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Investigating the accuracy of photointerpreted unvegetated channel widths 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-nineteenth 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 metrics such as unvegetated channel width have been studied. With few exceptions, these measures are estimated from aerial imagery without mention of error in relation to actual channel conditions and/or investigator bias. This issue is not unique to central Platte River studies, as a general lack of commentary is apparent regarding the direct comparison of channel planform characteristics interpreted from aerial imagery relative to those measured in the field. Here we present a case study where data collected by the Platte River Recovery Implementation Program was used to make multiple comparisons using three years of field-measured unvegetated channel widths and those photointerpreted from aerial imagery. Widths were interpreted by three investigators, who identified similar widths in almost all cases. Photointerpretation from imagery collected during the fall resulted in unvegetated width estimates that were more consistent with field measurments than estimates derived using imagery collected in June. Differences were attributed to three main factors: (1) influences of discharge on photointerpretation of unvegetated channel width; (2) increases in vegetative cover throughout the growing season; and (3) resolution of imagery. Most importantly, we concluded that photointerpretation of unvegetated widths from imagery collected during high flows can result in significant over estimation of unvegetated channel width.

1. Introduction and 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 extremely wide channel widths largely free of in-channel vegetation (Eschner et al., 1983; Johnson, 1994; Simons and Associates and URS Greiner Woodward Clyde, 2000; Murphy et al., 2004; Schumm, 2005). Basinwide 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 and URS Greiner Woodward Clyde, 2000; Murphy et al., 2004; Schumm, 2005). The CPR channel narrowed in response to these alterations through encroachment of riparian cottonwood forest into historically active and largely unvegetated channel areas (Johnson, 1994; Fig. 1). As a result, the contemporary CPR has become a complex multichannel system with an anastomosed to braided planform where channel widths have decreased by an average of 80 to 90% since the mid-1800s (Murphy et al., 2004; Fig. 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 twentieth century and continued into the twenty-first 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 involved measurement and evaluation of channel width at locations where focal species were observed in order to infer habitat requirements (Atkins, 1979; Lingle et al., 1984; Shenk and Armbruster, 1986; Ziewitz, 1987; Biology Workgroup, 1990; Faanes et al., 1992; Austin and Richert, 2001). Geomorphology-focused studies involved the tracking of channel width measurements through time to identify changes in channel morphology caused by physical processes (Williams, 1978; Eschner et al., 1983; Johnson, 1994; Murphy et al., 2004; Horn et al., 2012).

Several definitions of channel width were used in CPR studies including wetted, unvegetated, and unobstructed width. Although some width metrics have been measured directly in the field, most were derived through interpretation of aerial imagery or planform maps (Williams, 1978; Atkins, 1979; Lingle et al., 1984; Faanes et al., 1992; 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 caused by georectification

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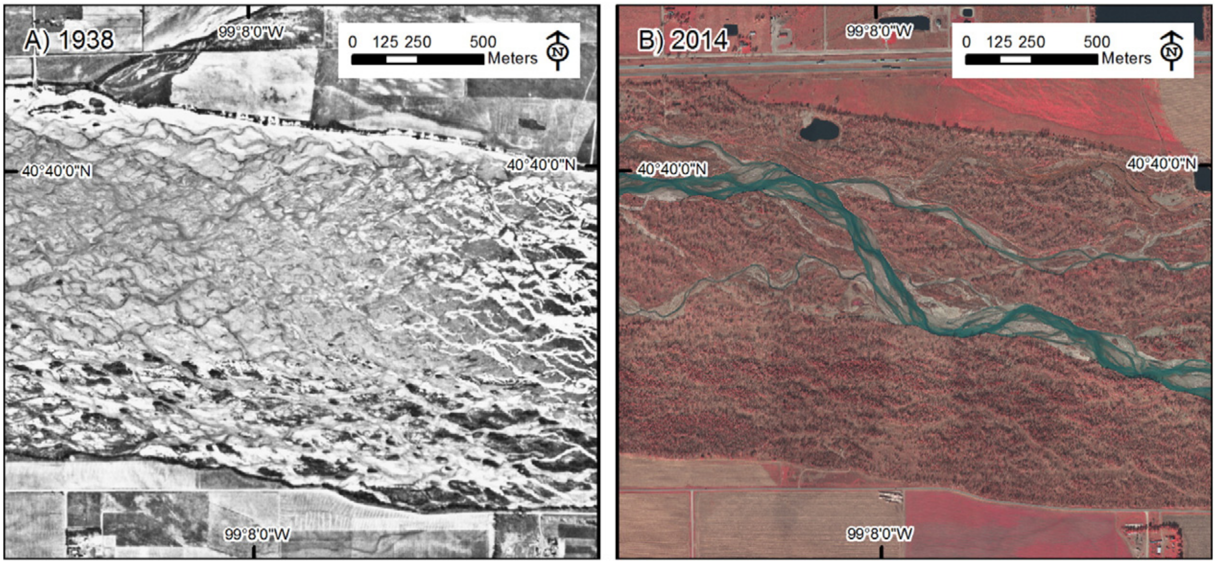

Fig. 1. Comparison of the central Platte River channel near Kearney, Nebraska, USA, in 1938 and 2014. The 1938 black and white imagery was collected by the Agricultural Stabilization and Conservation Service (ASCS) and was later scanned into a tiff format by the USGS. The 2014 imagery was collected by a Program contractor using a color and infrared scanner at a ground resolution of 0.15 m.

and/or random errors caused by the precision of feature identification (Micheli and Kirchner, 2002; Gaeuman et al., 2003; Mount et al., 2003; Mount and Louis, 2005; Hughes et al., 2006; Swanson et al., 2011; Lea and Legleiter, 2016). However, the potential for error associated with estimating planform channel characteristics in the CPR, like unvegetated width, from aerial imagery as compared to field measurements have not been quantified or discussed. Accurate estimation of unvegetated channel width in the CPR is vitally important given the growing body of evidence suggesting that riparian vegetation can strongly influence the morphology of braided rivers (Gran and Paola, 2001; Tal et al., 2004; Eaton et al., 2010; Camporeale et al., 2013).

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 used unvegetated channel width measurements at sample transects along the CPR to compare (i) widths interpreted by three different investigators at the same locations using the same aerial imagery (ii) widths interpreted at the same location on two sets of aerial imagery by a single investigator; and (iii) widths measured in the field versus those interpreted from aerial imagery by a single investigator. These comparisons allowed us to determine (i) if unvegetated channel widths interpreted by the three investigators were similar or not; (ii) if photointerpreted estimates of unvegetated channel width using aerial imagery collected at different times of the year and at different flow rates were similar or not; and (iii) if measures of unvegetated channel width collected in the field and photointerpreted estimates were similar or not. Finally, we evaluated implications for future monitoring and research efforts along the central Platte River and other systems with similar flow and channel characteristics where planform metrics are often estimated from aerial imagery.

2. Methodology

2.1. Study area

The focus area of our study is a 145-km reach of the central Platte River in Nebraska, USA, extending from Lexington downstream to Chapman. This reach of river is known as the Associated Habitat Reach (AHR; Fig. 2) for three threatened or endangered avian species: the whooping crane (*Grus americana*), piping plover (*Charadrius melodus*), and interior least tern (*Sterna antillarum athalassos*; Department of the Interior, 2006). The climate of the AHR is quite variable with warm summers, cold winters, and an annual average precipitation that increases from about 56 cm near Lexington to about 63 cm near Chapman (Stone, 1993). The landscape of the AHR is largely comprised of lowland tallgrass prairie, sandhills prairie and riparian forests (Rothenberger and Bicak, 1993).

The Platte River channel within the AHR has narrowed dramatically over the last century as a result of water development in Colorado, Wyoming, and Nebraska (Simons and Associates and URS Greiner Woodward Clyde, 2000; Murphy et al., 2004). Approximately 50% of the active river 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 exist but are typically submerged by flows >100 m^3/s, which have a recurrence interval (RI) at Kearney of about 1.3 years. Despite the extensive channel narrowing and flow splits, typical width-to-depth ratios remain >50:1 at most flows and typically range from 100:1 to 300:1 at flows of 35 m^3/s (RI $\approx$ 1 year) to 230 m^3/s (RI $\approx$ 3.33 years). Furthermore, despite a drainage area of just under 150,000 km^2 at the U.S. Geological Survey gage at Grand Island (Fig. 2; USGS, 2016), 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 (Murphy et al., 2004). The result is a complex multichannel, anastomosed to braided planform where flows are quite variable and active channel widths are quite sensitive to discharge.

2.2. Data

2.2.1. Field-collected unvegetated channel width data

Field measurements of unvegetated channel width were collected annually during the summers of 2010, 2011, and 2012 (Fig. 3), through the Program's system-scale geomorphology and vegetation monitoring protocol (Program, 2010). This protocol was developed by Program stakeholders and included the collection of data during July and August along transects within 40 anchor point locations distributed at approximately 4-km intervals throughout the AHR (Fig. 2). Each anchor point, which was defined as a fixed location along the AHR with a width about equal to the bankfull width of the channel and a length of ~304 m, consisted of three transects separated by ~152 m (Fig. 4A). The spacing of the anchor point transects was designed to capture potentially variable channel characteristics within each anchor point, while accounting

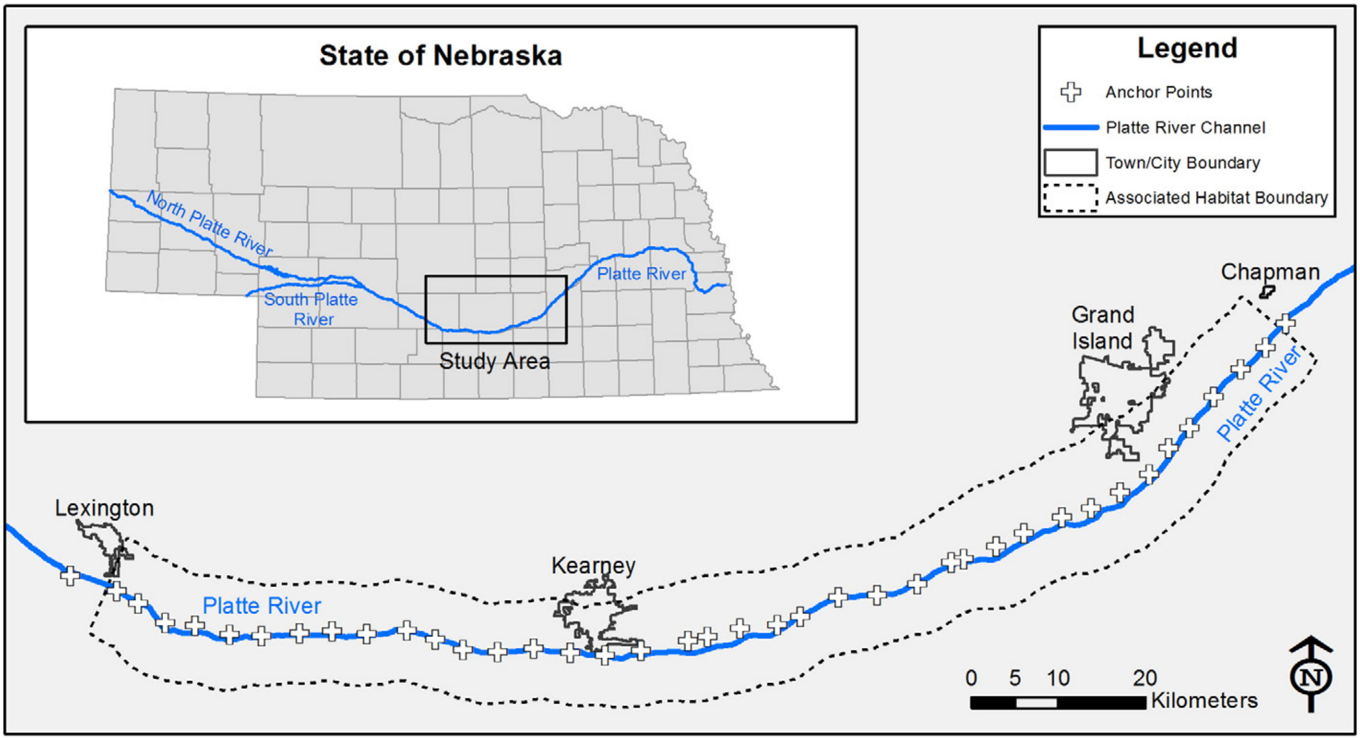

Fig. 2. Associated Habitat Reach (AHR) of the central Platte River showing towns and anchor point locations within the Associated Habitat boundary.

for data collection budgets and timeframes. As part of the sampling protocol, half (20) of the anchor points, spaced at 8-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. The total number of transects surveyed annually varied from 84 to 87 and was >75 (25×3) as a result of the number of anchor points where flow is split by large islands. At these locations, data is collected at subanchor points on each channel (Fig. 4B).

A real-time kinematic global positioning system (RTK GPS) unit was used to survey each transect. Specific survey points along each transect included those necessary to develop channel cross sections and geomorphic metrics such as unvegetated channel width. To develop the unvegetated channel widths, the edges of vegetation that defined unvegetated transect segments (segments whose total area was 25% or less vegetated, as judged by the data collector) were surveyed and marked with a unique identifier when stored in the RTK GPS unit. At the completion of the monitoring campaign, the collected data was downloaded from the RTK GPS unit, and ESRI ArcMap software (Environmental Systems Research Institute, 2012) was used to measure unvegetated channel segments by drawing lines to connect the edge-of-vegetation points. Lengths of unvegetated channel segments along each transect were added together to develop a field-measured total unvegetated channel width for each transect. Lastly, the developed unvegetated channel width measurements were checked against aerial imagery to identify and correct any major errors resulting from surveying mistakes.

2.2.2. Photointerpreted unvegetated width data

Aerial imagery collected for the Program during June and fall 2010–2012 (Fig. 3) was used to develop multiyear, multiseason, and

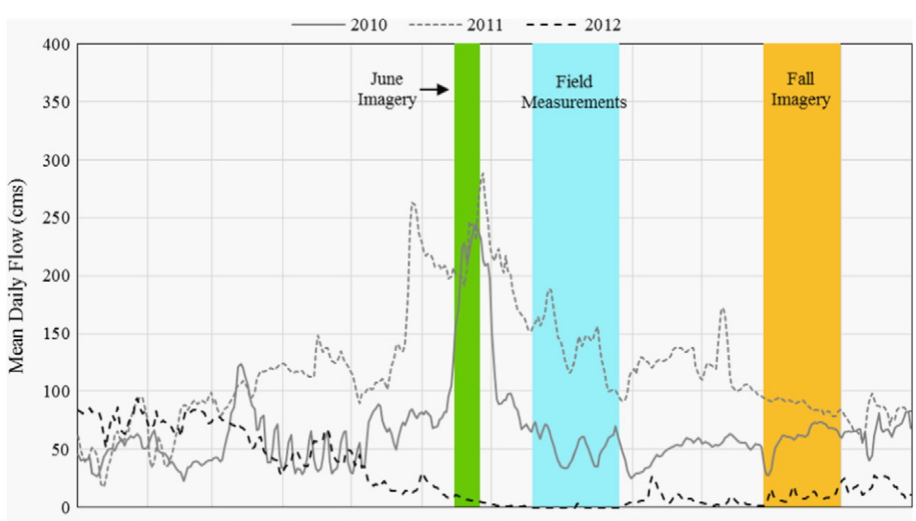

Fig. 3. Time series of data collection efforts and Platte River flows as measured at the Grand Island, Nebraska, USGS gage, 2010–2012.

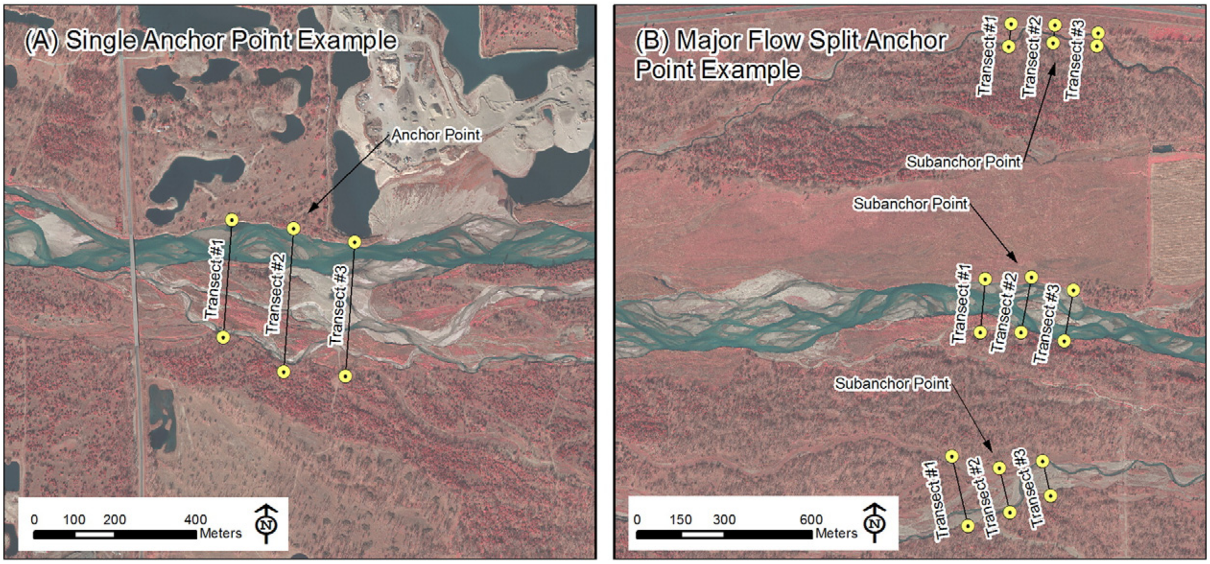

Fig. 4. Example of an anchor point at a location where there are no major flow splits **(A)**, as well as an anchor point that has been split into subanchor points **(B)** due to major flow splits in the channel.

multiinvestigator estimates of unvegetated channel width. June imagery was collected using a large format digital camera in four-band and color-infrared formats at a ground resolution of 0.61 m, and fall imagery was collected using a similar camera in a color-infrared format at a ground resolution of 0.15 m. The resolutions of the imagery series are different because the June imagery includes the entire AHR (Fig. 2), while the fall imagery includes only the active and historical channel areas of the AHR and can therefore be processed at a finer resolution under the given budget constraints. Both sets of imagery were georeferenced using ground controls by the contractor who collected the imagery.

The unvegetated channel widths were photointerpreted by first loading the imagery series into ESRI ArcMap software (Environmental Systems Research Institute, 2012). Once loaded, the estimates of unvegetated channel width were developed for each transect within each anchor point sampled during the field campaign for that year. For example, when 2010 imagery was loaded, unvegetated channel widths were interpreted from the imagery along transects sampled during the 2010 field campaign (i.e., all 20 pure panel anchor points and 5 rotating panel anchor points). The unvegetated channel widths were estimated simply by investigator judgment. That is, the investigator drew lines along the perceived unvegetated segments (i.e., 25% or less vegetation) of each transect, measured the lengths of each unvegetated segment, and totaled them to determine an estimated unvegetated channel width for each transect. Investigator #3 photointerpreted unvegetated channel widths from June and fall imagery for each year, 2010–2012. This resulted in two photointerpreted estimates of unvegetated channel width per transect per sampled anchor point per year, which were eventually compared to the field measurements. To evaluate investigator bias, investigators #1 and #2, in addition to investigator #3, photointerpreted unvegetated widths for fall imagery.

2.3. Statistical analyses

We compared unvegetated channel width measurements using iterative bootstrap sampling. For each comparison, we randomly drew a sample of 29 transects from the 84 to 87 transects within the 25 anchor points and subanchor points within each year to compare 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. The sample was limited to 29 transects to reduce the potential for spatial autocorrelation as a result of the sampling of multiple transects from a single anchor point. We used unvegetated channel width measurements at sample transects to compare (i) fall photointerpreted widths between three investigators; (ii) June versus fall photointerpreted widths; and (iii) field-measured versus photointerpreted widths from June and fall imagery. All analyses were conducted using Program R (R Development Core Team, 2013) and RStudio (RStudio, 2015).

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 photointerpreted width estimates were assumed to represent the error in the photointerpreted estimates. For example, if the field measurement was 100 m and the photointerpreted estimate was 120 m, the error, which was defined as the photointerpreted estimate minus the field measurement, was considered to be +20.0 m.

Paired *t*-tests were used to assess differences in photointerpreted and field-measured unvegetated channel width at each transect. Separate paired *t*-tests were performed on each bootstrap sample to assess differences between estimates derived using June and fall imagery. We used a repeated measures ANOVA to assess differences in width

Table 1
Comparison of estimates of unvegetated channel width from fall imagery by three investigators, and the number of significant differences between investigators based on iterative bootstrap sampling.

Metric	Investigator	2010	2011	2012
		Average (Standard error)		
Average estimates of unvegetated channel width (m)	#1	146 (11)	193 (15)	113 (9)
	#2	183 (12)	169 (14)	132 (9)
	#3	173 (10)	180 (15)	137 (9)
Significant differences between investigators' estimates (%)	#1, #2, and #3	0	0	2

Table 2
Comparison of estimates of unvegetated channel width from June and fall imagery by investigator #3, and the number of significant differences between widths interpreted from the different imagery series.

Metric	Imagery Series	2010	2011	2012
		Average (Standard error)		
Average estimates of unvegetated channel width (m)	June	239 (13)	220 (17)	173 (14)
	Fall	166 (13)	199 (16)	130 (11)
Significant differences between investigator #3's estimates from June and fall imagery (%)	June and Fall	100	100	100

measurements and 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. The *P*-values from the paired *t*-test and ANOVA were recorded and repeated over 1000 iterations with replacement for each comparison: 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 errors and unvegetated channel width values.

3. Results

3.1. Evaluation of fall photointerpreted widths between three investigators

We found investigator estimates of unvegetated channel width using fall imagery to be very similar. Of the 1000 samples within each year, we found 0% of estimates were significantly different between investigators in 2010 and 2011 and only 2% were significantly different in 2012 (Table 1). Based on the 1000 samples, the largest discrepancies between the mean of investigator estimates was in 2010, where average unvegetated channel width estimates varied by 37 m (146–183 m; Table 1).

3.2. Evaluation of June versus fall photointerpreted widths

From 2010 to 2012, 100% of all bootstrapped estimates of June and fall unvegetated channel width, as photointerpreted by investigator #3, were significantly different within years (Table 2). In all years, the unvegetated channel width estimates photointerpreted from the June imagery were greater than those interpreted from the fall imagery. The greatest average differences were in those interpreted from 2010 imagery (73 m), and the smallest were in those interpreted from 2011 imagery (21 m; Table 2).

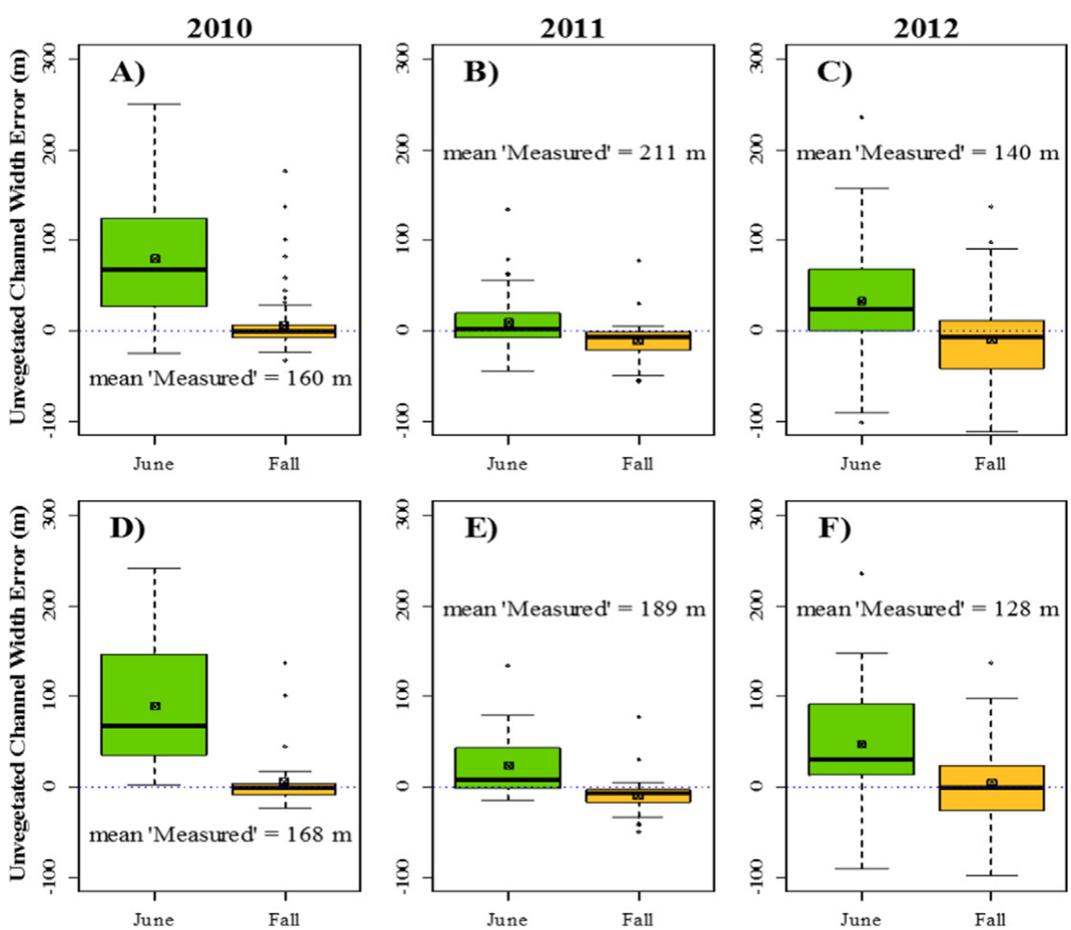

Fig. 5. Population distribution of photointerpreted estimates of unvegetated channel width error **(top)** and bootstrapped estimates of error **(bottom)** to show that the bootstrapped sampled data sets are representative of the population data sets. Boxes represent 25th–75th percentiles, whiskers represent 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 errors, respectively. The 'mean measured' numbers are the means of the measured widths in each year.

Table 3
Mean and standard error of measurement errors in photointerpreted estimates of unvegetated channel width collected by investigator #3 as compared to field measurements for 1000 bootstrap samples; percent refers to the percentage of the bootstrap samples where photointerpreted estimates were significantly different than field measurements at a 95% confidence level ($\alpha = 0.05$).

Year	Imagery series	Average (m)	Standard error (m)	Lower confidence interval (m)	Upper confidence interval (m)	Significant differences (%)
2010	June	88	12	2	241	100
	Fall	6	6	−24	137	3
2011	June	23	6	−16	134	33
	Fall	−9	4	−50	78	91
2012	June	46	12	−90	235	87
	Fall	5	10	−99	236	15

3.3. Evaluation of field-measured versus photointerpreted widths from June and fall imagery

Photointerpreted unvegetated channel widths from fall aerial imagery were generally more similar to field measurements than estimates derived from June imagery, as photointerpreted by investigator #3 (Fig. 5). 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; Fig. 5 and Table 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 (Table 3). Differences for fall imagery were significant in 3% of the 2010 iterations, 91% of the 2011 iterations, and 15% of the 2012 iterations (Table 3).

4. Discussion

We found that the unvegetated channel width estimates derived from fall imagery by the three different investigators were similar in all but a very few cases (Table 1). This indicates the method of estimating unvegetated channel width from aerial imagery series used in this study is repeatable by different investigators. Consequently, the use of different investigators within years and across years should not introduce investigator bias into the developed unvegetated channel width data sets and appears to be an acceptable practice.

In addition, we found that differences in estimates of unvegetated channel width photointerpreted from aerial imagery collected in June, as compared to those interpreted by the same investigator from imagery collected in the fall, were almost always statistically significant (Table 2). Furthermore, when compared to field measurements, the magnitude of differences between the field-measured unvegetated channel widths and the widths interpreted from fall aerial imagery by a single investigator were typically small, but the differences between field-measured and photointerpreted widths from June imagery by the same investigator were much larger (Fig. 3, Table 3).

The positive bias and magnitude of difference when interpreting unvegetated channel widths from June imagery can be largely explained by basin hydrology (Fig. 3). June aerial imagery often coincided with the late-spring runoff when flows through the AHR were at or near their annual peak. Field measurements and fall aerial imagery were typically collected after the late-spring runoff when flows were 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 ~210 and 22 m^3/s, respectively (Fig. 6). Many of the vegetated bars present in the fall imagery were fully submerged in June as a result of the much higher flow (Figs. 3 and 6). Submerged vegetated or partially vegetated bars were difficult to identify in imagery, leading to an overestimation of unvegetated channel width based on that imagery series (Fig. 3, Table 3).

Differences between fall 2011 photointerpreted and field measurements were most likely attributed to flows as well. Fall flows were considerably lower than those experienced during field measurements (Fig. 3), which led to underestimates of unvegetated widths from the fall imagery (Fig. 5, Table 3). However, although differences in 2011 were statistically significant, the fall estimates at transects were generally very similar to field measurements (e.g., averaged <10 m of difference). The lack of statistical agreement is likely a result of the very precise yet negatively biased distribution of errors (Fig. 5, Table 3). If flows were more similar during the field measurement and fall imagery time periods in 2011, we would expect an increase of statistical agreement between the data sets, likely comparable to those observed in 2010 and 2012.

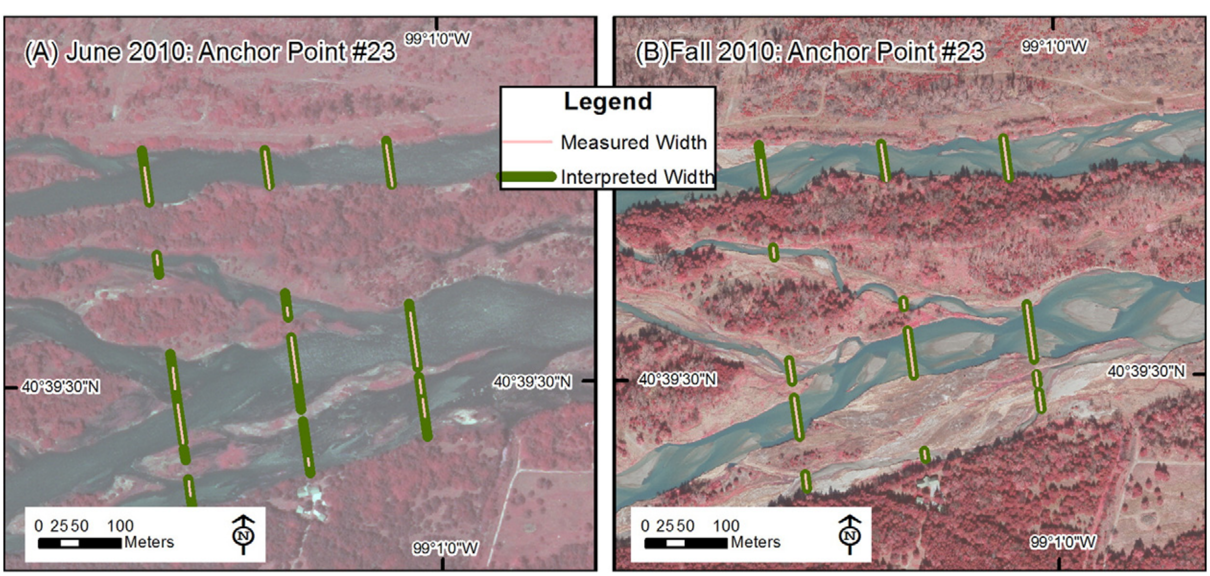

Fig. 6. Anchor point #23 in aerial imagery collected in June **(A)** and October **(B)** of 2010 with photointerpreted and field-measured unvegetated channel widths along each of the three transects. Average discharge through the Associated Habitat Reach on the date of June imagery collection was about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

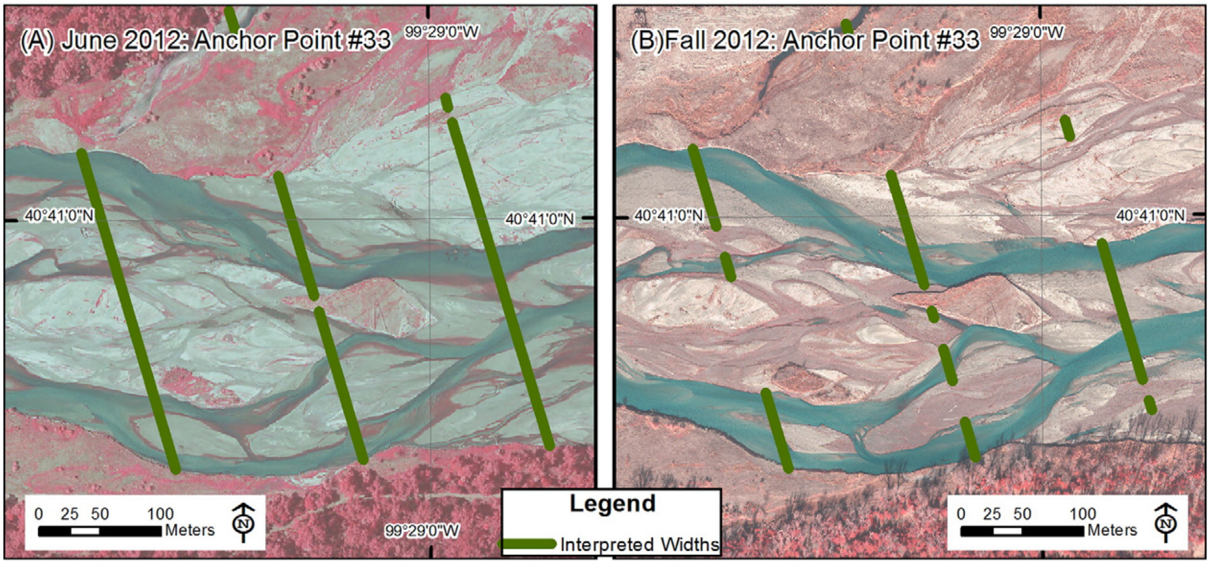

Fig. 7. Anchor point #33 as it appears in aerial imagery collected in June **(A)** and fall **(B)** of 2012 with estimated widths. There is a subtle but apparent increase in the abundance of vegetation from June to fall in the nonwetted portions of the active river channel.

The resolution of the imagery also likely contributed to differences in estimates of unvegetated channel width between fall and June imagery. 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 Fig. 7 where surface features (e.g., sandbars, banks, bedforms, trees, etc.) are more clearly defined in the fall imagery (Fig. 7B) than the June imagery (Fig. 7A). 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., 2011). 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 source of photointerpretation error was encroachment of annual vegetation in the channel during the growing season in low flow years. For example, the difference between June and fall photointerpreted unvegetated channel widths was fairly large in 2012 (Fig. 5) even though flows during the collection of June and fall imagery were nearly equal (Fig. 3) as a result of increased vegetation abundance on low sandbars in the fall (Fig. 7). The majority of the channel bed, largely free of vegetation in June following 2 years of medium to high flows (Fig. 7A), was exposed during the growing season and colonized by annual vegetation (Fig. 7B). Consequently, the unvegetated widths estimated from June imagery were larger than those measured in the field and estimated from fall aerial imagery.

5. Conclusions

Using high-resolution aerial imagery collected in the fall, a single investigator was able to photointerpret accurate estimates (range of average error = −9 to 6 m) of unvegetated channel widths measured during the summer. However, photointerpreted widths from June imagery (peak flow season) by the investigator tended to be much greater (range of average error = 23–88 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 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.

Our conclusions can be used to assist researchers and decision makers as they consider how to allocate research and monitoring budgets in the Platte River and other systems 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 researchers to increase the spatial and temporal resolution of the remote sensing data to be collected. In other braided systems, where planform channel characteristics are sensitive to discharge, these results can be used to inform the design of sampling and data collection regimes. Future research should be aimed at the comparison of other field-measured and imagery-derived metrics, as well as the evaluation of similar metrics along rivers with different flow regimes and planform characteristics.

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