.6 °C. Rearing occurred from late March through the end of July. The young-of-year life stage occurred in the Snake River beginning in mid-April and continuing through early June. Habitat used by juvenile and adult white sturgeon indicated a tolerance for a wide range of conditions using both riverine and reservoir environments. In riverine sections, sturgeon were often captured along current breaks in or near the thalweg of runs and pools. Sturgeon captured in reservoirs tended to use the middle and upper transition areas. There was little evidence that they used the lower pool. Juveniles and adults were captured in a temperature range of 8.0 to 24.2 °C, with most fish collections occurring in a temperature range of 12.0 to 23.0 °C. Overall, juvenile and adult sturgeon were captured most often at depths greater than 6 m and water velocities less than 1.50 m/s. Dissolved oxygen (DO) levels at juvenile and adult white sturgeon sampling locations ranged from 7.3 to 15.1 mg/l. To minimize the possibility of stress or mortality of fish, we did not sample white sturgeon at locations when the near-substrate DO level was less than 70% saturation.

1. INTRODUCTION

The white sturgeon (*Acipenser transmontanus*) is a large, long-lived, and late-maturing fish species. Within Idaho, it inhabits two major river drainages—the Kootenai River and the Snake River downstream of Shoshone Falls. White sturgeon also inhabit two tributaries of the Snake River—the Salmon and Clearwater rivers (Cochner et al. 1985). The State of Idaho considers white sturgeon in the Snake River to be a species of special concern (Mosley and Groves 1990). The species has only limited access to its historical habitat because of the development of the hydroelectric system on the Snake River. The Snake River in Idaho offers a contrast in population status between river segments with viable, reproducing populations to river segments with few individuals and no detectable recruitment. For example, the river segments downstream of both Hells Canyon and Bliss dams contain sizeable populations and show signs of recent reproduction. However, middle sections of the Snake River between Swan Falls and Hells Canyon dams, as well as sections upstream of Bliss Dam, contain only small populations and show little or no detectable recruitment (Cochner et al. 1985; Lepla and Chandler 1995, 1997; Jager et al. 2000; Lepla et al. 2001). Many factors contributed to the current status of white sturgeon in the Snake River. These factors include altered habitat, pollution, historical exploitation, and dams.

Previous efforts to study white sturgeon in the Snake River focused on describing population sizes, distributions, and movement to learn about population dynamics. Only general observations have been made regarding the habitat associated with sturgeon collections (Coon et al. 1977 Coon 1978; Cochner 1981, 1983; Lukens 1981, 1984; Cochner et al. 1985). Consequently, the white sturgeon's use of Snake River habitat has not been assessed in relation to the species' various life stages.

In 1991, Idaho Power Company (IPC) began evaluating the status of sturgeon populations and their habitat use in the Snake River as a part of its efforts to renew federal licenses for its hydroelectric projects. This particular study describes habitat used by various life stages of white sturgeon from Bliss Dam downstream to the mouth of the Salmon River and details habitat suitability criteria for Snake River sturgeon. These criteria are based both on our field observations and on our review and assessment of the relevant literature. This information was used to evaluate the effects of hydroelectric operations on white sturgeon habitat availability in the Snake River. The findings of those evaluations are presented in IPC technical reports by Brink (2000) for the Lower Salmon Falls–Bliss reach, Brink and Chandler (2000) for the Bliss–C.J. Strike reach, Chandler and Lepla (1997) for the C.J. Strike–Swan Falls reach, Myers and Chandler (2001) for the Oxbow Bypass reach, and Chandler et al. (2002) for the Snake River downstream of Hells Canyon Dam.

2. STUDY AREA

This study covered the following six reaches of the Snake River from Bliss Dam downstream to the confluence with the Salmon River (Figure 1):

- Bliss–C.J. Strike
- C.J. Strike–Swan Falls
- Swan Falls–Brownlee
- Brownlee–Oxbow
- Oxbow–Hells Canyon
- Hells Canyon–Salmon River

2.1. Bliss–C.J. Strike Reach

This reach of the Snake River extends 66 mi and encompasses three major types of habitat between Bliss Dam at river mile (RM) 560.0 and C.J. Strike Dam at RM 494.0 (Figure 2). The upper 13 river miles of this reach, between Clover Creek (RM 547.6) and Bliss Dam (RM 560.0), is located in a narrow river corridor creating several large rapids and deep, turbulent run and pool habitats. The canyon area has a gradient of 1.15 m/km (6.2 ft/mi). Riverbanks are typically steep and covered with boulders and sagebrush. The Snake River downstream of Clover Creek (RM 547.6) to the upper end of C.J. Strike Reservoir (RM 518.0) flows through relatively flat terrain with a gradient of 0.33 m/km (1.7 ft/mi). Cochnauer (1981) characterized this section as containing slow-moving runs with shallow riffles, few deep pools, and abundant aquatic vegetation during summer months. C.J. Strike Reservoir (RM 494.0–518.0) impounds approximately 24 river miles of the mainstem Snake River and 9.7 river miles of the Bruneau River. The reservoir has a surface area of approximately 7,500 acres and total storage capacity of 240,000 acre-feet. The mean depth of the reservoir is 10.1 m, and the maximum depth is 42.4 m. Myers and Pierce (1997) have reported the reservoir at times has very low levels of dissolved oxygen (< 2 mg/l) in the lower 8 mi of the pool.

2.2. C.J. Strike–Swan Falls Reach

The Snake River downstream of C.J. Strike Dam is relatively shallow. It meanders 25.4 river miles through an area developed for agriculture before it enters Swan Falls Reservoir at RM 468.6 (Figure 3). Steep canyon walls prevail in the lower section of the reach, confining the river to a narrow reservoir with a surface area of 875 acres. Constructed in 1901, Swan Falls Dam (RM 458) is the oldest hydroelectric facility on the Snake River. The lower portion of this reach contains the Snake River Birds of Prey National Conservation Area. Water quality in this reach is affected by point and nonpoint sources, including irrigated agriculture, grazing, confined animal feed operations adjacent to the project area, and upstream sources from the middle Snake River above C.J. Strike Reservoir (Myers and Pierce 1997).

2.3. Swan Falls–Brownlee Reach

The Snake River below Swan Falls Dam (RM 458) is free flowing for 118 river miles before it enters Brownlee Reservoir (Figure 4). The first 8 mi of river (RM 458–450) downstream of Swan Falls Dam is relatively high in gradient, with vertical canyon walls, turbulent runs and rapids, and intermittent deep pools. Downstream of this stretch, the gradient decreases and the river becomes shallow, with numerous island complexes and braided channels. This stretch extends for 110 river miles through farmlands before entering Brownlee Reservoir near RM 340.

Brownlee Reservoir has approximately 1 million acre-feet of active storage and a surface area of 6,100 acre-feet at full pool (2,077 ft mean sea level). Its average depth is 32 m, with a maximum depth of 92 m. During winter, IPC often draws down the reservoir as much as 30 m to meet flood-control requirements established by the U.S. Army Corps of Engineers.

Brownlee Reservoir is about 55 mi in length and used for power generation, flood control, and recreation. Several large tributaries empty into this reach, including the Boise, Malheur, Payette, Owyhee, and Weiser rivers. Nutrient loading from agricultural, municipal, and industrial sources is high in this reach. Maximum water temperatures in the Snake River upstream of Brownlee Reservoir near Weiser, Idaho, can reach 27 °C during late summer months. Summer water temperatures near the surface of Brownlee Reservoir (< 1 m) during July and August can range from 24 to 31 °C.

2.4. Brownlee–Oxbow Reach

The Brownlee–Oxbow reach (RM 284.6–273) is one of the shortest segments in the Snake River, extending only 12 river miles before reaching Oxbow Dam (Figure 5). Oxbow Reservoir begins in the tailrace of Brownlee Dam and has a surface area of 1,150 acres. Maximum depths reach about 30 m, and the water level commonly fluctuates 1.2 m. Wildhorse River is the only major tributary entering the Snake River in this reach. Oxbow Reservoir has been designated as water quality limited, due primarily to processes occurring in Brownlee Reservoir (Myers and Pierce 1999). During low-flow years, severe water quality conditions can be present in up to 73% of the bottom 2-m layer of the Oxbow Reservoir. The maximum recorded water temperature in the reservoir is 25 °C.

2.5. Oxbow–Hells Canyon Reach

The third dam in the Hells Canyon Complex (HCC) is Hells Canyon Dam (RM 247.6), which impounds water for 22 river miles. This reservoir has a surface area of 2,412 acres at full pool and a total storage capacity of 167,720 acre-feet. Hells Canyon Reservoir has a maximum depth of 60 m and is characterized by steep shorelines with basalt outcrops and talus. During July and August in low-flow years, up to 52% of the reservoir's bottom 2 m is characterized by poor water quality conditions such as low dissolved oxygen (DO) levels. This reach consists primarily of impounded reservoir habitat and little free-flowing habitat other than the Oxbow Dam tailrace and Oxbow Bypass.

2.6. Hells Canyon–Salmon River Reach

The Snake River downstream of Hells Canyon Dam is free flowing for 107 river miles before entering Lower Granite Reservoir (Figure 6). This section of river also runs through the deepest river-carved canyon in North America, which creates a series of turbulent rapids and runs intermixed with many deep pools. High mountain peaks, basalt canyon rimrocks, and steep sage-covered lower slopes characterize the Hells Canyon corridor. Several large tributaries—including the Imnaha, Salmon, and Grande Ronde rivers—join the Snake River upstream of Lower Granite Reservoir. For the period of record (1950–2000), the median flow measured at the

U.S. Geological Survey (USGS) Anatone gauge in thousands of feet per second (kcfs) is 2,626.1 kcfs. Maximum water temperature downstream of Hells Canyon Dam generally peaks near 24 °C. Levels of DO in the Hells Canyon Dam tailrace can drop as low as 2.8 mg/l for several weeks during late summer months when the poor quality water arrives from Brownlee Reservoir. The DO levels recover (~ 7 mg/l) within at least 9 river miles downstream of the dam from several rapids that aerate the water.

3. METHODS

We determined the physical habitat used by white sturgeon by measuring the following habitat variables:

- water depth in meters (m)
- water temperature in degrees Celsius (°C)
- mean column and near-substrate water velocity in meters per second (m/s)
- DO in milligrams per liter (mg/l)

During the 10 years of study between Bliss Dam and the Salmon River, we measured these variables at locations where eggs and larvae were collected, at all random setlines and gill net sets, and where telemetered white sturgeon were monitored. We measured water depth to the nearest 0.1 m with a calibrated sounding reel attached to a boat-mounted boom assembly. Water velocities were quantified using a Marsh-McBirney Flo-Mate™ Model 2000 portable flowmeter¹ with 6.8- to 34.0-kg sounding weights. Mean column velocities were calculated by averaging the velocities measured at 0.2 and 0.8 of the water depth. Water temperatures and DO readings were recorded with a Hydrolab Surveyor® II sensor system at specific sampling sites². USGS flow gauges and temperature–DO monitors installed in the dams also provided continuous hourly data throughout individual reaches of the study area.

To collect white sturgeon eggs, we primarily used artificial substrate mats. These mats consisted of latex-coated animal hair cut into 76 × 91-cm sections and secured to angle-iron frames as described by McCabe et al. (1989). We typically placed the mats in spawning areas from March to July each year, depending on water temperatures and flow rates. The mats were fished on the bottom and occasionally anchored in place with 2.3- to 4.5-kg weights, depending on the hydraulic conditions. We checked the mats at least once per week during the time they were deployed.

¹ Flo-Mate is a trademark of Marsh-McBirney, Inc.

² Surveyor is a registered trademark of the Hydrolab Corporation.

On an experimental basis, we also used stationary plankton nets to sample sturgeon eggs and larvae in the Bliss–C.J. Strike (1991–1993) and C.J. Strike–Swan Falls (1994–1996) reaches. The nets were constructed of 1.59-mm knotless mesh attached to a D-shaped frame 0.8 m in diameter. Plankton nets were weighted and fished on the bottom in spawning areas. Even though these upper reaches of the study area contain relatively sizeable sturgeon populations, we had little success in collecting eggs or larval sturgeon using the plankton nets. Therefore, we did not continue to use this gear downstream between Swan Falls and Hells Canyon dams since those reaches have a low abundance of sturgeon. We also did not sample with plankton nets downstream of Hells Canyon Dam because we were concerned about possible effects to species listed under the Endangered Species Act (ESA). Using criteria established by Beer (1981) and Wang et al. (1985), we assigned each collected egg and larva to a developmental stage.

The older life stages of sturgeon were sampled with baited setlines and gill nets. Setlines were the primary gear used to capture sturgeon because of the method's versatility in effectively sampling a wide range of conditions. Each setline was 27 m long and equipped with 6 circular tuna hooks. Two hooks of each size (12/0, 14/0, and 16/0) were attached in random order to the mainline and spaced 3 m apart. A few setlines were rigged exclusively with 10/0 hooks to capture smaller white sturgeon. We used line weights (10 kg) to anchor the ends of our setlines and attached a float line and buoy for retrieval. Each week of the sampling period, we fished up to 12 setlines over a three-day period and checked the setlines at daily intervals. To supplement our effort using baited setlines, we used sinking-style gill nets in reaches upstream of Hells Canyon Dam. We fished all gill nets for 1-hour intervals or less in areas where water velocities permitted. Each net was constructed of multifilament twine and measured 38.4 m long, with bar mesh sizes ranging from 1.9 to 12.7 cm. We did not use gill nets downstream of Hells Canyon Dam because of the potential risk in capturing species listed as threatened or endangered under the ESA.

In addition, a number of juvenile and adult white sturgeon in the study reaches were fitted with radio and ultrasonic transmitters to monitor movement behavior and habitat use. Sturgeon sampled by our collection gear were surgically examined to identify sex and maturity using methods outlined in Conte et al. (1988) and Beamesderfer et al. (1989). We then tagged a select number of fish of various sex and maturity with external radio and sonic transmitters attached at the base of the dorsal fin with braided stainless steel wire. For reporting purposes, only the sonic codes are presented in the text of this chapter when a fish received both tags. A complete list of radio and sonic codes are presented in summary (Tables 1 to 5). The tags operated on various frequencies (kHz) and emitted unique codes to identify individual fish. IPC technicians monitored the tagged sturgeon at least once per week during the telemetry studies. Monitoring was conducted from a jet boat using either a Lotek™ SRX_400™ radio receiver³ and a 3- to 6-element yagi antenna or a Sonotronics Model USR-4D™ receiver⁴ with a directional hydrophone.

³ Lotek and SRX_400 are trademarks of Lotek Wireless.

⁴ USR-4D is a trademark of Sonotronics, Inc.

We used our observations of sturgeon eggs, larvae, and telemetered spawners to describe timing and habitat conditions associated with spawning, incubation, and larval life stages in the Snake River. For these particular life stages, we relied on habitat suitability indices (HSI) based on white sturgeon habitat information developed by Wang et al. (1985), McConnell (1989), Parsley et al. (1993), and Parsley and Beckman (1994). Where possible, we plotted our observations of spawning, incubation and larval life stages from the Snake River for comparison with the HSI.

We used observations from random setline sampling to define habitat use and develop HSI curves for juvenile and adult sturgeon in the Snake River. The HSI defined the suitability of each habitat descriptor on a scale of 0 to 1 (0 = unsuitable and 1 = most suitable) based on catch per unit of effort. We also relied on observations of habitat use by telemetered juvenile and adult sturgeon to assist in constructing suitability curves when sample sizes from setline data were less than 5 observations. The curves were fit by eye to the habitat use data. As a part of our sampling protocols, we did not fish for sturgeon in most reaches when water temperatures were above 23 °C or DO levels were less than 70% saturation. Therefore, we used temperature and DO information developed by McConnell (1989) and by Klyashtorin (1974) to describe suitability for these habitat descriptors.

4. RESULTS

4.1. Spawning and Incubation

4.1.1. *Sampling Results*

The following sections provide detailed information about our results for each year's spawning period by study reach.

4.1.1.1. **Bliss–C.J. Strike Reach**

From 1992 to 1997, we used artificial substrate mats to sample 32 locations between RM 520 and 560 during spawning periods. We also conducted limited sampling with stationary plankton nets from an anchored boat at 16 locations during 1992 and 1993. Our sampling effort during spawning periods typically began in the weeks from April through early June, while water temperatures ranged between 10 and 18 °C. From 1992 through 1997, we collected a total of 291 eggs from 5 sites, the majority (286) of which were collected by artificial substrate mats deployed in the high-gradient canyon section of the reach between Bliss Dam and King Hill. This section of river includes several large rapids along with deep, turbulent runs and pools for staging and spawning sturgeon. During 1991–1993, we also tagged a total of 18 reproductive white sturgeon in the Bliss–C.J. Strike reach to assist us in identifying staging and spawning locations within the reach (Table 1). The results from the individual spawning years are presented below.

1992 Spawning Period—Suitable spawning temperatures (10–18 °C) occurred from January 25 to June 6 in 1992. We collected seven eggs between April 21 and May 18 in the upstream end of the Porterfield Hole (RM 555.8), which is a large, deep, and turbulent pool (Figure 2). Mean daily water temperatures at the time of egg collections ranged from 14.3 to 17.1 °C, and depths ranged between 12.8 and 18.3 m. The embryonic development of eggs indicated that spawning events occurred on April 18–20, May 3, and May 15. Mean daily flows and temperatures during this time ranged from 6.26 to 7.73 kcfs and 13.7 to 16.5 °C (Figure 7a). The spring hydrograph during 1992 was essentially flat; no peak freshet occurred during the spawning period. Poor snowpack conditions and lower than normal spring runoff made 1992 one of the poorest water years on record.

Before the 1992 spawning period, we tagged four reproductive sturgeon (S275, S2534, S2525, and S2345) with sonic transmitters in the canyon section of the reach between King Hill and Bliss Dam. We fitted an additional six reproductive sturgeon (S2633, S2426, S2354, S3335, S2227, and S2543) with transmitters near the lower end of the reach in C.J. Strike Reservoir. We captured S275, a female, near King Hill (RM 547). By April 20, 1992, she had traveled 9 mi upstream to the Porterfield Hole. We monitored this fish between the Porterfield Hole and the Upper Jet Hole (RM 556.1) for two weeks before she returned downstream to the location of her capture. We assumed that this upstream and subsequent downstream movement was associated with staging and spawning because it corresponded with the timing of egg collections at the Porterfield Hole. Mean column velocities and daily temperatures recorded at her locations ranged from 0.61 to 1.05 m/s and from 13.6 to 16.2 °C. Depths ranged between 5.5 and 6.7 m.

A second female (S2534) was tagged in the Porterfield Hole during October 1991. We were unable to locate this fish consistently during the 1992 spawning period. Female S2534 was last recorded in January 1992 near the Upper Jet Hole and eventually relocated at RM 555.2 on May 26. No specific movement or location associated with spawning were determined (Figure 7b).

We also tagged two reproductive males (S2525 and S2345) near the upper end of the reach (RM 554) during December 1991. However, we were also unable to locate these fish consistently during the 1992 spawning period. Male S2525 traveled 1 river mile upstream (RM 555) from his capture location by April 7, but he was not relocated until July 1992 at RM 551.9. Male S2345, also monitored at RM 554 in January 1992, was not relocated until May 4, back at his capture location. No spawning-related movements or locations were determined (Figure 7b).

Based on the movement behavior of three reproductive sturgeon originally tagged in C.J. Strike Reservoir, spawning in 1992 apparently occurred 4 river miles upstream of C.J. Strike Reservoir. Female S2633 and males S2426 and S2354 traveled upstream of C.J. Strike Reservoir to RM 521.8 and RM 523.6 between April 14 and April 26. They returned to the reservoir by early May. Although we did not collect any eggs at these locations, female S2633 was recaptured in July 1992 and surgically identified as spent. The timing of their movements coincided with the upstream movement of female S275 located 20 mi upstream, as well as with the subsequent spawning activity at the Porterfield Hole (Figure 7b). Mean column and near-substrate velocities at RM 521.8 were 0.32 and 0.57 m/s, with similar velocities measured at RM 523.6 (0.4–0.49 m/s). The maximum depths at RM 521.8 and 523.6 were 13.7 m and 14.8 m, respectively. Mean daily flows and temperatures during this interval ranged from 6.45 to

7.96 kcfs and from 13.6 to 16.2 °C. We deployed artificial substrate mats at RM 520.8 and 523.5 while these fish were present, but we removed them by mid-May because the locations had become excessively loaded with silt.

We were unable to monitor two females (S3335 and S2543) and one male (S2227) consistently during the spawning period. Therefore, no definitive spawning-related movements were identified from these fish. However, female S3335 was recaptured in February 1993 and surgically identified as spent, indicating that spawning had occurred in 1992 (Figure 7b).

1993 Spawning Period—In 1993, suitable spawning temperatures occurred from March 4 to June 19. We collected a total of 103 white sturgeon eggs from April 30 to June 4. As in 1992, we collected most eggs (102) in the high-gradient canyon section of the reach in a deep pool at the Porterfield Hole. We also collected one egg in a pool just upstream of C.J. Strike Reservoir in the Grass Hole (RM 521.8) (Figure 2).

The mean daily water temperatures at the time of egg and larval collections ranged from 13.5 to 18.2 °C, with depths ranging between 6.7 and 19.0 m. The embryonic development of eggs indicated that spawning occurred on April 30 at the Grass Hole and May 5–7 and June 3 at the Porterfield Hole. Mean daily temperatures and river flows during the spawning events ranged from 13.2 to 15.7 °C and from 7.15 to 10.5 kcfs (Figure 8a). We observed that the spawning events coincided with near optimal water temperatures. However, these events occurred prior to the peak flow downstream of Bliss Dam in June, which occurred near the end of the period of suitable spawning temperatures. The reduction and delay of spring flows in the middle Snake River were due, in part, to the refilling of drought-stricken reservoirs in the upper Snake River Basin upstream of Shoshone Falls.

Before the 1993 spawning period, we attached sonic transmitters to eight white sturgeon. Two males (S87 and S2254) were captured at RM 558.0 and RM 556.1, respectively, in the canyon section downstream of Bliss Dam. Both males S87 and S2554 were captured in June 1992 and remained near their capture locations until late March and early April 1993, respectively.

Male S87 moved downstream to the Porterfield Hole (RM 555.8) by March 24 and was recorded at this location when sturgeon eggs were collected on May 6 (Figure 8b). Mean column velocities and temperatures ranged from 0.19 to 0.75 m/s and 12.9 to 18.8 °C. Depths at this fish's location ranged from 9 to 21 m. Mean daily flows downstream of Bliss Dam during this time ranged from 7.01 to 10.6 kcfs.

The second fish, male S2254, moved 0.5 river miles upstream to RM 558.6 by April 15 and was recorded at this location until May 26. This location was approximately 0.1 river miles downstream of Bliss Rapids (Figure 8b). Although no eggs were collected by nearby artificial substrate mats, mean column velocities and temperatures at male S2254's location ranged from 0.41 to 1.17 m/s and 13.3 to 18.1 °C during the spawning interval. Maximum depth at RM 558.6 was 11 m.

The other six fish (males S258, S249, and 2353 and females S293, S356, and S2227a) were captured in C.J. Strike Reservoir. We tagged males S258, S249, and S2353 during March and early April between RM 508 and 513. They quickly traveled upstream to the Grass Hole by

mid-April (Figure 8b). All three male sturgeon were present in the Grass Hole on April 30 when we collected a single, newly spawned egg at this location. Mean column velocities and water temperatures measured over these sonic-tagged fish in the Grass Hole ranged from 0.18 to 0.53 m/s and from 12.0 to 18.9 °C. Male S249 eventually returned to C.J. Strike Reservoir by late May. Males S258 and S2353 were last recorded in the area of the Grass Hole and Hammett Narrows (RM 523.6), respectively, before their tag signals were lost (Figure 8b).

Three late vitellogenic females (S293, S356, and S2227a) were also among the six fish tagged in C.J. Strike Reservoir before the 1993 spawning period. However, we could not determine any spawning-related movements from these fish. All three females were captured during May and June 1992, and we assumed that they would be available for spawning by the spring of 1993 based on their mean egg diameters (2.2–2.6 mm). Unfortunately, we lost the signals from S293 and S356 soon after release, and the remaining female (S2227a) was not located upstream of C.J. Strike Reservoir during the spawning period (Figure 8b).

1994 Spawning Period—Suitable spawning temperatures in 1994 occurred from February 28 to June 23. Based on the embryonic development of 32 collected sturgeon eggs, seven spawning events occurred in 1994. We collected the eggs on May 6 and May 27 from the pool at the Porterfield Hole and from a high-velocity run just downstream of Bliss Rapids at RM 558.8 (Figure 2). Water temperatures at the time of egg collections ranged from 14.8 to 17.1 °C. Depths ranged between 8 and 15 m. Mean column velocities at the Porterfield Hole and just downstream of Bliss Rapids ranged from 0.68 to 1.00 m/s. We estimated that spawning occurred on May 3, May 5, and May 22–26. Mean daily flows and water temperatures during these events ranged from 7.87 to 8.53 kcfs and 14.3 to 16.3 °C. The amount of spring runoff during 1994 was similar to runoff in 1992, with lower than normal river flows and no peak freshet occurring during the spawning period (Figure 9a).

1995 Spawning Period—The window of suitable spawning temperatures was relatively wide in 1995, beginning January 10 and ending June 24. We collected a total of 147 eggs between April 24 and June 12 in the pool at the Porterfield Hole and in a high-velocity run downstream of Bliss Rapids (Figure 2). Water temperatures and depths associated with egg collections ranged from 13.7 to 16.3 °C and from 4 to 15 m. Mean column velocities at these two sites ranged from 0.12 to 1.15 m/s. Many of the eggs we collected in the Porterfield Hole were found in the large, turbulent back eddies of this pool. Water velocities in these areas tended to surge, with some near-substrate velocities often reading higher than mean column measurements. Based on the embryonic development of the collected eggs, we believe that spawning occurred April 20–21, April 23–24, April 27–30, May 7, May 13–14, May 20, and June 11. Mean daily flows and water temperatures during these dates ranged from 6.58 to 25.5 kcfs and from 12.3 to 15.8 °C. Although 1995 was considered to be a normal water year for the middle Snake River, most spawning events seemed to occur before peak spring runoff, which occurred from near the end of May into early June. However, using artificial substrate mats to collect sturgeon eggs during peak flows may be less efficient (Figure 9b).

1996 Spawning Period—We collected only two eggs during 1996. One egg was sampled on May 20 at the Upper Pump Hole (RM 554.5), at a depth of 6 m and a mean daily water temperature of 14.9 °C. We found the other egg at the Porterfield Hole on June 10 (Figure 2). This egg was collected at a depth of 15 m and a mean daily water temperature of 18.9 °C. Both

eggs were located in turbulent pool habitats. We estimated that spawning occurred on May 20 at a mean daily flow of 15.1 kcfs and a mean daily water temperature of 15.0 °C. The second spawning event occurred on June 9 while flows were 17.7 kcfs and temperatures were near 18.8 °C. The bimodal peaks observed in the 1996 hydrograph resulted from water management in the upper Snake River Basin. Water management practices can substantially alter the magnitude and timing of the spring hydrograph. Suitable spawning temperatures in 1996 occurred between April 6 and June 8 (Figure 9c).

1997 Spawning Period—During the 1997 spawning period, we deployed artificial substrate mats from April 11 to June 6 at seven locations between RM 554.0 and RM 558.7. However, no eggs were collected. Suitable spawning temperatures (10–18 °C) occurred from April 15 to June 14. During this period, flows ranged between 14.7 and 40 kcfs (Figure 10). Flows peaked at nearly 41 kcfs during spring runoff that year, which ranked as one of the highest recorded water years for the Snake River. These higher flows and subsequently higher velocities made it difficult to maintain the artificial substrate mats in locations that we had successfully sampled during previous years. Also, the higher flows and velocities likely kept more eggs in transport and perhaps prevented eggs from adhering to or settling onto the substrate mats. These conditions likely reduced our ability to collect white sturgeon eggs considerably during the 1997 spawning period.

4.1.1.2. C.J. Strike–Swan Falls Reach

From 1994 to 1996, we deployed artificial substrate mats and conducted stationary plankton net sampling from late March to mid-June to collect sturgeon eggs during spawning periods. Artificial substrate mats were sampled at 11 locations between C.J. Strike Dam (RM 494) and RM 477. Plankton nets were fished at three locations between the dam and RM 477, with the majority of sampling effort focused within 0.3 river miles of C.J. Strike Dam. During our survey of this study reach, we also attached sonic and radio transmitters to 12 reproductive white sturgeon between C.J. Strike Dam (RM 494) and the town of Grand View, Idaho (RM 486) to assist us in identifying spawning locations (Table 2). We collected only one nonviable sturgeon egg during our survey in 1996. The results from the individual spawning years are presented below.

1994 Spawning Period—Water temperatures suitable for spawning (10–18 °C) in 1994 occurred from March 29 to May 27 in this reach. Flows past C.J. Strike Dam during the spawning period ranged from 8.0 to 10.1 kcfs. The amount of spring runoff during 1994 was similar to runoff in 1992, with lower than normal river flows and no peak freshet occurring during the spawning period (Figure 11a). No white sturgeon eggs or larvae were collected during the 1994 spawning period.

We also captured and tagged two reproductive male white sturgeon (S114 and S105) in the spillway of C.J. Strike Dam (RM 493.9) on March 22 and April 7, respectively. Both sturgeon moved very little after their release, remaining within the immediate vicinity of C.J. Strike Dam. By May 13, male S105 had moved from the spill gate area to the tailrace, while male S114 remained in the spill gate area throughout the spawning interval (Figure 11a). The mean column velocity in the spill gate area during the 1994 spawning period was 0.0 m/s. The river channel downstream of C.J. Strike Dam forms a U shape between the tailrace and the spillway area,

creating a large backwater area in front of the spillway. The mean column velocity in the tailrace where male S105 was located on June 6 was 1.41 m/s. Water temperatures and depths recorded at the locations recorded for males S105 and S114 ranged from 14.2 to 17.2 °C and from 2.6 to 7.3 m.

1995 Spawning Period—In 1995, suitable water temperatures for spawning occurred from March 17 to June 25 in this reach. Flows past C.J. Strike Dam during the spawning period ranged from 4.68 to 31.08 kcfs. Because these flows exceeded the hydraulic capacity of the C.J. Strike power plant (15.5 kcfs), IPC spilled water at C.J. Strike Dam on several occasions. All of these spill events occurred within the range of suitable spawning temperatures, with the highest recorded spill (16.1 kcfs) occurring June 10 while the water temperature was 15.4 °C. No white sturgeon eggs or larvae were collected during the 1995 spawning period.

We fitted four reproductive sturgeon with sonic transmitters to determine movement and locations associated with 1995 spawning conditions. Two female sturgeon (S115 and S348) were captured in the tailrace. One male (S132) and a third female (S142) were tagged 1.3 to 4.8 mi downstream of C.J. Strike Dam. We captured female S115 in September 1994 and were able to locate her sporadically in the tailrace until June 2, 1995 (Figure 11b). We captured female S348 on April 27, 1995, during the spawning interval. We monitored this female in the tailrace until May 12. On June 19, we found her 1.3 mi downstream at RM 492.6 (Figure 11b). The third female (S142) was captured in October 1994 and later tracked 7.2 mi downstream during the winter. Female S142 began moving upstream by January 26, 1995, and she appeared to stage in the tailrace on March 15, 1995. Unfortunately, we lost her tag signal during the spawning interval and did not relocate her until June 22, approximately 7.5 mi downstream. She was later recaptured at this location on December 20, 1995, and surgically determined to have spawned in 1995 (Figure 11b). No definitive spawning location was determined from her movements. However, the low gradient in this reach of the Snake River suggests that spawning probably occurred in the area immediately downstream of C.J. Strike Dam.

Male S132 showed movements similar to those of female S142. This fish also overwintered close (within 2.5 river miles) to C.J. Strike Dam and began moving upstream before the spawning period. We located male S132 in the tailrace on May 10, 1995, a date and location that coincided with suitable spawning temperatures and the beginning of peak spring flows. This fish moved 1.4 mi downstream by June 19, 1995, as flows peaked. We last recorded this fish 7.2 mi downstream of C.J. Strike Dam on August 7, 1995 (Figure 11b).

Although turbine noise and spill events often hampered the detection of sonic-tag signals in the tailrace, we were able to locate three of the four sturgeon (females S142 and S348 and male S132) in the tailrace during mid-May when water temperatures were optimal for spawning and flows were at or near the hydraulic capacity of the C.J. Strike power plant. As temperatures exceeded the range for spawning and as peak flows decreased by June 25, all three sturgeon had moved downstream of the tailrace. Mean column velocities recorded in tailrace areas where male S132 and females S115 and S348 were located during the spawning interval ranged from 0.90 to 1.78 m/s. Depths and temperatures during this time ranged from 3.4 to 4.0 m and 12.8 to 17.6 °C.

1996 Spawning Period—In 1996, suitable spawning temperatures occurred for about 10 weeks from April 7 to June 7. Flows exceeding the hydraulic capacity of the C.J. Strike power plant

began in late February, and water was passed over the spillway three times during the spawning interval. The highest recorded spill during 1996 (29.92 kcfs) occurred on April 6 while water temperatures were 11.4 °C. We collected one nonviable sturgeon egg by plankton net sampling on May 23, 1996, at the bridge near the lower end of the C.J. Strike Dam tailrace (RM 493.7). The water flow and temperature at the time of collection were 14.3 kcfs and 15.3 °C, respectively.

Before the 1996 spawning period, we captured and tagged four late vitellogenic female sturgeon (S455, R114, S106, and S96) and two male sturgeon (R118 and S267). The transmitter signals from females S455 and S106 and male S267 were lost before the spawning interval began. We last recorded female S455 3.5 river miles downstream of C.J. Strike Dam in February, female S106 at RM 493.6 during March, and male S267 in the tailrace during mid-April. These sturgeon were located only sporadically, and no movement associated with spawning was discernible (Figure 11c).

Female S96 was also lost midway through the spawning period. We originally captured this fish 7.3 river miles downstream of the dam in June 1995. She overwintered near C.J. Strike Dam. By March 12, 1996, female S96 traveled upstream to the tailrace as flows began exceeding 26 kcfs and the water temperature was 6.2 °C. This fish remained in the tailrace for about two weeks before returning downstream 2.4 river miles to RM 491.5. This downstream movement was followed by a return trip upstream to RM 492.7 by April 12. Flows during this time were near peak levels, and temperatures were suitable for spawning (12.1 °C). Female S96 remained at RM 492.7 for seven days and was last recorded 3.5 mi downstream of C.J. Strike Dam on April 25 (Figure 11c).

The fourth female (R114) showed movement patterns similar to movement patterns for female S142 and male S132, which we tracked in 1995. Female R114 overwintered 2.5 river miles downstream of the dam before traveling upstream to the spillway by late February. The water temperature at this time was 6.5 °C. River flows had exceeded plant capacity, and 2 kcfs of water was passing at the spillway. Female R114 remained in the spillway until peak flows decreased and the spill gates were closed on April 30. During the time we monitored R114 in the spillway, flows passing the spill gates ranged from 2 to 10 kcfs and temperatures ranged between 6.5 and 21.1 °C. The mean column velocity over her locations was 0.35 m/s, and depths ranged between 1.5 and 4.9 m. Female R114 then moved from the spillway to the tailrace of C.J. Strike Dam and remained near the turbine outflows until May 23, a date that coincided with the collection of one nonviable egg. Water temperature and flows on May 23 were 15.3 °C and 14.3 kcfs. While no velocities were recorded on May 23, the mean column velocity measured at her tailrace location during similar flows (14.2 kcfs on May 1) was 1.55 m/s. Female R114 subsequently moved out of the tailrace and was located 3.7 river miles downstream eight days later (Figure 11c). The presence of R114 in the tailrace and the timing of egg collection corresponded with optimal spawning temperatures and the near maximum hydraulic capacity of the power plant.

We captured male R118 on April 9, 1996, at RM 492.7 when we surgically determined this fish to be reproductive. Male R118 remained at RM 492.7 for 13 days before moving downstream to RM 491.8 where he was last recorded on May 1. Mean column velocities and depths at locations measured at RM 492.7 ranged from 1.0 to 1.5 m/s and from 3.7 to 4.6 m. Temperature during this time ranged from 11.1 to 12 °C (Figure 11c). Although we did not collect any eggs near

RM 492.7, male R118 was later recaptured on June 12 with setline sampling and appeared to have spawned.

4.1.1.3. Swan Falls–Brownlee Dam Reach

During the 1997, we deployed artificial substrate mats at nine locations downstream of Swan Falls Dam between RM 453.1 and 458.0 during the spawning period. Water temperatures suitable for spawning occurred from April 16 to May 30.

1997 Spawning Period—On May 27 and 28, we collected two sturgeon eggs in pools near the tail end of rapid and turbulent runs at RM 453.7 and 453.1 (Figure 4). Both pools were relatively deep (7.6–8.8 m) with strong back eddy currents (0.69–1.97 m/s at mean column). Also, one sturgeon larva was incidentally sampled at RM 309.5 in Brownlee Reservoir during subsurface trawls for larval centrarchids on May 21. The larva was collected at 4 m below the surface. Using the embryonic development of the eggs and larva, we estimated three spawning dates: May 14, May 27, and May 28. Mean daily temperatures and flows on these dates ranged from 17.5 to 17.8 °C and 17.2 to 19.9 kcfs (Figure 12a).

We also monitored the spawning behavior of two reproductive sturgeon (S339 and R133) during the spring of 1997 to assist us in identifying spawning locations and conditions in this reach (Table 3). We tagged a third fish (S375) but were unable to locate this sturgeon during the spawning period. Male S339 and female R133 were captured a 1.4 mi apart during late 1996, and each fish overwintered near its capture location (RM 454.7 and 456.1). As water temperatures became suitable for spawning in the spring of 1997, both male S339 and female R133 moved to RM 453.7 by May 12. Within this section, the Snake River's channel narrows, creating a few deep pools with turbulent run and rapid habitats for about 0.5 mi. Female R133 remained at this site for only two days before traveling upstream to another narrow, turbulent channel at RM 456.8. Male S339 stayed at RM 453.7 for several weeks and was present when eggs were collected in this pool on May 28. A second egg was also collected 0.6 mi downstream at RM 453.1 one day earlier on May 27, 1997 (Figure 12b). Mean column velocities and temperatures associated with fish positions at RM 453.7 ranged from 1.8 to 2.5 m/s and 15.5 to 17.7 °C while depths ranged from 4.5 to 8.8 m.

4.1.1.4. Brownlee–Oxbow Dam Reach

We used substrate mats to sample six locations downstream of Brownlee Dam during the 1999 spawning period. We deployed the mats from April 14 to June 16 while temperatures ranged from 9.4 to 16 °C. The substrate mats failed to collect any eggs in this reach during the 1999 sampling effort. In addition, no sturgeon were captured during our survey of this reach.

4.1.1.5. Oxbow–Hells Canyon Dam Reach

We sampled four locations downstream of Oxbow Dam with artificial substrate mats during the 1999 spawning period. We deployed the mats from April 21 to June 25 while water temperatures ranged between 9.7 and 17.0 °C. As in the Brownlee–Oxbow reach, we were unable to collect any eggs during 1999 using substrate mats.

1999 Spawning Period—No spawning ripe sturgeon were sampled in the spring of 1999, although two late vitellogenic females (S2443 and S2525) were captured and tagged in March and April 1998. Based on the color and mean size of their eggs when they were captured, we assumed that these females would be ready for spawning during the spring of 1999. As suitable spawning temperatures approached in 1999, female S2443 moved upstream to Oxbow Dam on May 13 and was located just above the tailrace in the Oxbow Bypass at RM 269.9. The mean column velocity of 0.4 m/s and the water temperature of 11.5 °C suggest that her behavior was related to pre-spawn staging. The mean daily flow from Oxbow Dam was 30.6 kcfs during this time. No further observations were made on this fish until June 17, 1999, when female S2443 was located 1.2 mi upstream in the Oxbow Bypass at RM 271.1. Temperature and mean column velocity measured in this swift run were 15.6 °C and 1.12 m/s. About 11.1 kcfs was spilling through the Oxbow Bypass during this time. This fish shed her sonic and radio tags upstream two weeks later in a deep pool at RM 271.3 (Figure 13).

The second female (S2525) showed less movement prior to the 1999 spawning period. With the exception of one downstream movement to RM 266.7, this fish remained within 0.5 mi (RM 269.2) below Oxbow Dam from November 1998 through June 1999. Although we cannot be definite, we assume that female S2525 staged and spawned near this location. This section of river channel is relatively narrow and forms turbulent rapids with high water velocities during periods of high flow. These conditions are similar to conditions at other known spawning sites. Mean daily flows during the spawning period below Oxbow Dam ranged from 15.1 to 53.2 kcfs (Figure 13). During this time, mean column velocities measured at female S2525's location ranged from 0.93 to 2.63 m/s. We determined that her tags were shed at RM 269.2 by mid-July, based on the separation of signals originating from the radio and sonic transmitters.

4.1.1.6. Hells Canyon Dam–Salmon River Reach

From 1998 through 2000, we deployed artificial substrate mats at 46 locations between Hells Canyon Dam and the mouth of the Salmon River. The mats were placed from April through June while water temperatures ranged between 9 and 18 °C. Five spawning events were documented during 1998 and 1999 based on the collection of 11 sturgeon eggs. No eggs were collected during our sampling efforts in 2000. We also tagged and monitored three reproductive sturgeon between Hells Canyon and the mouth of the Salmon River to assist in identifying spawning locations and conditions used during 1999 and 2000 spawning periods (Table 5). The results from the individual spawning periods are presented below by year.

1998 Spawning Period—Suitable water temperatures (10–18 °C) for spawning occurred from April 20 to June 28. Mean daily flow during this time ranged from 27.8 to 93.4 kcfs. On June 11, one newly spawned sturgeon egg was collected with an egg mat at RM 235.8 (Figure 6). Mean column velocity and depth at the collection site was 1.2 m/s and 16 m. Mean daily water temperature and flow conditions during this time were 15.9 °C and 45.8 kcfs (Figure 14).

1999 Spawning Period—In 1999, spawning temperatures occurred from April 20 to June 21. Mean daily flows during the spawning period ranged from 15.1 to 53.2 kcfs. We documented four spawning events by the collection of 10 sturgeon eggs at RM 196.8, 224.4, 235.8, and 236.3 (Figure 6). Based on the developmental stages of the eggs, spawning events were estimated to have occurred on June 3, June 8, June 9, and June 29 while habitat conditions ranged from

16.0 to 18.5 °C and 39.6 to 29.0 kcfs (Figure 15a). Mean column water velocities and depths at the collection sites ranged from 0.42 to 1.2 m/s and 7 to 14 m.

We also tagged one reproductive sturgeon (S249) prior to the 1999 spawning interval (Table 5). Female S249 was tagged on March 22, 1999, at RM 224.4. She was monitored at this location for about four weeks. The mean column velocity and depth measured at her location were 0.59 m/s and 10 m. We assumed that this fish was staging at RM 224.4 and spawned in the turbulent run-rapid habitat immediately upstream between April 19 and May 5, 1999. Water temperatures and flows during this time ranged from 10 to 12 °C and from 53.2 to 32.7 kcfs (Figure 15b).

By May 6, 1999, female S249 departed from RM 224.4 and moved downstream for several weeks. Her departure from this location was assumed to be the result of post-spawning behavior. We made several unsuccessful attempts to recapture her so that we could surgically verify that she was spent. Although we did not sample any sturgeon eggs at RM 224.4 during her presence, three sturgeon eggs were collected at this site several weeks later on June 10, 1999. By July 16, female S249 had traveled 61 mi downriver to RM 163.7. This extensive downstream movement was quickly followed by a 31-mi return upstream to RM 195.5 by August 24, 1999. This fish shed the transmitter tag 4 mi upstream at RM 199.2 during early September 1999 (Figure 15b).

2000 Spawning Period—The window of suitable spawning temperatures in 2000 occurred from April 9 to about June 20. Mean daily flows during this period ranged from 8.2 to 32.4 kcfs. No sturgeon eggs were collected during 2000. As the spawning period began, we tagged two reproductive female sturgeon (S455/S248 and S294) (Table 5). The first female (S294) was captured at RM 211.7 on April 4, and she showed movement behavior similar to those by female S249 during the 1999 spawning interval. Female (S294) staged at the capture site for several weeks as water temperatures increased, and then she quickly departed downstream. We assumed that female S294 spawned near RM 211.7 before she departed this site around April 26. Water temperature and flows during the time female S294 was located at RM 211.7 ranged from 8.6 to 12.6 °C and from 28.5 to 31.4 kcfs. Mean column velocities and depths at her location were 0.56 m/s and between 11 and 15 m. By June 27, female S294 moved 13.1 mi downstream to RM 199 and remained there for 16 days before returning 24.1 mi upstream to RM 223.1 by August 4, 2000 (Figure 16).

The second spawning female (S455/S248) was tagged at RM 228.8 (Steep Creek) on April 11, 2000. This same female had been originally tagged (S455) at Steep Creek (RM 228.8) on September 4, 1998, and was staged as early vitellogenic (Table 5). Female S455 was monitored at this location until anglers removed her tag sometime between May 12 and May 19, 1999. About 255 days later, we recaptured this fish for the second time at Steep Creek on April 11, 2000, and retagged her (S248) as ripe for spawning. The indicated time elapsed between stages of maturity from early vitellogenic to spawning ripe condition was about 1.5 years (577 days). As the 2000 spawning period approached, female S248 showed a movement behavior similar to the behavior of females S294 and S249, although her overall movements were not as extensive. Female S248 was monitored at Steep Creek for six weeks until she departed from the site by May 25. Water temperatures and flows during this time ranged from 10.4 to 14.8 °C and from 27.8 to 11.5 kcfs. The mean column velocity and depth recorded at her location were 0.54 m/s and from 7 to 11 m. After this fish departed from Steep Creek, she was not relocated until

June 26, after the spawning period, at RM 230.8. Water temperatures by this time were 18.3 °C and outside the range of suitable spawning temperatures. Four weeks later, female S248 returned to Steep Creek (Figure 16). We assumed that she spawned within the vicinity of Steep Creek. However, it was unclear exactly where she spawned because numerous turbulent runs and rapids provide suitable spawning velocities between Steep Creek and RM 230.8. Our deployment of artificial substrate mats failed to collect any eggs in this area.

4.1.2. Suitability Criteria for Spawning and Incubation

Based on the embryonic development of sturgeon eggs collected in reaches between Bliss Dam and the mouth of the Salmon River, sturgeon spawned in the Snake River at water temperatures between 12.0 and 17.7 °C, with a mean temperature of 14 °C. Overall, most spawning activity appeared to occur in a temperature range between 12 and 16 °C. The reported range of suitable spawning temperatures for white sturgeon typically occurs between 10 and 18 °C (Parsley et al. 1993). In the Snake River, these temperatures generally occur between March and June. Although we have not documented spawning at the lower temperatures, water temperatures associated with known spawning events in the Snake River fall within the suitability criteria reported for white sturgeon on the Columbia River by Parsley et al. (1993) (Figure 17a). Using the temperature regimes in the Snake River and the temperature range in which we collected the majority of eggs (12–16 °C), we believe that peak spawning activity likely occurs from mid-March to the end of May upstream of the HCC and from late April to mid-June downstream of the complex (Figure 18).

We found that spawning-related movement varied among reproductive sturgeon. This variability likely relates to the proximity of monitored fish to spawning habitat. The lack of consistency in observed behavior might simply be a result of where the fish were captured in the reach and the geographic proximity of spawning habitat. Although we were unable to track all tagged sturgeon consistently, most individuals showed movement patterns associated with pre- and post-spawning behavior. The most notable movements were associated with reproductive sturgeon that were tagged in reservoirs and subsequently tracked upstream to spawning sites above the reservoir. In riverine sections, reproductive adults tended to travel less distance before spawning. In fact, some individuals showed no discernable movement during the spawning period.

In general, we located sturgeon at spawning sites from March through early June while temperatures were between 7.0 and 18.8 °C. We often located spawning sturgeon in pools and runs with nearby high, turbulent water velocities such as those associated with high-gradient runs, tailouts near rapids, or dam tailraces. Mean column velocities and depths associated with telemetered sturgeon at the spawning sites ranged from 0.0 to 2.72 m/s and from 2 to 21 m. While these depths encompassed the range of spawning criteria developed for Columbia River sturgeon (Parsley and Beckman 1994), most of our mean column velocity readings were relatively low and likely represented staging activity rather than actual spawning events (Figure 17b,c).

Post-spawning movements were evident from several sturgeon that, after two to four weeks, typically left the spawning area. In a few instances after a spawning period, we recaptured individuals and surgically confirmed that they had spawned. Post-spawning behavior was also

variable, since some fish were monitored in the spawning areas throughout the remainder of the year.

Water temperatures during our collections of incubating eggs ranged from 13 to 19 °C (with a mean of 14 °C; Figure 19a), which is considered to be optimal for egg incubation by Wang et al. (1985). Embryonic criteria defined by Wang et al. (1985) indicated that incubation would typically occur from mid-March through early June above the HCC and from late April to the end of June downstream of the complex (Figure 18). As with our observations of spawning adults, we commonly found incubating eggs in turbulent pools and runs with mean column velocities and depths ranging from 0.1 to 2.0 m/s and from 4 to 19 m. Our observations of depths were comparable with suitability criteria reported for incubating eggs in the Columbia River (Figure 19b). However, most eggs were collected at relatively lower velocities (Figure 19c). It is likely that this difference was a result of using artificial substrate mats, a passive form of collection gear. We typically deployed the mats at locations with relatively low water velocities so that eggs could settle onto the mats. Mats set in high velocity areas were often difficult to maintain and generally inefficient under such conditions. Therefore, our observations of spawning and incubation habitat likely do not represent the entire range of conditions used during these events, particularly water velocities. Incubating eggs in the Snake River were often collected over coarse substrates ranging from gravel to boulder, which is similar to substrate use documented in the Columbia River by Parsley et al. (1993). Boulder substrates showed higher use for incubating eggs in the Columbia River; however, this again may have been an artifact of our use of substrate mats in lower velocity areas. Given incubating eggs were commonly associated with large substrates, we define the HSI for gravel to bedrock as optimal substrates for incubating eggs (Figure 19d). Except for mean water column velocities, our observations were similar to suitability criteria reported for white sturgeon spawning and incubation by Wang et al. (1985) and Parsley et al. (1993). Therefore, we suggest using these suitability criteria to represent spawning and incubation conditions in the Snake River.

4.2. Larvae

4.2.1. Sampling Results

We conducted stationary plankton net sampling to collect white sturgeon larvae on an experimental basis in the Bliss–C.J. Strike (1991–1993) and C.J. Strike–Swan Falls (1994–1996) reaches. Based on our low success rate in these reaches, we did not conduct larval sampling in downstream reaches between Swan Falls Dam and the mouth of the Salmon River during our 1996–2000 sturgeon surveys. In addition, we restricted our use of plankton net sampling downstream of Hells Canyon Dam out of concern for affecting species listed under the ESA. However, we did collect a total of four sturgeon larvae. The following sections discuss these collections and the habitat conditions associated with them.

4.2.1.1. Bliss–C.J. Strike Reach

During 1993, we collected three larval white sturgeon in the Porterfield Hole, which is located in the upper canyon section of the Bliss–C.J. Strike reach. We documented several spawning events

at the Porterfield Hole from 1992 through 1997 through egg collection and detected reproductive adult sturgeon with sonic tags. The larvae, ranging in age from 1 to 5 days, were collected on May 14 and May 20. The depths of collection were 7 and 14 m, while mean column and near-substrate water velocities were 0.90 and 0.58 m/s, respectively. Water temperatures on these dates ranged from 17.0 to 18.6 °C.

4.2.1.2. Swan Falls–Brownlee Reach

IPC technicians incidentally collected one larval white sturgeon on May 21, 1997, at RM 309.5 in Brownlee Reservoir during subsurface trawls for larval centrarchids. The larva was found 4 m below the water surface in water measuring 18 °C. At the time of collection, the maximum water column depth at this location was 14 m. The embryonic development of the larva indicated that it was 1-day-old post hatch and likely spawned on May 14. However, the spawning origin of this larva was uncertain because several days had passed. Because white sturgeon larvae are typically mobile, they have a greater chance of being dispersed downstream by the river currents. Thus, larvae are generally less accurate indicators of where spawning occurs (Perrin et al. 2000).

4.2.2. Suitability Criteria for Larvae

Given that our larval white sturgeon sampling was conducted on an experimental basis and in only two reaches, we based habitat suitability criteria for larvae in the Snake River from information obtained on white sturgeon by McConnell (1989) and Parsley et al. (1993). Although we collected only four larvae, the range of habitat conditions associated with these collections fell within the range of the documented suitability criteria (Figure 20). Using temperature regimes found in the Snake River from Bliss Dam downstream to the Salmon River and embryonic criteria developed by Wang et al. (1985), we estimated that the larval life stage for white sturgeon would typically occur in various reaches of the Snake River from late March through the end of July (Figure 18).

4.3. Young-of-Year

4.3.1. Sampling Results

Our gill net sampling collected no young-of-year white sturgeon. Although the mesh sizes of the gill nets we used upstream of Hells Canyon Dam were likely capable of capturing some age-0 fish, our primary collection gear during the white sturgeon studies consisted of setlines. Setlines are more likely to collect sturgeon greater than 50 cm total length (TL). We did not conduct any gill net sampling downstream of Hells Canyon Dam out of concern for affecting ESA listed species.

4.3.2. Suitability Criteria for YOY

Based on suitable spawning temperatures and the subsequent development of eggs and larvae, we estimated that the young-of-year life stage (age-0) occurred in various Snake River reaches beginning in mid-April (Figure 18). We relied on suitability criteria for young-of-year white

sturgeon in the Snake River from habitat information from McConnell (1989), S. Doroshov (UC Davis, pers. comm.), and Parsley and Beckman (1994) (Figure 21).

4.4. Juvenile

4.4.1. Sampling Results

We generally conducted sampling for white sturgeon between March and November while water temperatures ranged between 5 and 24 °C. We captured juvenile sturgeon in a temperature range of 8 to 24 °C, with most fish collections occurring at temperatures of 12 to 23 °C. However, because we did not sample year-round in any given reach, our sampling does not reflect the full range of temperatures in the Snake River. Also, our sampling protocols prevented us from fishing for sturgeon in most reaches (except downstream of Hells Canyon Dam) while water temperatures were above 23 °C. We waived the temperature criteria for sampling this reach since fish showed only minimal signs of capture stress while handled in these higher temperatures. However, we did observe a decline in catch rates as temperatures exceeded 23 °C (Figure 22). Readings of DO associated with the capture of juvenile sturgeon ranged from 7.3 to 14.5 mg/l. We did not sample sturgeon at locations when near-substrate DO level was less than 70% saturation.

The juvenile sturgeon we captured between Bliss Dam and the mouth of the Salmon River were at depths ranging from 2 to 28 m. We found most fish at depths between 6 and 20 m (Figure 23). Mean column and near substrate velocities at our sample locations ranged from 0.0 to 2.625 m/s. We captured juveniles in mean column velocities from 0.0 to 1.90 m/s and near substrate velocities from 0.0 to 1.7 m/s, with most fish sampled in velocities less than 1.5 m/s (Figures 24 and 25).

4.4.2. Suitability Criteria for Juveniles

In general, water temperatures in most reaches between Bliss Dam and the mouth of the Salmon River vary seasonally between 1.3 and 24.0 °C. The highest water temperatures in the Snake River occur in the lower end of the Swan Falls–Brownlee reach. Maximum summer temperatures near Weiser reach 27 °C and near-surface (< 1 m) temperatures in Brownlee Reservoir range between 24.4 and 31.0 °C. We based temperature suitability criteria for juvenile white sturgeon in the Snake River on information provided by McConnell (1989) and S. Doroshov (UC Davis, pers. comm.). Although we did not sample the full temperature range, our observations encompassed the limits defined by these criteria (Figure 26a). To address DO tolerances, we relied on Klyashtorin's (1974) data describing DO thresholds over a range of temperatures for four species of Russian sturgeon. Linear relationships were fit to these data by Jager et al. (2001), who showed that DO values less than 4.5 mg/l reduced growth, while levels less than 1.8 mg/l were lethal within upper temperature ranges (Figure 27).

As for other criteria, depths greater than 14 m and water velocities less than 0.25 m/sec were the most suitable for juveniles (Figure 26b,c,d). A few small fish ($n = 3$; 67–83 cm TL) were sampled in areas with surprisingly high near-substrate and mean column velocities ranging from

1.6 to 1.90 m/s or about 2 body lengths/s. These data suggested that larger juvenile sturgeon (less than 120 cm TL) were likely capable of negotiating velocities up to 2.5 m/s based on 2 body lengths/s. We compared velocities used by telemetered fish. One individual—although it was somewhat larger than 120 cm TL—was located in mean column velocities of 2.7 m/s. Swimming performance studies have shown that *Acipenser* spp. of the Volga River can sustain swimming at velocities of 1.2 to 4.5 body lengths/s (Malinin et al. 1971). Based on this information, we extended the suitability of upper velocities to 2.75 m/s (mean column) for juvenile sturgeon. However, it should be noted that the suitability values for these velocities were very low (< 0.07), findings that suggest these upper velocities would likely seldom be used by juvenile sturgeon (Figure 26c,d).

4.5. Adult

4.5.1. Sampling Results

Water temperatures during our sampling efforts in the Snake River ranged between 5 and 24 °C. As mentioned earlier, we did not sample year-round, and thus our observations do not represent the full range of water temperatures in the Snake River. However, adult sturgeon were captured in a range of temperatures from 8 to 24 °C. Catch rates tended to decline as water temperatures approached 24 °C, and no sturgeon were caught at temperatures less than 8 °C (Figure 28). The DO readings we recorded at locations where adults were sampled were similar to those observed during sampling of juvenile fish. The levels of DO ranged from 7.3 to 15.1 mg/l.

Adult sturgeon were also sampled at depths ranging between 1.5 and 30.5 m, with most observations occurring at depths greater than 6.0 m (Figure 29). Water velocities at locations sampled with setline gear ranged from 0.0 to 2.57 m/s mean column and 0.0 to 2.2 m/s near-substrate. We captured sturgeon in mean column velocities from 0.0 to 1.64 m/s and near substrate velocities from 0.0 to 1.25 m/s. The highest catch rates were typically associated with slower water velocities, generally less than 0.50 m/s (Figure 30 and Figure 31).

4.5.2. Suitability Criteria for Adults

Given that sampling was not conducted during the full temperature range in the Snake River, we based temperature suitability criteria for adult sturgeon on information from McConnell (1989) and S. Doroshov (UC Davis, pers. comm.). Overall, our temperature observations encompassed the limits defined by the HSI criteria (Figure 32a). As for DO criteria, we relied on DO thresholds described by Klyashtorin (1974) (Figure 27).

Water depths greater than 6 m had the highest suitability for adult sturgeon (Figure 32b). One sturgeon was sampled with setlines in very shallow water (less than 2 m), although this depth appears seldom used based on the amount of effort (5,865 hrs) expended by our collection gear in this depth range.

The range of suitable water velocities for adult white sturgeon extended from 0.0 to 3.0 m/s (mean column) and 0.0 to 2.75 m/s (near-substrate). Overall, most adult white sturgeon were

sampled in water velocities less than 1.5 m/s, with highest suitability occurring at mean column and near-substrate velocities less than 0.50 m/s. The highest mean column velocities recorded at capture locations for adult sturgeon did not exceed 1.65 m/s, which may be an artifact of reduced sampling efficiency by setline gear at these higher velocities. We observed that several telemetered fish made limited use of near-substrate and mean column velocities of up to 2.46 and 2.91 m/s. Based on these findings, we used the observations from telemetered fish to extend the suitability of the upper velocities to 3.0 m/s (mean column) and 2.50 m/s (near-substrate) for adult sturgeon, although the suitability at these upper velocities was very low (Figure 32c, d).

5. DISCUSSION

Both confirming white sturgeon spawning and identifying spawning habitat present unique challenges because no actual spawning events have been observed in nature (Perrin et al. 2000). Parsley et al. (1989, 1993) reported breaching and rolling of mature adults before newly spawned eggs were collected in the tailrace of Columbia River dams. These behaviors may be indicators of spawning activity. IPC crews sampling for eggs at the Porterfield Hole observed similar behavior (Lepla and Chandler 1995). Aside from these types of behaviors, indirect measures and observations are required to identify both the time and location of spawning (Perrin et al. 2000).

Water temperatures suitable for white sturgeon spawning (10–18 °C) typically occur between March and June, a period that often coincides with spring runoff in the Snake River. The observed movement behavior of reproductive adults and the timing of egg collections suggested that most spawning activity occurred within a temperature range of 12 to 16 °C (with a mean temperature of 14 °C), which is optimal for white sturgeon egg development (Wang et al. 1985). Based on temperature regimes in the Snake River, peak-spawning activity (12–16 °C) likely occurs from mid-March through the end of May in reaches between Bliss and Brownlee dams and from late April to mid-June downstream of Hells Canyon Dam. Incubation through exogenous feeding of larvae (post-yolk) would primarily occur through the end of June between Bliss and Brownlee dams. Downstream of Hells Canyon Dam, the incubation period extends to the end of July.

In general, suitable spawning temperatures tended to occur three to six weeks earlier downstream of Bliss, C.J. Strike, and Swan Falls dams than downstream of Hells Canyon Dam and the mouth of the Salmon River. The longest period of suitable spawning temperatures occurred below Bliss Dam. However, the length of this period varied considerably among years, depending on the influence from thermally moderated spring water and hydrologic conditions in the upper Snake River Basin. During wet years, springs along the north side of the Snake River between Milner Dam and King Hill provide less than 50% of the water annually leaving the basin below King Hill. During dry years, these springs can contribute more than 68% of the water supply (Clark et al. 1998). This large volume of spring groundwater also has a relatively constant temperature of 14 °C and serves to moderate the river's peak summer and winter temperatures (Lukens 1981).

The Snake River below the confluence of the Salmon River generally experienced the latest onset of suitable spawning temperatures because of the influence from the Salmon River. Water

temperatures in the Salmon River are typically 1.3 to 5.4 °C cooler than temperatures during spawning periods upstream of the confluence to Hells Canyon Dam. A comparison of spawning times in four large river systems showed that white sturgeon typically spawn during the period from February through May in the Sacramento River (Perrin et al. 2000), April through June in the Columbia River (Parsley et al. 1993), May through July in the Kootenai River (Marcuson 1994), and late June through August in the Fraser River (Perrin et al. 2000).

While suitable water temperatures are an important requirement for spawning, the most commonly reported factor influencing the year-class strength of sturgeon species is flow during spawning and incubation. Several researchers have reported a positive relationship between spring river flow and recruitment for many species of sturgeons. These species include Siberian sturgeon (*A. baeri*) (Tsyplakov 1978, Votinov and Kas'yanov 1978), lake sturgeon (*A. fulvescens*) (Auer 1996), and white sturgeon (Kohlhorst et al. 1989, Miller and Beckman 1995, Counihan et al. forthcoming). Also, several studies have described the positive relationships between the quantity of flow and white sturgeon spawning habitat (Parsley and Beckman 1994, Chandler and Lepla 1997, Brink and Chandler 2000). White sturgeon spawn in extremely fast-flowing water (Parsley et al. 1993). Observations gathered from telemetered reproductive adults and the collection of eggs indicated that spawning and incubation areas in the Snake River were commonly associated with turbulent pools, high-velocity runs, and nearby rapids. These telemetered fish used a wide range of depths (2–21 m). Similarly, eggs were also collected from a wide range of depths (4–19 m). Upper velocities approached 2.0 to 2.7 m/s in some locations.

Researchers have proposed a number of benefits from spawning in fast, turbulent waters. For example, high-velocity flows remove fine sediments from spawning areas that might otherwise suffocate eggs (Parsley et al. 1993). Also, broadcasting eggs in fast, turbulent water may enhance egg viability by dispersing adhesive eggs, thereby preventing clumping and disease. Dispersal probably also reduces egg and larval predation and minimizes competition among post-larval fish (McCabe and Tracy 1994). Although high water velocities were available in almost all of the areas we sampled, most velocities recorded at specific locations where we found either spawning adults or eggs were lower than the spawning and incubation criteria reported for Columbia River white sturgeon by Parsley et al. (1993). Although several reproductive adults served as good indicators for potential spawning areas, we believe most of our observations likely occurred during pre-spawn (staging) behavior and not during an actual spawning event. In addition, the use of artificial substrate mats may have contributed to our observations of lower velocities. The mats are a passive form of collection gear, and we typically deployed them at locations with relatively low velocity so that eggs could settle onto the mats. Although we tried to place artificial substrate mats in high-velocity areas, it was often difficult to maintain mats in these areas and their efficiency in these areas was generally low. Therefore, our observations probably do not represent the entire range of conditions used during spawning and incubation, particularly regarding water velocities.

We also observed a trend in our sampling success that was inversely related to the magnitude of spring runoff. Typically, fewer eggs were collected during higher flow years. In the Columbia River, sampling included plankton nets and 3-m-wide beam trawl nets, which are probably more conducive to collecting eggs and larvae in high-velocity areas. However, because our observations (other than mean water column velocities) are similar to suitability criteria

reported for white sturgeon spawning and incubation by Wang et al. (1985) and Parsley and Beckman (1994), we suggest using these criteria to represent spawning and incubation conditions in the Snake River.

The most suitable spawning areas in this study area of the Snake River appear to be those that lie in high-gradient river segments between Bliss Dam and King Hill, between Swan Falls Dam (RM 458) and RM 451 (upstream of Walters Ferry), and below Hells Canyon Dam. These corridors are confined by steep canyon walls and have characteristics that include long, turbulent runs, large, deep pools, and rapids that provide staging and spawning areas. The free-flowing segments of Snake River below King Hill, C.J. Strike Dam, and Walters Ferry are relatively low gradient and shallow, with numerous island complexes and braided channels. These characteristics suggest that these segments are not significant spawning areas for white sturgeon.

It is also believed that year-class strength for sturgeon species (including white and lake sturgeon) is set within the first few months (M. Parsley, USGS, pers. comm., Nilo et al. 1997). The importance of the spring hydrograph to recruitment trends has been observed, particularly in the sturgeon population downstream of Bliss Dam (IPC, unpubl. data). Trend data from three surveys in the Bliss–C.J. Strike reach showed noticeable changes in recruitment levels. The abundance of juvenile white sturgeon (less than 92 cm TL) composed about 64% of the population sampled from 1979 through 1981 (Cochner 1981), as compared with the period 1991 through 1993 when less than 6% of the catch consisted of sturgeon less than 120 cm TL. This decline in the abundance of young white sturgeon corresponded with an unusually prolonged drought that lasted eight consecutive years (1987–1994). These years were characterized by below normal river flows, a condition that was likely exacerbated by variable flows from Bliss Project operations during 1988 through 1990. A third survey conducted in 2000 showed that the number of juvenile white sturgeon had increased 45% (IPC, unpubl. data). This increase coincided with several years (1995–2000) of favorable hydrologic conditions, including normal and above-normal spring runoff during spawning periods.

In contrast, no decline in the abundance of juvenile sturgeon less than 92 cm has been observed in the population downstream of Hells Canyon Dam (Coon et al. 1977, Lukens 1984, Lepla et al. 2001). The abundance of spawning habitat in the Hells Canyon river corridor and a larger spring hydrograph probably contribute to maintaining positive recruitment trends in that reach. Median flows during spawning months in the Snake River below Hells Canyon Dam (USGS station 13290450) and Anatone, Washington (USGS station 13334300) for the periods of record (1965–2000 and 1958–2000) were 26.8 and 59.4 kcfs, respectively. We suggest that the magnitude and timing of the spring hydrograph during spawning through the larval life stage appear to be the most important factors maintaining positive recruitment trends in Snake River sturgeon populations.

We collected three white sturgeon larvae in habitats where eggs and spawning adults were found and at one location far downstream of potential spawning sites. Three larvae were collected in the Porterfield Hole, which is located in the high-gradient river corridor of the Bliss–C.J. Strike reach. It is a deep and turbulent pool with strong back eddy currents. The larvae were near the substrate in water of relatively low velocity. Of particular interest was the incidental capture of a larva in the Swan Falls–Brownlee reach. IPC technicians collected this larva from the drift at 4 m below the water surface at RM 309.5 in Brownlee Reservoir. The spawning origin of this larva

was uncertain because one day had elapsed since hatch. Over this time, white sturgeon larvae are typically mobile and have a greater chance of being dispersed downstream by the river currents. Kohlhorst (1976) and McCabe and Tracy (1994) reported sturgeon larvae about 115 to 121 mi downstream of known egg incubation and probable spawning sites. Thus, larvae are generally less accurate indicators of where spawning occurs (Perrin et al. 2000).

The habitat use of juvenile and adult white sturgeon indicates that these fish can tolerate a wide range of conditions in both riverine and reservoir environments. In riverine sections, we often captured sturgeon along current breaks in or near the thalweg of runs and pools. These fish may position themselves in these areas because potential food settles out from the river's drift. Sturgeon sampled in reservoirs tended to use the middle section and upper transition areas, while use of the lower pool was typically low. This tendency may also be related to food opportunities and, in some cases, poor water quality in the lower sections of some reservoirs. Our observations of habitat use by telemetered fish were comparable with observations of habitat use by sturgeon sampled with setline gear. Overall, sturgeon were captured most often at depths greater than 6 m and in water velocities less than 1.50 m/s. However, some sturgeon were found at sites with relatively high velocities (up to 2.91 m/s) or very shallow depths (less than 2 m). Because these instances were few, our findings indicate that sturgeon use these conditions infrequently.

Although we do not include the use of substrate type in this report, sturgeon in the Snake River are commonly found over a wide range of substrates. Lepla and Chandler (1995, 1997) reported juvenile and adult sturgeon in the Bliss–C.J. Strike and C.J. Strike–Swan Falls reaches over substrate types ranging from silt in reservoirs to sand through bedrock in riverine sections. Catch data and suitability indices for juvenile white sturgeon in the Columbia River showed that substrates from hard clay to bedrock were suitable (Parsley et al. 1993, Parsley and Beckman 1994).

We found little information on the temperature tolerances of juvenile and adult white sturgeon. White sturgeon are considered a cool/coldwater species, a classification that suggests they are better suited to water temperatures below 25 °C. In culture facilities, water temperatures from 18 to 22 °C are considered to be optimal for sturgeon growth; California sturgeon farms often use this temperature range for production (S. Doroshov, UC Davis, pers. comm. electronic mail). Water temperatures above 23 °C appear to increase stress and the likelihood of temperature-related mortality for some white sturgeon. During our field studies, we observed a decline in catch rates as temperatures exceeded 23 °C. Signs of stress, such as redness of ventral surfaces and fins, appeared more frequently during capture and handling in higher temperatures than they did during sampling at lower temperatures. Similar observations of temperature-related stress were documented at Pacific Northwest National Laboratories in Washington. Juvenile sturgeon undergoing acclimation from 17 to 24 °C quit feeding and three fish died (D. Geist, PNNL, pers. comm.).

The extent of temperature-related mortality in Snake River sturgeon populations is unknown. Water temperatures in several reaches of the Snake River routinely peak near 24 to 25 °C during the summer. These increased temperatures might increase the risk of mortality; however, no sturgeon mortalities have been attributed directly to these elevated temperatures. Our telemetry studies tracked several Snake River sturgeon throughout summer maximums approaching 24 to 27 °C and found no mortality among these individuals. Although the upper lethal threshold

temperature for white sturgeon is unknown, it likely occurs somewhere between 28 and 30 °C. We posed our hypothesis to S. Doroshov (UC Davis, pers. comm. electronic mail) who believed that this assumption was accurate.

Similarly, no quantitative information is available on DO thresholds for white sturgeon across a wide range of temperatures. Studies on hypoxia and white sturgeon generally discuss only one to three temperature observations or simply describe behavioral responses to hypoxia (Burggren and Randall 1978, Cech et al. 1984, Ruer et al. 1987, Crocker and Cech 1997). Klyashtorin (1974) studied the DO thresholds of four Russian species of sturgeon (0.36 kg) over a range of oxygen and temperature levels and found that DO values less than 4.5 mg/l reduced growth, while levels less than 1.8 mg/l were lethal at upper temperature ranges. Klyashtorin also found similarities among these four sturgeon species and speculated that other members of the sturgeon family may have DO sensitivities similar to those species investigated. This assumption appears to be strengthened by the work of Burggren and Randall (1978) who evaluated the effects of hypoxia on 1-kg white sturgeon at one water temperature. They reported a sharp decrease in respiration activity for white sturgeon at levels below 3.9 mg/l (60 mm Hg at 15 °C), a finding that is consistent with Klyashtorin's results.

Low DO conditions commonly occur in several segments of the Snake River during summer and fall months, particularly in areas of C.J. Strike Reservoir, HCC reservoirs, and dam tailraces associated with these reservoirs. In C.J. Strike Reservoir, Myers and Pierce (1997) have reported that at times the reservoir had very low levels of DO (< 2 mg/l) in the lower 8 mi of the pool. These low oxygen levels were generally established by June and confined at depths greater than 10 m, which could restrict sturgeon use in this area during certain times of the year. During low and median water years, 23 to 35% of the bottom 2-m layer in the lower end of C.J. Strike Reservoir can be lethal to sturgeon (Table 6). Typically by September, DO levels exceed 6 mg/l throughout the reservoir. While these lower levels limit use of some areas in the lower pool during summer months, Lepla and Chandler (1995) reported that telemetered sturgeon in C.J. Strike Reservoir generally showed minimal use of the lower end of the reservoir regardless of DO levels. Of the few telemetered sturgeon (4) that did encounter low oxygenated areas (0.75–4.9 mg/l) in the main channel of the lower pool (RM 499–502), monitoring efforts showed that these individuals moved to nearby elevated benches (7.6–15.5 m) where conditions were not problematic (> 6.1 mg/l) (IPC, unpubl. data). Although poor water quality at times may limit use of some lower reservoir areas, no sturgeon mortalities have been linked to the periodic low DO levels in C.J. Strike Reservoir.

Below C.J. Strike Dam, DO levels in the tailrace have been recorded as low as ~4.3 to 5.1 mg/l during below normal water years, but they do not fall below minimum state standards during higher flow years (1995 and 1996) (Myers and Pierce 1997). The intervals with low DO levels are typically brief, usually lasting less than a week, and do not appear problematic for sturgeon below C.J. Strike Dam (Lepla and Chandler 1997). Oxygen levels are not low enough to cause mortality, and observations of telemetered fish at the dam in 1994 also showed little change in movement regardless of whether DO levels were less than or greater than 6 mg/l. In addition, no reduction in fish condition was apparent since relative weights (in riverine habitat) and growth rates were similar to those found below Bliss Dam.

Low DO levels also occur within the Hells Canyon Complex of reservoirs and downstream of Hells Canyon Dam, resulting in suboptimal, or in some cases lethal, conditions for white sturgeon. During low-flow years, low DO conditions lethal to sturgeon can comprise up to 80% of the bottom 2-m layer in Brownlee Reservoir (Table 7). In worst-case scenarios, the transition area at the upstream end of the pool can become anoxic throughout the water column, which occurred during July 1990. Low river inflows and excessive nutrient levels resulted in DO levels (< 0.86 mg/l) lethal for sturgeon throughout the water column near the upper end of Brownlee Reservoir (RM 324). The lethal DO conditions, which probably were exacerbated by high water temperatures ($25\text{--}26$ °C), caused the deaths of 28 adult white sturgeon at that location on July 20, 1990 (IPC, unpubl. data).

Oxbow and Hells Canyon reservoirs also experience severe water quality conditions during low-flow years as a result of receiving anoxic water from Brownlee Reservoir. Although no sturgeon mortalities have been attributed to poor water quality in these two reservoirs, low DO levels lethal to sturgeon can comprise up to 73% of the bottom 2-m layer in Oxbow Reservoir and 42 to 55% in Hells Canyon Reservoir during summer months in low-flow years (Tables 8 and 9). Below Hells Canyon Dam, DO levels measured in the tailrace can also drop as low as 2.8 mg/l for several weeks during late summer months. However, these conditions likely persist for only a few miles below the dam, and no mortality of sturgeon has been attributed to these events. Habitat data collected over telemetered sturgeon 9 mi downstream of Hells Canyon Dam showed recovery of DO to levels near 7 mg/l as a result of reaeration from upstream rapids. Given the relatively brief period of low DO conditions that occur near the very top of this reach, the risk of mortality to this sturgeon population is low.

6. SUMMARY AND CONCLUSIONS

We located spawning white sturgeon at spawning sites from March through early June while water temperatures were between 7.0 and 18.8 °C. Spawning sturgeon were often found in pools and runs with nearby high, turbulent water velocities such as those associated with high-gradient runs, tailouts from rapids, or dam tailraces. Mean column velocities and depths measured over telemetry sturgeon at the spawning sites ranged from 0.0 to 2.72 m/s and from 2 to 21 m. HSI criteria indicate that temperatures between 9 and 19 °C, velocities greater than 0.7 m/s, and depths greater than 2 m were suitable for spawning.

The embryonic development of white sturgeon eggs collected in reaches between Bliss Dam and the mouth of the Salmon River indicated that sturgeon spawned in the Snake River when water temperatures were between 12.0 and 17.7 °C. The mean water temperature was 14 °C, a level that is considered optimal for the development of white sturgeon eggs. Overall, most spawning activity appears to occur between 12 and 16 °C. As with spawning adults, we commonly found incubating eggs in turbulent pools and runs with mean column velocities and depths ranging from 0.1 to 2.0 m/s and from 4 to 19 m. HSI criteria indicate that temperatures from 6 to 20 °C, velocities from 0.79 to 2.6 m/s, depths between 3 and 24 m, and substrates larger than sand were suitable for incubation.

Based on temperature regimes in the Snake River and temperatures encountered during most egg collections (12–16 °C), we believe that peak spawning activity occurs from mid-March to the end of May upstream of the HCC and from late April to mid-June downstream of the complex. Egg incubation primarily occurs from mid-March through early June upstream of the HCC and from late April to the end of June downstream of the complex.

We obtained our limited number of larval white sturgeon samples from two widely different habitats that included both riverine and reservoir environments. Larvae in the riverine section were sampled at the substrate in a deep turbulent pool where eggs and spawning adults were found. The capture of one larva in Brownlee Reservoir (4 m below the surface) highlights the mobility of this life stage and its potential to drift long distances from spawning sites during the dispersal phase. Habitat conditions associated with the collection of larvae included depths of 4 to 14 m, velocities of 0.00 to 0.90 m/s, and temperatures of 17.0 to 18.6 °C. HSI criteria indicate that suitable conditions for larval rearing include temperatures of 5.0 to 27.4 °C, velocities of 0.6 to 2.6 m/s, and depths of 3.9 to 30.4 m. The larval life stage is estimated to occur in various reaches of the Snake River from late March through the end of July.

We sampled no young-of-year white sturgeon with gill nets, and our setlines only captured sturgeon greater than 50 cm TL. HSI criteria for young-of-year white sturgeon in the Snake River, based on habitat information from McConnell (1989) and Parsley and Beckman (1994), indicated that suitable habitat conditions for young-of-year sturgeon include water temperatures between 0.1 and 28.0 °C, water velocities between 0.0 and 1.90 m/s, and depths greater than 6.1 m. We estimated that age-0 sturgeon begin to be found in various reaches of the Snake River by mid-April through early June.

The habitat used by juvenile and adult white sturgeon indicated a tolerance for a wide range of conditions, including both riverine and reservoir environments. In riverine sections, we often found sturgeon along current breaks in or near the thalweg of runs and pools. Sturgeon captured in reservoirs tended to use the middle and upper transition areas, while their use of the lower pool was low. We captured juveniles and adults at temperatures between 8.0 and 24.2 °C, with most collections occurring between 12 and 23 °C. Catch rates declined as temperatures exceeded 23 °C. Overall, juvenile and adult sturgeon were most often captured at depths greater than 6 m and water velocities less than 1.50 m/s. Although we found a few sturgeon at sites with relatively high velocities (up to 2.91 m/s) and very shallow depths (less than 2 m), the low number of collections under these conditions indicates that these conditions are not used frequently.

At locations where we sampled juvenile and adult white sturgeon, DO readings ranged from 7.3 to 15.1 mg/l. To minimize the stress and possible mortality of fish, we did not sample sturgeon at locations when the near-substrate DO level was less than 70% saturation. Linear relationships applied to data developed by Klyashtorin (1974) for several species of Russian sturgeon showed that DO values less than 4.4 mg/l reduced growth, while readings less than 1.8 mg/l were generally lethal at water temperatures between 3 and 28 °C. Low DO conditions commonly occur in several Snake River reservoirs during summer and fall months, resulting in suboptimal, or in some cases lethal, conditions for white sturgeon, particularly in Brownlee Reservoir.

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Table 1. Reproductive white sturgeon tagged with sonic transmitters (S) in the Bliss–C.J. Strike reach of the study area, 1991–1993.

Tag Number	Sex	TL (cm)	Date Tagged	Location of Capture (RM)
Reservoir				
S2543	Female	267	910924	502.1
S3335	Female	196	911003	509.5
S2633	Female	222	920317	502.8
S293	Female	241	920505	506.5
S356	Female	189	920507	506
S2227	Female	243	920602	505.8
S2227a	Male	210	911008	510.7
S258	Male	193	930317	508.1
S2353	Male	195	930317	508.9
S249	Male	196	930405	513.3
River				
S275	Female	289	910730	547.5
S2534	Female	195	911014	555.8
S2426	Male	178	910626	516.9
S2354	Male	202	910723	533.4
S2525	Male	187	910820	552.9
S2345	Male	185	910822	553.4
S87	Male	241	920630	556.1
S2254	Male	200	920630	558.2

Table 2. Reproductive white sturgeon tagged with sonic (S) or radio (R) transmitters in the C.J. Strike–Swan Falls reach of the study area, 1994–1996.

Tag Number	Sex	TL (cm)	Date Tagged	Location of Capture (RM)
S115	Female	210	940906	493.9
S142	Female	182	941025	492.6
S106	Female	159	950323	490.4
S348	Female	195	950425	493.9
S96	Female	187	950620	486.8
S455	Female	177	950822	486.7
R114	Female	211	950919	492.8
S114	Male	253	940322	493.9
S105	Male	187	940407	493.9
S132	Male	219	940713	489.1
S267	Male	192	950329	492.7
R118	Male	187	960409	492.8

Table 3. Reproductive white sturgeon tagged with sonic (S) and radio (R) transmitters in the Swan Falls–Brownlee reach of the study area, 1996–1997.

Tag Number	Sex	TL (cm)	Date Tagged	Location of Capture (RM)
S375 / R131	Female	257	961105	455.3
133	Female	268	961211	456.1
339 / R121	Male	276	961105	454.7

Table 4. Reproductive white sturgeon tagged with sonic transmitters in the Oxbow–Hells Canyon reach of the study area, 1998–1999.

Tag Number	Sex	TL (cm)	Date Tagged	Location of Capture (RM)
S2443 / R76	Female	250	980323	263.8
S2525	Female	236	980406	269.9

Table 5. Reproductive white sturgeon tagged with sonic transmitters in the Hells Canyon–Salmon River reach of the study area, 1999–2000.

Tag Number	Sex	TL (cm)	Date Tagged	Location of Capture (RM)
S249 / R21	Female	240	3/22/99	224.4
S455 / R143 (¹ S248 / R43)	Female	206 (205)	9/04/98 (4/11/00)	228.8 (228.8)
S294 / R44	Female	225	4/04/00	211.7

¹Fish recaptured and retagged.

Table 6. Risk values for white sturgeon associated with the bottom 2-m layer of C.J. Strike Reservoir, based on temperature and dissolved oxygen criteria by Klyashtorin (1974).

Category	1992	1995	1997
Risk Free	57%	75%	-
Reduced Growth	8%	3%	-
Lethal	35%	23%	-

Table 7. Risk values for white sturgeon associated with the bottom 2-m layer of Brownlee Reservoir, based on temperature and dissolved oxygen criteria by Klyashtorin (1974).

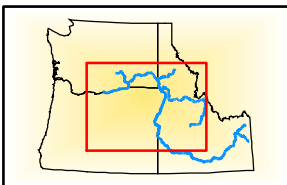
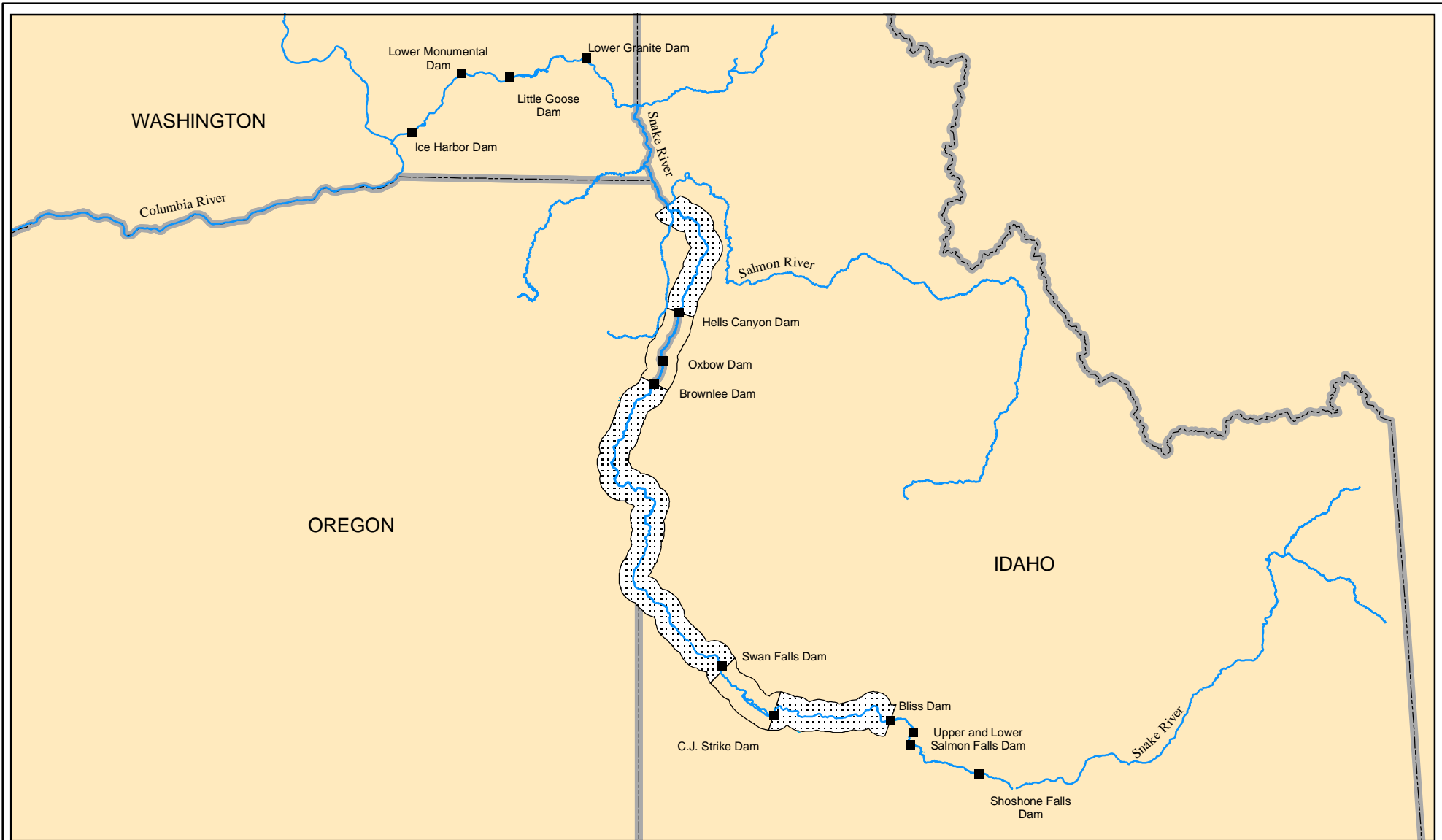
Category	Date								
	1992	6/10/92	6/25/92	7/7/92	8/3/92	8/17/92	9/1/92	9/15/92	9/28/92
% Risk Free		36.4	24.1	18.3	8.5	4.1	13.2	25.2	41.7
% Reduced Growth		9.1	14.7	19.1	12.8	15.4	16.5	24.2	15.3
% Lethal		54.5	61.1	62.6	78.7	80.4	70.3	50.6	43.0
	1995	6/5/95	6/19/95	7/4/95	7/16/95	8/8/95	8/22/95	9/12/95	9/26/95
% Risk Free		87.5	55.9	47.1	41.9	27.7	30.1	61.7	59.1
% Reduced Growth		5.2	19.2	12.3	17.6	23.0	20.1	2.6	2.8
% Lethal		7.3	25.0	40.6	40.6	49.3	49.8	35.7	38.1
	1997	6/11/97	6/24/97	7/9/97	7/22/97	8/6/97	9/2/97	9/17/97	
% Risk Free		46.9	52.1	35.9	15.2	6.7	50.9	59.0	
% Reduced Growth		4.4	3.0	10.9	26.1	33.9	9.6	3.7	
% Lethal		47.1	43.5	51.7	57.2	58.9	37.9	35.6	

Table 8. Risk values for white sturgeon associated with the bottom 2-m layer of Oxbow Reservoir, based on temperature and dissolved oxygen criteria by Klyashtorin (1974).

Category	Date									
	1992	6/1/92	6/15/92	7/1/92	7/15/92	8/1/92	8/15/92	9/1/92	9/15/92	10/1/92
% Risk Free	100.0	93.1	68.1	49.1	6.0	4.7	2.4	14.2	40.8	100.0
% Reduced Growth	0.0	2.7	17.6	35.0	21.2	35.0	79.3	78.4	34.1	0.0
% Lethal	0.0	4.3	14.5	16.0	72.9	60.3	18.2	7.4	25.1	0.0
1995	6/1/95	6/15/95	7/1/95	7/15/95	8/1/95	8/15/95	9/1/95	9/15/95	10/1/95	10/15/95
% Risk Free	96.4	97.3	95.5	96.4	92.3	89.8	0.1	0.0	0.0	100.0
% Reduced Growth	3.6	2.7	1.8	3.6	3.8	10.2	73.9	83.0	100.0	0.0
% Lethal	0.0	0.0	2.7	0.0	3.9	0.0	26.0	17.0	0.0	0.0
1997	6/1/97	6/15/97	7/1/97	7/15/97	8/1/97	8/15/97	9/1/97	9/15/97	10/1/97	10/15/97
% Risk Free	97.4	100.0	97.4	98.3	90.7	70.9	86.9	100.0	100.0	100.0
% Reduced Growth	0.9	0.0	2.6	1.7	9.3	29.1	11.3	0.0	0.0	0.0
% Lethal	1.7	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0

Table 9. Risk values for white sturgeon associated with the bottom 2-m layer of Hells Canyon Reservoir, based on temperature and dissolved oxygen criteria by Klyashtorin (1974).




Category	Date									
	1992	5/31/92	6/14/92	6/30/92	7/14/92	7/31/92	8/14/92	8/31/92	9/14/92	9/30/92
% Risk Free	98.3	58.6	52.6	39.8	20.1	13.1	9.5	4.5	1.5	25.4
% Reduced Growth	0.5	39.7	43.7	51.2	37.6	42.4	58.9	40.8	56.2	73.1
% Lethal	1.2	1.7	3.6	9.0	42.3	44.6	31.5	54.7	42.3	1.5
1995	6/1/95	6/15/95	7/1/95	7/15/95	8/1/95	8/15/95	9/1/95	9/15/95	10/1/95	10/15/95
% Risk Free	100.0	100.0	100.0	99.2	95.2	93.2	8.4	1.2	0.0	73.5
% Reduced Growth	0.0	0.0	0.0	0.8	4.8	6.8	86.9	89.0	100.0	26.5
% Lethal	0.0	0.0	0.0	0.0	0.0	0.0	4.7	9.8	0.0	0.0
1997	6/1/97	6/15/97	7/1/97	7/15/97	8/1/97	8/15/97	9/1/97	9/15/97	10/1/97	10/15/97
% Risk Free	99.6	99.6	99.6	95.7	92.9	85.8	90.7	99.6	99.6	100.0
% Reduced Growth	0.0	0.0	0.0	3.9	6.7	13.8	8.9	0.0	0.0	0.0
% Lethal	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.0

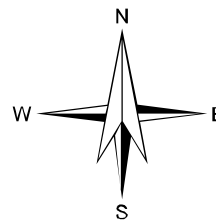


Vicinity Map



Legend

-  Study Reach
-  Dam
-  River

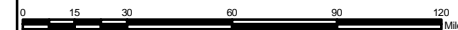


Hells Canyon Project - FERC No.1971

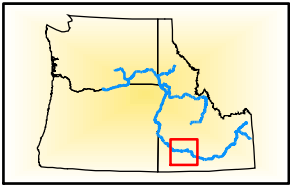
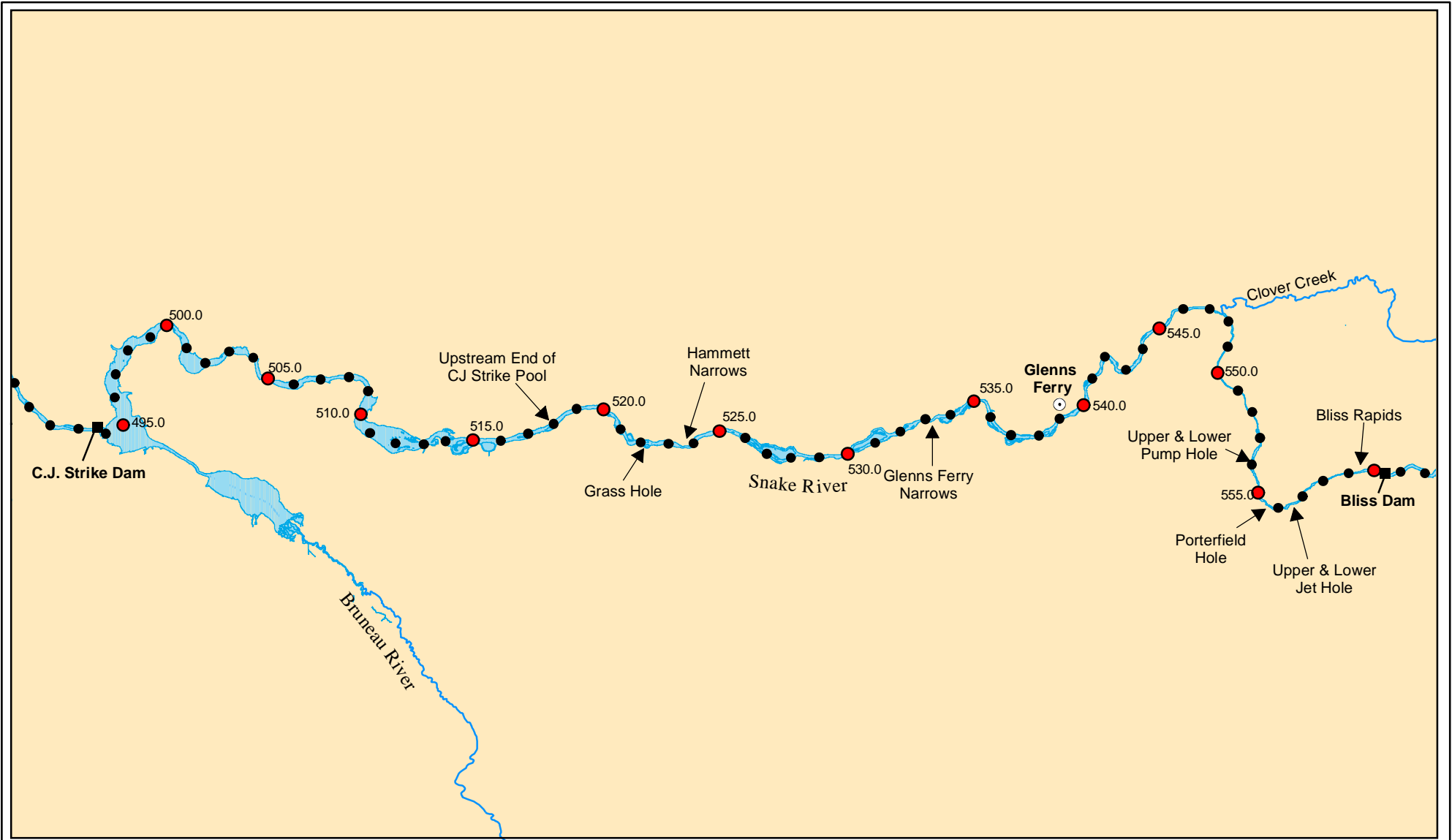
Tech Report E.3.1-6, Chapter 2 Figure 1

Map of the Snake River reaches from Bliss Dam (Rm 560) to the mouth of the Salmon River (Rm 188) that Idaho Power Company samples for white sturgeon, 1991-2000

Scale 1:3,484,874

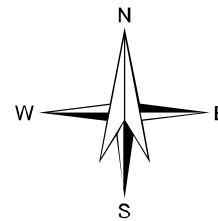


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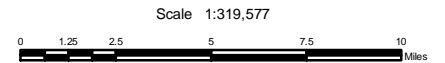


Legend

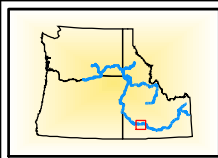
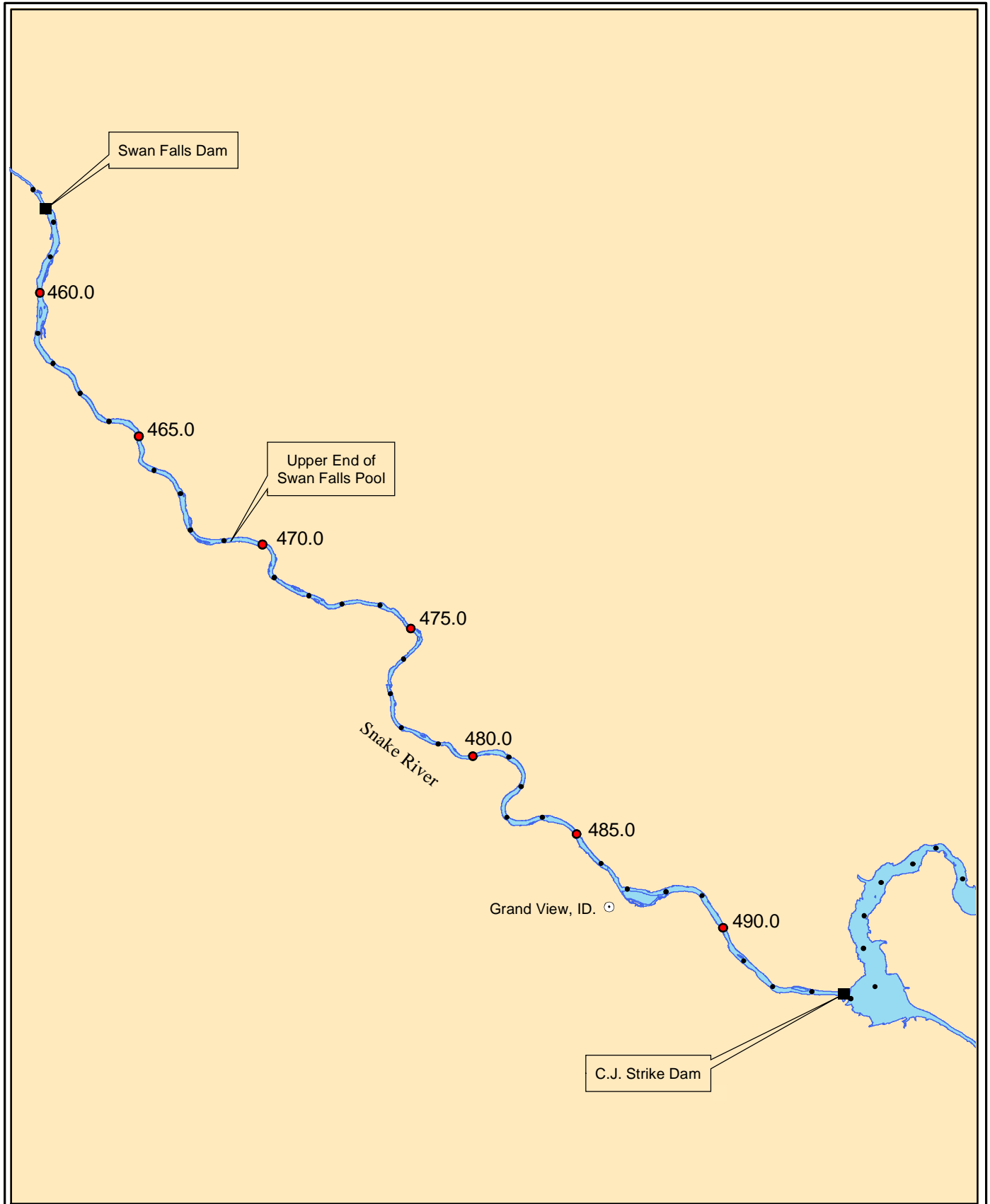
- Five Mile Marker
- One Mile Marker
- Dam
- ~ River or Stream



Hells Canyon Project - FERC No.1971
 Tech Report E.3.1-6, Chapter 2 Figure 2
 Map of the Snake River between
 Bliss (RM 560) and CJ Strike (RM 494) dams



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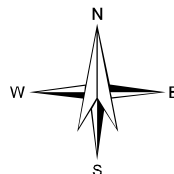


Vicinity Map



Legend

- Dam
- Five Mile Marker
- One Mile Marker
- ~ River

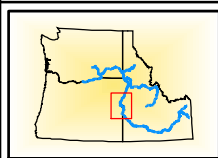
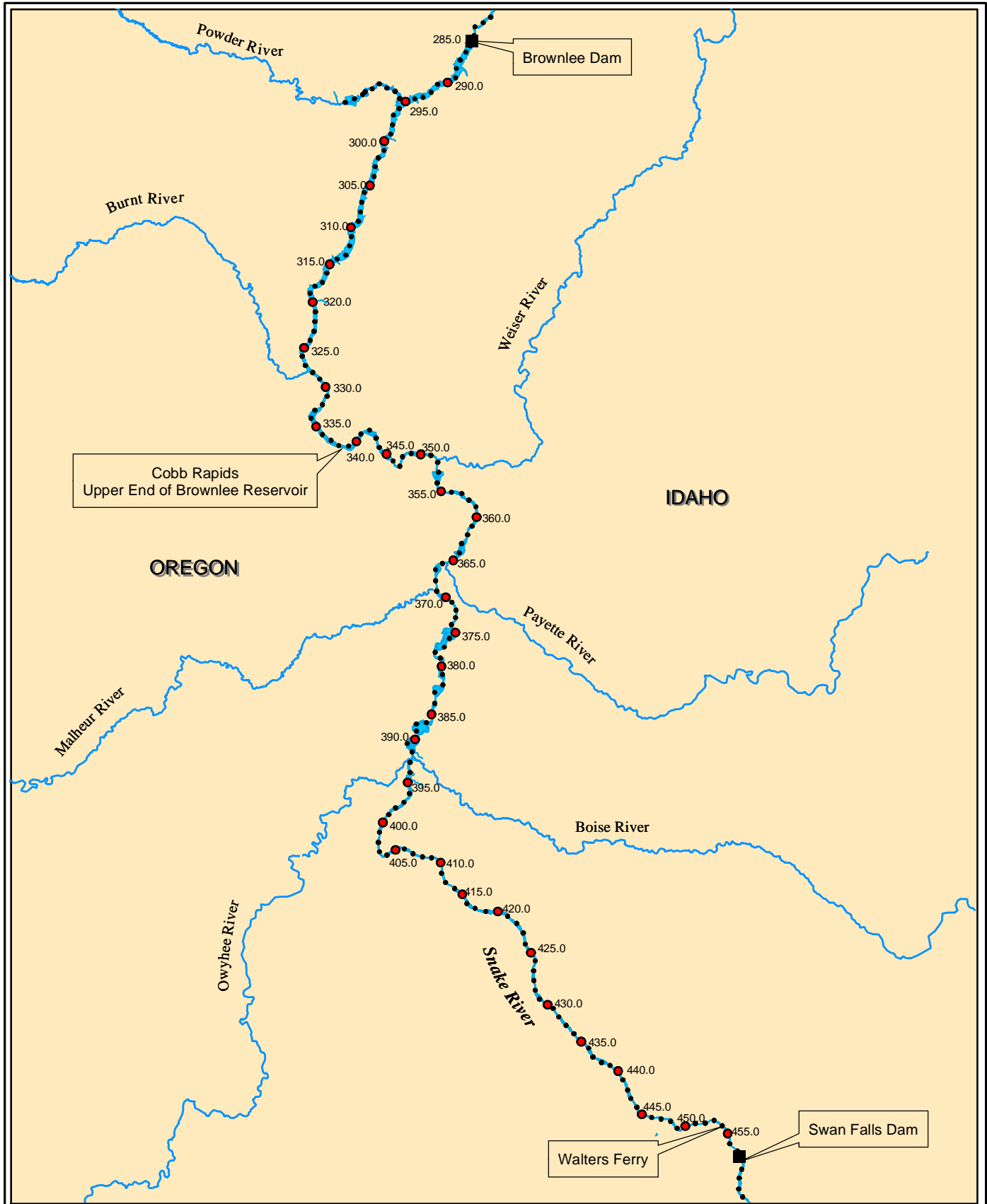


Hells Canyon Project - FERC No. 1971
 Tech. Report E.3.1-6, Chapter 2 Figure 3
 Map of the Snake River between C.J. Strike
 (RM 494) and Swan Falls (RM 458) dams.

Scale 1:222,250



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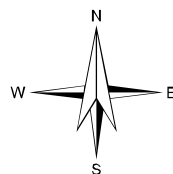


Vicinity Map



Legend

- Dam
- Five Mile Marker
- One Mile Marker
- ~ River

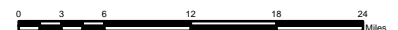


Hells Canyon Project - FERC No. 1971

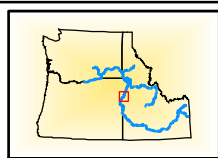
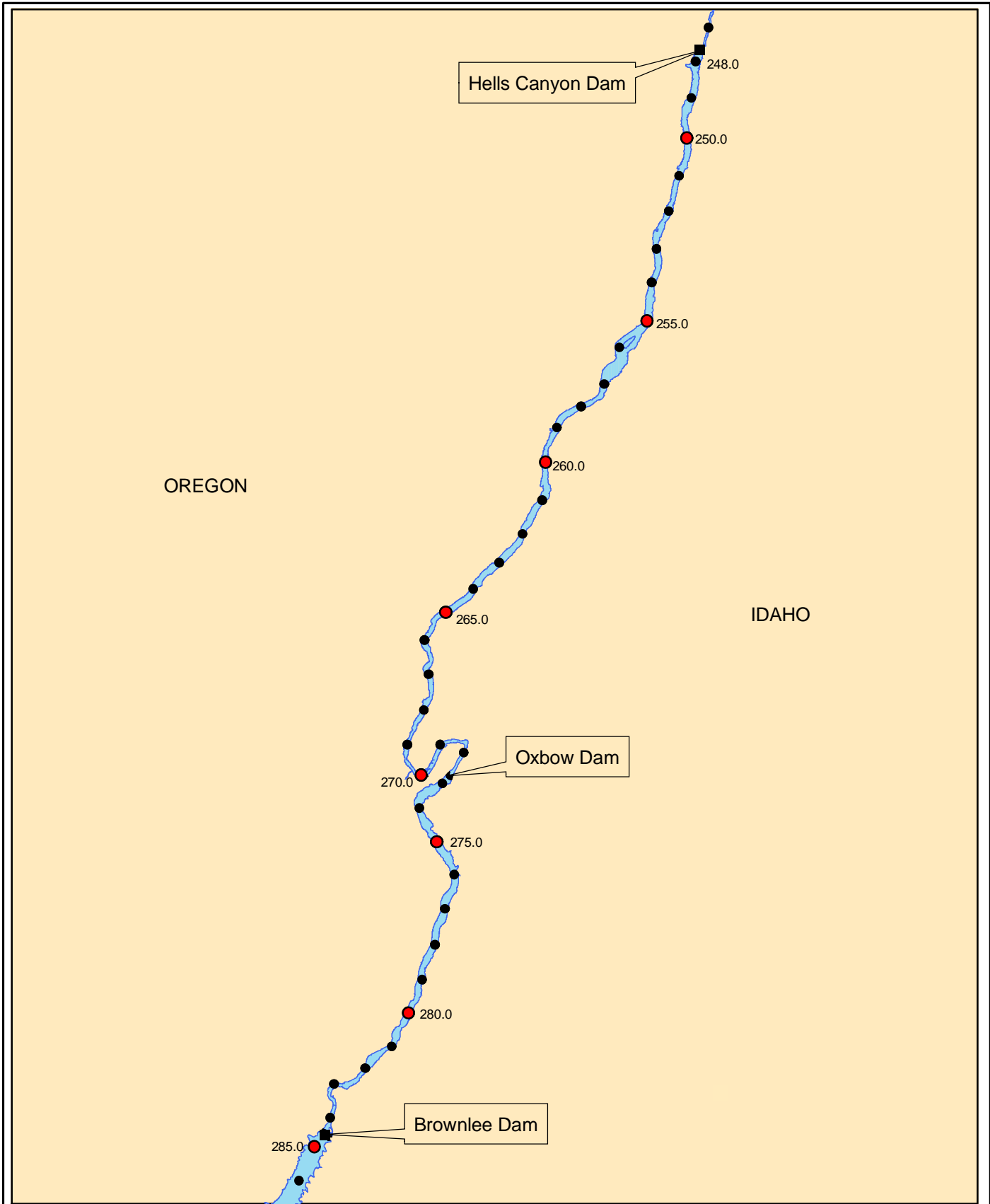
Tech. Report E.3.1-6, Chapter 2 Figure 4

Map of the Snake River between Swan Falls (RM 458) and Brownlee (RM 284.6) dams.

Scale 1:847,370



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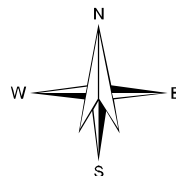


Vicinity Map



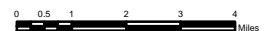
Legend

- Dam
- Five Mile Marker
- One Mile Marker
- ~ River

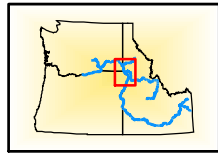
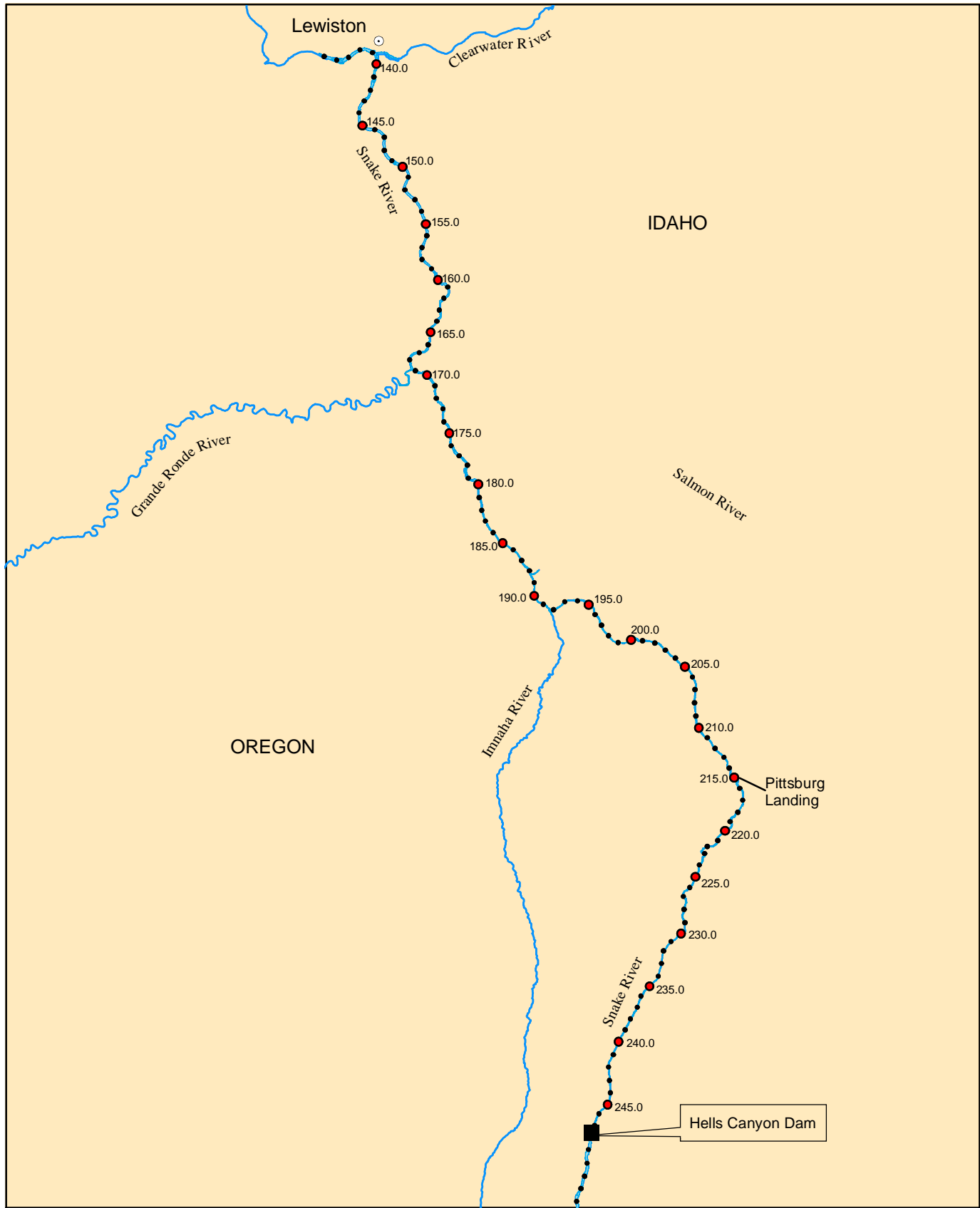


Hells Canyon Project - FERC No. 1971
Tech. Report E.3.1-6, Chapter 2 Figure 5
 Map of the Snake River between Brownlee (RM 284.6) and Hells Canyon (RM 247.6) dams.

Scale 1:222,855



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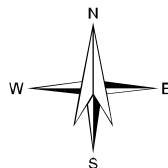


Vicinity Map



Legend

- Dam
- Five Mile Marker
- One Mile Marker
- ~ River



Hells Canyon Project - FERC No. 1971
 Tech. Report E.3.1-6, Chapter 2 Figure 6

Map of the Snake River between Hells Canyon Dam (RM 247.6) and Lewiston, ID (RM 139).

Scale 1:654,836



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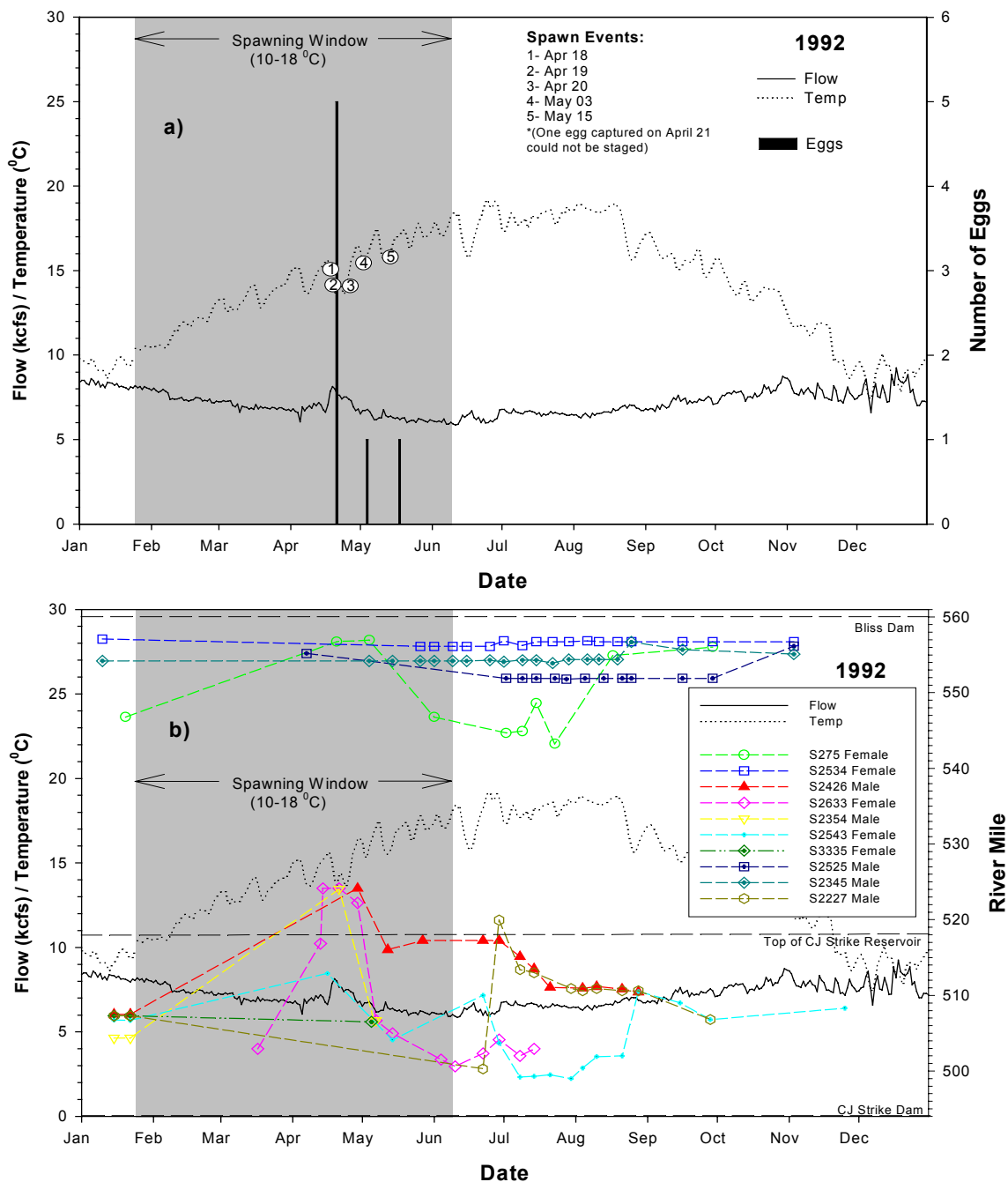


Figure 7. Mean daily flow and water temperatures associated with a) the collection of white sturgeon eggs and the estimation of spawning events based on the embryonic development of eggs and b) the movement behavior of reproductive white sturgeon during the 1992 spawning period in the Snake River between Bliss (RM 560) and C.J. Strike (RM 494) dams.

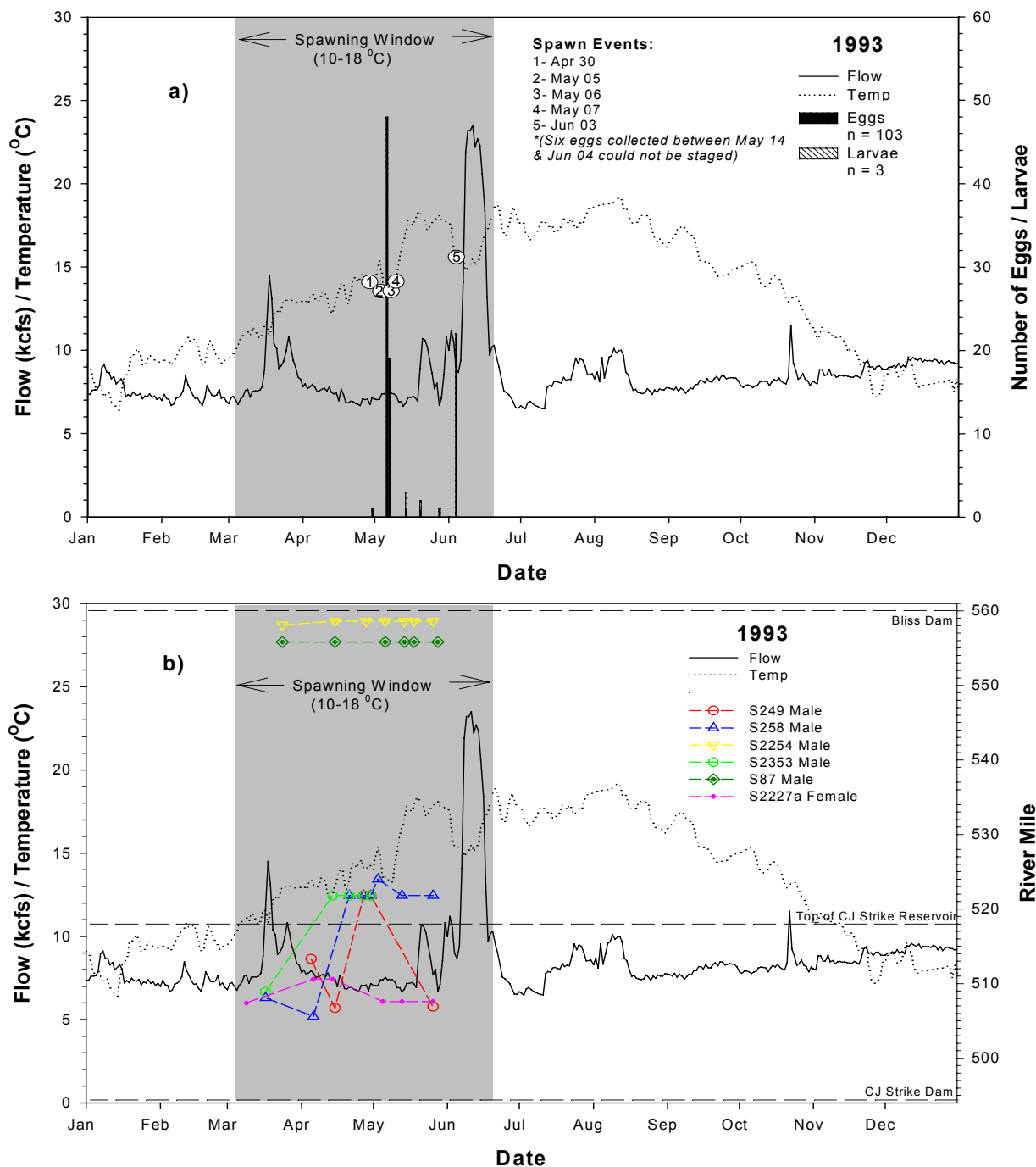


Figure 8. Mean daily flow and water temperatures associated with a) the collection of white sturgeon eggs and the estimation of spawning events based on the embryonic development of eggs and b) the movement behavior of six reproductive white sturgeon during the 1993 spawning period in the Snake River between Bliss (RM 560) and C.J. Strike (RM 494) dams.

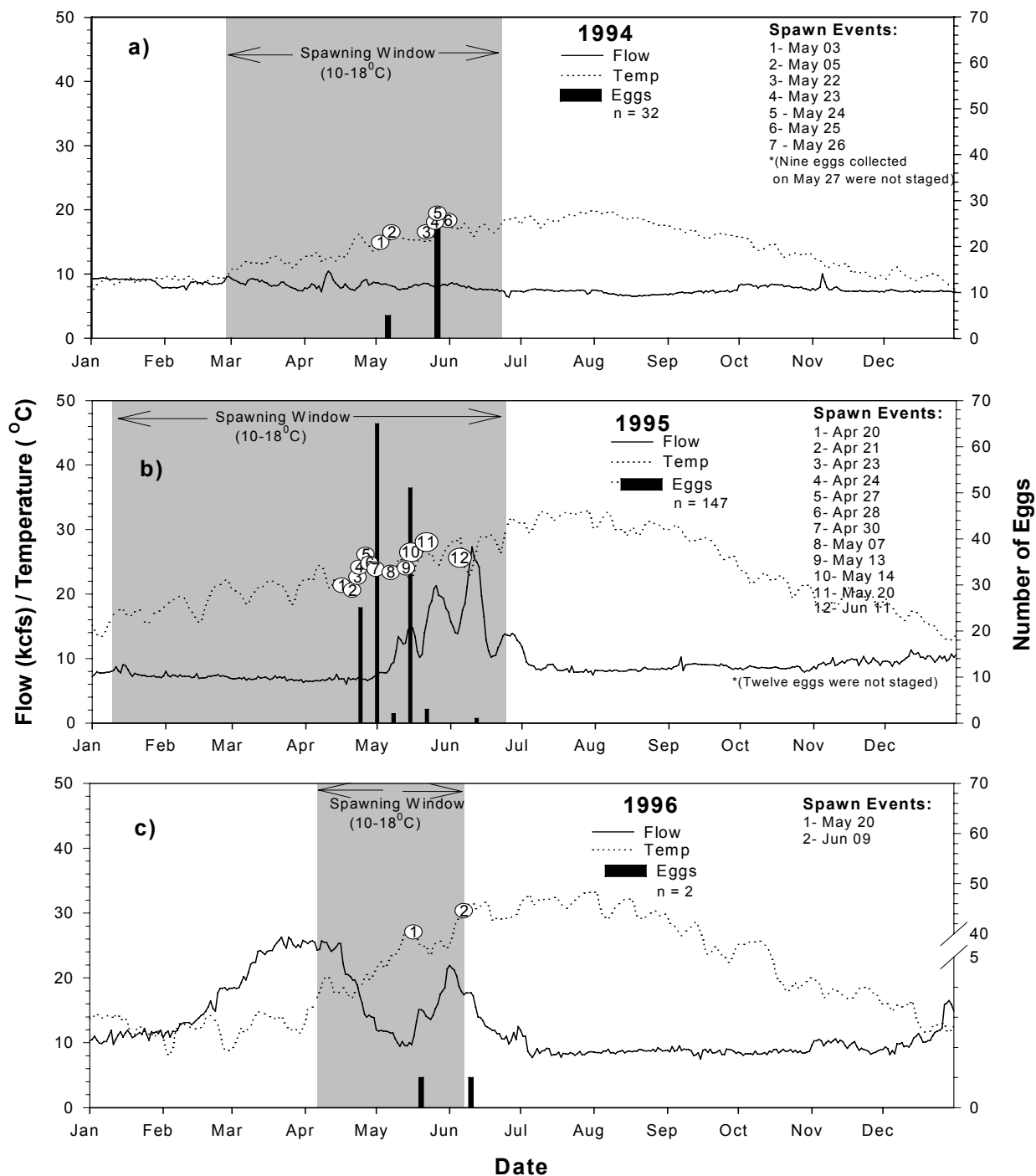


Figure 9. Mean daily flow and water temperatures associated with the collection of white sturgeon eggs and the estimation of spawning events based on the embryonic development of eggs during a) 1994, b) 1995, and c) 1996 spawning periods in the Snake River between Bliss (RM 560) and C.J. Strike (RM 494) dams.

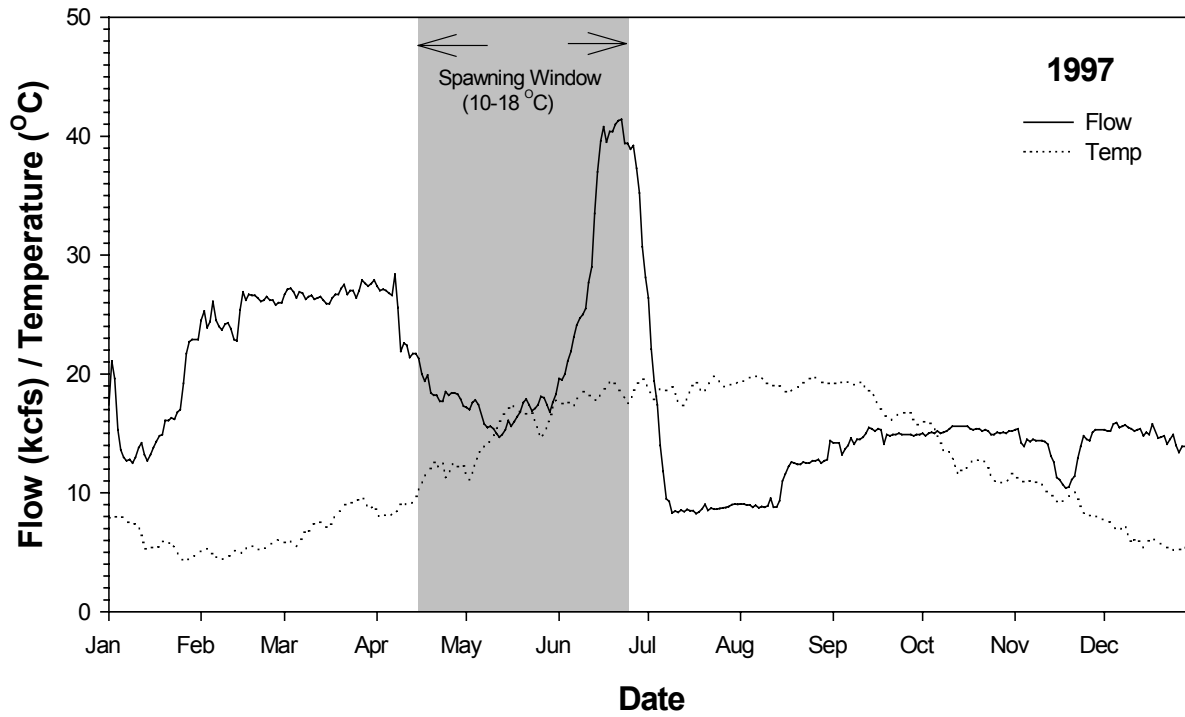


Figure 10. Mean daily flow and water temperatures associated with the 1997 spawning period in the Snake River between Bliss (RM 560) and C.J. Strike (RM 494) dams.

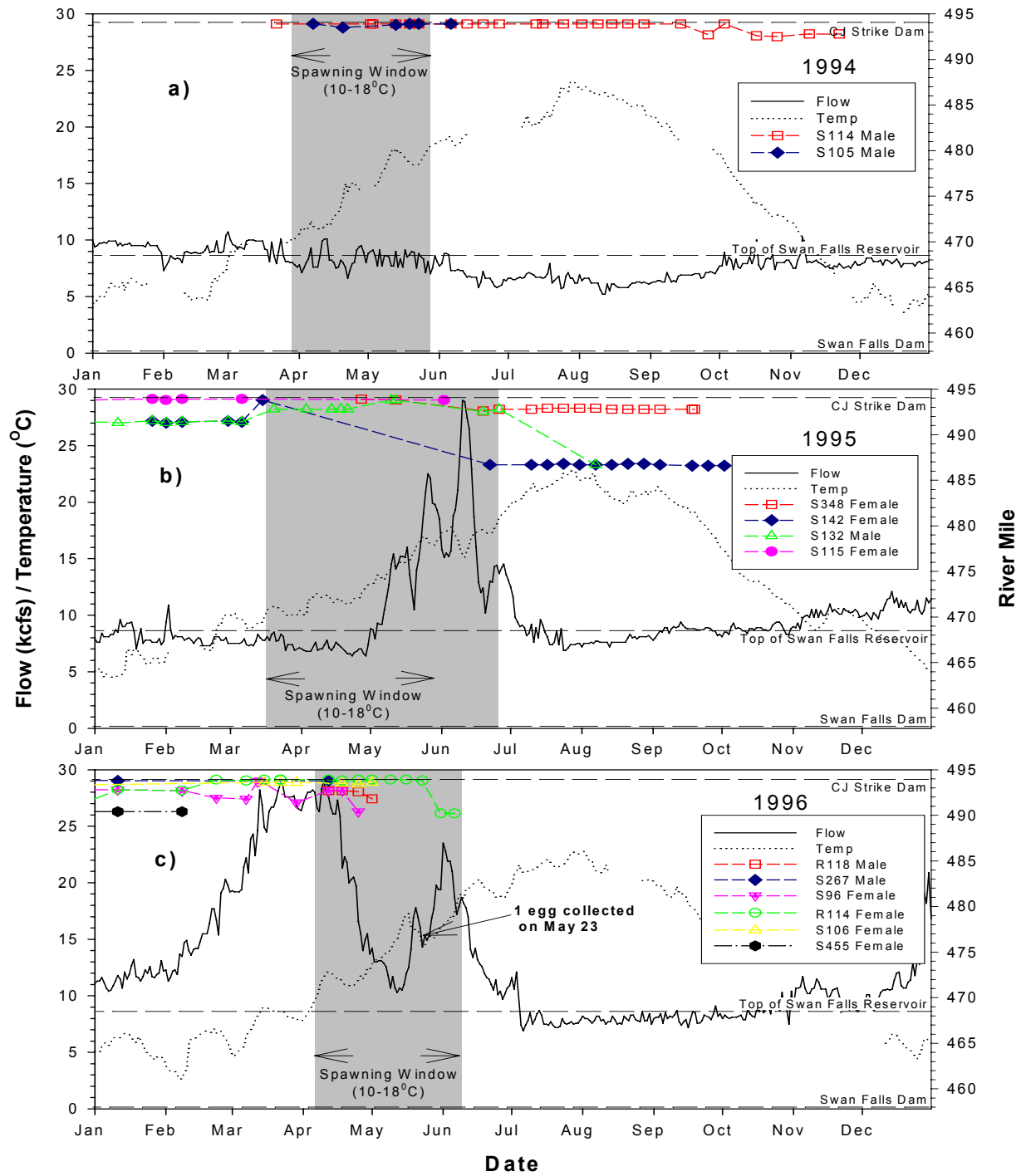


Figure 11. Mean daily flow and water temperatures associated with the movement behavior of 12 reproductive white sturgeon during a) 1994, b) 1995, and c) 1996 spawning periods in the Snake River between C.J. Strike (RM 494) and Swan Falls (RM 458) dams.

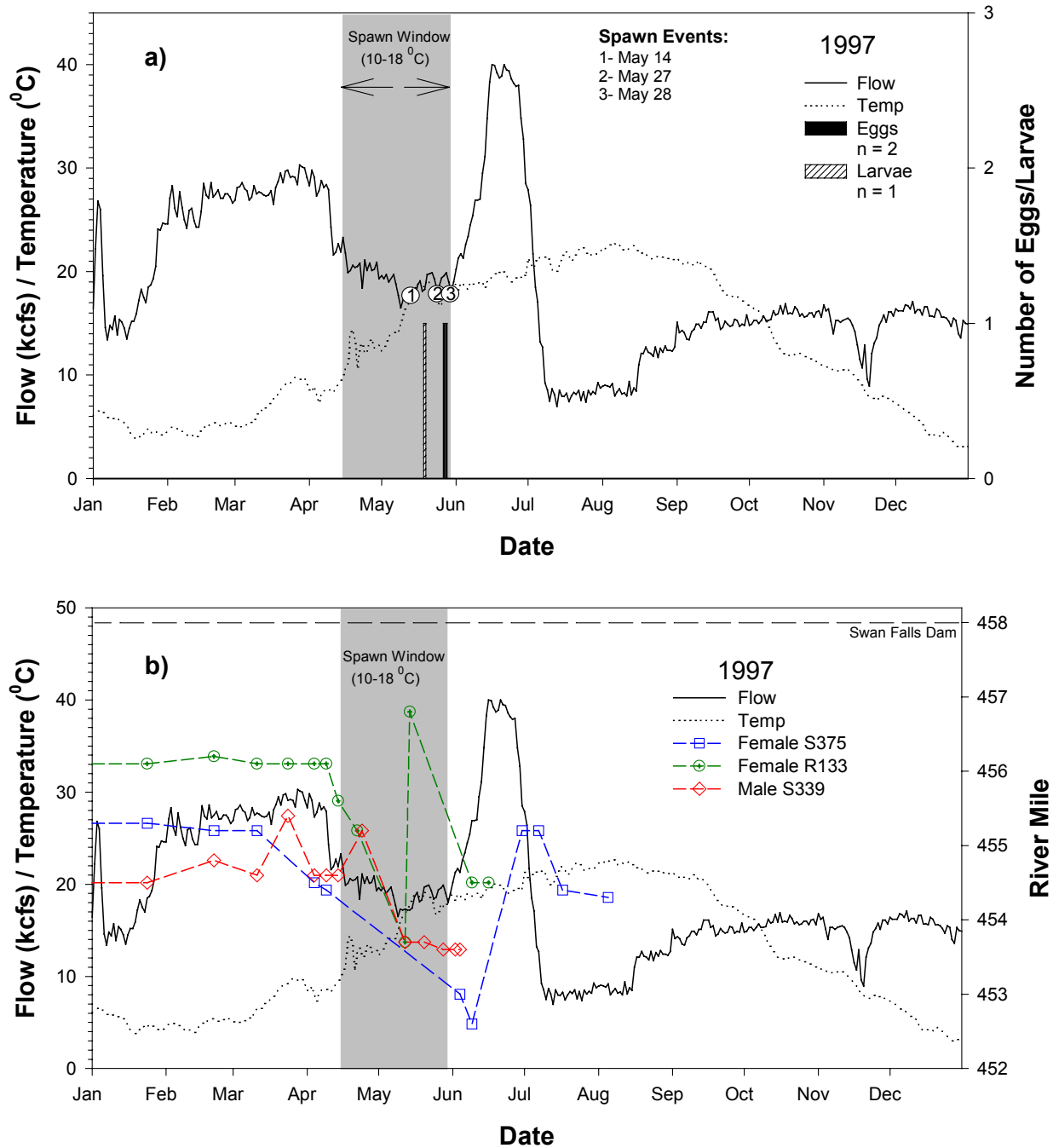


Figure 12. Mean daily flow and water temperatures associated with a) the collection of white sturgeon eggs and the estimation of spawning events based on the embryonic development of eggs and b) the movement behavior of three reproductive white sturgeon during the 1997 spawning period in the Snake River downstream of Swan Falls Dam (RM 458).

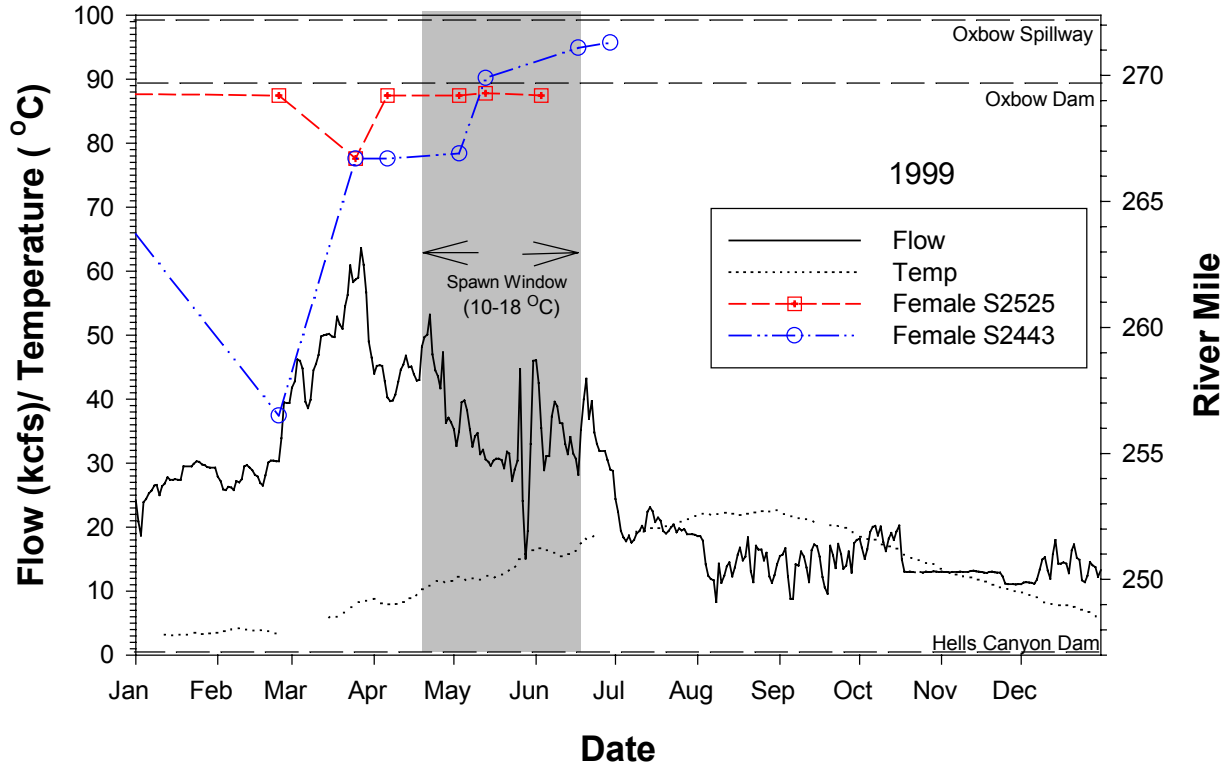


Figure 13. Mean daily flow and water temperature associated with movement behavior of two reproductive female white sturgeon during the 1999 spawning period in the Snake River between Oxbow (RM 273) and Hells Canyon (RM 247.6) dams.

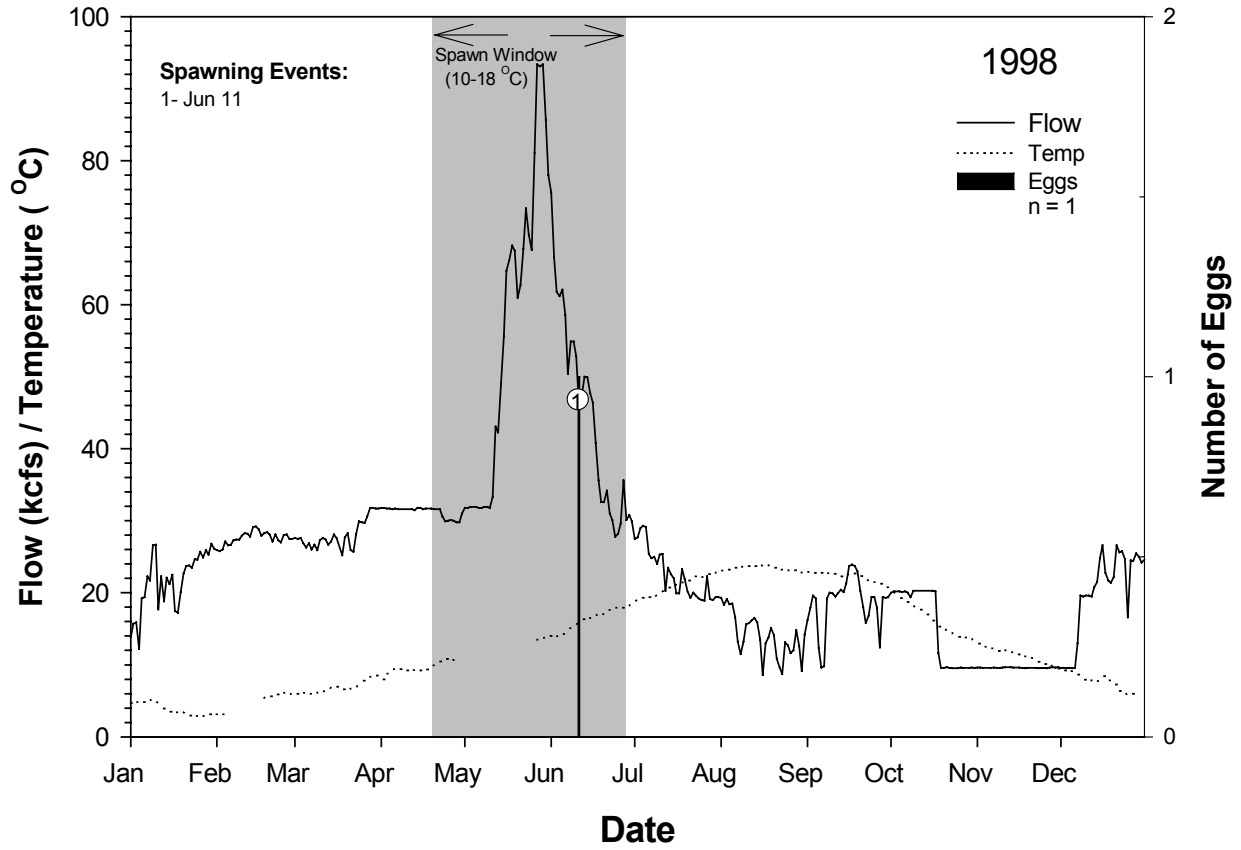


Figure 14. Mean daily flow and temperatures associated with the collection of white sturgeon eggs and the estimation of spawning events back-calculated from egg development during the 1998 spawning period in the Snake River between Hells Canyon Dam (RM 247.6) and the mouth of the Salmon River (RM 188).

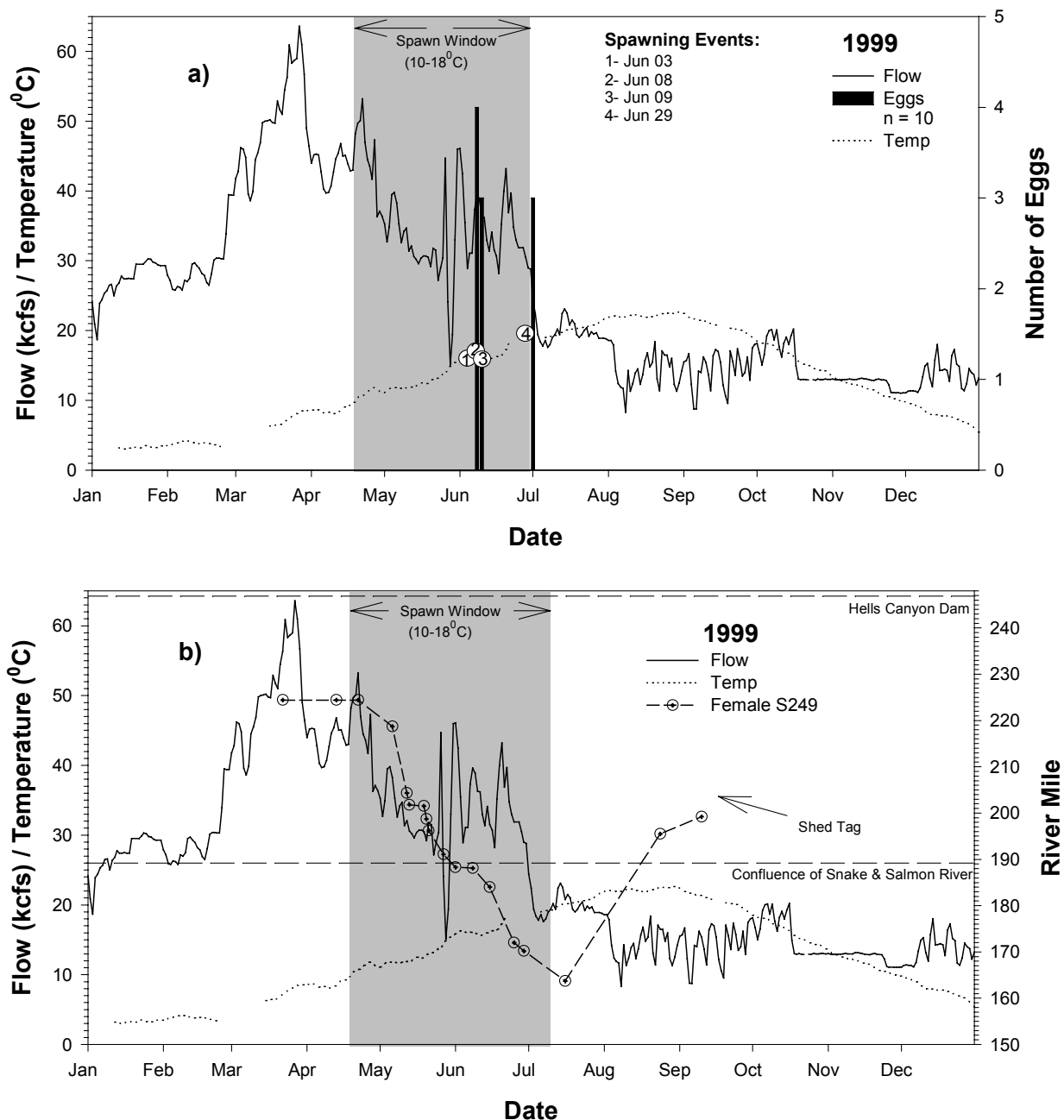


Figure 15. Mean daily flow and temperatures associated with a) the collection of white sturgeon eggs and the estimation of spawning events based on egg embryonic development and b) the movement behavior of one reproductive female white sturgeon during the 1999 spawning period in the Snake River between Hells Canyon Dam (RM 247.6) and the mouth of the Salmon River (RM 188).

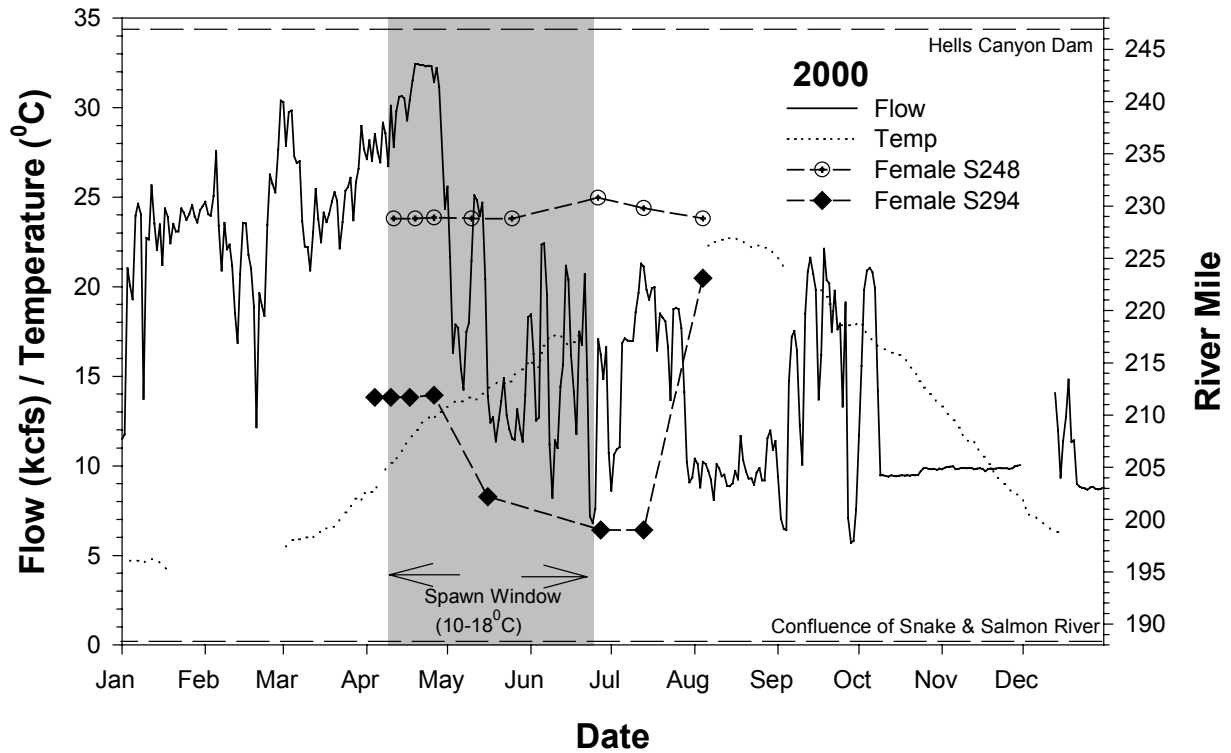


Figure 16. Mean daily flow and water temperatures associated with the movement behavior of two reproductive female white sturgeon during the 2000 spawning period in the Snake River between Hells Canyon Dam (RM 247.6) and the mouth of the Salmon River (RM 188).

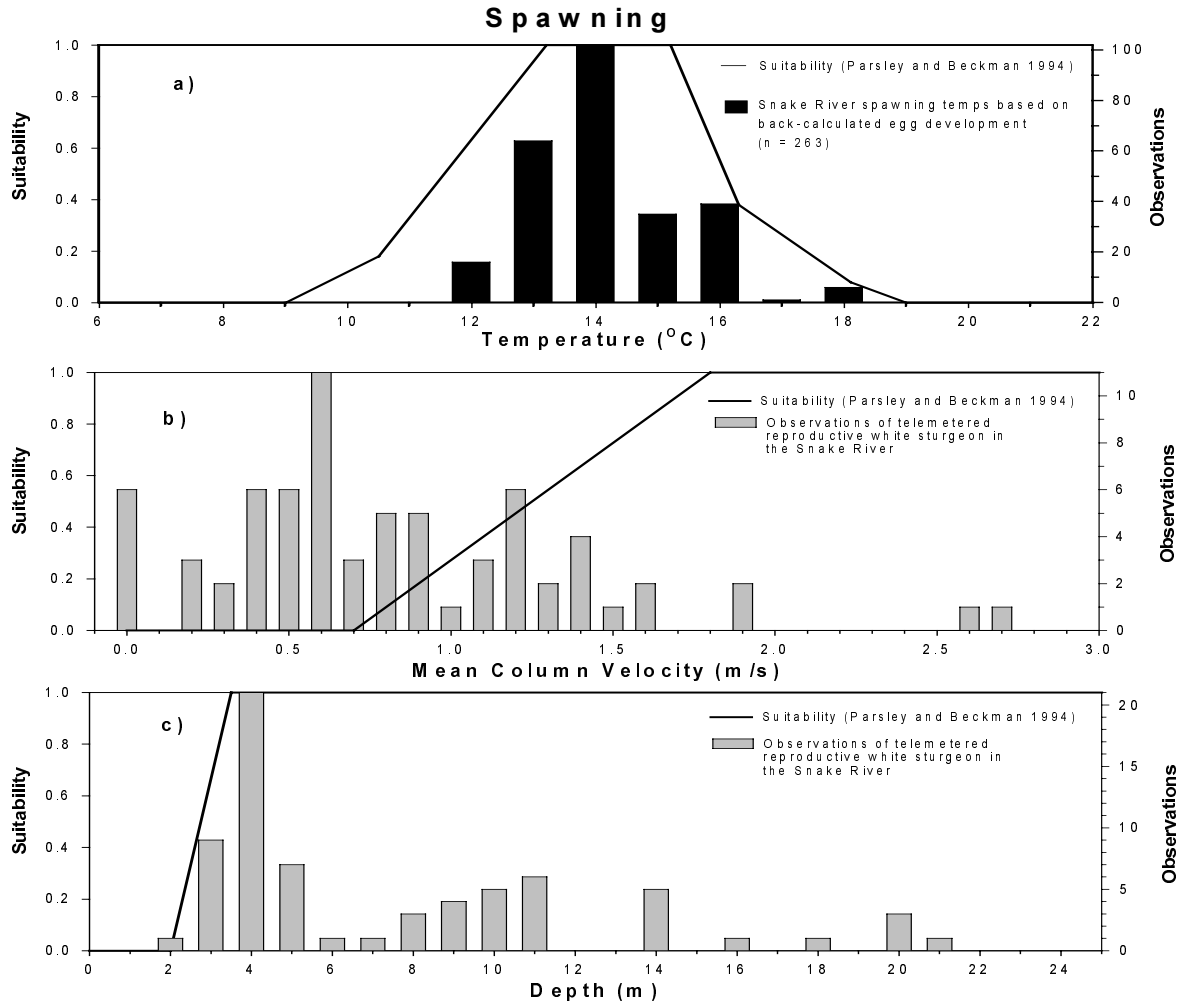


Figure 17. Habitat criteria curves depicting the suitability of a) water temperatures, b) mean column velocity, and c) depth for spawning white sturgeon. Habitat suitability criteria obtained from Parsley and Beckman (1994). The black bars indicate observations of water temperatures during spawning based on back-calculated egg development. The gray bars indicate observations of telemetered, reproductive white sturgeon at spawning locations in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188).

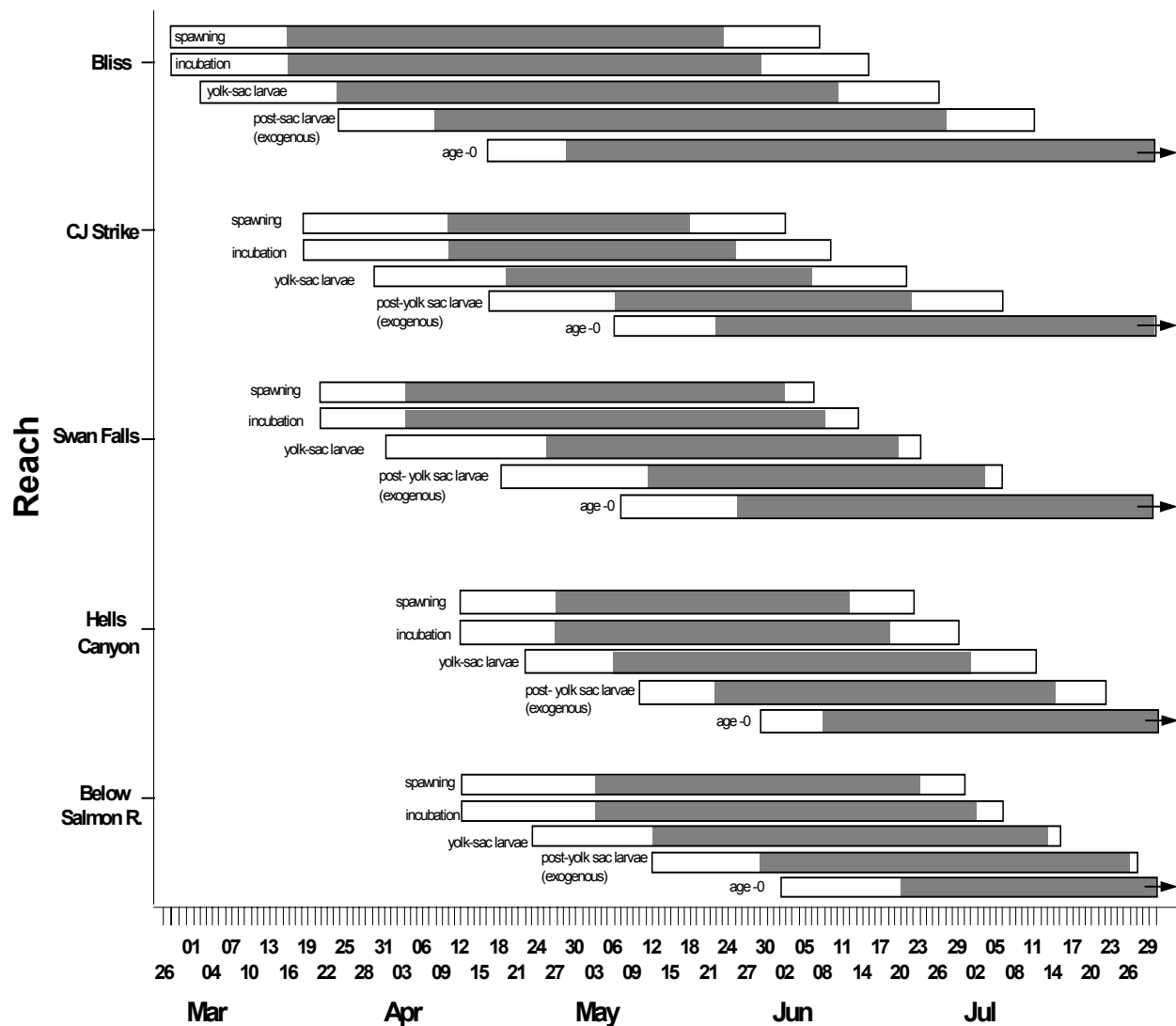


Figure 18. Estimated periods for spawning to age-0 life stages of Snake River white sturgeon. The occurrence of various life stage intervals were calculated based on the initiation of spawning using median Julian dates associated with lower (10 °C) and upper (18 °C) water temperature limits suitable for spawning in Snake River reaches, 1990–2000 and on embryonic development by Wang et al. (1985). The shaded portion of the bars represent peak occurrence of the various life stages given peak spawning activity expected between 12 and 16 °C (based on egg collections in the Snake River) and subsequent embryonic development.

Incubation

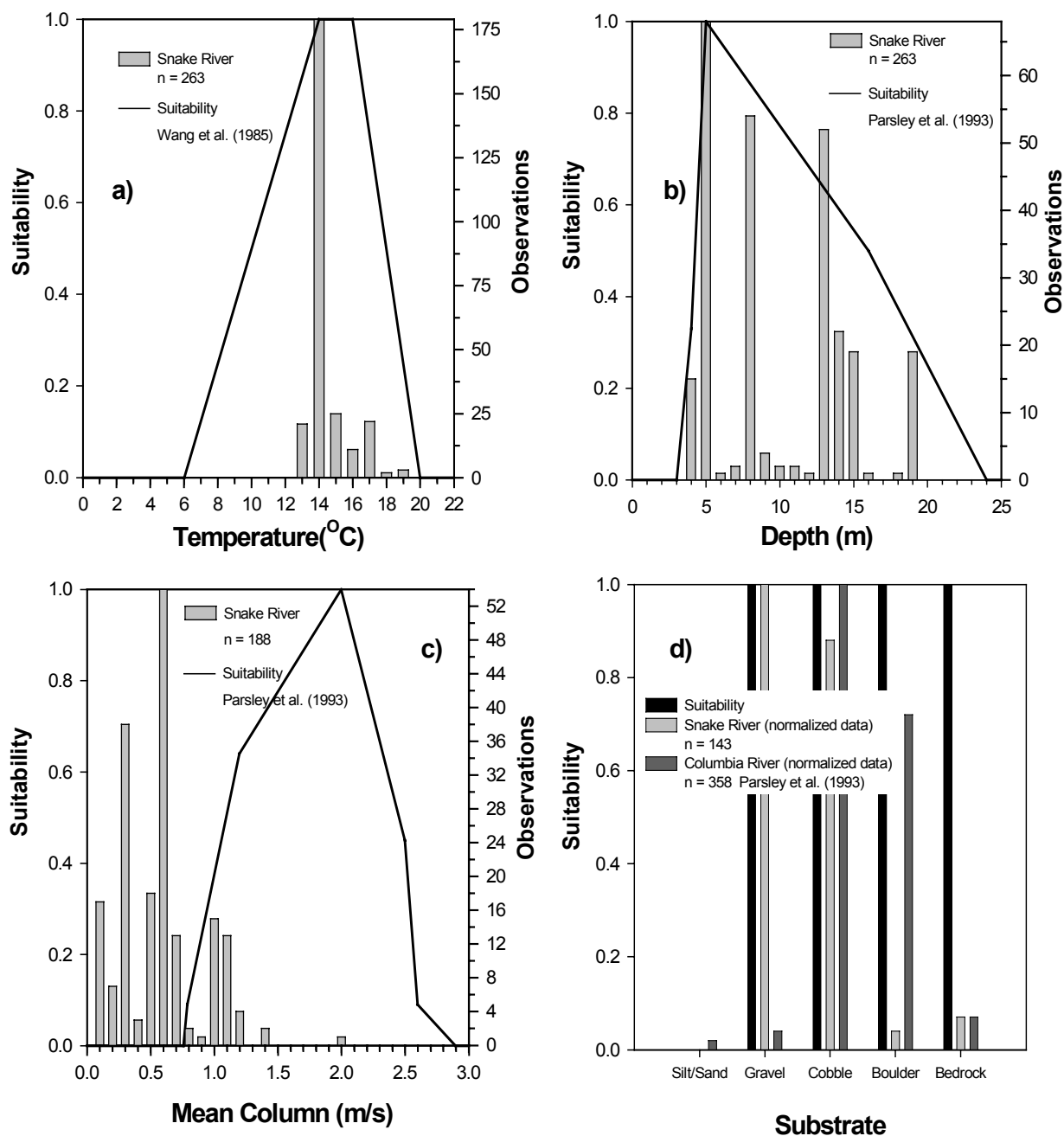


Figure 19. Habitat criteria curves depicting the suitability of a) water temperatures, b) depth, c) mean column velocity, and d) substrate types for white sturgeon egg incubation. Habitat suitability criteria based on information by Wang et al. (1985) and Parsley et al. (1993). The shaded bars indicate observations from incubating eggs in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188).

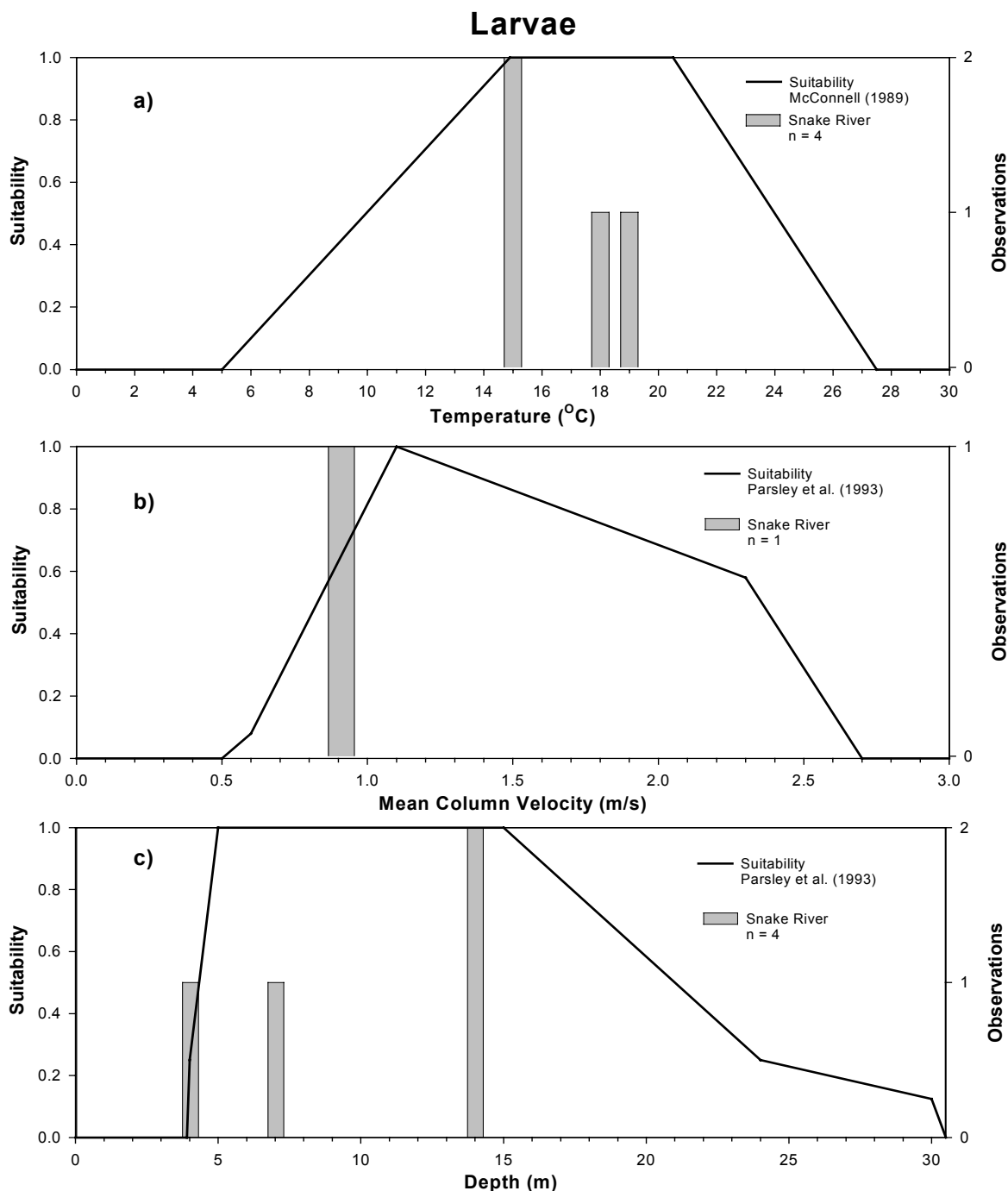


Figure 20. Habitat criteria curves depicting the suitability of a) water temperatures, b) mean column velocity, and c) depths for larval white sturgeon. Habitat suitability criteria based on information presented in Parsley et al. (1993) and McConnell (1989). The shaded bars indicate observations associated with the collection of larval white sturgeon in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188).

Young-of-Year

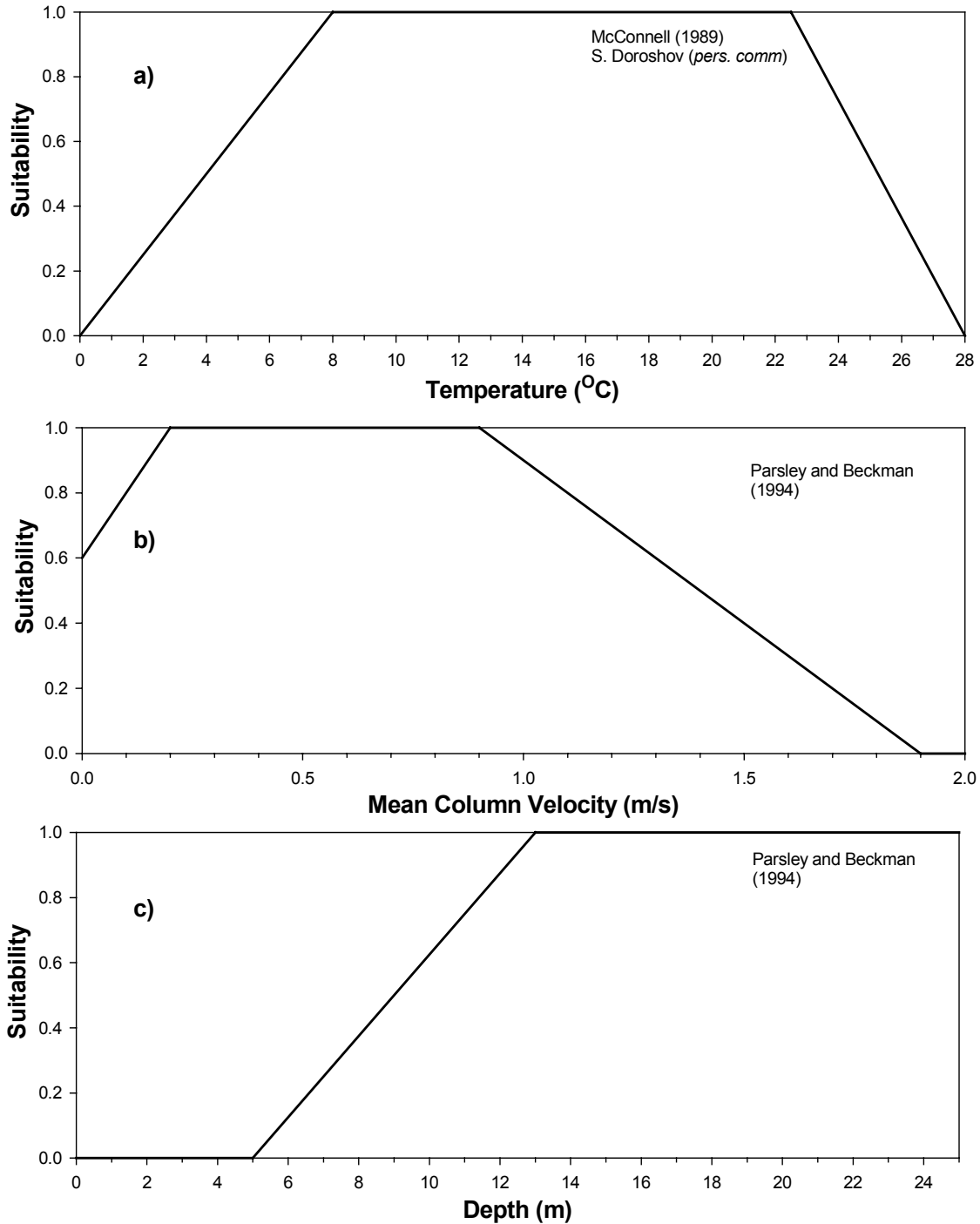


Figure 21. Habitat criteria curves depicting the suitability of a) water temperatures, b) mean column velocities, and c) depths for young-of-year white sturgeon. Habitat suitability criteria based on information from Parsley and Beckman (1994), McConnell (1989), and S. Doroshov (UC Davis, *pers. comm.*).

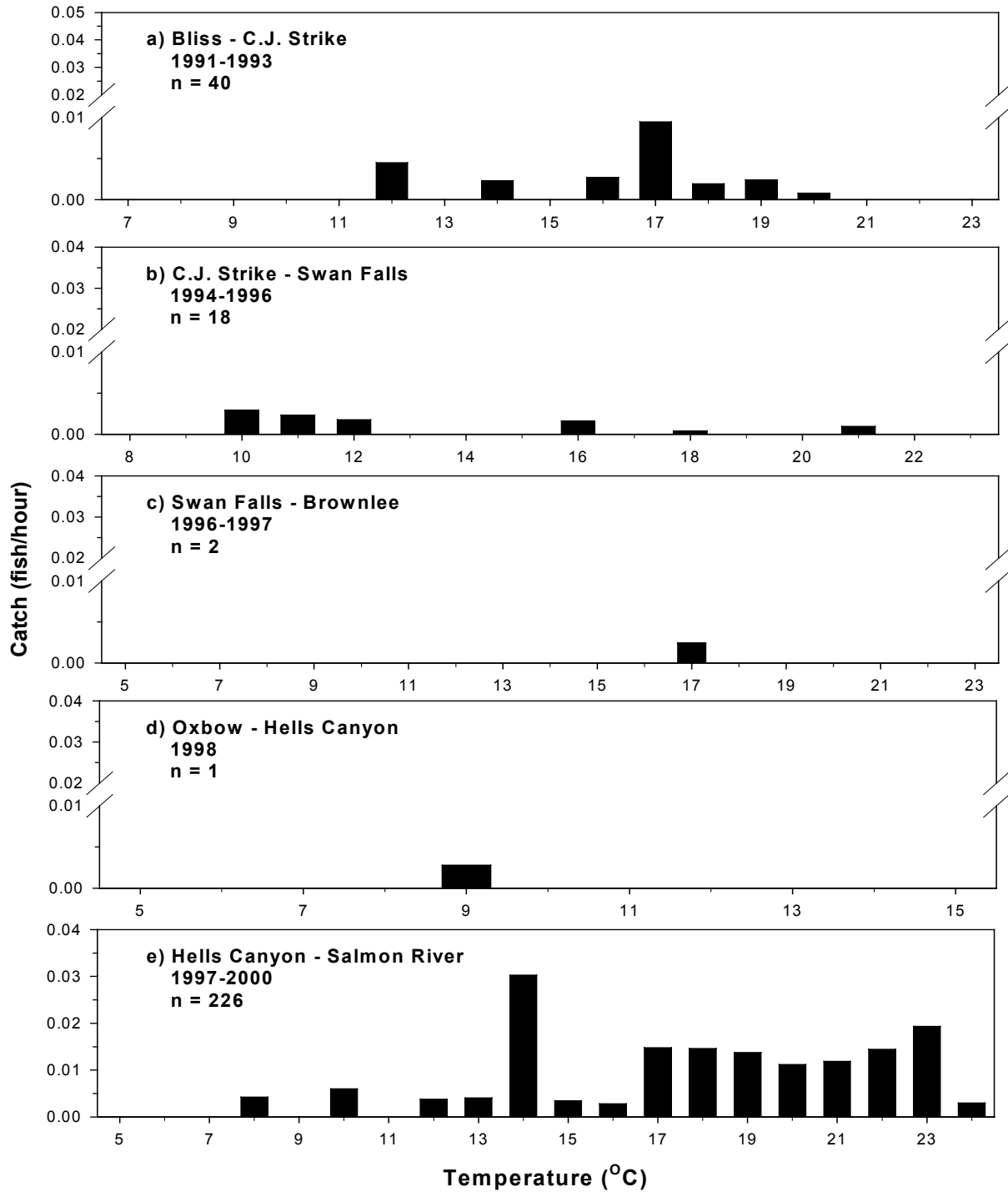


Figure 22. Catch rates by temperature for juvenile white sturgeon less than 120 cm TL sampled with setlines in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188). Catch rates are based on random sampling effort.

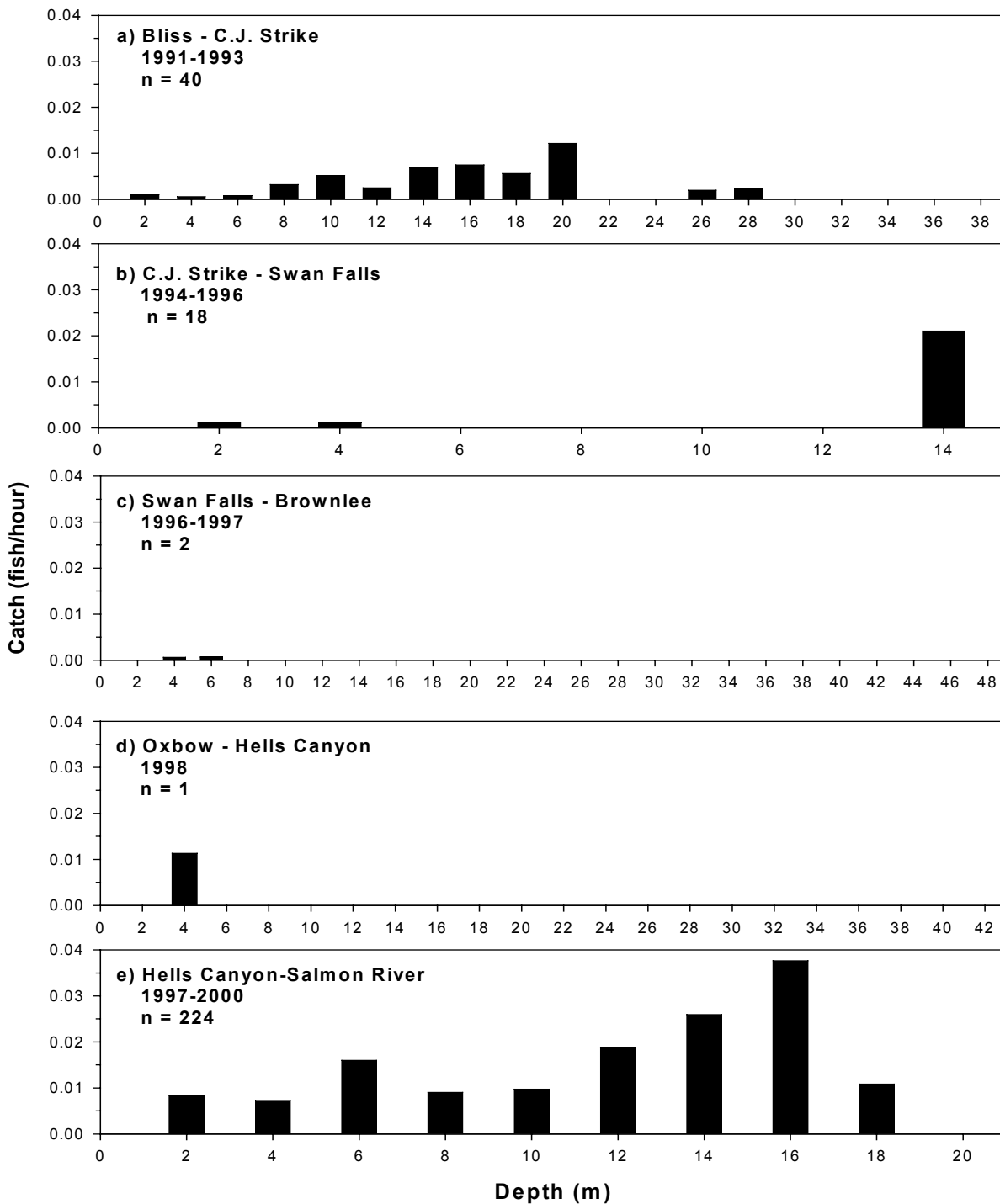


Figure 23. Catch rates by depth for juvenile white sturgeon less than 120 cm TL sampled with setlines in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188). Catch rates are based on random sampling effort.

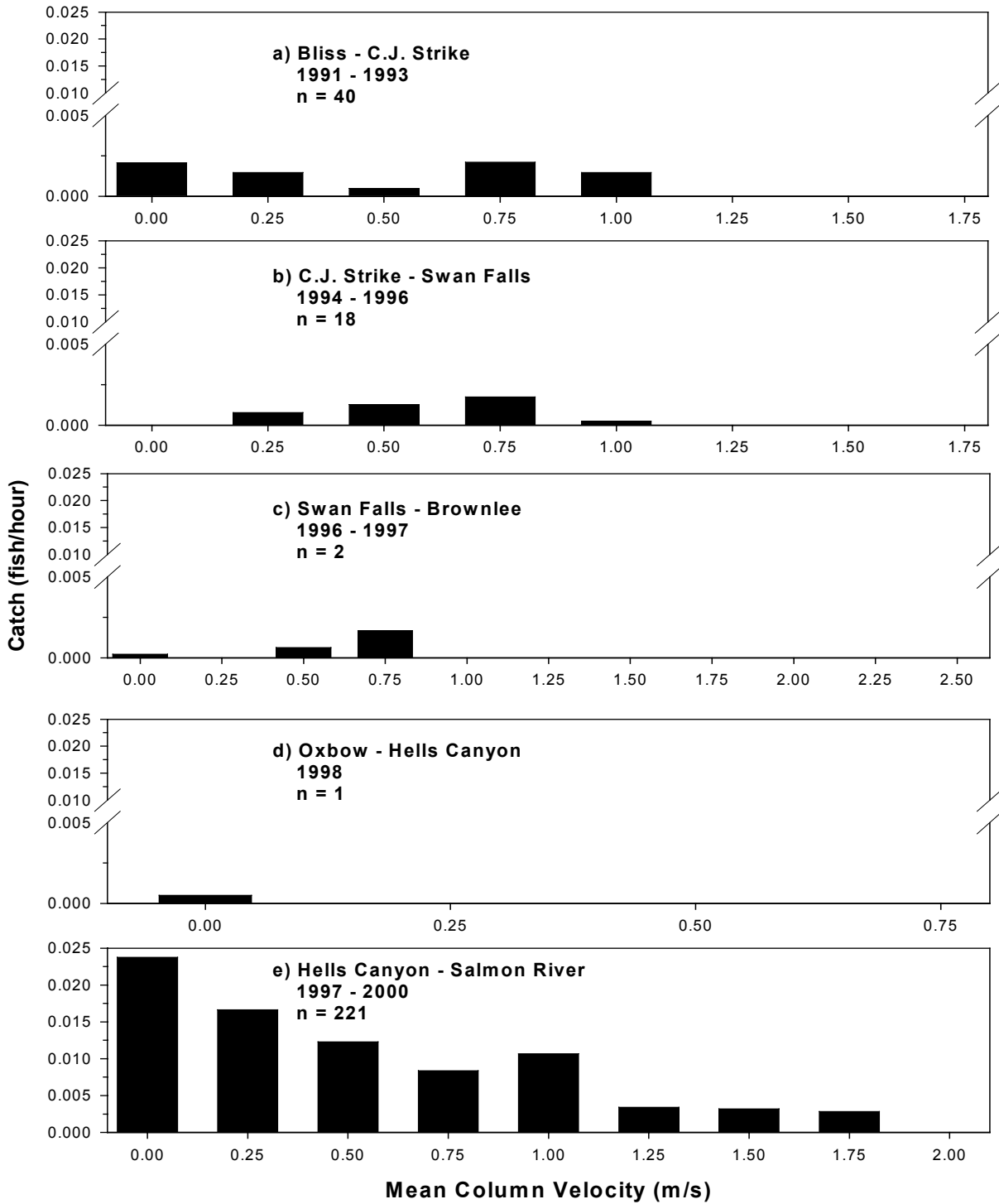


Figure 24. Catch rates by mean column velocity for juvenile white sturgeon less than 120 cm TL sampled with setlines in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188). Catch rates are based on random sampling effort.

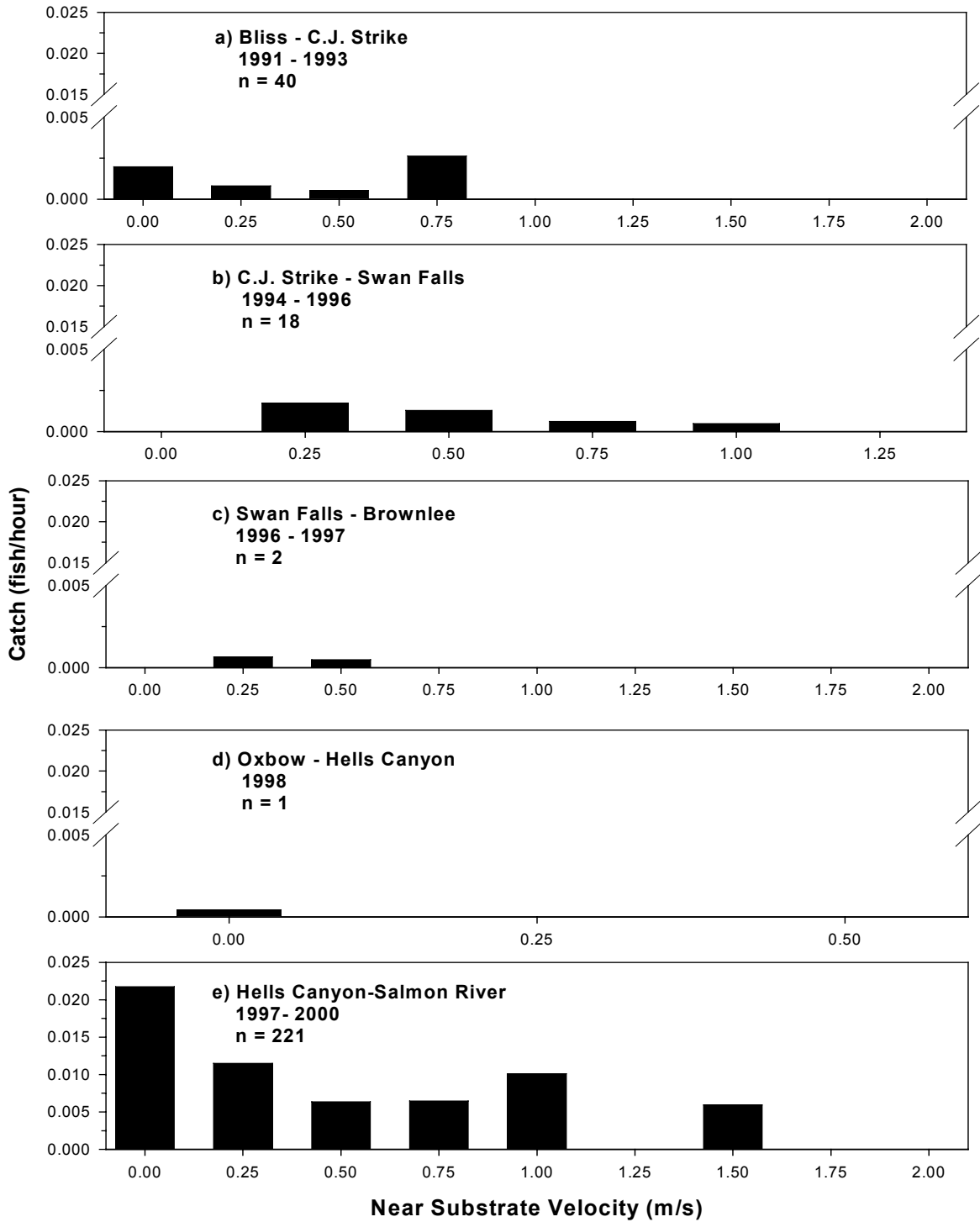


Figure 25. Catch rates by near-substrate velocity for juvenile white sturgeon less than 120 cm TL sampled with setlines in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188). Catch rates are based on random sampling effort.

Juvenile

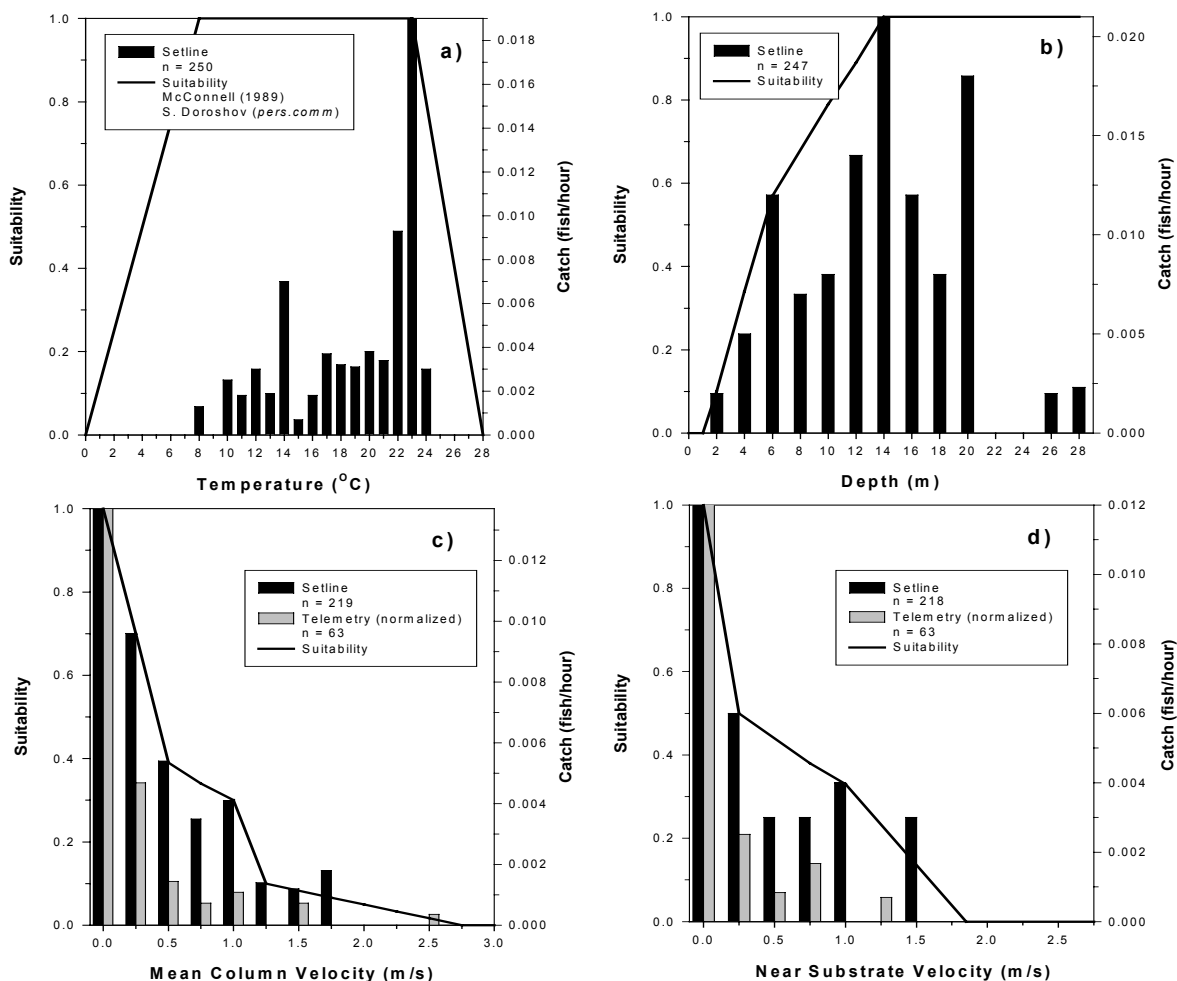


Figure 26. Habitat criteria curves depicting the suitability of a) water temperatures, b) depth, c) mean column velocity and d) near-substrate velocity for juvenile white sturgeon in the Snake River. Suitability curves for temperature are based on information from McConnell (1989) and S. Doroshov (UC Davis, *pers. comm. electronic mail*). Shaded bars indicate setline (black) and telemetry (gray) observations of white sturgeon in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188).

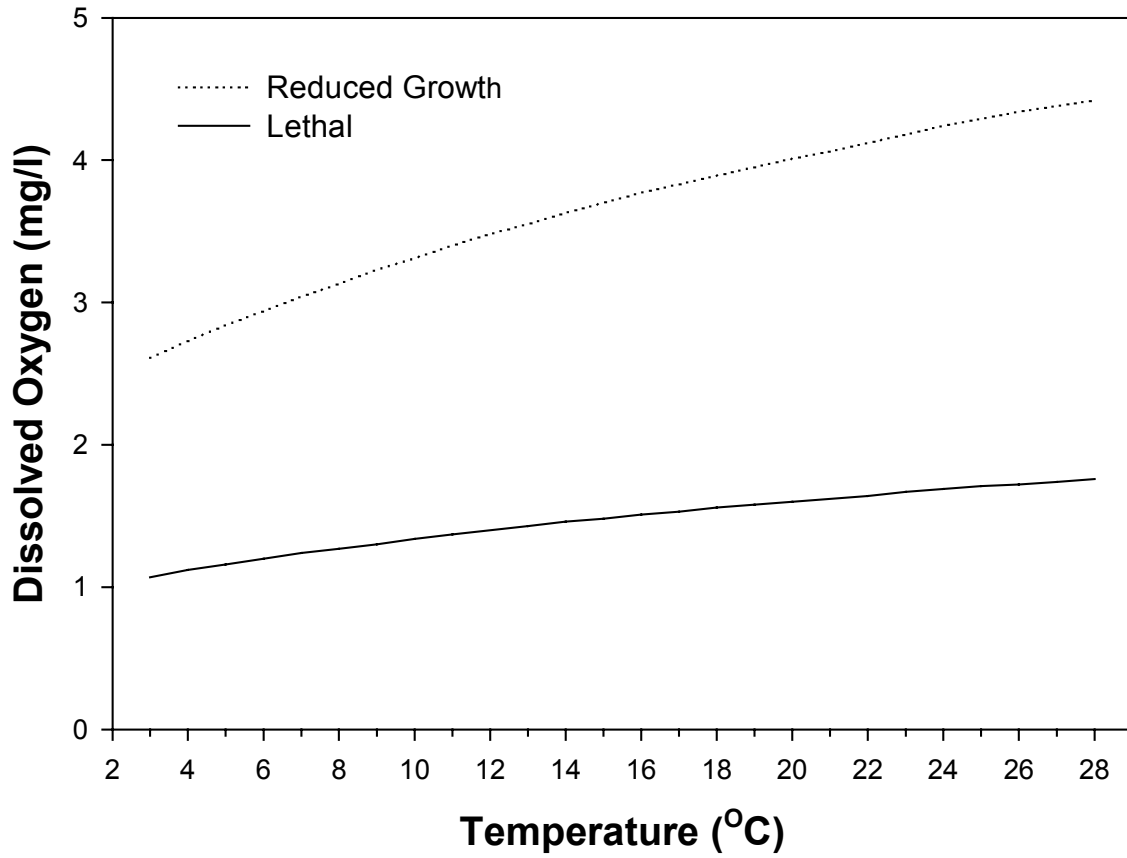


Figure 27. Reduced growth and lethal dissolved oxygen thresholds for four species of Russian sturgeon including *Acipenser guldenstadtii*, *A. baeri*, *A. stellatus*, and *Huso huso* x *A. ruthenus* (Klyashtorin 1974).

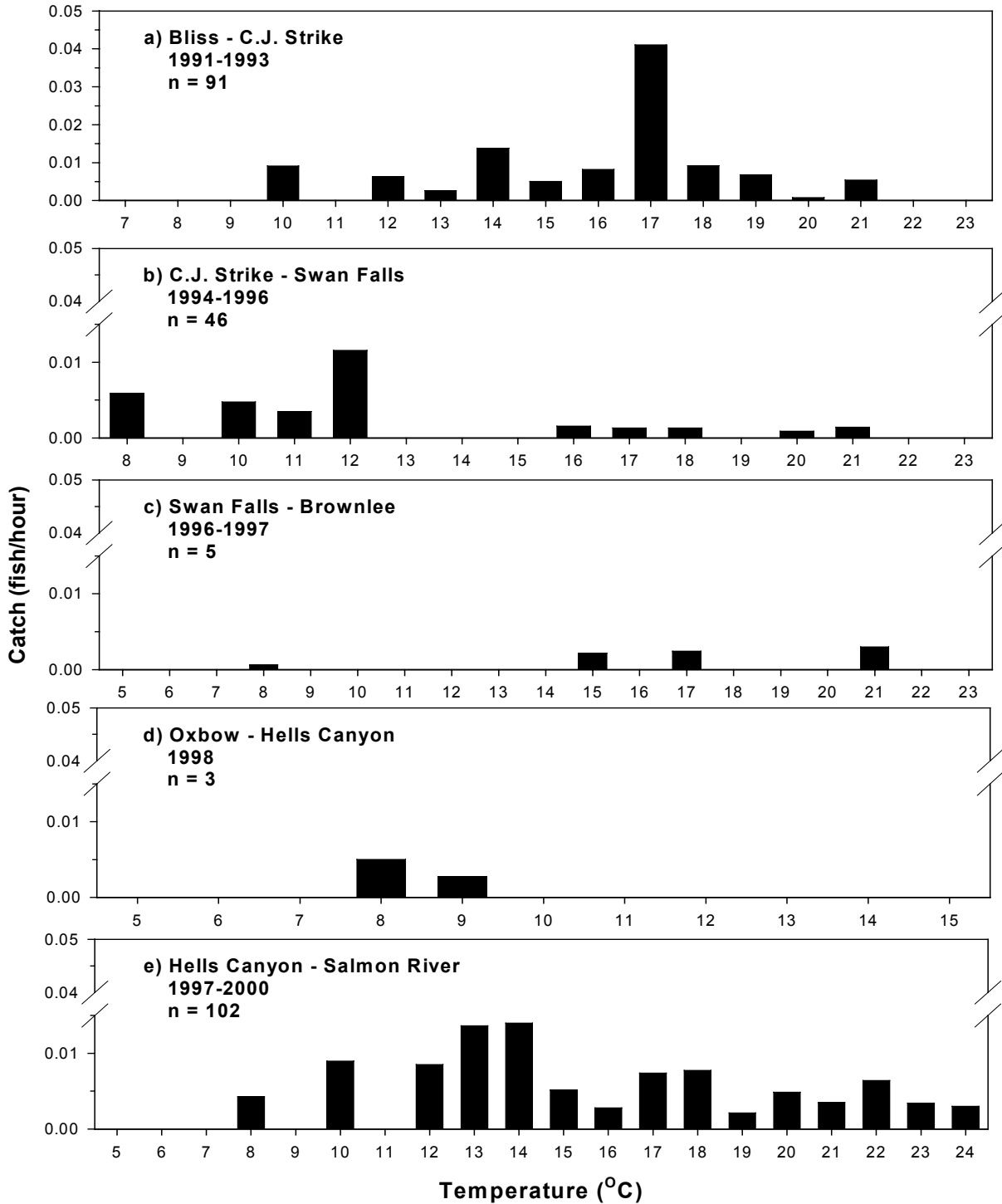


Figure 28. Catch rates by temperature for adult white sturgeon greater than 120 cm TL sampled with setlines in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188). Catch rates are based on random sampling effort.

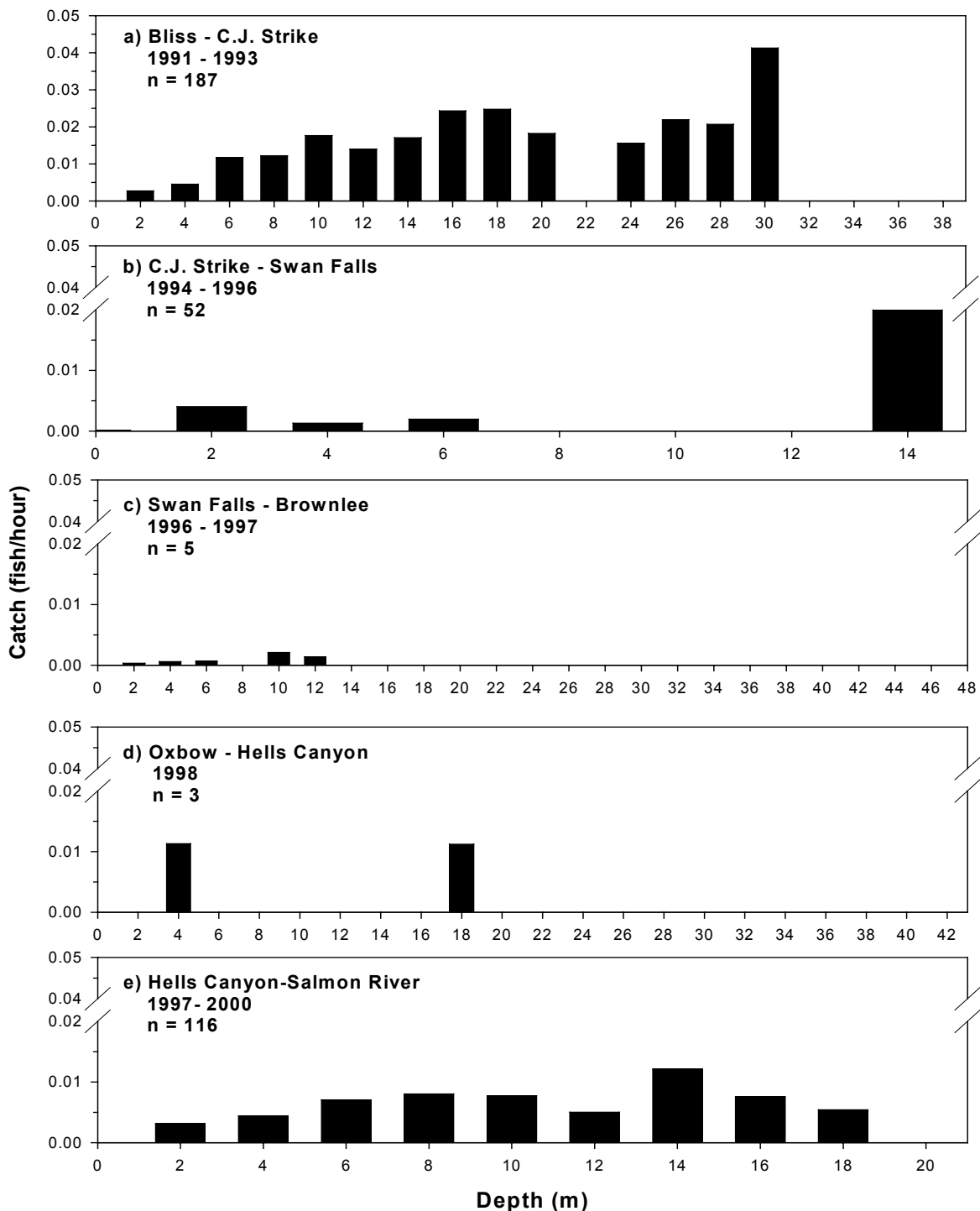


Figure 29. Catch rates by depth for adult white sturgeon sampled with setlines in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188). Catch rates are based on random sampling effort.

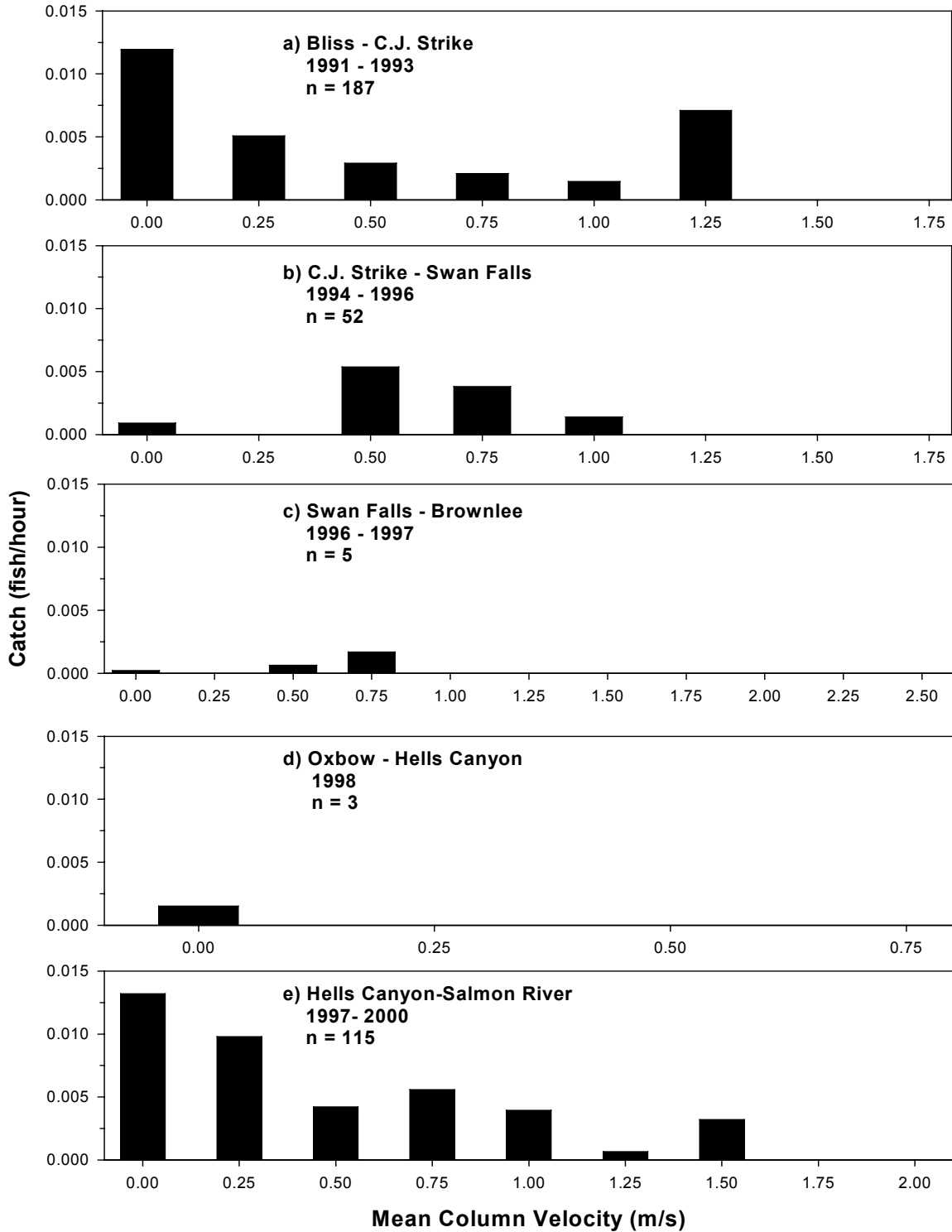


Figure 30. Catch rates by mean column velocity for adult white sturgeon sampled with setlines in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188). Catch rates are based on random sampling effort.

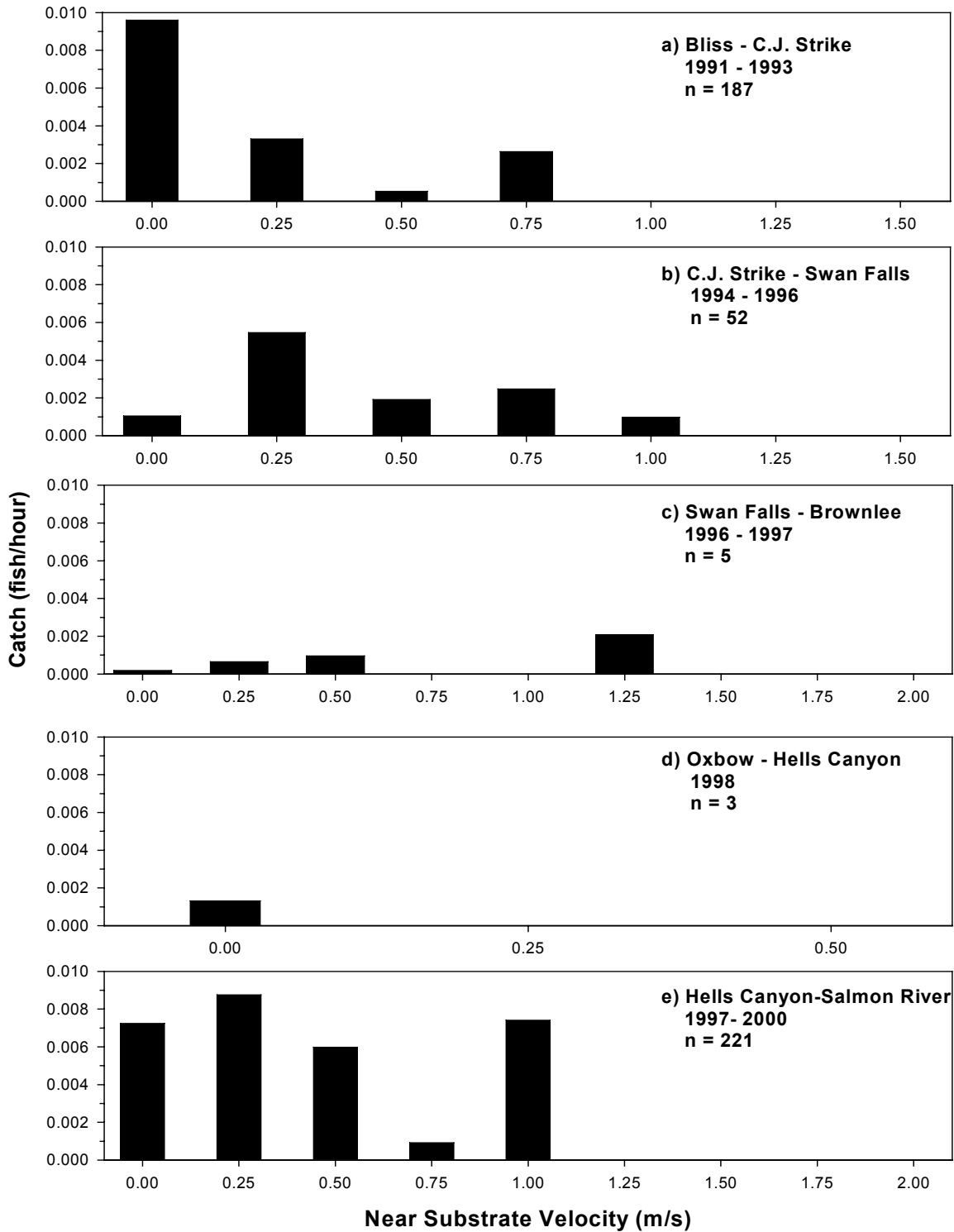


Figure 31. Catch rates by near-substrate velocity for adult white sturgeon sampled with setlines in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188). Catch rates are based on random sampling effort.

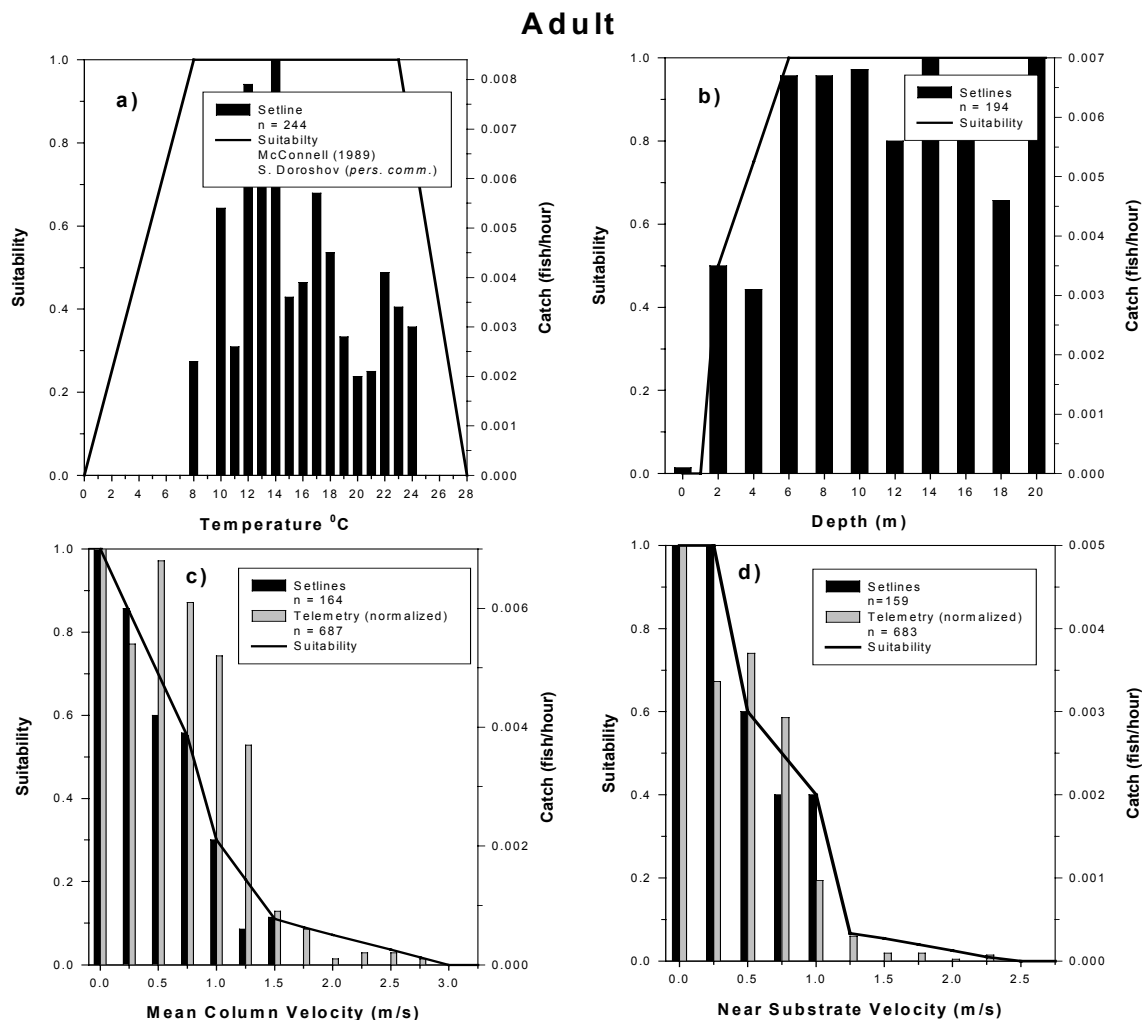


Figure 32. Habitat criteria curves depicting the suitability of a) water temperatures, b) depth, c) mean column velocity, and d) near-substrate velocity for adult white sturgeon in the Snake River. Temperature suitability curves based on information from McConnell (1989) and S. Doroshov (UC Davis, *pers. comm. electronic mail*). Shaded bars indicate setline (black) and telemetry (gray) observations from white sturgeon in the Snake River between Bliss Dam (RM 560) and the mouth of the Salmon River (RM 188).