HNF-64542
Revision 0

Hanford Reach Fall Chinook Salmon Redd Monitoring Report for Calendar Year 2018

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-09RL14728

P.O. Box 650
Richland, Washington 99352

Approved for Public Release
Further Dissemination Unlimited

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Hanford Reach Fall Chinook Redd Monitoring Report for Calendar Year 2018

J. J. Nugent and C. T. Lindsey
Mission Support Alliance

Date Published
February 2020

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APPROVED
By Lynn M. Ayers at 9:50 am, Feb 06, 2020

Release Approval Date

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1.0 INTRODUCTION

The U.S. Department of Energy, Richland Operations Office (DOE-RL) conducts ecological monitoring on the Hanford Site to collect and track data needed to ensure compliance with an array of environmental laws, regulations, and policies governing DOE-RL activities. Ecological monitoring data provide baseline information about the plants, animals, and habitats under DOE-RL stewardship at the Hanford Site required for decision making under the *National Environmental Policy Act* (NEPA) and *Comprehensive Environmental Response, Compensation, and Liability Act*. DOE/EIS-0222, *Final Hanford Comprehensive Land Use Plan Environmental Impact Statement* (CLUP) evaluates the potential environmental impacts associated with implementing a comprehensive land-use plan for the Hanford Site for at least the next 50 years, and ensures that DOE-RL, its contractors, and other entities conduct activities on the Hanford Site in compliance with NEPA.

The vision for the DOE-RL-managed portion of the Hanford Site focuses not only on the clean up of nuclear facilities and waste sites but on the protection of groundwater and the Columbia River, as well as and the restoration of the Hanford Site lands for access and use (DOE/RL-2009-10). To reach these goals DOE-RL is working closely with partners, such as the U.S. Fish and Wildlife Service and National Park Service, to enable use of the Hanford Site land consistent with the CLUP. As the Hanford Site moves toward accomplishing this vision, monitoring the ecological resources present to determine whether there is a need for conservation and/or protection of any resources will be critical for making informed decisions for responsible site stewardship.

DOE-RL places priority on monitoring plant and animal species or habitats that fit into one or more of the categories below:

- Regulatory protections or requirements
- Rare and/or declining species (i.e., federally or state listed endangered, threatened, or sensitive)
- Significant interest to federal, state, or Tribal governments or the public.

DOE/RL-96-32, *Hanford Site Biological Resources Management Plan*, (BRMP) ranks wildlife species and habitats (Levels 0–5) based on the level of concern for each resource. Fall Chinook salmon (*Oncorhynchus tshawytscha*) spawning areas are ranked as Level 5 resources, the highest ranking level in BRMP. According to the BRMP, "resources classified as Level 5 are the rarest and most sensitive habitats and species and are considered irreplaceable or at risk of extirpation or extinction." The management goal of Level 5 resources is preservation and requires a high level of status monitoring.

Commonly referred to as king salmon, Chinook are the largest of the Pacific salmon (Myers et al. 1998, Netboy 1958). The Columbia River supports three major runs (spring, summer, and fall) of Chinook salmon, generally based on the season during which the adults re-enter the estuary to begin their upstream migration to spawn. Chinook salmon that spawn in the Hanford Reach of the Columbia River are fall-run fish. Fall Chinook salmon enter freshwater at an advanced stage of maturity, move rapidly to their spawning areas on the mainstem or lower tributaries of the rivers, and spawn within a few days or weeks of freshwater entry (Myers et al. 1998, Fulton 1968, Healey 1991). Adult fall Chinook salmon destined for the Hanford Reach are upriver brights (fish retain their silver color during upstream migration) that enter the Columbia River in late summer and spawn in the fall. Spawning in the Hanford Reach typically begins in mid-October and lasts through November. The population of fall Chinook salmon that spawns in the Hanford Reach of the Columbia River is the largest run remaining in the Pacific Northwest and has regional, ecological, cultural, and economic importance that reaches areas downstream on the Columbia River and along the Pacific Ocean coast as far as southeast Alaska (Dauble and Watson 1997). These fall Chinook salmon have

been vital in efforts to preserve and restore other depleted Chinook salmon stocks in the Columbia Basin (Anglin et al. 2006).

Dauble and Watson (1997) found the initiation of spawning ranged from September 28 to October 26 with a median date of October 16. Females fan out nests or "redds" in suitable gravel substrate and deposit eggs in a pocket while males simultaneously extrude milt to fertilize the eggs. Redds are readily identifiable at this time and appear as clean swept gravel patches amidst darker undisturbed substrate covered by algae (periphyton). "Redd life" is a term describing the period during which periphyton growth has not rendered the redd substrate indiscernible from the surroundings. Redd life is typically about 6 weeks on the Hanford Reach (PNL-7289); however, redds have been recorded to remain visible for over 16 weeks (HNF-53665, HNF-56705).

Fall Chinook salmon redds have been monitored at the Hanford Site annually since 1948, including aerial counts, to provide an index of relative abundance among spawning areas and years (HNF-52190, HNF-54808, HNF-56707, HNF-58823, HNF-59813, HNF-63012, HNF-64540). The counts are used to document the onset of spawning, locate spawning areas, and determine intervals of peak spawning activity. These data also allow for planning to avoid impacts such as disturbance or siltation to redds from Hanford Site activities. Understanding the location and abundance of spawning is a critical part of the management of this important population and facilitates protection of essential fish habitats safeguarded under the *Magnuson-Stevens Fishery Conservation and Management Act*.

The information collected during the aerial surveys is vitally important for the implementation of the Hanford Reach Fall Chinook Protection Program (HRFCPP; USACE 2006). The HRFCPP is an agreement among Public Utility District No. 2 of Grant County, Washington (Grant); Public Utility District No. 1 of Chelan County, Washington (Chelan); Public Utility District No. 1 of Douglas County, Washington (Douglas); DOE acting by and through the Bonneville Power Administration (BPA); National Oceanic and Atmospheric Administration Fisheries (NOAAF); Washington Department of Fish and Wildlife (WDFW); and the Confederated Tribes of the Colville Indian Reservation (CCT). The goal of this program is to protect Hanford Reach fall Chinook salmon during critical periods of their life cycle through operational constraints imposed on the Priest Rapids Hydroelectric Project.

2.0 METHODS

Aerial surveys of fall Chinook salmon redds were conducted in areas of the Hanford Reach consistent with past survey efforts and the historical data set (Figure 1). Eight additional sub-sections (100-B/C, 100-K, 100-N, 100-D, 100-H, 100-F, Dunes, and 300 Area) were added beginning in 2011 to monitor the abundance and distribution of fall Chinook salmon redds in areas of the Columbia River adjacent to contaminated groundwater plumes of the Hanford Site (Figure 2; DOE/RL-2018-32). These eight new sub-sections were divided so that redd counts and direct comparisons to historical records can still be made in the original areas.

The primary physical factors influencing the accuracy of aerial counts include depth of water over redds and water clarity. Wind action, available light, orientation of the river, and direction of the current can also affect redd counts. The accuracy of aerial counts also decreases with increasing numbers and density of redds within a large aggregate of redds (Visser et al. 2002). Flights are cancelled if weather conditions are not favorable (i.e., wind, fog, or low clouds). Field measurements suggest that the upper depth limit for detecting redds during aerial surveys conducted on the Hanford Reach was 3 to 4 m (10 to 13 ft) (PNL-7289), while other studies indicate that fall Chinook salmon spawn in water up to 9 m (30 ft) deep

(Swan 1989); therefore, a proportion of redds located in deeper water may not be detected during aerial surveys (PNL-7289). Because it is seldom possible to view all redds from the air, these counts provide only an annual index of relative abundance and distribution of fall Chinook salmon spawning in the Hanford Reach of the Columbia River.

Beginning in mid-October, under the terms of the HRFCPP, river flows are reduced in the morning every Sunday (the day of the week with the lowest power demand) to the Priest Rapids Dam minimum operating discharge of 1,000 m^3/sec (36,000 ft^3/sec).

This allows the Agency (NOAAF, WDFW, and CCT) and Utility (Grant, Chelan, Douglas, and BPA) Party Monitoring Team to perform a ground survey of redd distribution at Vernita Bar just downstream of Priest Rapids Dam. These drawdowns occur every Sunday morning until the initiation of fall Chinook spawning has been set both above and below the 1,416 m^3/sec (50,000 ft^3/sec) flow elevations. A final drawdown is conducted on the Sunday prior to Thanksgiving to establish the minimum critical flow needed to protect pre-emergent fall Chinook. This weekly reduction in river flow can afford excellent viewing conditions and, when possible, flights are scheduled concurrent with the Sunday morning drawdowns.

Flights are scheduled to encompass the entire fall Chinook salmon spawning period, usually mid-October (initiation of spawning) through the end of November (end of spawning). Three to four flights are typically conducted during this period. Early flights (October) are conducted to establish the initiation of spawning, and later flights (November) occur during and just after the peak spawning period to establish the maximum redd count for the season by area and for the entire Hanford Reach. Multiple flights are necessary to minimize the effect of poor visibility or other sources of count variability that may occur during a single flight. Multiple flights also ensure comparability within the long-term database through consistency with past efforts. As a courtesy and consistent with past practices, aerial redd count information is shared with the HRFCPP parties to assist in the implementation of protective measures.

Survey flight altitudes range from 244 to 366 m (800 to 1,200 ft) with air speeds of 120 to 161 km/hr (75 to 100 mi/hr). Widely spaced fall Chinook salmon redds are individually counted, while tightly grouped clusters of redds are estimated in groups of 10 or 50. Heavy spawning areas require multiple aerial passes to collect complete counts. Observations begin in Richland at the Interstate 182 bridge and end at Priest Rapids Dam. Flights are conducted near noon to bracket the highest angle of the sun for optimum viewing conditions. Observers wear polarized glasses, as necessary, to reduce glare. All redds observed are documented by survey area on large format printed maps.

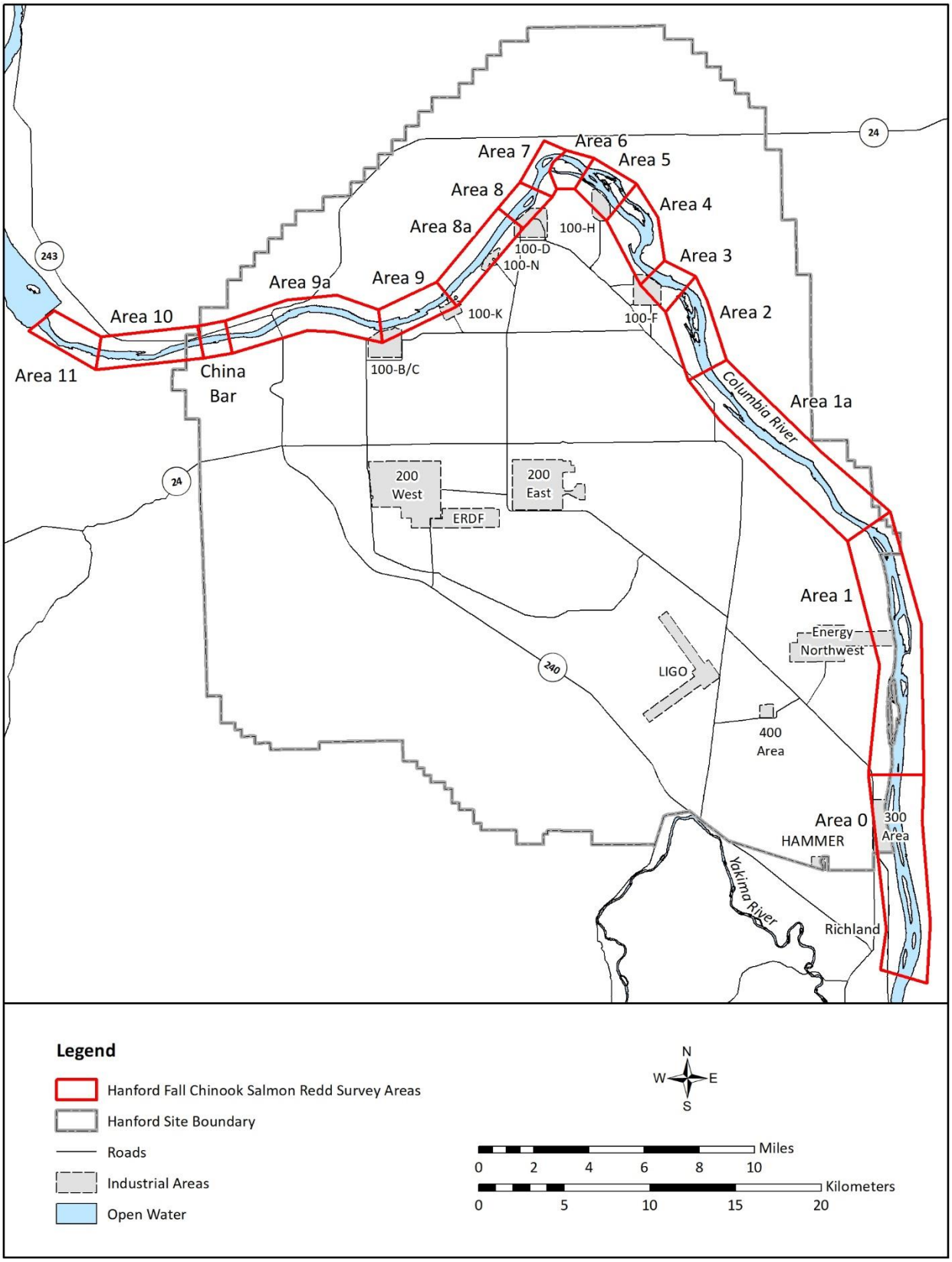

Figure 1. Aerial Survey Areas for Fall Chinook Salmon Redds Used Historically and in 2018

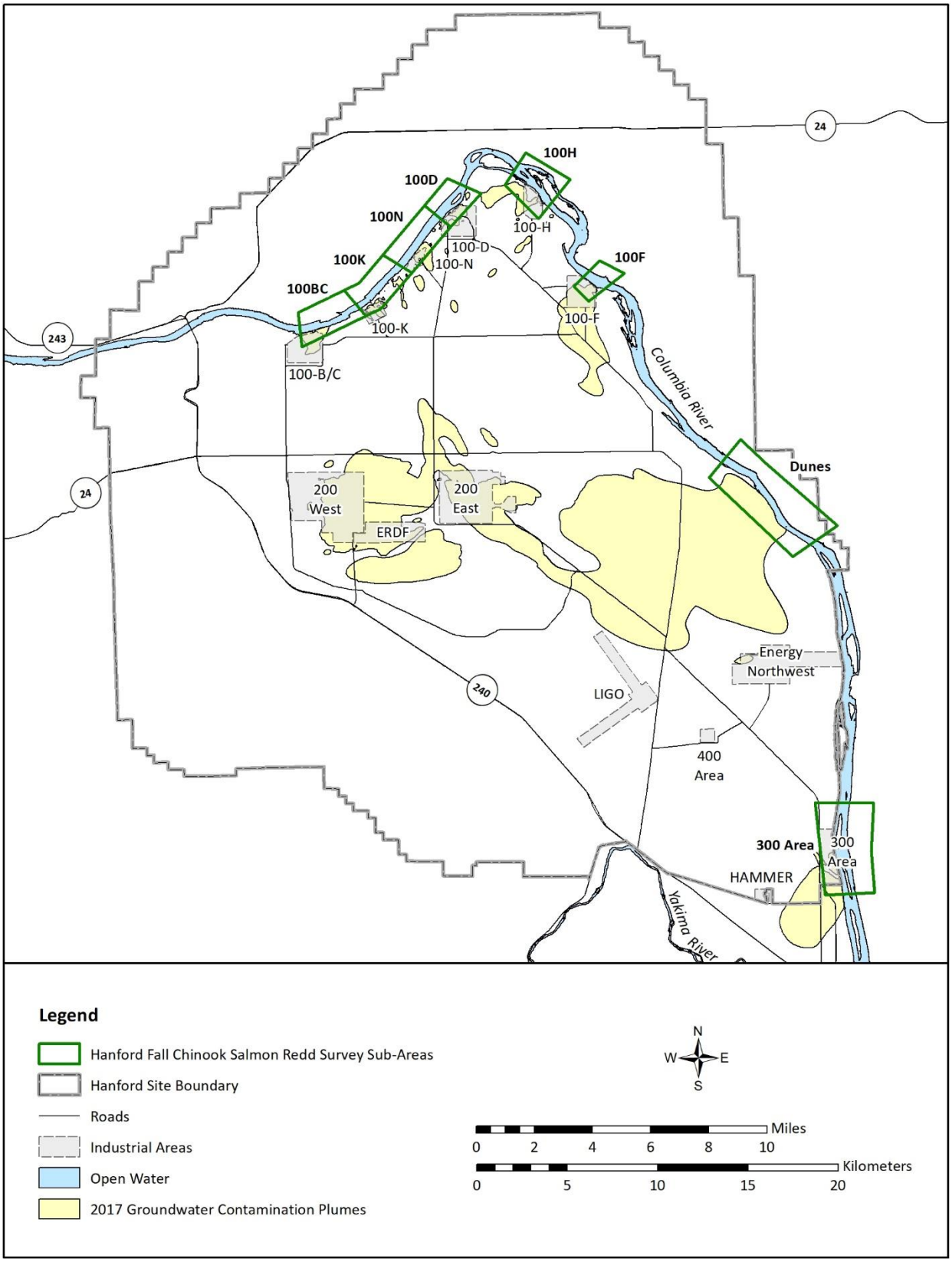

Figure 2. Fall Chinook Salmon Survey Sub-areas Adjacent to Groundwater Contamination Plumes

Because long-term trends in both redd abundance and distribution are important monitoring components, Mission Support Alliance has taken several steps to ensure compatibility and consistency with past efforts, which include the following:

- Thoroughly reviewing and adopting past monitoring protocols
- Coordinating/training with former redd count personnel
- Coordinating and exchange of information with the WDFW and with the Grant County Public Utility District to support the ongoing HRFCPP
- Using maps detailing the entire survey reach as well as all historical sub-areas and spawning sites both as in-flight guidance documents and as field data recording forms
- Using the same air service, airplane, and pilots in 2018 that were used in previous years.

In addition to the visual counts, high quality vertical aerial photographs were taken of the entire length of the Hanford Reach from the Interstate 182 bridge to the Priest Rapids Dam. Photographs were captured by David Wyatt of Loftics Aerial Photography on the day following the final visual count conducted in 2018. A Nikon™ D800 digital single lens reflex camera with a full-frame sensor and a ZEISS™ Distagon T* 15mm f/2.8 ZF.2 lens for Nikon™ F Mount was used to take the photographs. The camera was mounted over an open hatch in the bottom of the aircraft. The aircraft was flown at 161 kph (100 mph) at an elevation of 823 m (2,700 ft) above ground level. The pilot aligned the plane with the center of the river channel and kept the airplane as level as possible. The flight required 270 degree turns to reposition at sharp bends in the river and two side patches of river had to be flown to capture photographs missed on the first pass. The camera's interval timer was set to automatically take a photograph every 6 seconds. Two sets of photographs were captured, one upstream (from the Interstate 182 bridge to Priest Rapids Dam) and another downstream (from Priest Rapid Dam to the Interstate 182 bridge). This produced photographs that captured the entire width of the Columbia River and overlapped by approximately three-fourths. Camera settings were as follows:

- Manual focus set at infinity
- Shutter speed set at 1/1000s
- Aperture set at f/5.6
- ISO set at 400
- File format was JPG Fine.

The photographs taken in 2018 were georeferenced using a Geographic Information System (GIS). The location of each fall Chinook salmon redd was then digitized. The methods for taking the aerial photography in 2018 were similar to methods used in 2013 (HNF-56707) to allow for comparisons of the two years. Data analysis of digitized redd locations was performed in the GIS. This included comparing redd locations from 2018 to those observed in 2013, and evaluating the locations of redds with respect to river flow elevation maps that show the extent of inundation of the river at varying water outflow levels at Priest Rapids Dam. Redd sizes were also measured utilizing measuring tools in the GIS. Other GIS tools used for analysis included Kernal Distance Estimation to determine areas with the greatest redd densities and utilizing the Average Nearest Neighbor Tool that measures the distance between the centroid of each feature and its nearest neighbor's centroid, and then averages all of these distances in order to determine the spatial pattern of the redd locations (clustered, random, or dispersed). The measures of statistical significance for the Average Nearest Neighbor Tool (z-scores and p-values) are sensitive to study area size. The study area used in this analysis was the area within the 2,832 m^3/sec (100,000 ft^3/sec) shoreline

from river kilometer (rkm) 638.5 (river mile [rm] 396.7) just downstream of Priest Rapids Dam to rkm 545.8 (rm 339.1) just downstream of Nelson Island near Richland, Washington. Less than 0.1% of the redds fell outside of this area in 2013 and 2018. This area is approximately 49.9 km^2 (19.3 mi^2).

3.0 RESULTS

Three fall Chinook salmon visual aerial redd count surveys and one flight to photograph the redds were completed along the length of the Hanford Reach during 2018. The first visual aerial redd count survey was performed on October 22, the second on November 5, and the third on November 16. The counts performed during each flight, by survey area, are shown in Table 1. The maximum count describes the highest number of redds documented in a survey area within any single flight. The visual redd count total is calculated by summing the maximum redd count from each survey area, which equaled 5,429 in 2018. The number of redds counted within the newer defined sub-areas coinciding with Hanford Site operational areas is shown in Table 2. Viewing conditions were excellent on the first flight except for a patch of fog from the 300 Area to the top of Wooded Island. This area was surveyed on the return leg of the flight after the fog lifted. Viewing conditions on the second and third flight were very good except for a muddy plume along the eastern shoreline below the 100-F Islands to near the downstream end of Savage Island. However, redds have not been identified in this area previously so the plume did not likely obscure any redds. For all survey areas, the peak redd count occurred on November 16.

Table 1. Summary of Fall Chinook Salmon Visual Aerial Redd Counts for the Calendar Year 2018 Aerial Surveys in the Hanford Reach, Columbia River.

Area	Description	10/22/2018	11/05/2018	11/16/2018	Maximum Count
0	Islands 17–21 (Richland)	0	0	0	0
1	Islands 11–16	0	4	88	88
1a	Savage Island/Hanford Slough	0	0	0	0
2	Islands 8–10	1	94	485	485
3	Near Island 7	3	22	350	350
4	Island 6 (lower half)	9	400	950	950
5	Island 4, 5, and upper 6	6	293	605	605
6	Near Island 3	0	125	310	310
7	Near Island 2	4	300	550	550
8	Near Island 1	0	70	170	170
8a	Upstream of Island 1 to Coyote Rapids	0	0	0	0
9	Near Coyote Rapids	0	40	51	51
9a	Upstream of Coyote Rapids to China Bar	0	0	0	0
China Bar	China Bar/Midway	0	9	25	25
10	Near Vernita Bar	15	1,120	1,840	1,840
11	Upstream of Vernita Bar to Priest Rapids Dam	0	4	5	5
	Total	**38**	**2,481**	**5,429**	**5,429**

Table 2. Summary of Fall Chinook Salmon Visual Aerial Redd Counts for the Calendar Year 2018 Aerial Surveys by Operational Area Sub-Sections.

Sub-area	10/22/2018	11/05/2018	11/16/2018	Maximum Count
300 Area	0	0	0	0
Dunes	0	0	0	0
100-F	3	22	350	350
100-H	6	293	605	605
100-D	0	70	170	170
100-N	0	0	0	0
100-K	0	0	0	0
100-BC	0	40	51	51
Total	**9**	**425**	**1,176**	**1,176**

The aerial photography flight was conducted on November 17. The weather was sunny with light winds and conditions were excellent for photographing the redds. The entire Hanford Reach was captured in photographs (Figure 3) and the redds were readily visible in the photographs. The redds appear as light patches against the otherwise darker river substrate. The photographs were georeferenced and the redds were digitized using a GIS. Figure 4 shows an example of how a patch of redds near Coyote Rapids appears in an aerial photograph and the resulting digitized redd locations. A total of 9,023 redds were identified and digitized from the photographs on the entire Hanford Reach. Locations of these redds are shown in Figures 5, 6, and 7. Shadows from Umtanum Ridge may have impeded visibility of redds in a small portion of the Vernita Bar and visibility of redds is more limited in deeper water. Similar to 2013, redds were visible in water up to 7 m (23 ft) deep, calculated by comparing river levels observed at the time of the survey to existing bathymetry data.

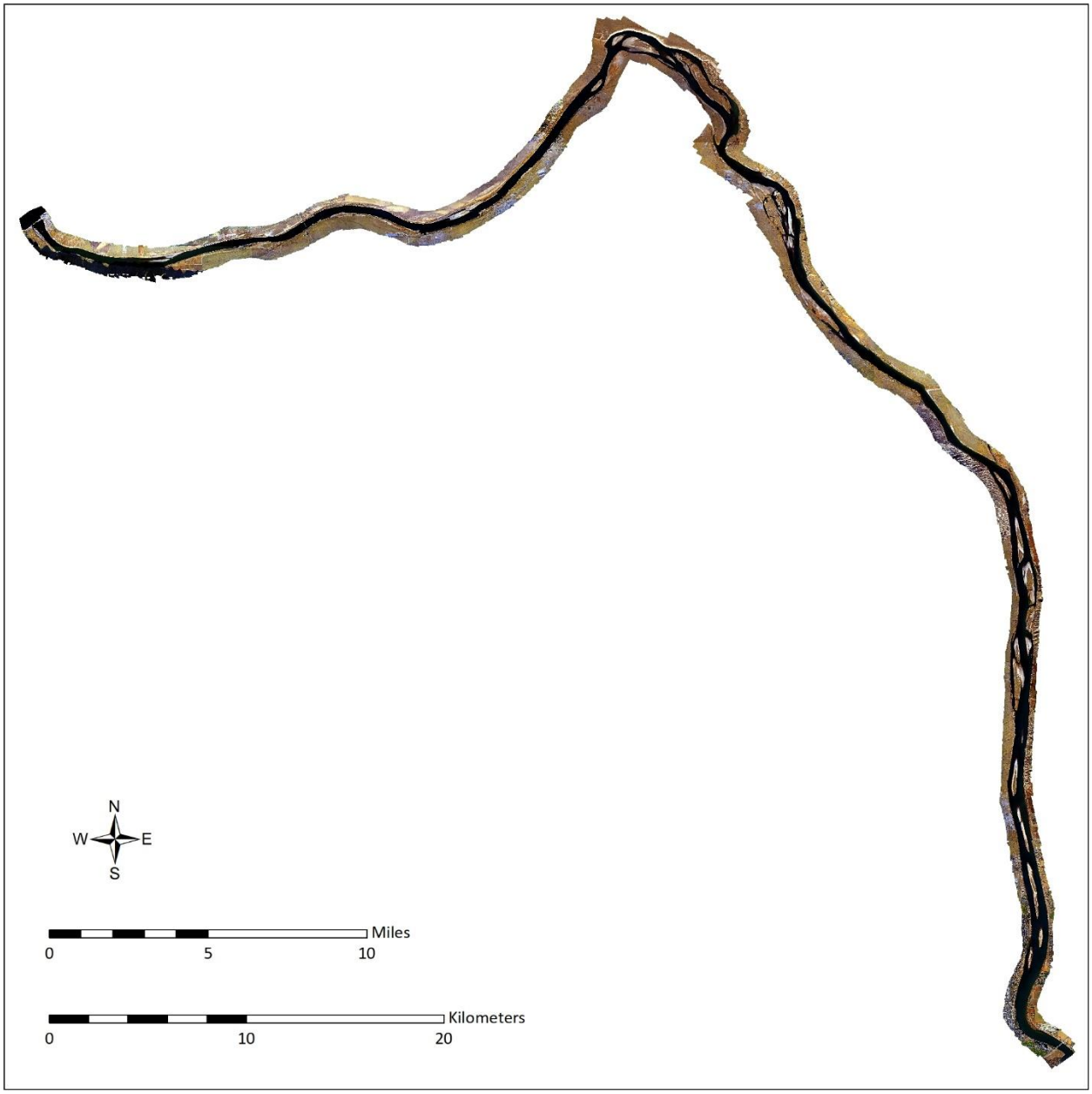

Figure 3. Georeferenced Aerial Photographs of the Hanford Reach Taken During 2018

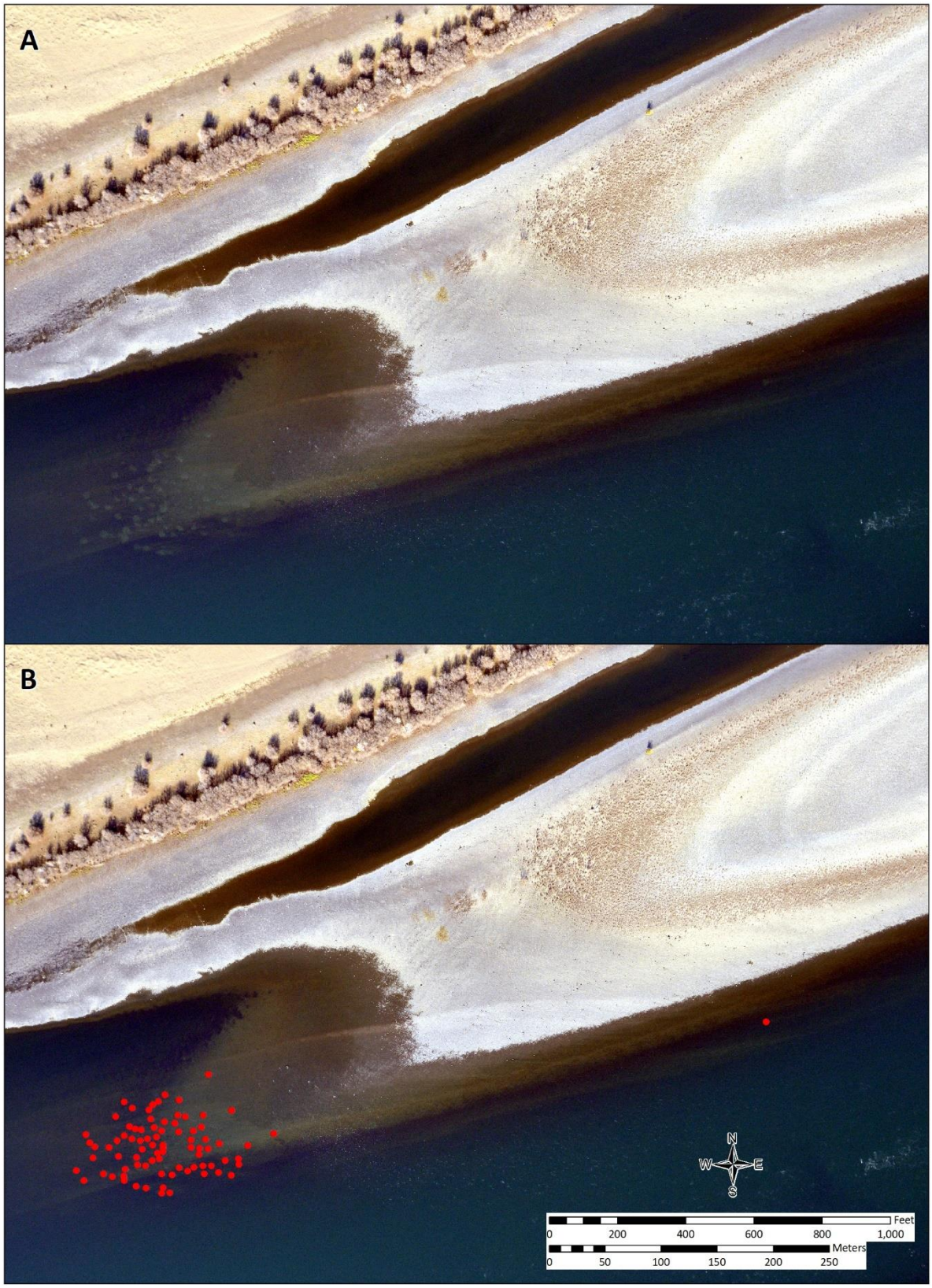

Figure 4. Example of Aerial Photograph Showing Fall Chinook Salmon Redds Near Coyote Rapids A) Actual Redds and B) Digitized

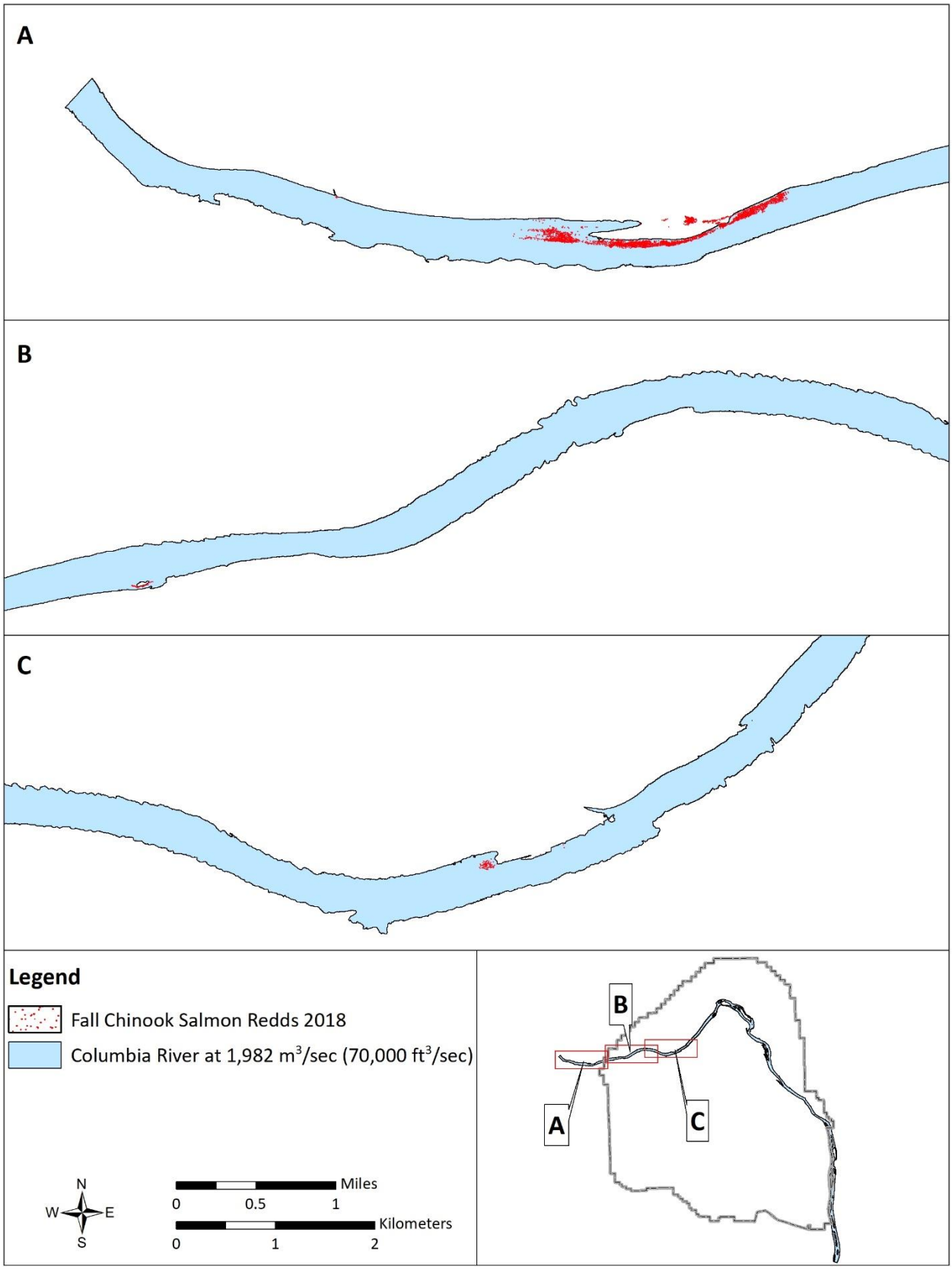

Figure 5. Upper Hanford Reach Digitized Fall Chinook Salmon Redd Locations for 2018

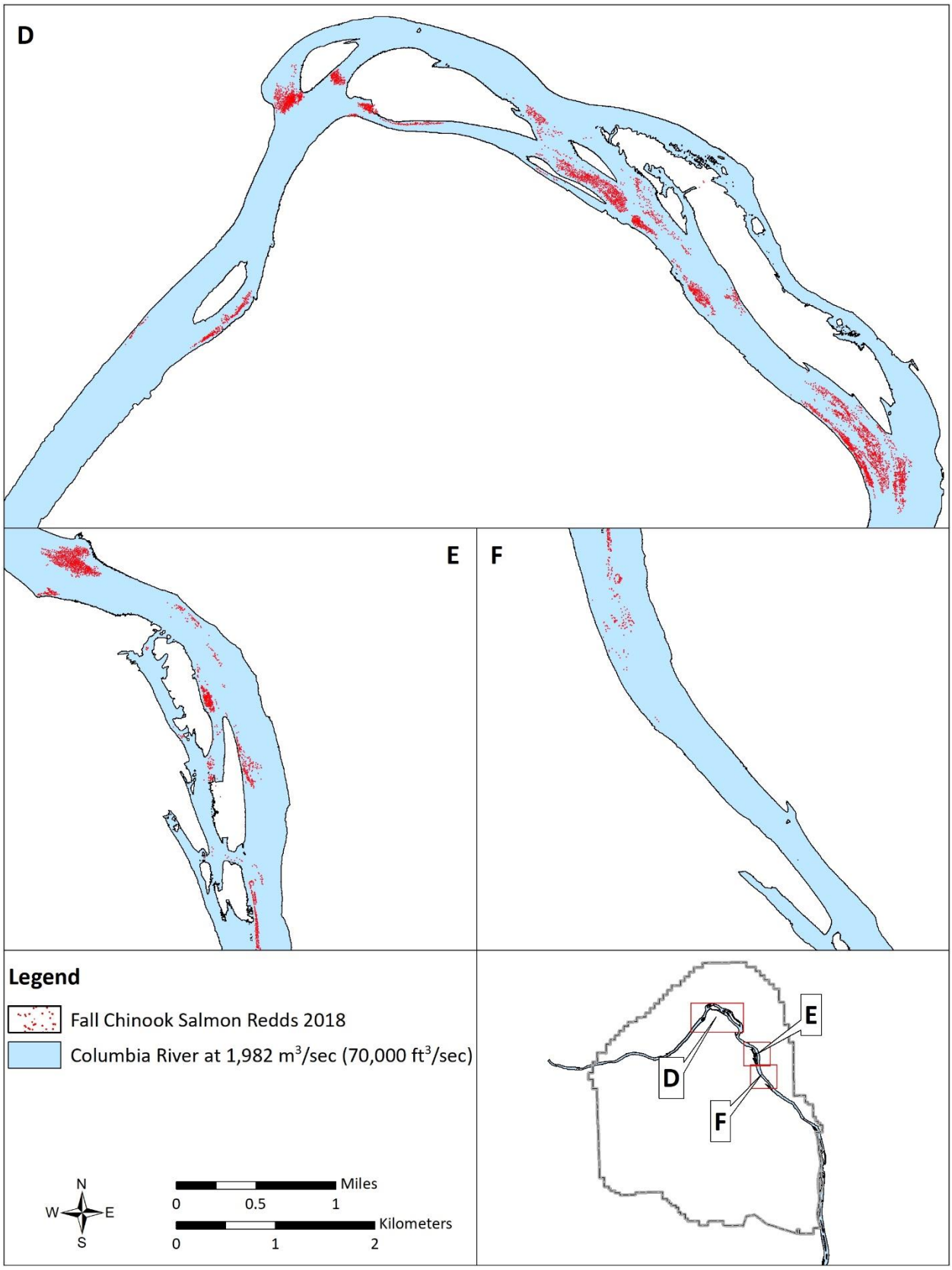

Figure 6. Middle Hanford Reach Digitized Fall Chinook Salmon Redd Locations for 2018

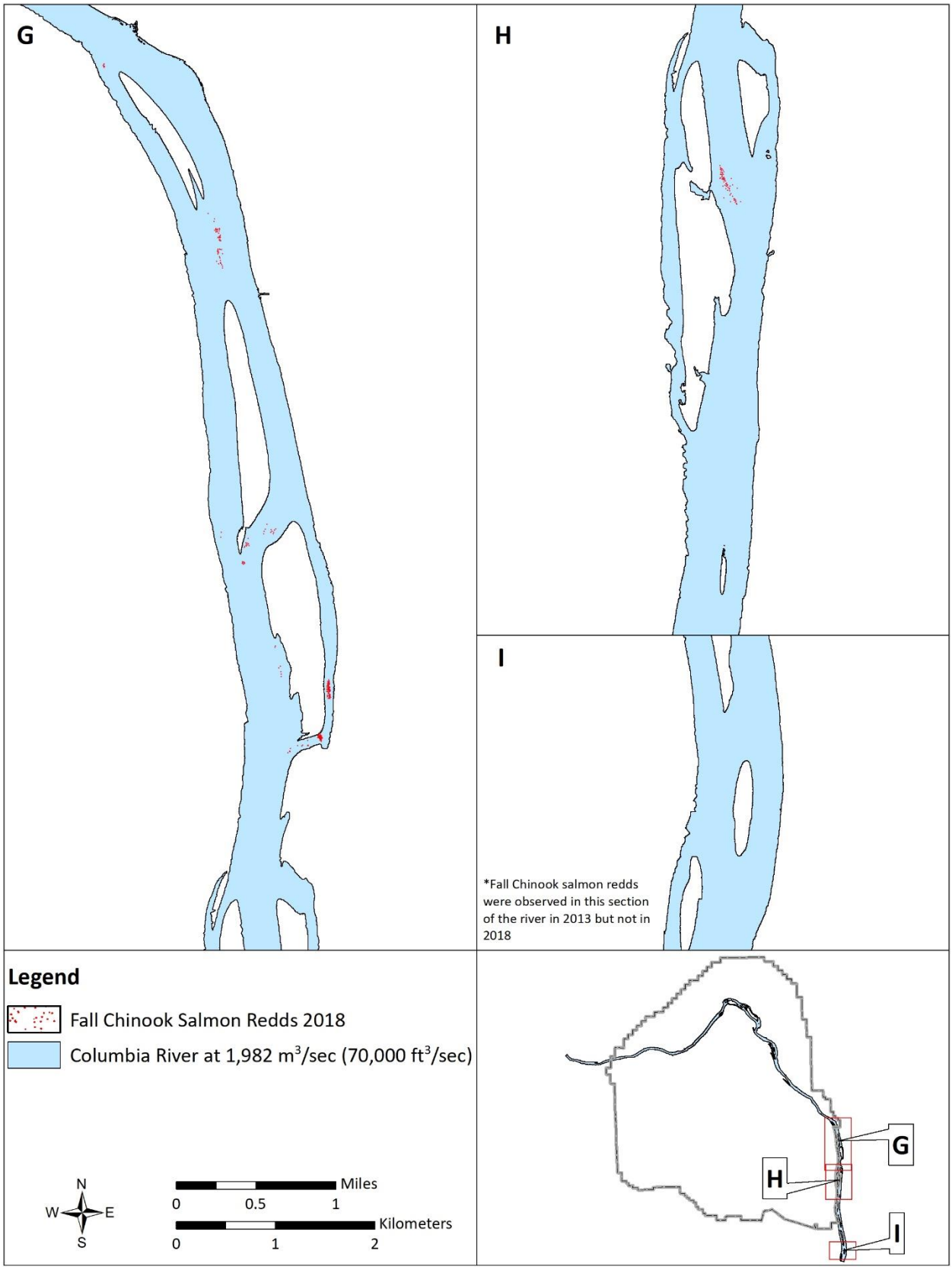

Figure 7. Lower Hanford Reach Digitized Fall Chinook Salmon Redd Locations for 2018

4.0 DISCUSSION

The peak annual visual redd count for 2018 (5,429) was the lowest count since 2009 and was well below the previous 10-year average (11,263); this was also the lowest estimated escapement year for the Hanford Reach since 2009 (42,277). The historical trend in redd counts since 1948 is shown in Figure 8. The reasons for the decline in the number of returning Hanford Reach fall Chinook salmon in 2018 is difficult to surmise, owing to the complexity of each phase of their life cycle and the variety of freshwater and saltwater environments that they encounter during their lives. Therefore, the discussion in this report is limited to numbers and placement of redds in the Hanford Reach. With the use of aerial photography, a total of 9,023 redds were estimated in the Hanford Reach. The aerial photograph count (9,023 redds) was 1.7 times that of the visual count (5,429 redds). This difference is similar to the results reported in 2013 when the aerial photograph count (26,193 redds) was 1.5 times that of the visual count (17,398 redds). The trend that was previously observed (Visser et al. 2002) where higher redd numbers decreases visual count accuracy was not observed when comparing the 2013 and 2018 counts. Visser et al. (2002) conducted comparisons of estimates of redds based on aerial photographs versus visual counts in a portion of the Hanford Reach (Areas 2, 3, 4, 5, and 7) in 1994 and 1995 and found differences of 2.2 times (8,248 versus 3,826) and 3.0 times (5,069 versus 1,704), respectively. In the same portion of the Hanford Reach in 2013 and 2018, the aerial photograph counts were 1.5 times (16,198 versus 10,545) and 1.9 times (5,530 versus 2,940) the visual counts, respectively. This demonstrates that aerial counts consistently document more redds than visual counts on the Hanford Reach, providing a better estimate of overall redd abundance and distribution. However, the relationship between the visual and aerial redd counts is not consistent, likely due to the variability in visual redd counts. Thus, in order to obtain the best estimates of redd abundance and location, aerial photographs would need to be collected and analyzed annually.

The relationship between annual visual fall Chinook salmon redd counts collected by the DOE-RL and the annual adult fall Chinook salmon escapement estimates generated for the Hanford Reach by WDFW is depicted in Figure 9. A regression analysis indicated that visual redd counts are a strong predictor of the WDFW escapement estimates, $F(1,53) = 340.6$, $p<0.001$. The relationship appears linear at all escapement levels.

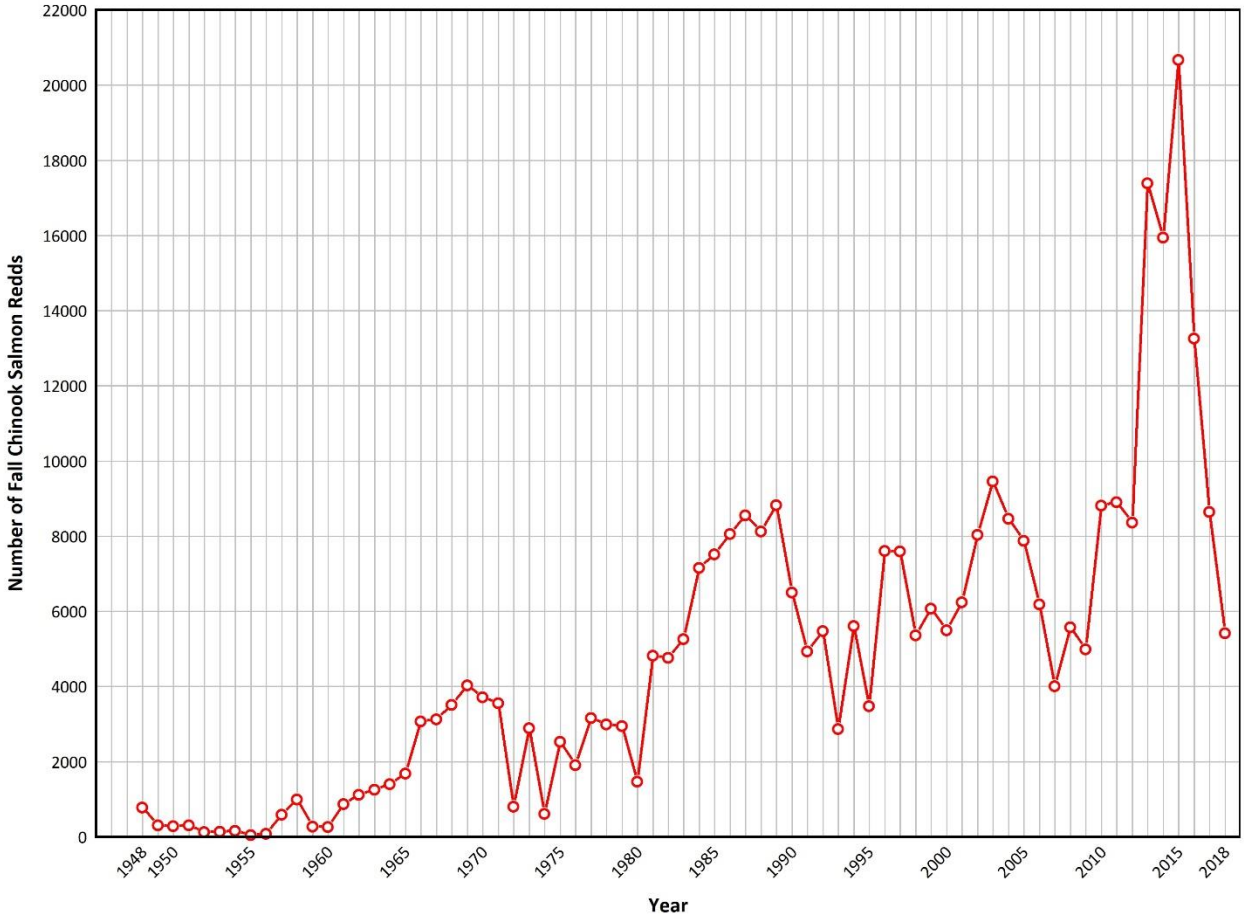

Figure 8. Visual Hanford Reach Fall Chinook Salmon Redd Counts 1948 to 2018

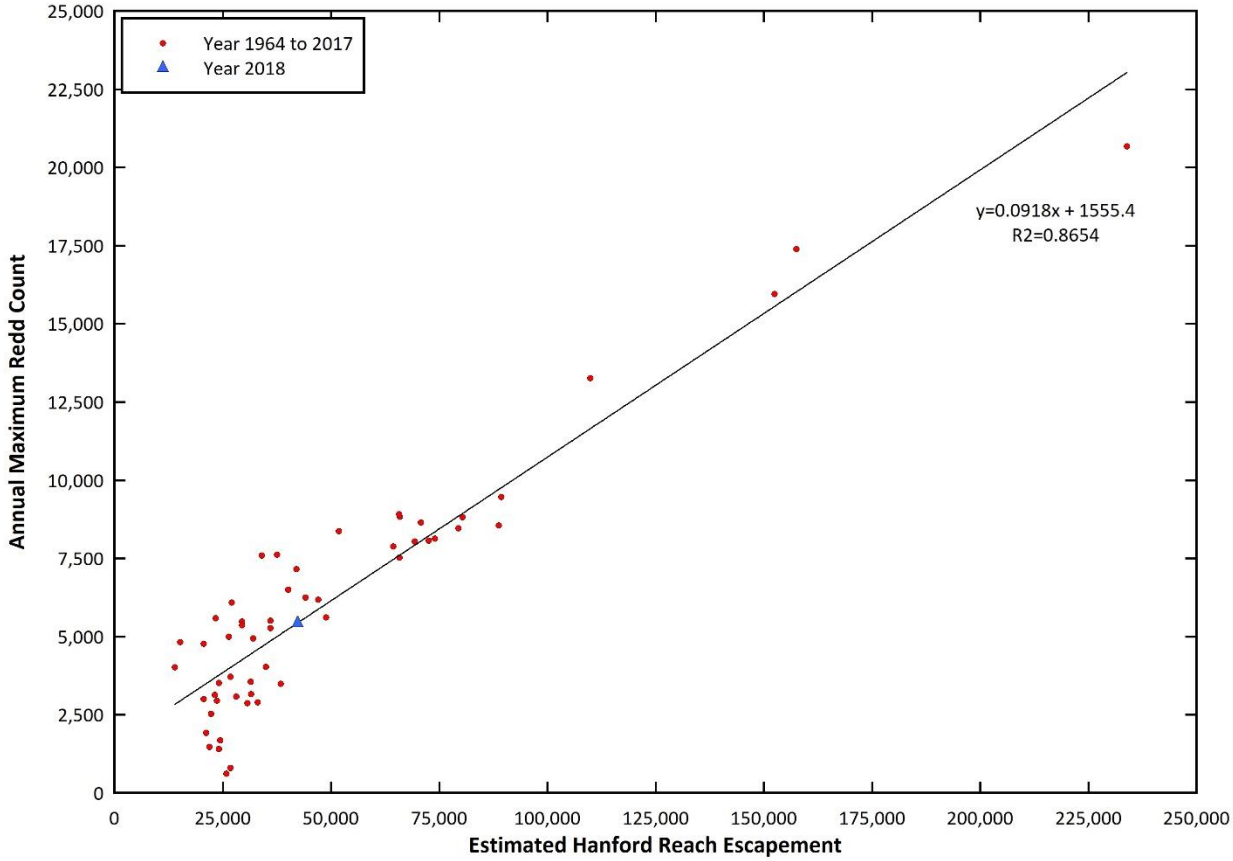

Figure 9. Relationship Between Annual Visual Fall Chinook Salmon Maximum Redd Count and Estimated Hanford Reach Escapement 1964 to 2018

Redd density was analyzed as a parameter indicating habitat quality, assuming that the most highly sought habitats in the river attract the most spawning activity. Redd density varied between 0 and 220 redds per hectare in 2018 (Figures 10, 11, and 12).

Two datasets (2013 and 2018) of aerial photograph redd counts now exist for the entire Hanford Reach. The 2013 dataset depicts a very high escapement level of adult fall Chinook salmon into the Hanford Reach, estimated at over 157,000, the second highest recorded since 1948. The dataset likely represents most of the locations used for spawning in this section of the Columbia River with the exception of a stretch along the Benton County shoreline inside of Locke Island and a small extent along the Franklin County shoreline near Homestead Island where photograph gaps occurred. The 2018 dataset characterizes a low escapement level of adult fall Chinook salmon into the Hanford Reach, estimated at 42,277, the lowest recorded since 2009, and likely represents the optimal spawning habitat in this section of the Columbia River. An analysis of the two data sets together supports this theory, because the spawning areas utilized in 2018 mostly occurred within the areas observed in 2013, and spawning in 2018 occurred in the highest density spawning areas from 2013. Figures 13, 14, and 15 illustrate both of these datasets.

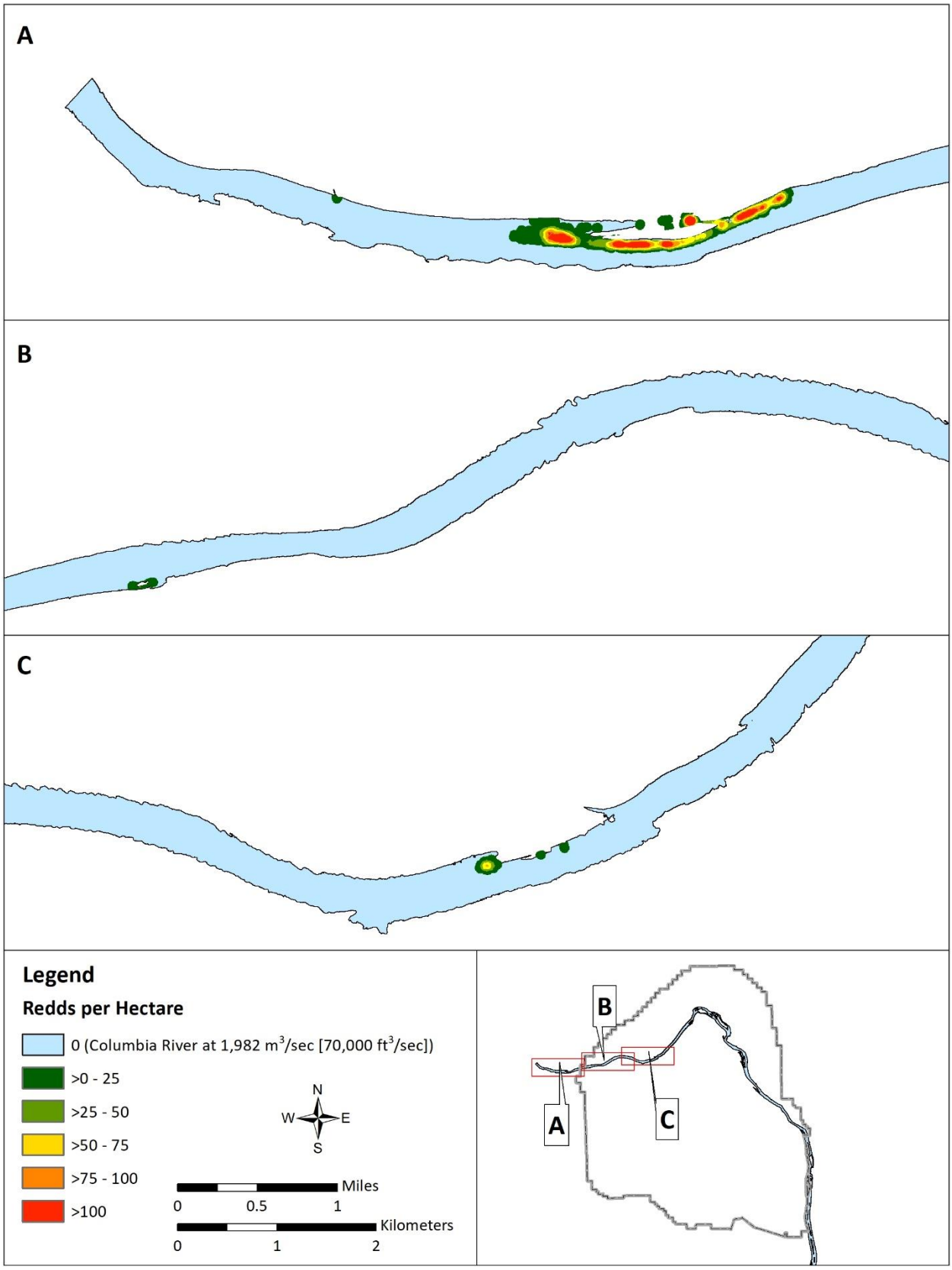

Figure 10. Upper Hanford Reach Fall Chinook Salmon Redd Density for 2018

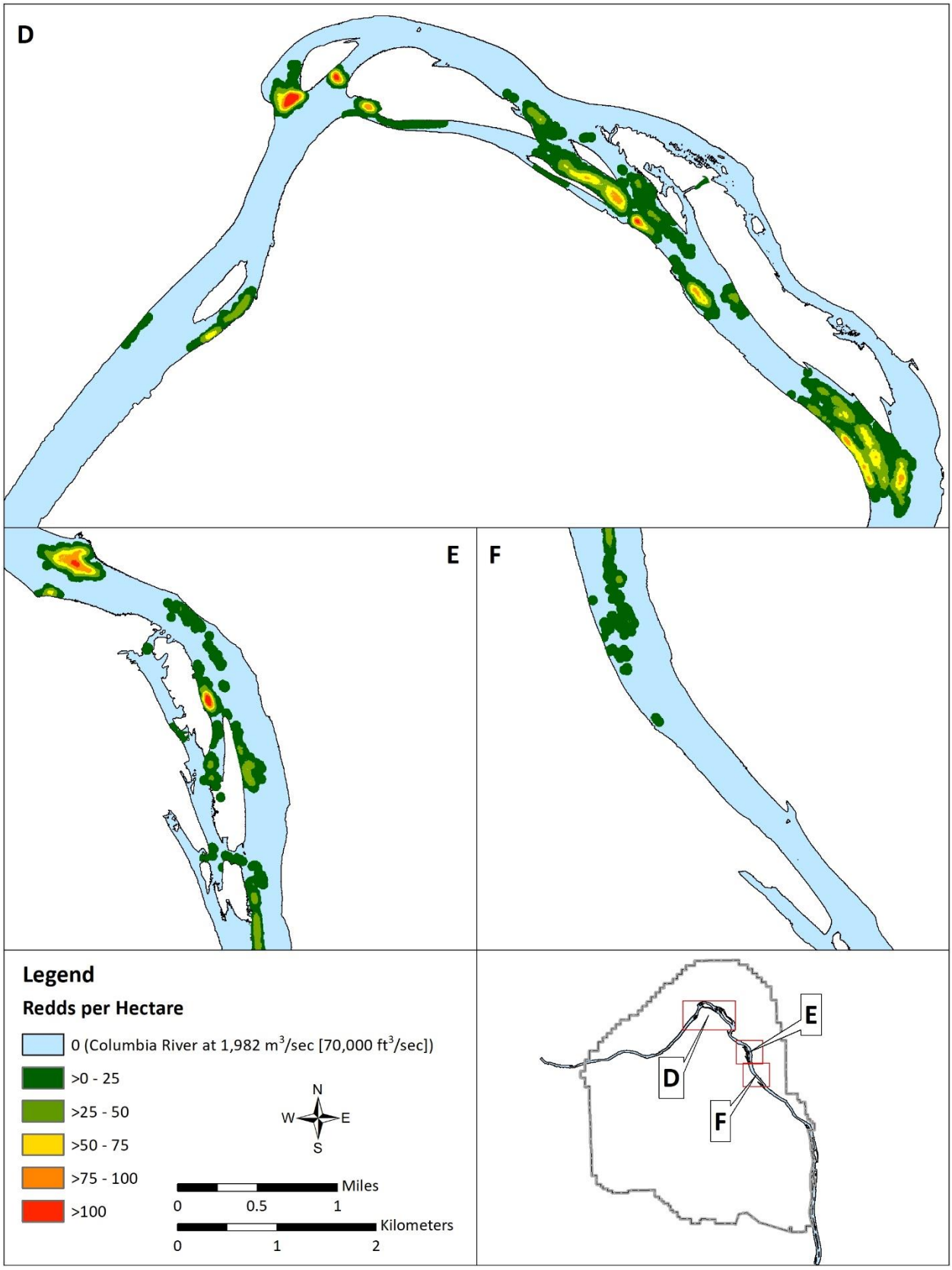

Figure 11. Middle Hanford Reach Fall Chinook Salmon Redd Density for 2018

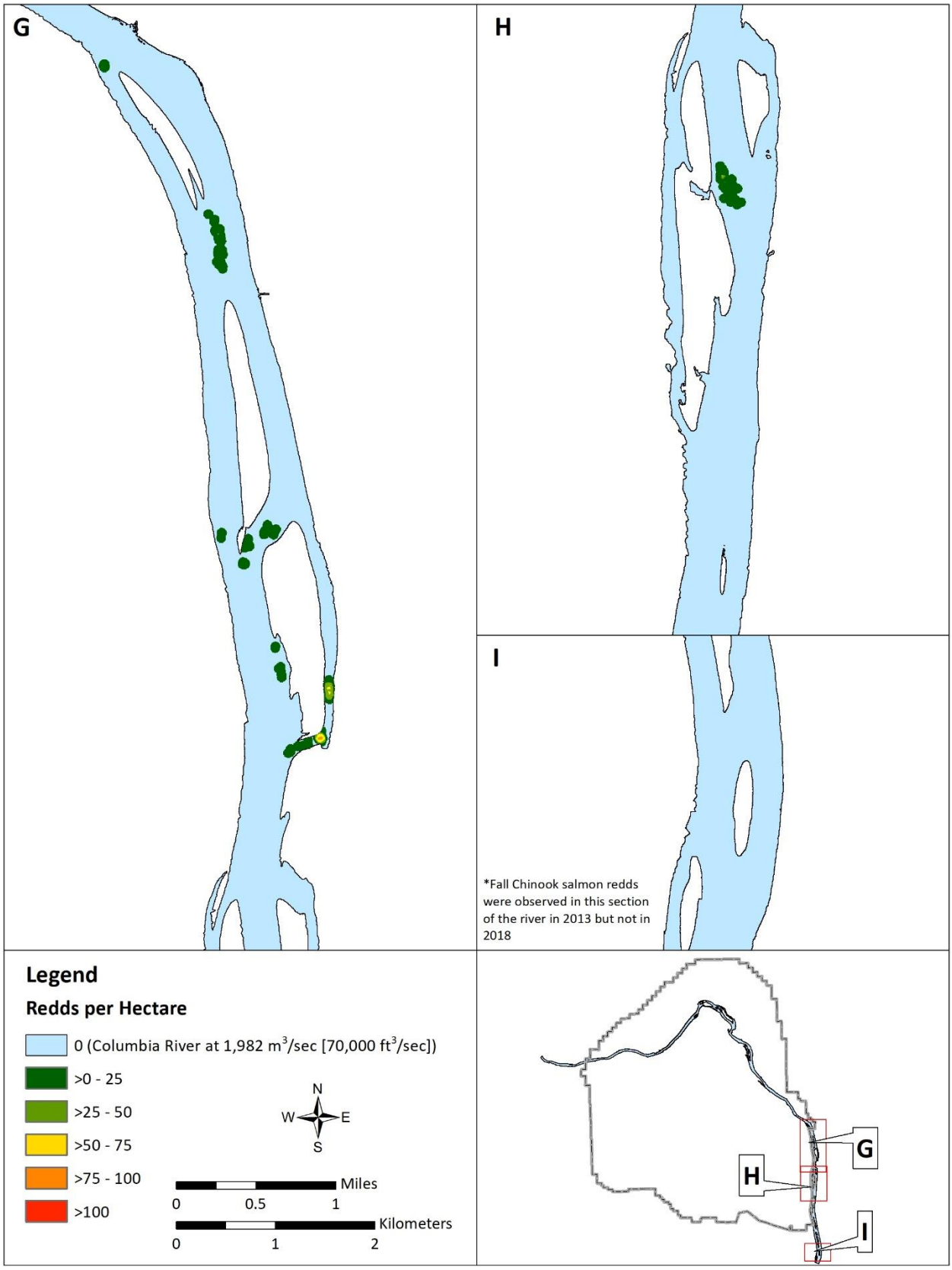

Figure 12. Lower Hanford Reach Fall Chinook Salmon Redd Density for 2018

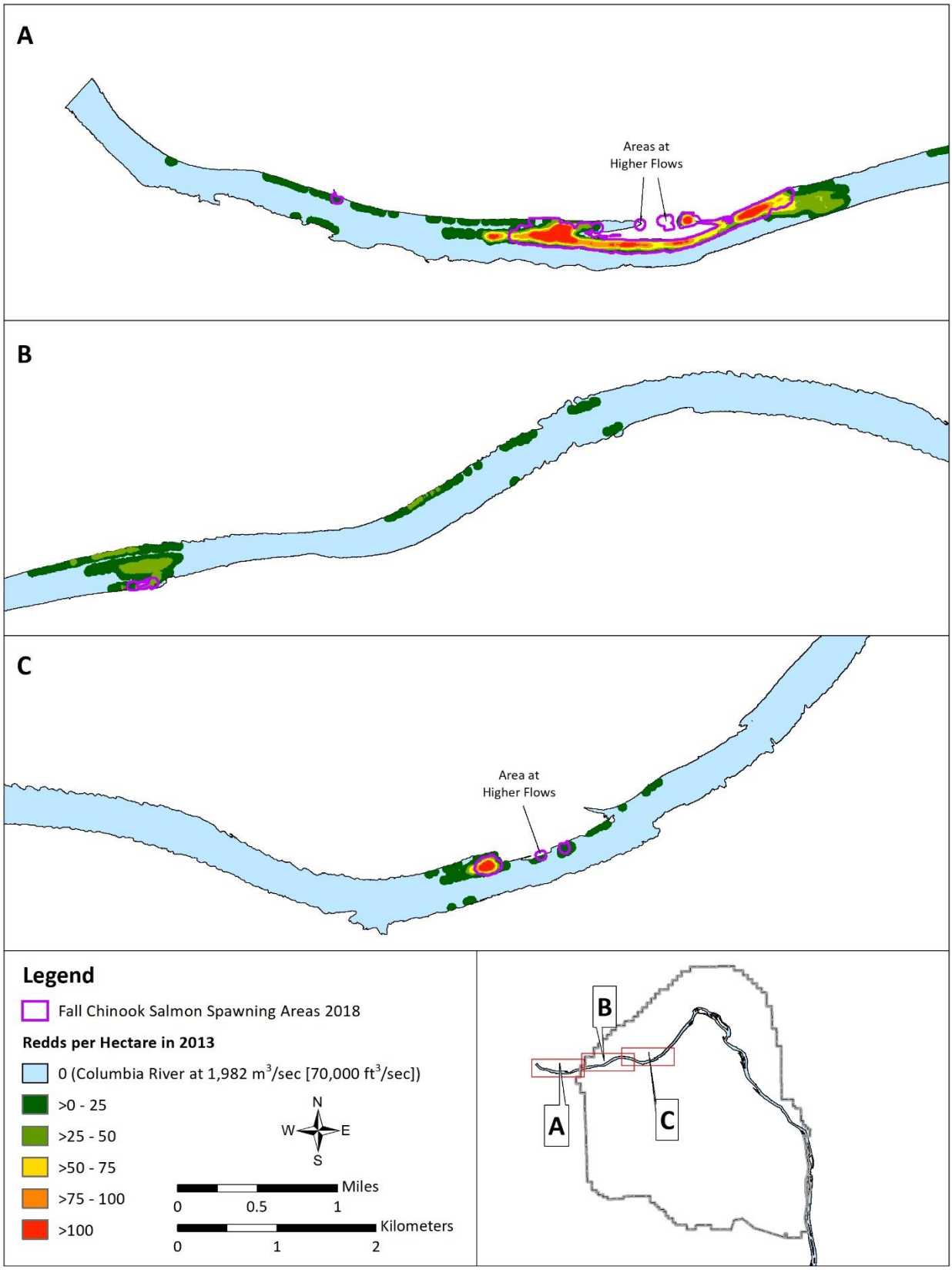

Figure 13. Upper Hanford Reach Fall Chinook Salmon Spawning Areas from 2018 Overlain on Redd Density from 2013

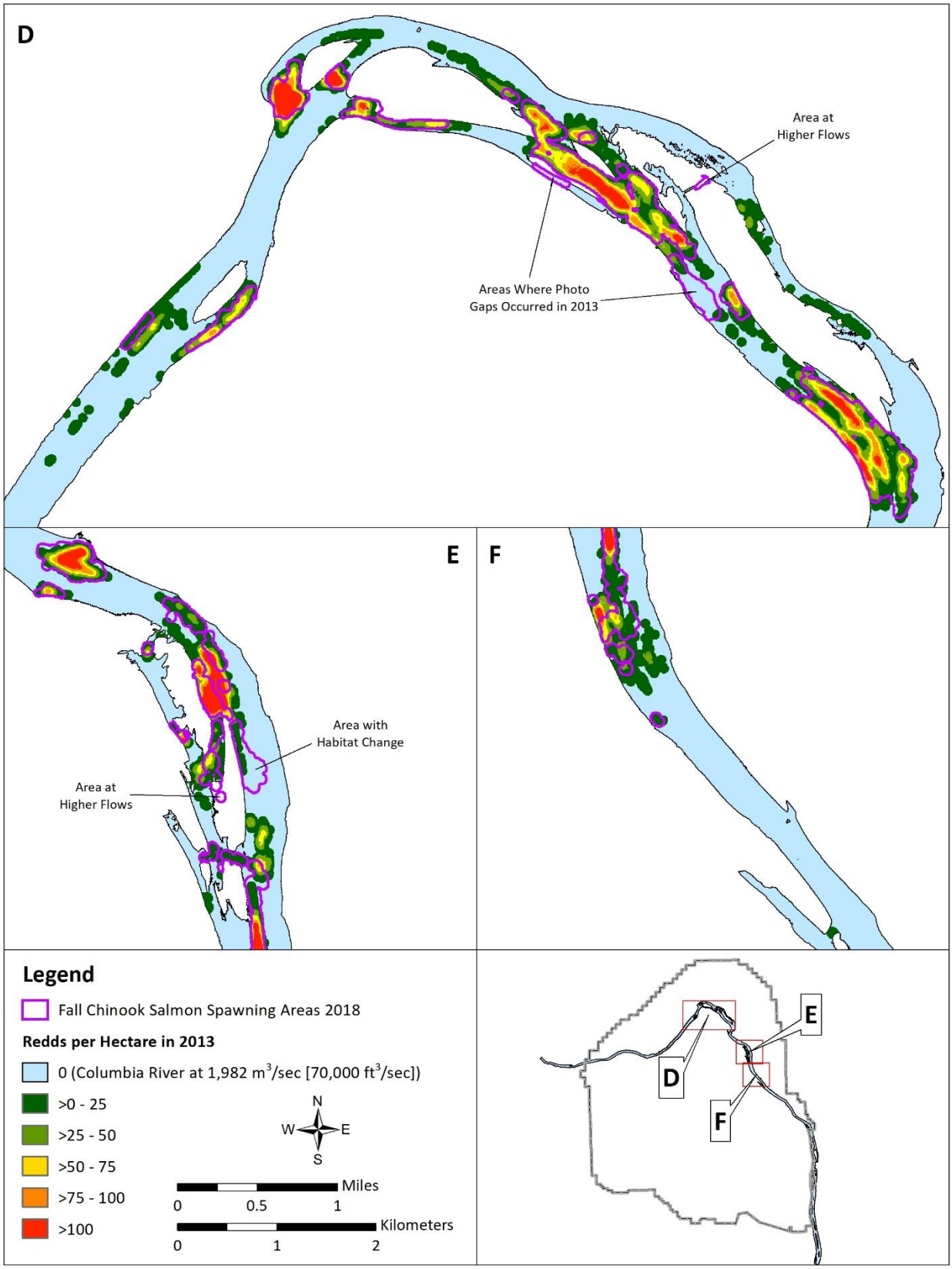

Figure 14. Middle Hanford Reach Fall Chinook Salmon Spawning Areas from 2018 Overlain on Redd Density from 2013

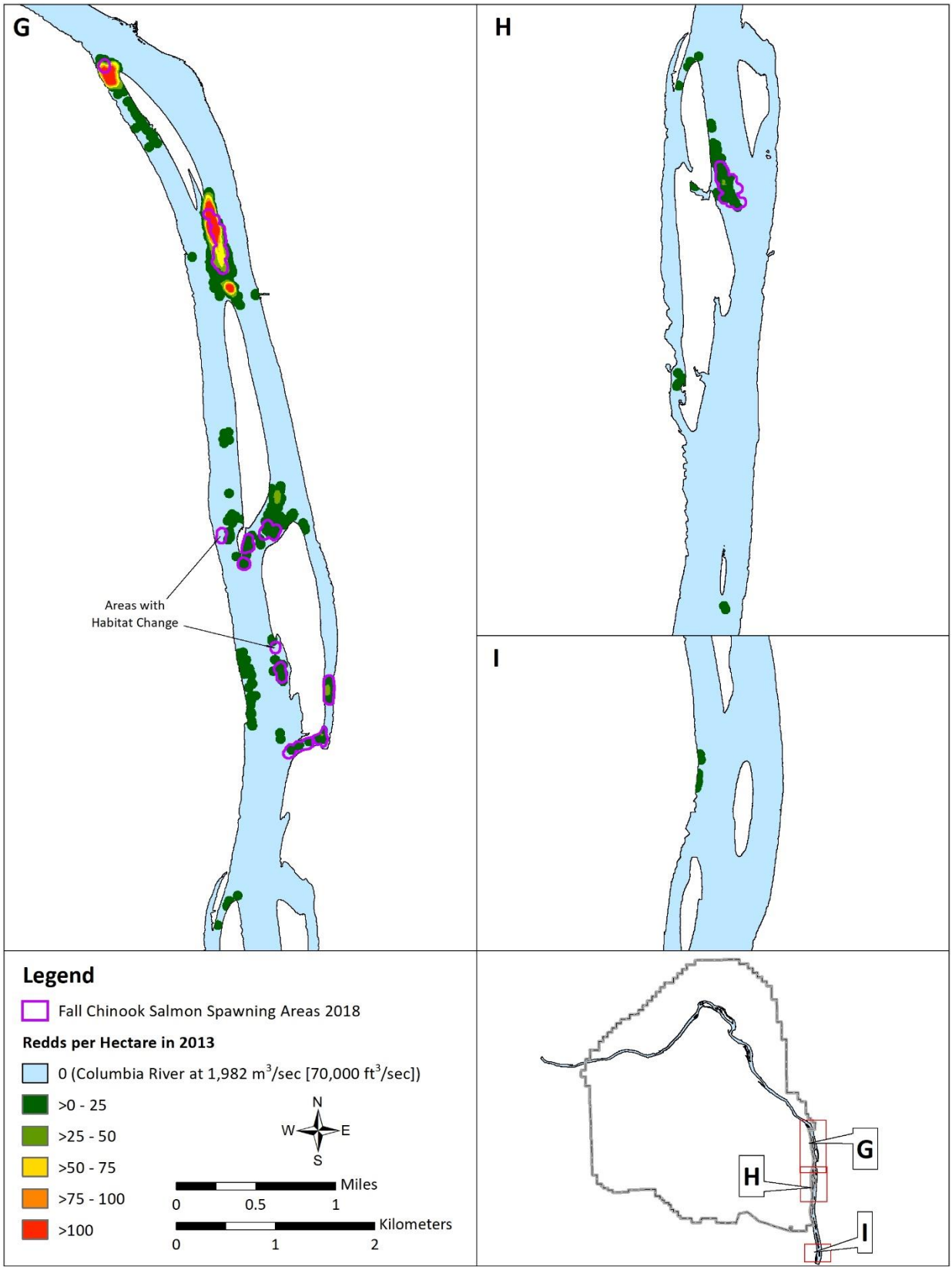

Figure 15. Lower Hanford Reach Fall Chinook Salmon Spawning Areas from 2018 Overlain on Redd Density from 2013

The distribution of redds in 2018 generally overlaps the distribution of redds in 2013 but is spatially contracted (Figures 13, 14, and 15). There are a small number of areas where redds were constructed in 2018 that were not observed in 2013. The 2018 dataset captured the areas missed in photograph gaps in 2013. Two of these areas occur on the Hanford Site shoreline near Locke Island. Redds were observed during 2018 at higher elevations than in 2013, above the 1,982 m^3/sec (70,000 ft^3/sec) flow level. This was documented at Vernita Bar, Locke Island, and 100-F Islands. Approximately 1.1% of redds were built above the 1,982 m^3/sec (70,000 ft^3/sec) flow level in 2013, while a significantly higher proportion (4.0%) of redds were constructed above this level in 2018 (Fisher's exact test, p-value <0.001). The HRFCPP restricts daytime flows not to exceed 1,982 m^3/sec (70,000 ft^3/sec) for 12 continuous hours in order to minimize redd construction at higher elevations. In the areas where redds were observed above the 1,982 m^3/sec (70,000 ft^3/sec) flow level, spawning may have occurred at night when flow levels are allowed to exceed 1,982 m^3/sec (70,000 ft^3/sec). The critical flow elevation for 2013 and 2018 was 1,841 m^3/sec (65,000 ft^3/sec), as determined during redd counts on Vernita Bar per the requirements of the HRFCPP. McMichael et al. (2005) found that fall Chinook salmon will spawn at night downstream of the Wanapum Dam on the Columbia River (just upstream of the Hanford Reach). Daytime flows were similar in 2013 and 2018 but nighttime flows were higher in 2018 than 2013. Daytime flows averaged 1,730 m^3/sec (61,100 ft^3/sec) (range: 1,087 to 2,945 m^3/sec [38,400 to 104,000 ft^3/sec]) in 2013 and 1,724 m^3/sec (60,900 ft^3/sec) (range: 1,051 to 1,988 m^3/sec [37,100 to 70,200 ft^3/sec]) in 2018. Nighttime flows averaged 2,820 m^3/sec (99,600 ft^3/sec) (range: 1,308 to 5,324 m^3/sec [46,200 to 188,000 ft^3/sec]) in 2013 and 3,143 m^3/sec (111,000 ft^3/sec) (range: 1,079 to 6,739 m^3/sec [38,100 to 238,000 ft^3/sec]) in 2018. Changing habitat characteristics may be another reason redds were in areas in 2018 but not in 2013. This may be occurring near the 100-F Islands where spawning substrates may be moving; additional research into bathymetry conditions would be necessary to confirm this hypothesis.

Redds were significantly clustered in 2013 (nearest neighbor ratio = 0.338871; z-score = -202.697435; p-value <0.001) and 2018 (nearest neighbor ratio = 0.231237; z-score = -139.638849; p-value <0.001). In 2013, the mean nearest neighbor redd (center of redd to center of redd) was 7.5 m (24.6 ft) with a range of 1.8 to 229.3 m (5.9 to 752.3 ft). Ninety-five percent of the redds in 2013 were within 13.7 m (44.9 ft) of another redd (center of redd to center of redd). In 2018, the mean nearest neighbor redd was 8.6 m (28.2 ft) with a range of 2 to 248 m (6.6 to 813.6 ft). Ninety-five percent of the redds in 2018 were within 16.4 m (53.8 ft) of another redd.

The size of individual redds observed in 2018 were similar to the size of the redds observed in 2013 (3 m^2 to 28 m^2 [32 ft^2 to 301 ft^2]) and consistent with size ranges recorded by other researchers on the Hanford Reach. Chapman et al. (1986) found redd sizes on Vernita Bar between 1978 and 1983 averaged 17 m^2 [183 ft^2] and ranged from 1.3 m^2 to 33 m^2 [14 ft^2 to 355 ft^2]. Visser et al. (2002) measured redd sizes from aerial photographs and found redds ranged from 18.7 to 23.3 m^2 (201.3 to 250.8 ft^2) in 1994 and 21.3 to 27.5 m^2 (231.4 to 296.0 ft^2) in 1995.

In general, the high density spawning areas (greater than 25 redds per hectare) in 2018 align with the high density spawning areas in 2013. These areas are likely the most optimal spawning areas. The merging of redd density maps from 2013 and 2018 display the most optimal spawning areas on the Hanford Reach (Figure 16, 17, and 18). Knowing these areas can help managers avoid potential impacts of Hanford Site operations to critical fall Chinook salmon spawning habitats.

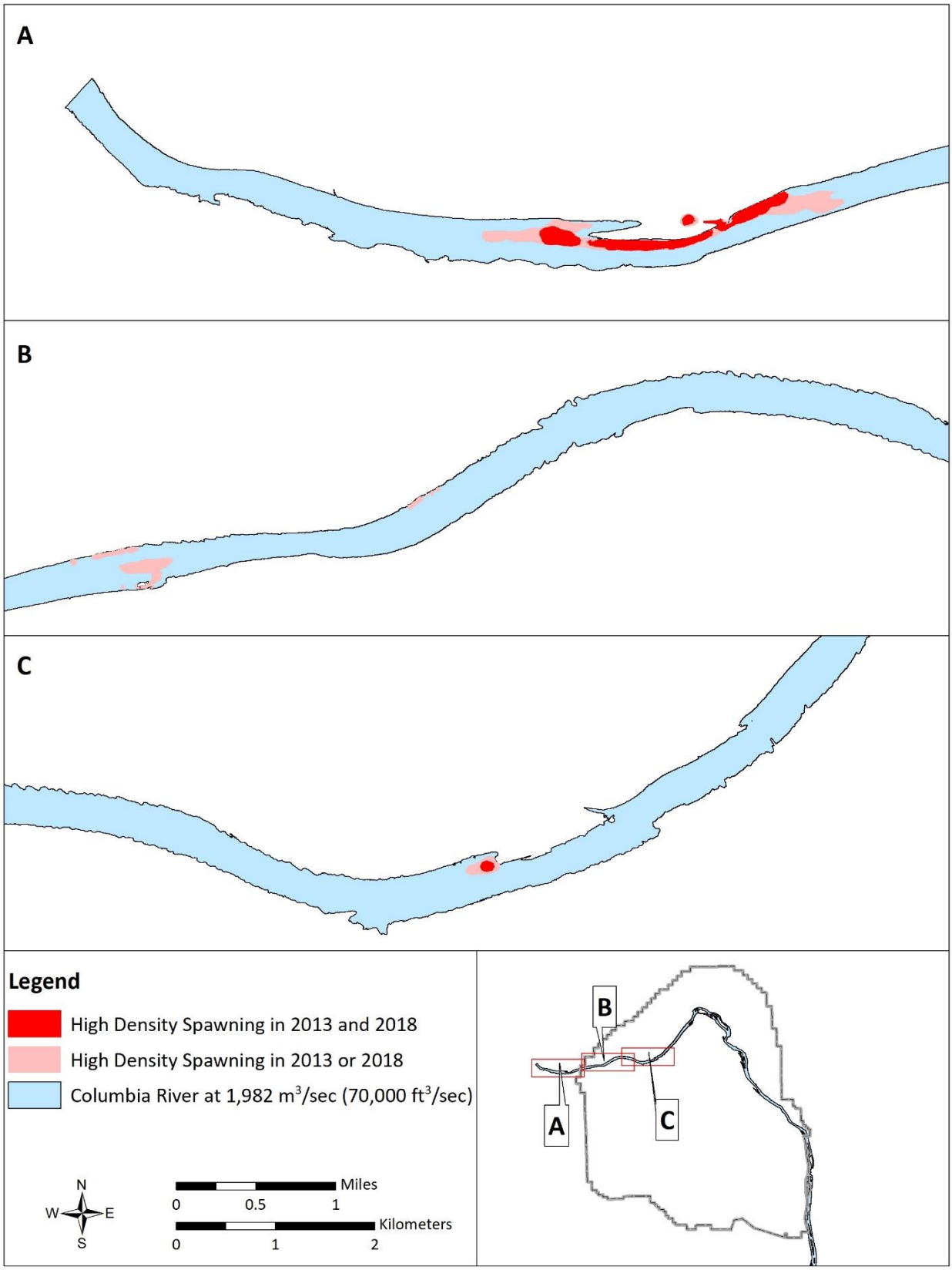

Figure 16. Upper Hanford Reach Fall Chinook Salmon High Density Spawning Areas (greater than 25 Redds per Hectare) from 2013 and 2018

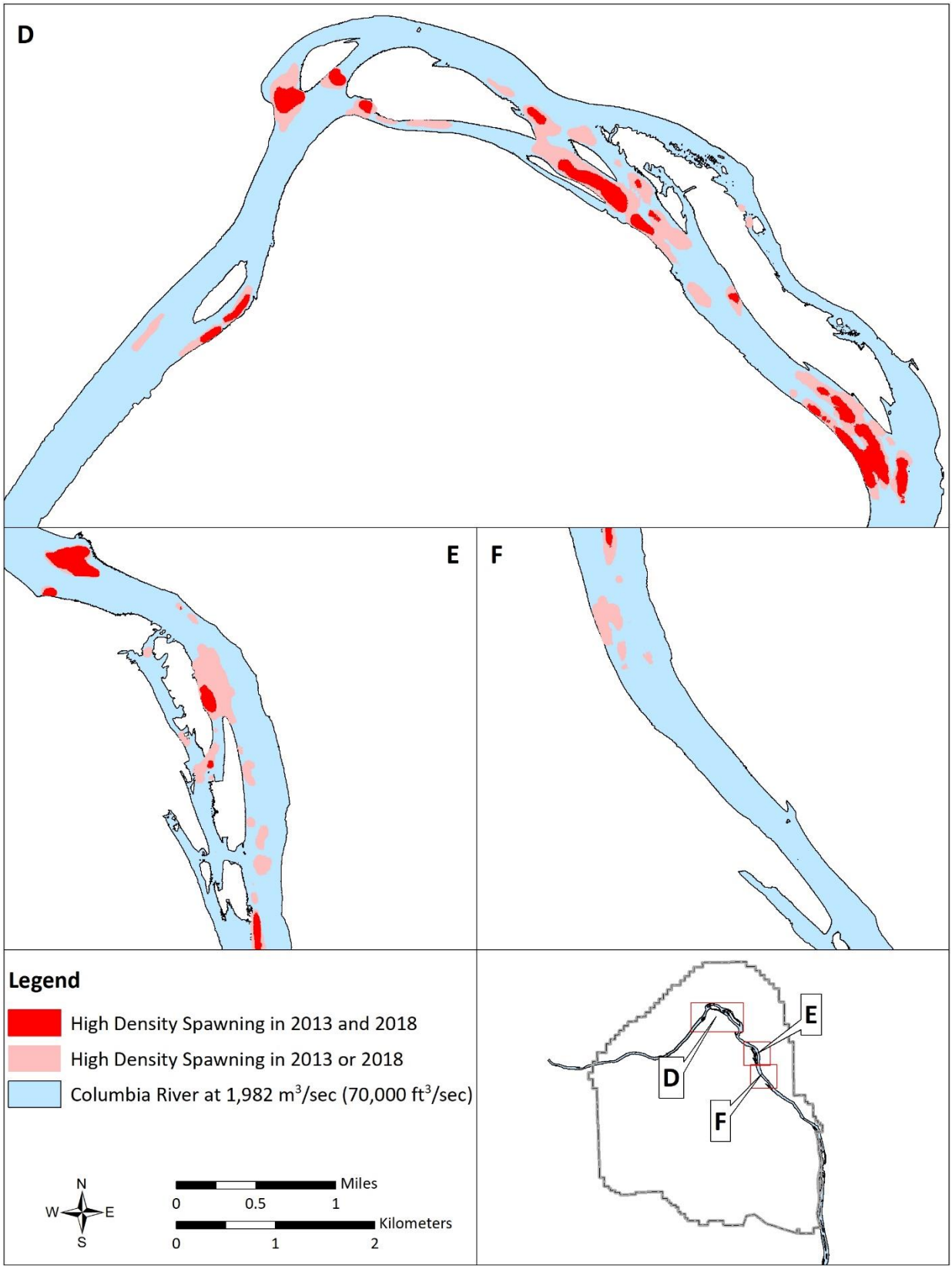

Figure 17. Middle Hanford Reach Fall Chinook Salmon High Density Spawning Areas (greater than 25 Redds per Hectare) from 2013 and 2018

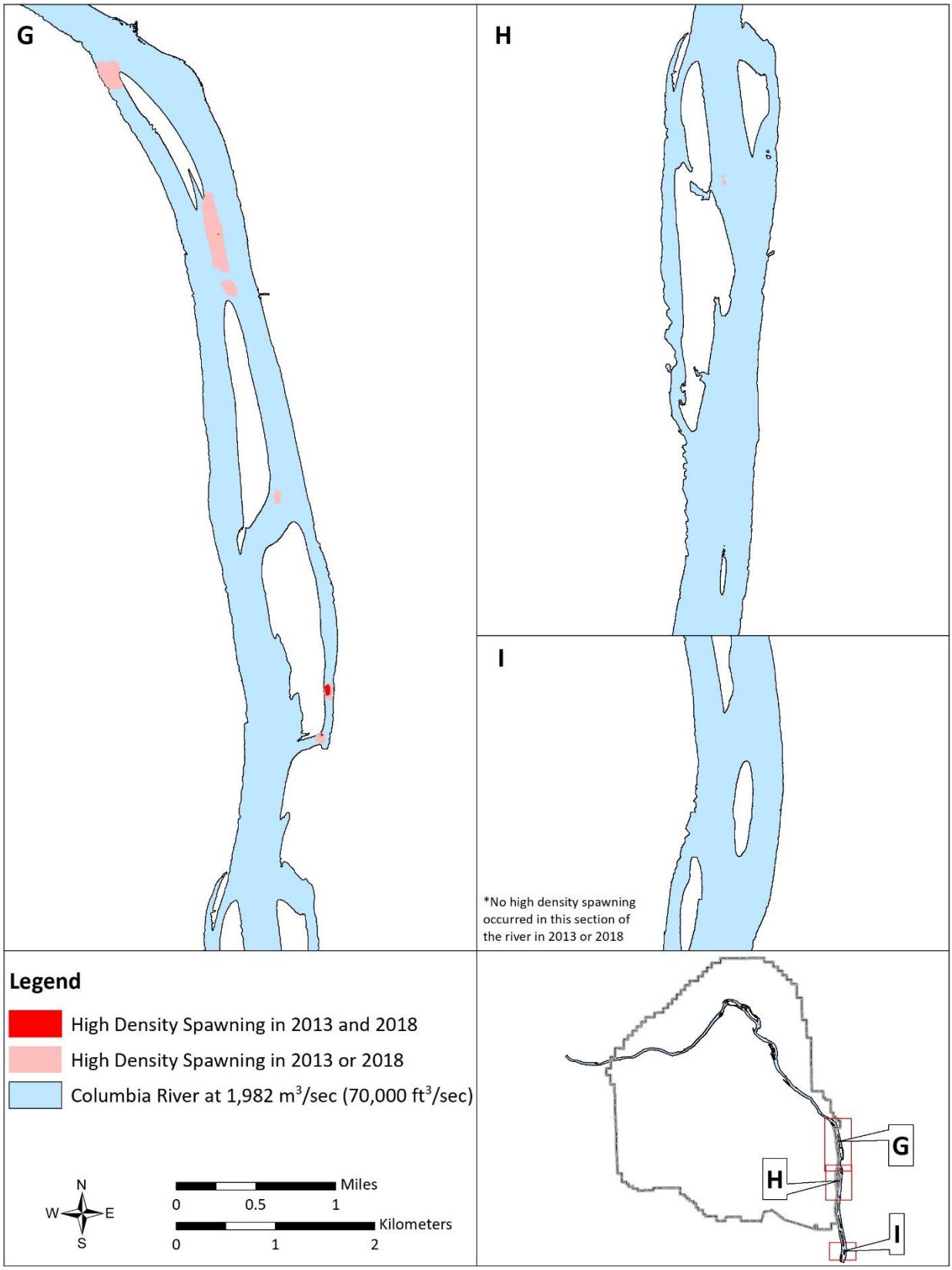

Figure 18. Lower Hanford Reach Fall Chinook Salmon High Density Spawning Areas (greater than 25 Redds per Hectare) from 2013 and 2018

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