Investigating differences between field-measured and photo-interpreted unvegetated channel width in a braided river system: a Platte River case study

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Abstract

The central Platte River in Nebraska, USA has undergone substantial channel narrowing since basin settlement in the mid-19th century. Many researchers have studied the causes of channel narrowing and its implications for endangered species that use wide shallow channel segments with barren sandbars. As a result, changes in habitat metrics such as unvegetated channel width have been studied numerous times. With few exceptions, these measures are estimated from aerial imagery without mention of error in relation to actual channel conditions. This issue is not unique to central Platte River studies as there appears to be a general lack of commentary regarding the direct comparison of channel planform characteristics interpreted from aerial imagery as compared to those measured in the field. Here we present a case study where data collected by the Platte River Recovery Implementation Program (Program) was used to make multiple comparisons between three years of field-measured unvegetated channel width and those photo-interpreted from aerial imagery by three different investigators collected annually during summer and fall timeframes. The three investigators interpreted similar widths in almost all cases, indicating that differences were data-related not due to the bias of individual investigators. Photo-interpretation from fall imagery resulted in estimates of unvegetated channel width that were more consistent with measurements collected in the field than estimates derived using June imagery. Differences were attributed to three main factors: 1) influences of discharge on photo-interpretation of unvegetated channel width; 2) increases in vegetative cover throughout the growing season; and 3) resolution of imagery. Most importantly, photo-interpretation of unvegetated widths from imagery collected during peak flow events can result in significant over-estimation of unvegetated channel width.

Keywords:

braided river, field measurements, photo-interpretation, planform channel characteristics, Platte River, unvegetated channel width

1.0 Introduction & Background

At the time of basin exploration in the early 1800s, the central Platte River (CPR) in Nebraska, USA exhibited a wide braided planform characterized by 900 – 1,500 m channel widths largely free of in-channel vegetation (Eschner et al., 1983; Johnson, 1994; Simons and Associates, 2000; Murphy et al., 2004; Schumm, 2005). Basin-wide settlement and water development beginning in the mid-1800s resulted in extensive alteration of hydrologic, sediment, and vegetation disturbance regimes in the CPR (Simons and Associates, 2000; Murphy et al., 2004; Schumm, 2005). The channel within the CPR narrowed in response to these alterations through encroachment of riparian cottonwood forest into historically active and largely unvegetated channel areas (Johnson, 1994). As a result, the contemporary CPR has become a complex multi-channel system with an anastomosed to braided planform where channel widths have decreased by an average of 80 to 90 percent since the mid-1800s (Murphy et al., 2004; **Figure 1**).

Studies investigating linkages between channel narrowing in the CPR and habitat reduction for species that use the channel began in the mid to late 20th century and continued into the 21st century. These studies generally involved the evaluation of CPR channel widths and can be classified into two subject categories; biology and geomorphology. Biology-focused studies typically involve measurement and evaluation of channel width at locations where focal species are observed in order to infer species habitat requirements (Atkins, 1979; Lingle et al., 1984; Shenk et al., 1986; Ziewitz, 1987; Biology Workgroup, 1990; Faanes et al., 1994; Austin and Richert, 2005). Geomorphology-focused studies involve the tracking of channel width measurements through time to identify changes in channel morphology due to physical processes (Williams, 1978; Eschner et al., 1983; Johnson, 1994; Murphy et al., 2004; Horn et al., 2012).

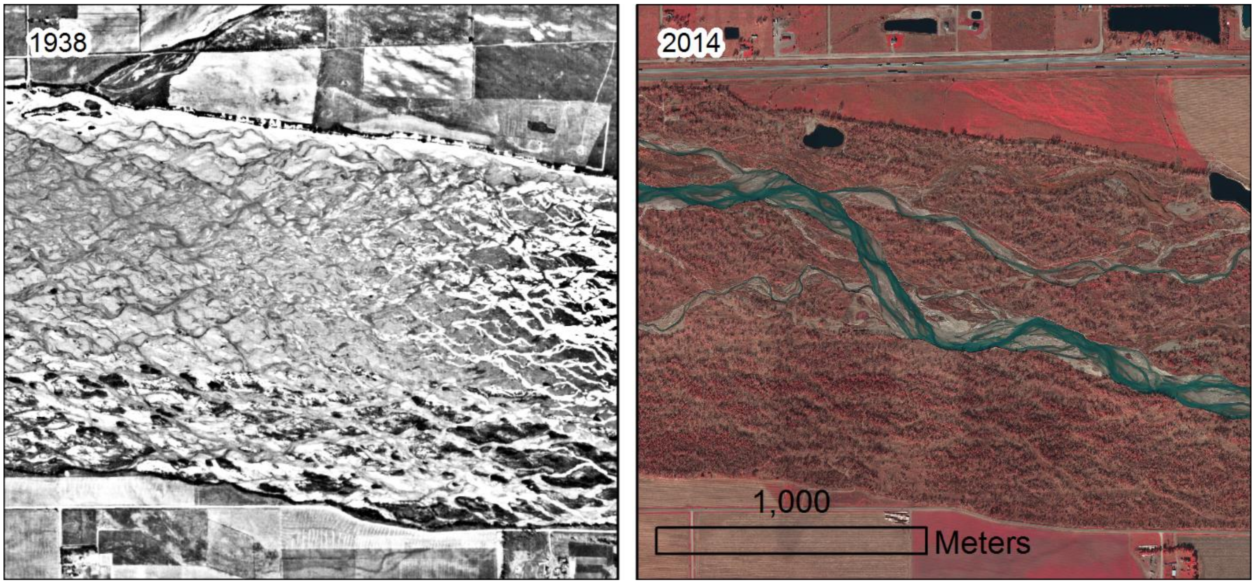


Figure 1. *Comparison of the central Platte River channel near Kearney, Nebraska USA in 1938 and 2014.*

Several definitions of channel width are used in CPR studies including wetted, unvegetated and unobstructed width. Although some width metrics have been measured directly in the field, most are derived through interpretation of aerial imagery or planform maps (Williams, 1978; Atkins, 1979; Lingle et al., 1984; Faanes et al., 1994; Johnson, 1994; Murphy et al., 2004; Horn et al., 2012). Researchers on other river systems have investigated systematic errors in channel characteristics estimated from aerial imagery due to georectification and/or random errors due to the precision of feature identification. However, the potential for error associated with estimating channel width measures from aerial imagery currently have not been quantified or discussed. As such, there appears to be a general lack of knowledge about how channel characteristics derived from aerial imagery compare to those measured directly in the field (Mount et al., 2003, Mount and Louis, 2005; Hughes et al., 2006; Swanson et al., 2010).

We used channel characteristic data collected on the CPR as a case study to assess the potential for errors associated with data collection methodology, data quality, timing of data collection efforts, and investigator bias. Specifically, we compared unvegetated channel width measurements collected in the field annually during the summer to widths interpreted from annual aerial imagery series collected in June and October or November (henceforth, fall). We also compared June and fall photo-interpreted widths as well as widths interpreted by three different investigators. These analyses allowed us to: 1) determine if interpreted widths from the three investigators were similar or not; 2) determine if photo-interpreted estimates of unvegetated channel width using aerial imagery collected during the June are similar to those obtained using imagery collected during the fall; 3) determine if measures of unvegetated channel width collected in the field are similar to photo-interpreted estimates obtained remotely using aerial imagery; and 4) evaluate implications for future Program monitoring efforts along the central Platte River.

2.0 Methodology

2.1 Study Area

The focus area of our study is a 145 km reach of the central Platte River extending from Lexington, Nebraska downstream to Chapman, Nebraska USA. This reach of river is known as the Associated Habitat Reach (AHR; **Figure 2**) for three threatened or endangered avian species; whooping crane (*Grus americana*), piping plover (*Charadrius melodus*), and interior least tern (*Sterna antillarum athalassos*; Department of the Interior, 2006). Despite the extensive channel narrowing in the AHR during the 20th century, typical width-to-depth ratios remain greater than 50:1 at most flows and typically range from 100:1 to 300:1 at flows of 35 m^3/s to 230 m^3/s. Flows throughout the AHR are highly variable and can fluctuate >30 m^3/s during a day as they are heavily influenced by diversions and returns associated with agriculture and hydropower uses.

Approximately 50% of the active channel within the AHR is split by large islands comprised of grasslands and riparian cottonwood forests. Smaller, unvegetated sandbars and sandbars covered with annual vegetation are typically submerged by flows >100 m^3/s. The result is a complex multi-channeled anastomosed to braided planform with unvegetated channel widths that are quite sensitive to discharge.

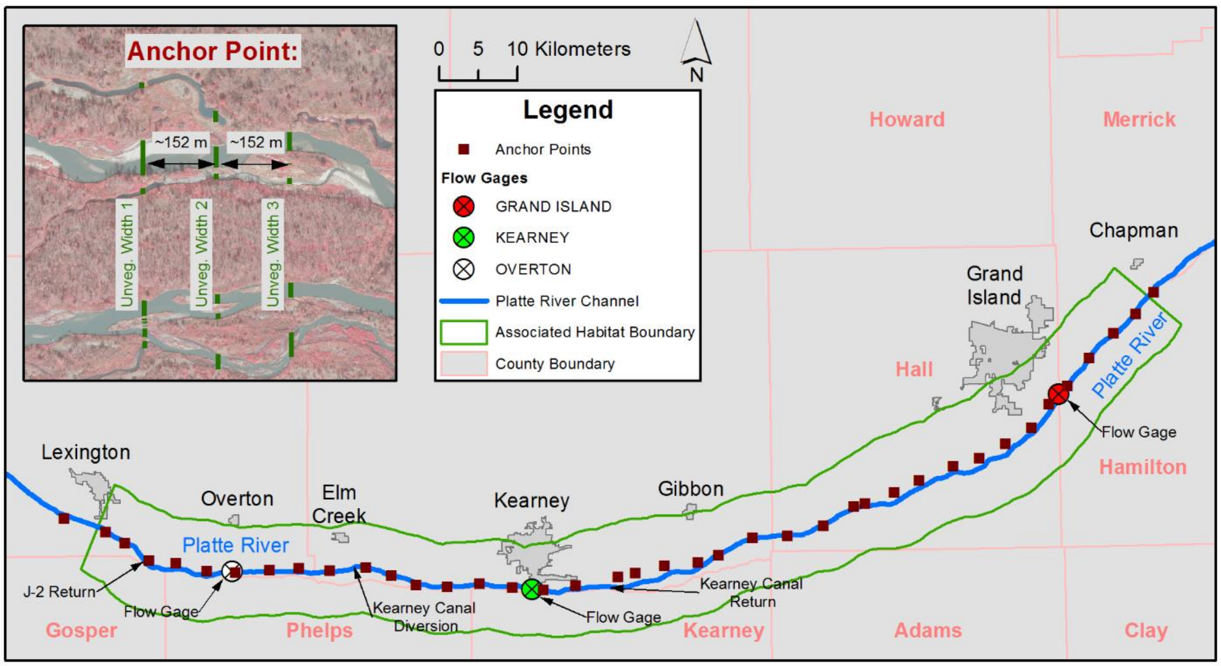


Figure 2. *Associated Habitat Reach (AHR) of the central Platte River including counties, towns and cities, major diversions and returns, USGS flow gages, and anchor point locations within the associated habitat boundary. An example of how unvegetated channel width measurements (green lines) were estimated using aerial imagery is shown in the top left corner.*

2.2 Data

2.2.1 Field-Collected Unvegetated Channel Width Data

Field-measured unvegetated channel width data was collected annually, 2010–2012, through the Program's system-scale geomorphology and vegetation monitoring protocol. The protocol included the collection of topographic and vegetation monitoring data during July and August along transects at 40 anchor point locations distributed at approximately four km intervals throughout the AHR (Program 2010; **Figure 2**). Half (20) of the anchor points spaced at eight km intervals were visited in all years and the remaining 20 anchor points were visited on a 4-year rotation; five anchor points per year. Each anchor point consisted of three transects separated by approximately 152 m (**Figure 2**). Data was collected along 25 anchor points each year with the total number of transects varying from 84 to 87 depending on the number of major flow splits at rotating anchor point locations. A real time kinematic global positioning system (RTK GPS) unit was used to survey topographic features along each transect and to delineate unvegetated channel segments. Data was downloaded from the RTK GPS unit and ESRI ArcMap software was used to measure unvegetated channel segments at each anchor point (Environmental Systems Research Institute, 2012). Lengths of unvegetated channel segments along each transect were added together to develop a field measured total unvegetated channel width for each transect.

2.2.2 Photo-Interpreted Unvegetated Width Data

Aerial imagery collected during June and fall, 2010–2012, was used to develop multi-year, multi-season, and multi-investigator estimates of unvegetated channel width. June imagery was collected at a ground resolution of 0.61 m and fall imagery at a ground resolution of 0.15 m. Data from these three years represented hydrologic conditions ranging from low (2012) to high (2011) flows with 2010 conditions considered to be average. Investigator #3 photo-interpreted unvegetated channel widths for June and fall imagery for each year, 2010 – 2012. This resulted in two photo-interpreted estimates of unvegetated channel width per transect per anchor point per year. Investigators #1 and #2 only photo-interpreted unvegetated widths for fall imagery.

2.3 Statistical Analyses

We compared field-measured and photo-interpreted unvegetated channel width measurements using iterative bootstrap sampling. For each comparison, we randomly drew a sample of 29 transects from the 25 anchor points within each year to compare field-measured and photo-interpreted estimates of unvegetated channel width. Extracting measurements from the same transects for each comparison allowed us to assess similarities of measurements at individual transects, as opposed to only identifying similarities of central tendencies and distributions possible without paired data. Sampling 29 transects each year was utilized to minimize spatial autocorrelation within anchor points. We used unvegetated channel width measurements at sample transects to compare: 1) fall photo-interpreted widths between three investigators; 2) June versus fall photo-interpreted widths; and 3) field-measured versus photo-interpreted widths from June and fall imagery. All analyses were conducted using Program R (R Development Core Team, 2013).

We considered field measurements to be the "true" measure of unvegetated channel width because of our ability to easily identify vegetation in the field. Differences between field-measured and photo-interpreted width differences in photo-interpreted estimates were assumed to represent the "error" in the photo-interpreted estimates. For example, if the field measurement was 100 meters (m) and the photo-interpreted estimate was 120 m, the 'error' associated with the photo-interpreted estimate was considered to be +20.0 m.

Paired t-tests were used to assess differences in photo-interpreted and field-measured unvegetated channel width at each transect. Separate paired t-tests were performed to assess differences between estimates derived using June and fall imagery (**Table 1**). We used a repeated measures ANOVA to assess differences in estimates derived using fall imagery by the three investigators. We used a confidence level of 95% ($\alpha = 0.05$) to determine whether estimates were significantly different. P-values of the paired t-test and ANOVA were recorded and repeated over 1,000 iterations with replacement for each comparison; analogous to a bootstrap method of resampling. We assessed the percentage of iterations where significant differences occurred in our three annual comparisons and generated boxplots to assess the central tendencies and distribution of investigator error and unvegetated width values.

3.0 Results

3.1 Evaluation of Fall Photo-Interpreted Widths between Three Investigators

We found investigator estimates of unvegetated channel width were very similar within years. Of the 1,000 samples within each year, we found zero percent of estimates were significantly different between investigators in 2010 and 2011 and only 2% were significantly different in 2012 (**Table 2**). Based on the 1,000 samples, the largest discrepancies between the mean of investigator estimates was in the 2010 where average unvegetated channel width estimates varied by 37 m (146 m – 183 m; **Table 2**).

Table 1. *Comparison of estimates of unvegetated channel width from fall imagery by three investigators and error in these estimates as compared to field measurements for investigator #3, based on iterative bootstrap sampling.*

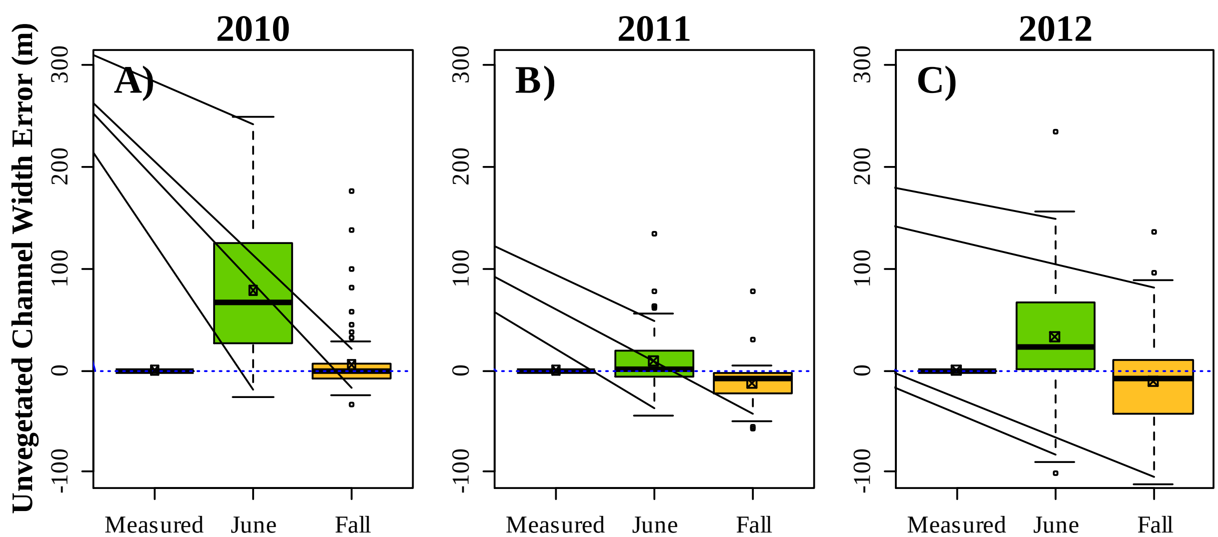
		Year		
Metric	**Investigator**	**2010**	**2011**	**2012**
		Average (Standard Deviation)		
Average Estimates of Unvegetated Channel Width (m)	Investigator #1	146 (60)	193 (83)	113 (46)
	Investigator #2	183 (64)	169 (73)	132 (50)
	Investigator #3	173 (55)	180 (83)	137 (49)
Significant Differences Between Investigators (%)	Investigator(s) #1,#2,#3	0	0	2

3.2 Evaluation of June versus Fall Photo-Interpreted Widths

From 2010–2012, 100% of all bootstrapped estimates of June and fall unvegetated channel width, as photo-interpreted by investigator #3, were significantly different. Photo-interpreted unvegetated channel width derived from June imagery had a mean of 239.4 m (SD = 69.5 m) in 2010, 220.1 m (SD = 90.6 m) in 2011, and 173.0 (SD = 77.6 m) in 2012. Photo-interpreted unvegetated channel width derived from fall imagery had a mean of 166.1 m (SD = 71.4 m) in 2010, 199.3 m (SD = 86.7 m) in 2011, and 130.0 m (SD = 60.6 m) in 2012.

3.3 Evaluation of Field-Measured versus Photo-Interpreted Widths from June and Fall Imagery

Photo-interpreted unvegetated channel widths from fall aerial imagery were generally more similar to field measurements than estimates derived from June imagery, as photo-interpreted by investigator #3 (**Figure 3**). This was most apparent in 2010 and 2012 where the central tendency of unvegetated channel widths derived from June imagery were positively biased (i.e., overestimated) and estimates derived from fall imagery tended to be unbiased or biased slightly negative (i.e., underestimated; **Figure 3**). Differences in unvegetated channel widths derived from June imagery were significantly different in 100% of the 2010 iterations, 33% of the 2011 iterations and 87% of the 2012 iterations. Differences for fall imagery were significant in 3% of the 2010 iterations, 91% of the 2011 iterations and 15% of the 2012 iterations.



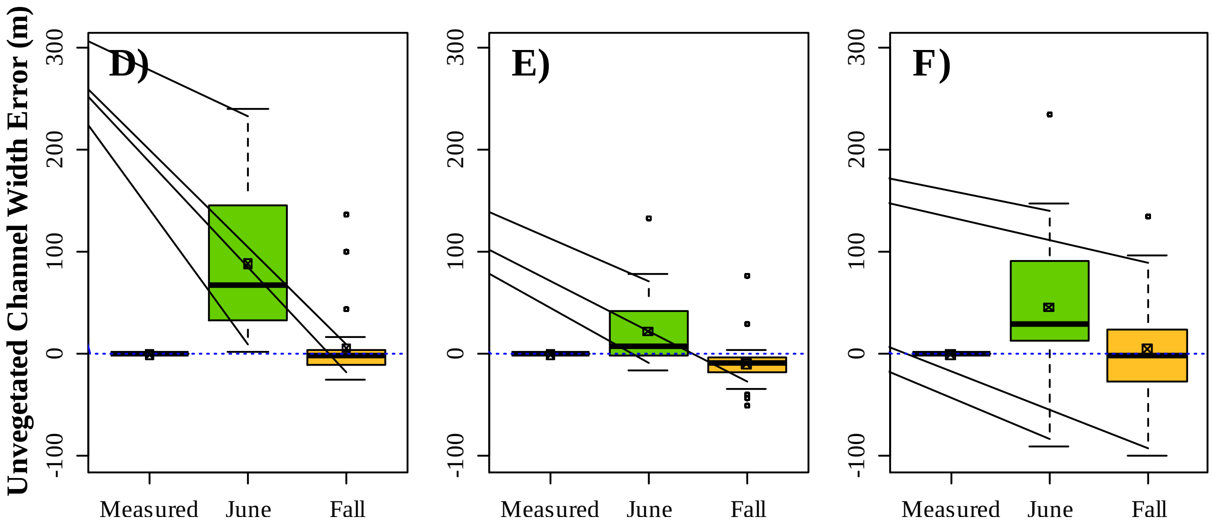


Figure 3. *Distribution of photo-interpreted estimates of unvegetated channel width error (top) and bootstrapped estimates of error (bottom). Boxes represent 25th – 75th percentiles, whiskers represent the range of data, dots represent extreme values, and lines in the center of the boxes and the small target-like boxes represent the median and average values for all observations, respectively. Dashed line at y=0 represents zero error in estimates obtained using imagery.*

Table 2. *Mean and standard deviation of errors in photo-interpreted estimates of unvegetated channel width collected by investigator #3 as compared to field measurements for 1,000 bootstrap samples. "Percent" refers to the percentage of the bootstrap samples where photo-interpreted estimates were significantly different than field measurements at a 95% confidence level (α = 0.05).*

Imagery Dataset	Mean (m)	STDEV (m)	LCI (m)	UCI (m)	Percent
June 2010	88	66	2	241	100
Fall 2010	6	34	-24	137	3
June 2011	23	33	-16	134	33
Fall 2011	-9	23	-50	78	91
June 2012	46	65	-90	235	87
Fall 2012	5	54	-99	136	15

4.0 Discussion

We found the magnitude of difference between the field-measured unvegetated channel widths and the widths interpreted from fall aerial imagery were typically small. The relative difference between field-measured and photo-interpreted widths from June imagery was much larger. Our results indicate unvegetated channel width estimates derived from fall imagery were similar across the three investigators in all but a very few cases in 2012.

The positive bias and magnitude of difference when interpreting unvegetated channel width from June imagery can be partially explained by basin hydrology (**Figure 5)**. June aerial imagery often coincides with the late-spring runoff when flows through the AHR are at or near their annual peak. Field measurements and fall aerial imagery are typically collected after the late-spring runoff when flows are much lower. The timing of data collection affects the unvegetated width measurement because, as an anastomosed to braided system, width-related metrics are sensitive to river discharge. For example, the average flow at Anchor Point #23 during the collection of June and fall 2010 imagery was approximately 210 m^3/s and 22 m^3/s, respectively (**Figure 6**). Many of the vegetated bars present in the October imagery were fully submerged in June due to the much higher flow (**Figures 5 and 6**). Submerged vegetated bars were difficult to identify in imagery, leading to an over-estimation of unvegetated channel width based on that imagery series.

Differences of fall 2011 photo-interpreted and field measurements was most likely attributed to flows as well. Fall flows were considerably different than those experienced during field measurements and statistical accuracy reflected this influence (**Figure 5**). Despite a lack of statistical accuracy, fall estimates at transects were generally very similar to field measurements in 2011 (e.g. averaged <10 m of difference) and the distribution of fall estimates shows a very precise yet negatively biased relationship, which lead to low statistical accuracy of fall estimates. If flows were more similar between the two time periods in 2011, we would expect an increase of statistical accuracy of fall measurements comparable to those observed in 2010 and 2012.

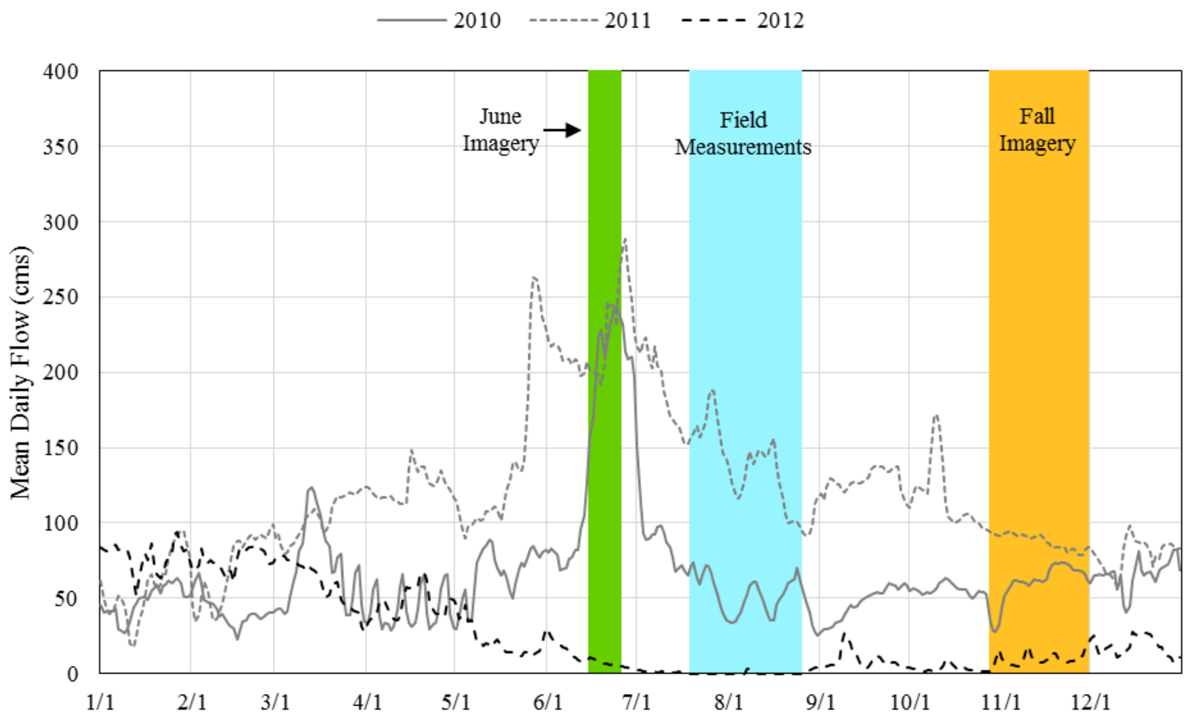


Figure 5. *Time series of Platte River flows measured at the Grand Island, Nebraska USGS gage, 2010–2012. Also shown are typical periods of data collection.*

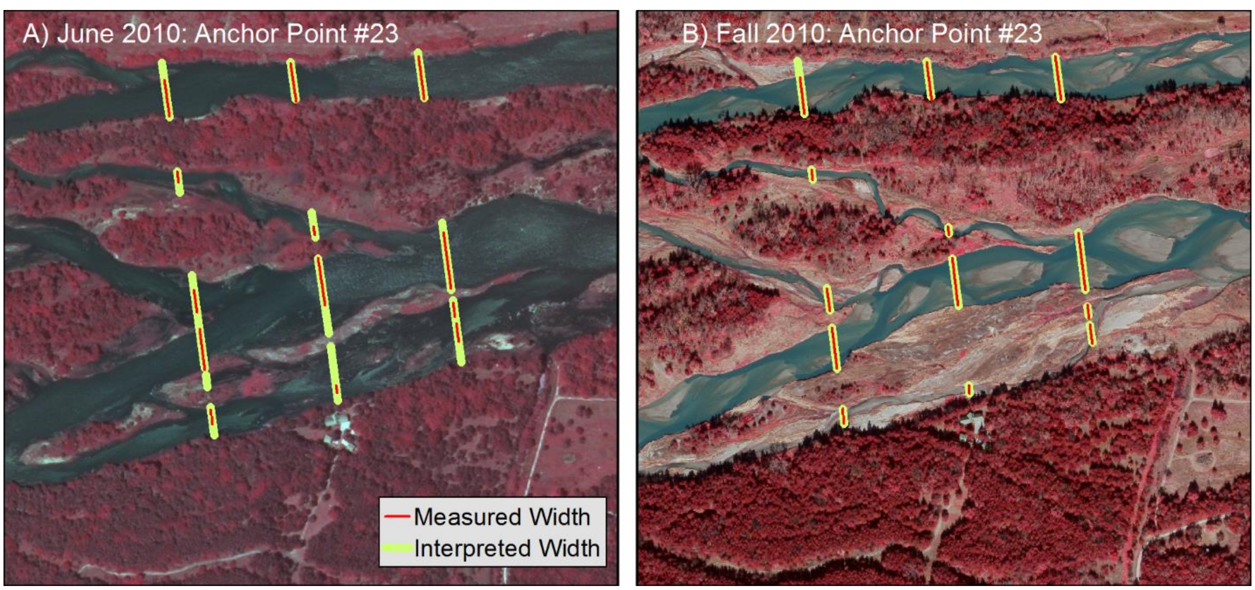


Figure 6. *Anchor Point #23 in aerial imagery collected in June (A) and October (B) of 2010 with photo-interpreted and field-measured unvegetated channel widths along each of the three transects. Average discharge through the Associated Habitat Reach on the date of June imagery collection was 210* m^3/s *while flow on the date of fall imagery collection was 22* m^3/s.

The resolution of imagery also likely contributed to differences in estimates of unvegetated channel width. The ground resolution of fall imagery (0.15 m) was four times finer than the June imagery (0.61 m). This difference is apparent in **Figure 6** where surface features (e.g., sandbars, banks, bedforms, trees, etc.) are more clearly defined in the fall imagery (**Figure 6B**) than the June imagery (**Figure 6A**). Similarly, other researchers have shown that resolution of aerial imagery directly influences the magnitude of the errors in planform characteristics estimated from the imagery (Mount et al., 2003, Mount and Louis, 2005; Swanson et al., 2010). We also believe the coarser resolution of the June imagery likely contributed to the larger estimates of unvegetated channel widths because it was more difficult to distinguish a sandbar as being vegetated unless vegetation was very dense (i.e., very red in the imagery).

In addition to river flow and imagery resolution, another potential source of photo-interpretation error is encroachment of annual vegetation in the channel during the growing season in low flow years. For example, the difference between June and fall photo-interpreted unvegetated channel widths was fairly large in 2012 even though flows during the collection of June and fall imagery were nearly equal due to increased vegetation abundance on low sandbars the fall of 2012 (**Figure 7**). The majority of the channel bed, largely free of vegetation in June following two years of medium to high flows, was exposed during the 2012 growing season and colonized by annual vegetation. Consequently, the unvegetated widths estimated from June imagery were larger than those measured in the field and estimated from fall aerial imagery.

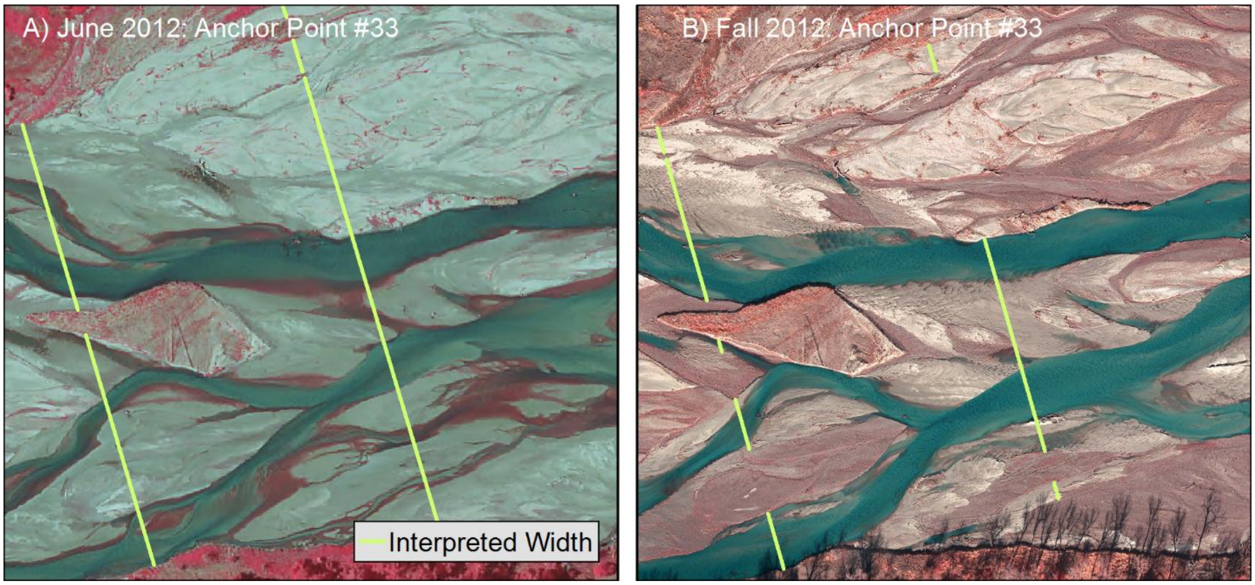


Figure 7. *Anchor Point #33 as it appears in aerial imagery collected in June (A) and fall (B) of 2012 with estimated widths. There is a subtle but apparent increase in the abundance of vegetation from June to fall in the non-wetted portions of the active river channel.*

5.0 Conclusions

Using high-resolution aerial imagery collected in the fall, three independent investigators were able to photo-interpret reasonable approximations (range of average error = -9 m – 6 m) of field measured unvegetated channel widths collected in the field during summer. However, photo-interpreted widths from June imagery (peak flow season) tended to be much greater (range of average error = 46 m – 83 m) than field measured unvegetated channel widths. High flows in June, imagery resolution and vegetation encroachment were likely the primary factors attributing to the increased error in estimates of unvegetated channel width derived from June imagery. Accordingly, we conclude that photo-interpreting unvegetated channel width from high-resolution aerial imagery can be a viable and reproducible alternative to implementing expensive field monitoring in braided river systems. However, interpretation from aerial imagery series collected at high flows can result in significant overestimation of unvegetated channel width. This is an especially important consideration for analyses of publically-available imagery in the Great Plains region of the United States. Many of those imagery series were collected in the April – July period, coinciding with the annual late-spring runoff period.

These conclusions will be used to assist Platte River Recovery Implementation Program decision-makers as they consider how to allocate the Program's research and monitoring budget in the future. Transitioning away from time- and money-intensive field monitoring of metrics like unvegetated channel width may free up resources for other research activities and/or allow the Program to increase the spatial and temporal resolution remote sensing data acquisition.

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